Climate Change and Evolved Pavements

25

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Climate Change and Evolved Pavements

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Chapter 1 - Introduction

1.1 Introduction

This project report concentrates on the local authority's most vulnerable and fragile road systems, the undesigned, unclassified roads. These roads generally form the greatest length of the highway network and because they have simply evolved with limited design, form the greatest financial risk to the local authority in the event of climate change. These highways cater for the present conditions and no more, any impact from climate through changes in temperature or rainfall may be the catalyst for widescale failure.

The research project was originally two separate research bids, one relating to elevated temperatures and the other linked to water inundation to the substructure. These bids were later combined into the current Climate Change and Evolved Pavements for the ADEEPT Engineering Committee Research Board. An initial scoping project had already been undertaken by the Southern Group of the County Surveyors' Society Soils and Materials Group which had produced a list of scenarios and adaptation measures to link the impact of climate change on the highway network. The current project expanded on this initial work and focused its emphasis on the unclassified road network.

For this project Capita were commissioned to look at the effect of climate change on the bound pavement element of the highway whilst Jacobs concentrated on the unbound or granular element of these fragile evolved highways. The work involved a questionnaire being sent to all local highway authorities in England, Wales, Scotland and The Roads Service Northern Ireland to ask whether each organisation had considered changing its operational, strategic and budgetary plans to reflect climate change.

The report has been formatted into three chapters with an executive summary overview:

- Background and Strategic Issues;
- Geotechnical and Drainage Issues;
- Pavement and Material Issues.

To avoid overwhelming the three chapters, the detailed background to climate change, links to other research and good practice guidance and more detailed technical advice on all types of surfacing encountered on evolved pavements have been included in the appendices at the end of the report together with the results of the questionnaire.

The combined report highlights the problems likely to occur from climate change and puts forward solutions to change standards and designs now to manage the impact on the network in the future.

Climate Change and Evolved Pavements
Chapter 2 – Executive Summary

2.1 Introduction

The effects of climate change are likely to result in drier, hotter summers and wetter and warmer winters. These changes will impact on highways and associated infrastructure and without adaption and mitigation will result increased deterioration and possible failure and potential loss of parts of the highway network.
This chapter reviews the background and influence of climate change on the current strategy and policy of a local highway authority.
The utilisation of personnel with skills and experience (including local knowledge) in highway engineering is vital to assist with the adaption and mitigation process. Specialist skills in geotechnical engineering, arboriculture and highway materials are also recommended to provide advice and assist with this process.

2.1.1 Legislation, National Plans and Initiatives

Several recent acts of parliament have addressed the issue of climate change and resultant effects. The Climate Change and Climate Change (Scotland) Acts target the long term reduction in carbon emissions to offset the changes in climate. The Energy Act and Planning Act address new energy-related technologies and adaption/mitigation of planning strategies and plans respectively. The Flooding and Water Management Act strengthens the UK approach to flood management.

The UK Low Carbon Transition Plan details energy efficiency measures and low/zero carbon energy sources.
National Indicators require Local Authorities to monitor CO_2 reduction and adaption to climate change.

The United Kingdom Climate Impacts Programme report provides a review of the UKCIP 2009 climate change projections.
The headline conclusions for climate change Indicate the following:-

- Hotter drier summers
- Milder wetter winters
- More extreme rainfall events
- Increased wind speeds
- Increased UV radiation in summer
- Rising sea levels

Maps of the UK show the projected changes in climate.

Appendix 1 provides more detail of UKCIP 2009 projections and provides guidance to local highway authorities. The web tools are recommended for use to obtain a more complete understanding of the climate change projections.
Considerable uncertainty exists with the UKCIP 2009 climate change projections and requires to be considered as part of the risk management process.

For Carbon Mitigation and Carbon Calculators Local highway authorities are required to take positive action to reduce greenhouse gas emissions and contribute to the UK national targets. Recent developments are reviewed with more detailed information provided in Appendix 1.

Embodied carbon considerations are recommended to include the full life cycle of the highway pavement.

Local highway authorities have to adopt a consistent and carry a risk management approach to the assessment of climate change risks.
Integration of climate change with other risks in a holistic process is recommended and a five stage evaluation recommendation is as follows:-

(a). Identify exposure units
(b). Identify climate hazards
(c). Assess climate change risk
(d). Employ risk management; and
(e). Review assessment and update as required (ongoing).

Additional information is provided in Appendix 1.

Climate change adaption and mitigation should be integrated into the asset management planning system and this process should also include life cycle and whole of life financial considerations.
Emergency planning should also review the resilience of the highway network and review loss of the network. Recent flooding events and the potential of "melted" surfaces may result in parts of the network becoming unavailable for continual use.

The concept of Business Continuity Management is recommended to local highway authorities to assist risk management and corporate governance.
The 2009 flooding in West Cumbria is an example of the more extreme flooding events currently experienced and the need for the resilient continuity of public services.

Climate change outcomes of increased rainfall combined with rising sea levels results in a greater risk of flooding which poses a major risk to the UK's built environment and infrastructure.
Key sources of flood risk in the UK have been reviewed and also how climate change may increase this risk, and how local highways authorities can help mitigate risk to the evolved highway network through use of flood maps, screening of past flood events and use of climate change scenarios.
Further information on flood risk management is provided in Appendix 1.

The recent Flood and Water Management Act 2010 legislation is designed to increase resilience and reduce flood risk is reviewed with emphasis on the role of the local highway authority. Flood risk management has improved responsibility within the legislation.
The introduction of Sustainable Drainage Systems and the development of national standards are briefly reviewed.

2.1.2 Impact of climate change on evolved pavements

The impact of drier summers and wetter winters will often relate to more extreme versions of the geotechnical effects we currently experience and so the main issues considered to date are principally increases in the following:-

- Soil Desiccation
- Surface water run-off

The impact on pavements will mainly arise from flooding and high temperatures leading to:-

- Lower strength of the pavement to withstand load
- Deformation of the Highway under load
- Whole sale melting of the road

2.1.3 Risk Assessments

Efficient asset management of infrastructure geotechnical issues in relation to climate change relies on reliable assessments of long-term behaviour to formulate appropriate design solutions and efficient management. This depends upon establishing the highway asset in more detail with the potential then for both proactive and reactive responses.

The benefits of a proactive approach is illustrated by reported improvements to marginally stable slopes being up to 75% cheaper than reactive approaches to failed slopes, with the added benefit that the proactive approach allows improved budgetary controls.

Highway asset inventories of road pavement condition, earthworks, drainage and vegetation can be used with flood risk mapping, geological mapping, topographical maps, slope aspect and other local knowledge to identify the sites most needing attention immediately and those likely to be at risk as a result of climate change.

2.1.4 Strategies

It is unlikely that the widespread collection of inventories on earthworks, drainage and landscape features, including their condition, will be possible given the size of a LA network, similarly treatment works to all the sites identified will be too costly, even if this is spread over many years. It is therefore necessary to identify those sites where the consequences of a failure could lead to major disruption to the public or very expensive remedial works. The combination of site risk and road importance can provide a system to prioritise inspections and determine their detail and frequency and plan any intervention n required.

Proactive strategies are preferred as they are much cheaper as long as the prediction of the effect is robust However faced with an almost impossible task of modelling the behaviour of in-situ soils and engineered fills, the geotechnical engineer must combine industry best practice, available data and case histories from other climates to produce viable solutions.

The production of surface water management plans (SWMPs) help to assess the risk of surface water flooding, identify options to manage risk to acceptable level, make the right investment decisions and plan the delivery of actions to manage flood risk. SWMPs will look at existing problems and inform planning decisions for new development. They therefore will register areas of the highway asset needing particular flood alleviation measures such as targeting of gulley maintenance in flood risk areas, suggesting modification to surfacing types and identification of areas needing additional capacity or flood alleviation areas. Porous or permeable pavements have been promoted as part of a more sustainable approach to drainage but Local highway authorities have previously aligned with the principle of sealing highway pavements will have some concern regarding the design life and maintenance profile for such pavements.

Routine maintenance plays an important part (eg preventing ruts channelling water away from drainage, gullies blocked with leaves/snow related grit, blocked grips from road edge to ditches, etc) although clearly additional capital works will be needed in some areas. Cyclic maintenance of earthworks drainage must also be addressed including subgrade drains, French drains, slope drains and SUDS.

2.1.5 Conclusions

A process of asset management inventory and prioritised ongoing condition monitoring, should enable the implementation of targeted adaptation and mitigation measures for the geotechnical and pavement engineering aspects proactively as the climate changes. The measures should take account of a risk assessment of the impact of failure on the infrastructure and the public.

Management of the potentially increased maintenance requirements for existing infrastructure will require intervention strategies that are preferably proactive based upon using comprehensive asset management databases and risk assessments. Implementing this process will provide confidence to clients that the risks posed by the geotechnical, pavement and surface water changes have been adequately managed and appropriate responses are in place giving value for money.

Climate Change and Evolved Pavements Chapter 3 - Background and Strategic Issues

3.1 Background on UK National and Legislative Developments

3.1.1 Legislation

The following paragraphs provide an overview of the main UK legislative and policy developments relating to climate change. The increasing importance of this issue is reflected in the recent creation of the Department of Energy and Climate Change (DECC) (1) and the passing of four related pieces of legislation which make provision for issues arising from climate change:

- The **Climate Change Act 2008** (2) – provides a framework for the UK's response to climate change in an holistic sense, including a legally binding target of 80% carbon emission reduction by 2050 compared to the 1990 baseline; management of emission reduction targets; and, the UK's capacity to adapt to climate change; (See appendix A1 for more details)

- The **Climate Change (Scotland) Act 2009** (5) – The Scottish Act is similar in scope to the UK (2008) Act, which it is designed to compliment; it is in fact a separate piece of legislation providing a framework for Scotland's approach to tackling climate change. The 2009 Act also sets an overall carbon reduction target of 80% by 2050 (based on 1990 levels); however, its interim targets are more stringent than those in the 2008 Act. Moreover, it sets annual targets for carbon reduction, as opposed to the 2008 Act which sets five-yearly targets. In terms of adapting to climate change, under the 2009 Act Scottish Ministers must report on proposed measures and how they should be implemented, and make subsequent progress reports on an annual basis.

- The **Energy Act 2008** (3) – this updates the previous Energy Act to provide legislation for new energy related-technologies (such as renewables and Carbon Capture and Storage); to address changes to the UK's energy requirements, the energy market and environmental concerns;

- The **Planning Act 2008** (4) – this updates UK planning legislation and makes provision for climate change by requiring regional spatial strategies and development plans to include policies which contribute to climate change mitigation and adaptation - in this sense it is closely related to the Energy Act 2008.

- The **Flood and Water Management Act 2010** (9) – this updates the approach to flood risk and water management. It is designed in part to implement recommendations made in the Pitt Review of the 2007 floods. The Act aims to strengthen and consolidate the UK's approach to flood risk management and coastal erosion. The Act provides a framework within which a range of flood risks, including those from climate change, can be managed. (See section 3.8 and appendix A1).

3.1.2 National Plans and Initiatives

3.1.2.1 UK Low Carbon Transition Plan

This is the holistic strategy for achieving the UK carbon emission reductions budgeted under the Climate Change Act 2008 (2). The plan details how the reductions will be achieved through implementing energy efficiency measures and low/zero carbon energy sources. It also considers how the UK economy will make the transit in terms of business and employment opportunities relating to low carbon technologies, infrastructure and investment.

3.1.2.2 National Indicators

There are 198 indicators which help local authorities, their partners and the Government measure progress on a range of issues. Three indicators directly relating to climate change have been introduced:

- NI 185: CO_2 Reduction from Local Authority (LA) operations
- NI 186: Per capita reduction in CO_2 emissions in the LA area
- NI 188: Planning to adapt to climate change

Indicators 185 and 186 deal with climate change mitigation strategies within LA administrative areas. NI 188 measures progress in assessing climate change risks and implementing adaptation strategies across all LA operations – including physical infrastructure and estates. Studies such as this one contribute to the climate change planning process in allowing LA's and their partners to better understand the risks to (for example) the evolved highway network, and potential adaptive measures. It is important that recommended adaptation measures do not contribute unnecessarily to the emissions measured in Indicators 185 and 186.

3.2 UK Climate Impacts Programme (UKCIP) (7)

The UKCIP has been established (in 1997) to help a range of sectors in the UK understand and manage the risks associated with a changing climate. Funded by DEFRA, it is based at Oxford University and presents projections for climate change from scenarios modelled by Met Office Hadley Centre global and regional climate models. The projections are presented online or in comprehensive reports and describe how the climate might change over different time periods and across the UK. The most recent projections were released in 2009 – and are used in this study as the basis for assessing the climate risks to the evolved highway network.

3.2.1 Background to UK Climate Impacts Programme (UKCIP) 2009 climate change projections (7)

UKCIP have produced a large amount of information on climate change. Appendix A1 gives some background information on global climate change, the UKCIP climate projections and their use.

Future changes in climate could be:-

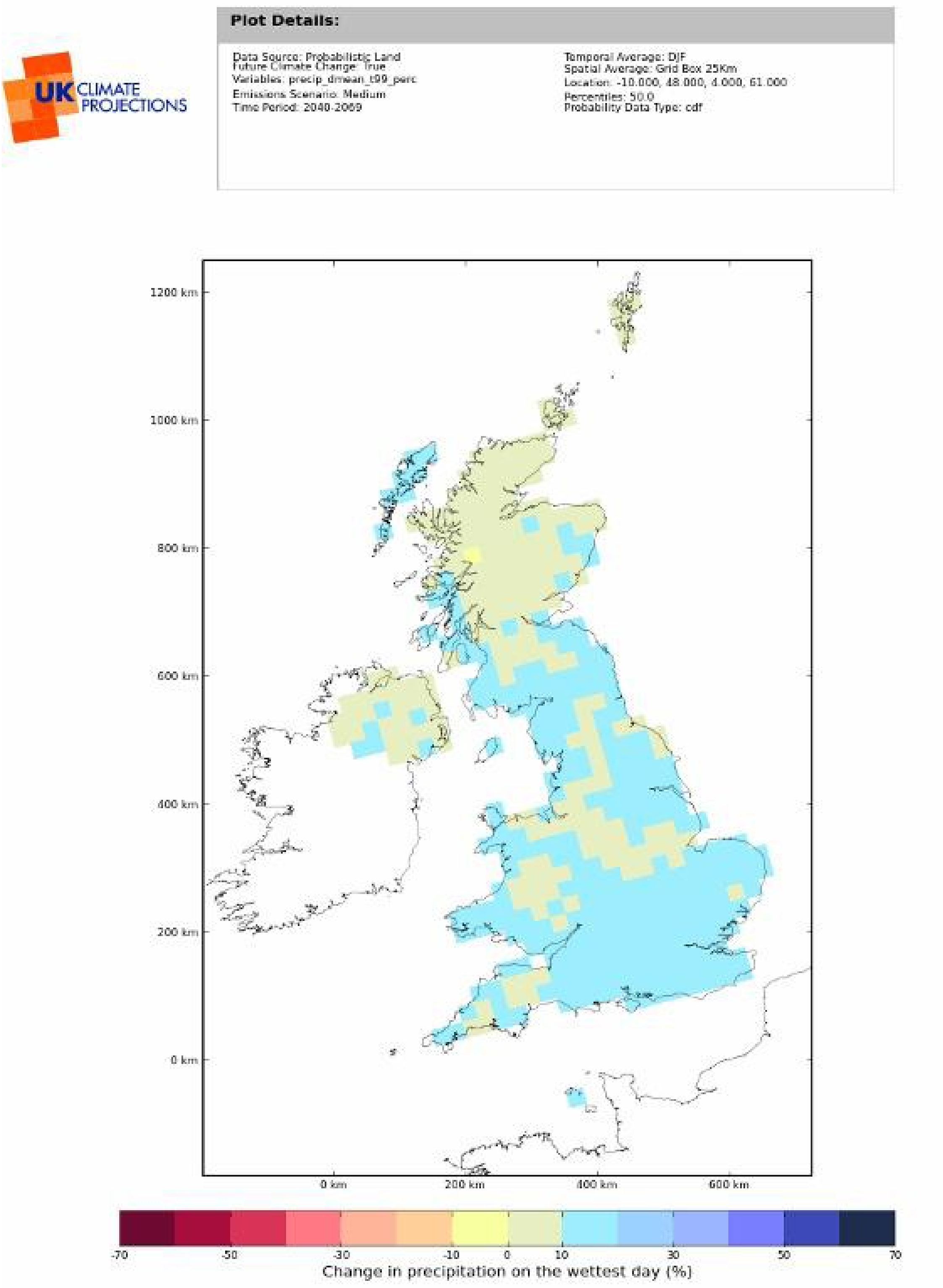
- Hotter drier summers
- Milder wetter winters
- More extreme rainfall events
- Increased wind speeds
- Increased UV radiation in summer
- Rising sea levels

These changes will vary across the country with geography, geology and topography, with the main hazards for pavement condition being:-

- Ingress of water
- Pavement surfaces melting during summer
- Increased temperatures causing expansion beyond the capacity of joints in rigid pavements
- Increased pressure on the drainage systems
- Slope instability
- Infrastructure washing away due to flooding by rivers or sea

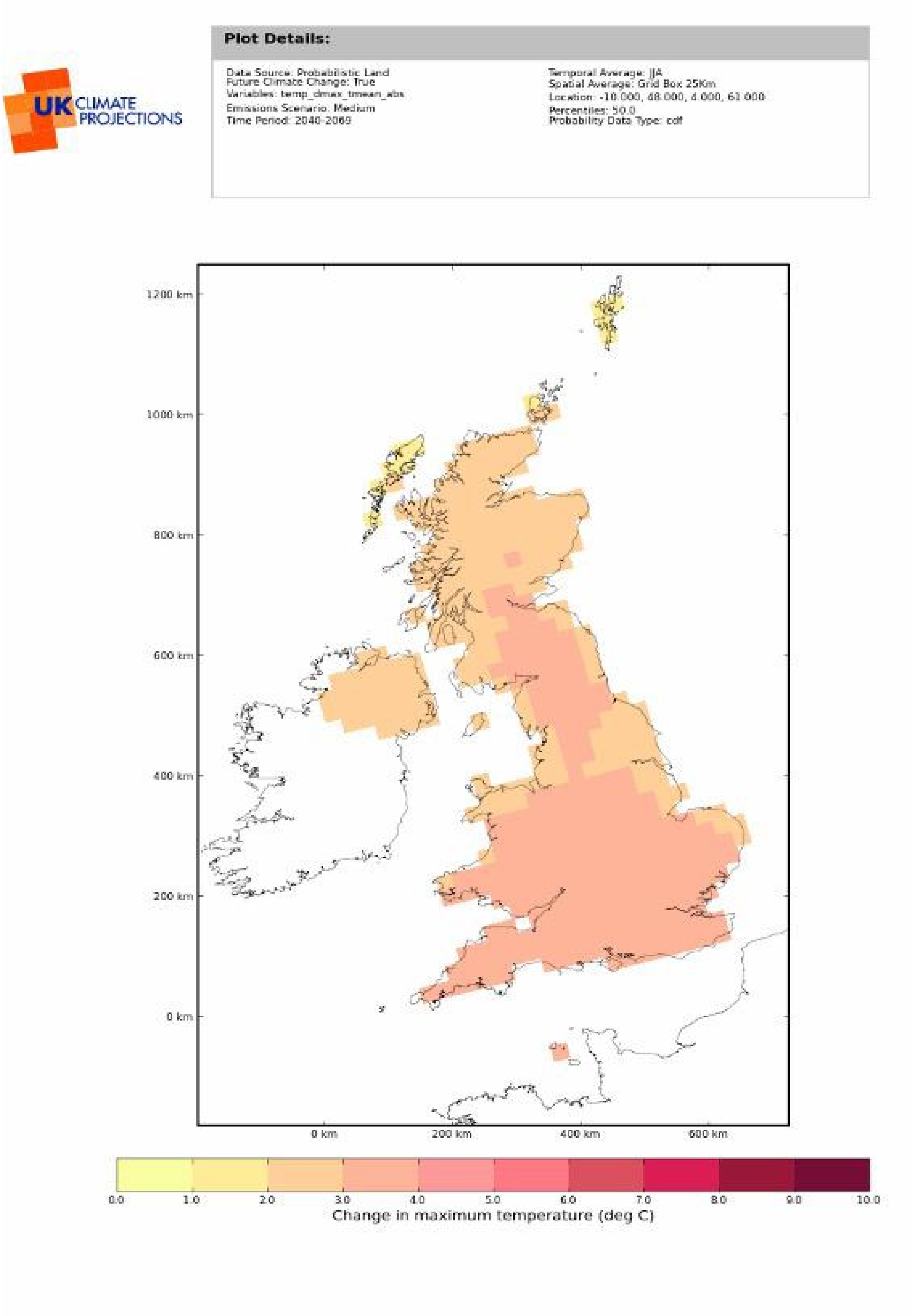
The following maps highlight recent trends in temperature and precipitation in the UK and present some of the UKCIP09 projections for change.

Map showing % change in wettest days of winter for the medium emissions scenario/2050s/central estimate (50% probability)



© UK Climate Projections, 2009 Figure 3.1

Map showing change in mean maximum summer temperature (°C) for the medium emissions scenario/2050s/central estimate (50% probability)



© UK Climate Projections, 2009 Figure 3.2

Map showing change in summer mean precipitation (%) for the medium emissions scenario/2050s/central estimate (50% probability)

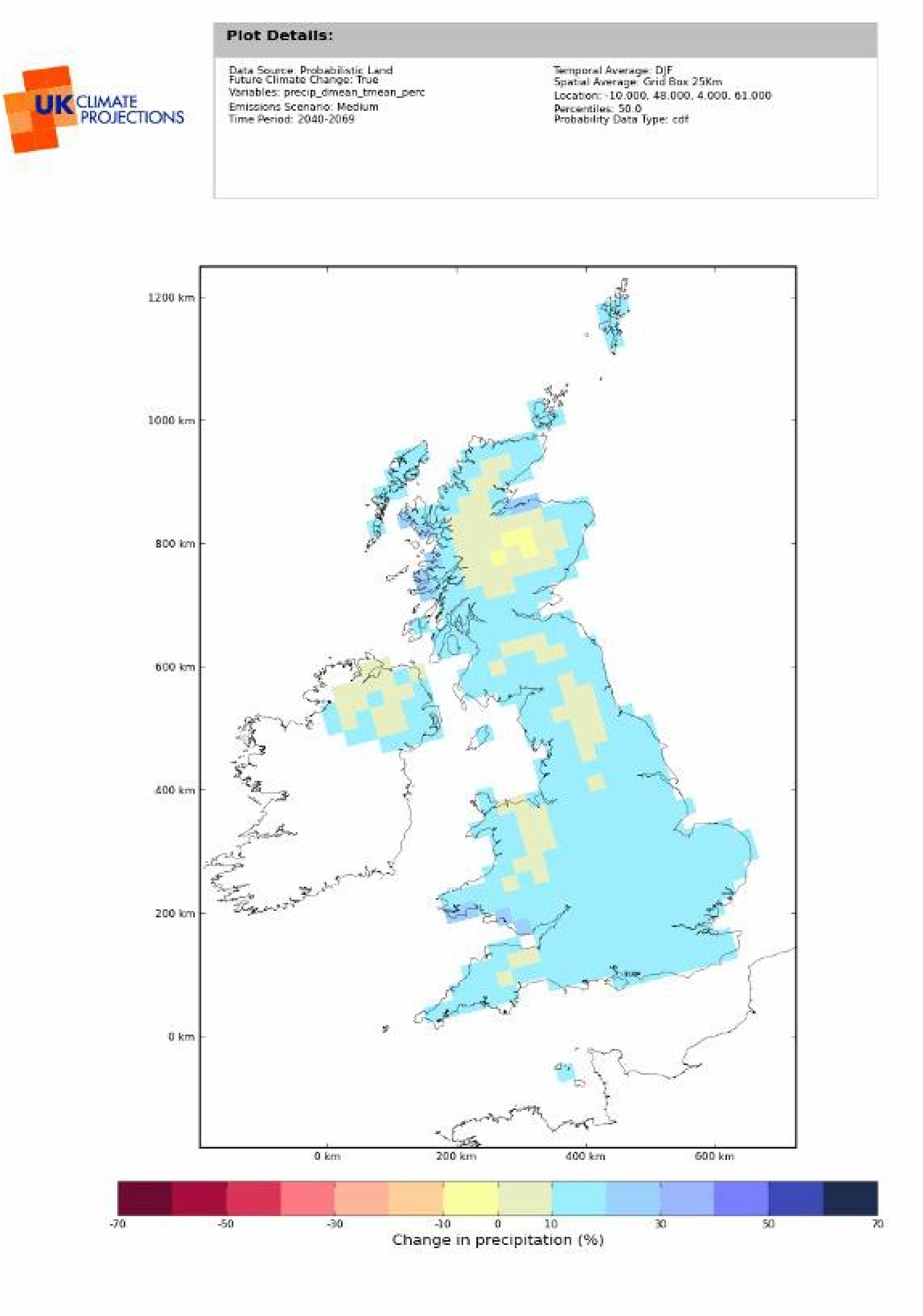


Figure 3.3

Map showing change in warmest day of summer temperature (°C) for the medium emissions scenario/2050s/central estimate (50% probability)

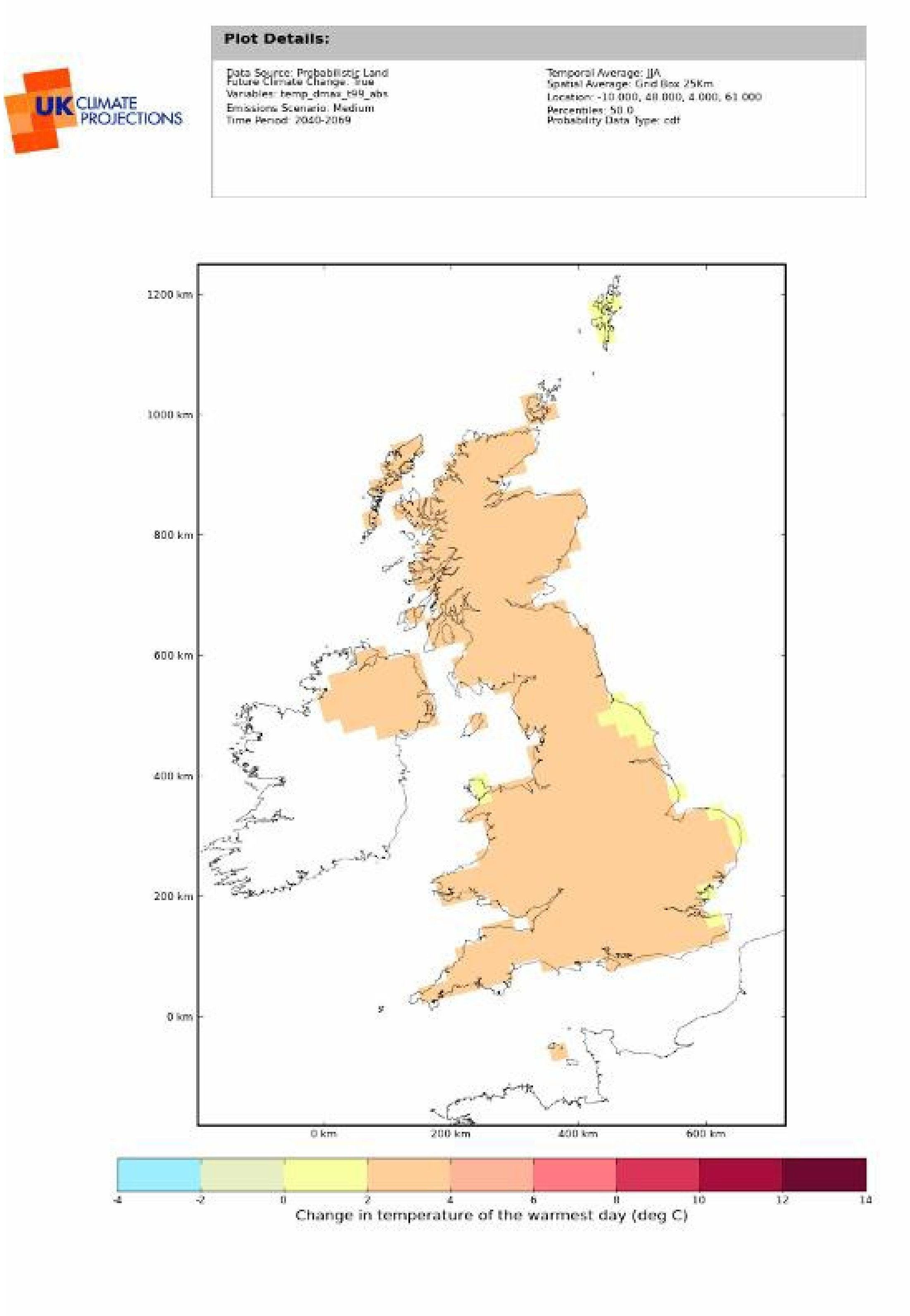


 Figure 3.4

3.2.2 Overview of Recent Publications

A number of recent publications for the highways industry have referred to the issues surrounding climate change these are:-

- Well Maintained Highways: Code of Practice Highway Maintenance Management (July 2005)
- Well Maintained Highways: Code of Practice Highway Maintenance Management (Complementary Guidance May 2009)
- Maintaining Pavements in a Changing Climate (June 2008)
- The effects of climate change on highway pavements and how to minimise them: Technical report PPR184 (October 2008)
- Sustainable Choice of Materials for Highway Works – A Guide for Local Authority Highway Engineers PPR 233 (June 2008)

More information on these publications can be found in appendix A1.

3.3 Carbon Mitigation and Carbon Calculators

3.3.1 Carbon Mitigation

The highways industry needs minimise its contribution towards the causes of climate change and support the UK Government's targets on greenhouse gas reductions. The industry needs to take positive action to assist the Government in meeting its greenhouse gas emission reduction targets and climate change commitments.

3.3.2 Carbon Emissions Life Cycle

This is the whole life cycle of a project from selection of design options, construction and maintenance. This will be achieved by using emissions reporting tools with the aim of minimising carbon emissions across the life cycle of the asset. For example by using a tool to consider the embodied carbon implications of design options, alternative materials specifications or infrastructure durability, project can be designed with lower carbon footprints.

3.3.3 Embodied Carbon

There are five main areas of carbon emissions in a typical construction project:-

- Project Management – the impact of managing the delivery of a project.
- Embodied Carbon – the impact of extraction, manufacture, production and assembly of the materials and components of a project.
- Construction – the impact of constructing the project on site.
- Operational – the impact of running and maintaining the project through its design life.
- Deconstruction – the impact of taking the components of the project apart for reuse, recycling or to landfill (Some of which may have a positive impact to the calculation).

Road pavements are a significant source of embodied carbon – when building major and minor roads and as maintenance activity such as overlay and patching work. The layers of the road can be rich in materials which have high embodied carbon content and there is a carbon implication from transport of materials to site and the energy expended laying them. Carbon calculation tools will allow the input of information about the pavement, the materials available and the transport and energy use on site to calculate the predicted embodied. It is hoped these tools will be used to estimate the whole life carbon emissions of pavements, allowing project and structural maintenance decisions to based not just on the immediate footprint of road construction but on its whole life emissions profile.

3.3.4 Questions for whole design life – To illustrate the above, a more carbon rich but durable road construction, which requires less frequent resurfacing through its design life, is expected to have an overall over lower lifetime carbon requirement than a pavement with less initial construction footprint but requiring more frequent maintenance intervention over time.

3.3.5 Carbon Calculators – Research jointly funded by the Highways Agency, Mineral Products Association and the Refined Bitumen Association has developed a carbon calculation tool specifically for asphalt pavements. Asphalt Pavement Embodied Carbon Tool (asPECT) see appendix A1 for more details.

3.3.6 Further information:- There are a number of other useful sources of information about Carbon calculation and mitigation including the following:-

- The UK Low Carbon Transition Plan (Appendix A1)
- Low Carbon Industrial Strategy (Appendix A1)
- Interim Advice Note 114/08 – Highways Agency Carbon Calculation and Reporting Requirements.
- Highways Agency – PartnerNET – Climate Change (Appendix A1)
- Transport Scotland's Carbon Management System (Appendix A1)

<u>3.4 Climate change risk assessment</u>

Introduction

The following section considers the approach to assessing the risks posed by climate change to local authorities and the evolved highways network.
There are significant sources of uncertainty surrounding future climate change and its impacts. It is important for local authorities to address and manage risk in such a way that reflects this uncertainty. Previously risk has generally been assessed on the basis of past climate, using (for example) extreme weather events as reference points for assessing the magnitude of possible future events. Although this approach is still important it is now also necessary to consider future scenarios for which there may be no precedent.

Aims

The aim is not to prescribe a method, but to provide broad guidance to help authorities develop a consistent approach to assessing climate change risks.
Authorities may have a comprehensive risk framework already in place; the approach described here could be adapted to fit in line with the authorities requirements. The authorities' approach should, however, generally incorporate the key elements highlighted.
It is important for decision makers to be aware that climate change risk assessment need not be carried out in isolation of other perceived risks to the highway network. The UKCIP risk report recommends climate and non-climate risks are assessed together. Doing so would enable an understanding of the potential interaction of climate and non-climate risks and contribute to a more holistic risk overview.

Links to useful resources and further reading to help local authorities develop robust climate change risk frameworks are provided at the end of this section.

The UKCIP09 (7) **projections are a key resource to aid this process. Use of their customisable output features is recommended to help local authorities understand how climate change risk may develop in their own respective**

Summary

Climate change presents risks to local authorities and the evolved highways network; these risks must be assessed and managed. This section presents a broad framework within which authorities can develop a consistent approach to assessing climate change risk in the context of their own situation.

There are five key stages within the framework:

1. Identify ‘exposure units’;
2. Identify climate ‘hazards’;
3. Assess climate change risk;
4. Employ risk management; and
5. Review assessment and update as required (ongoing).

Carrying out a climate change risk assessment will that incorporates these elements allow local authorities to formulate appropriate adaptation strategies. Resources could then be allocated to the areas/operations considered to be most at risk. This in turn could help minimise future risk to the network, posed by an uncertain climate future.

More information on climate change risk assessment can be found in appendix A1

<u>3.5</u> <u>Consequences for future Asset Management and Maintenance Planning</u>

3.5.1 The Asset Management System

The asset management system should include sufficient data to allow a risk assessment to be carried out to determine the most appropriate maintenance solution. Using the inspection/survey regimes and information from other sources (i.e. reports from members of the public) it may be possible to mitigate more extreme weather events. For example reacting quickly to first close sections of the highway and then treat to stabilise a melting road surface during hot weather. Quick action could first reduce the damage to the asset and then return the highway to full service, minimising the disruption to the highway user. It should also be possible to identify other locations which may be at risk from extreme weather events.

Feeding data into the asset management system allows more informed decision to be made and information on the effects of climate change should form part of the data. I.e. if a section of road surface is constantly melting, a more suitable treatment may be identified as part of the maintenance assessment (Resurfacing with a more suitable material, may be cheaper in a "whole life” view of this section of highway, rather than keep closing off and stabilising a melting surface).

3.5.2 Whole Life Infrastructure Asset Management

Whole life infrastructure asset management balances maintenance, repair, refurbishment, renewal, replacement and upgrade activities to optimise the long-term value of an asset. With the potential effects of climate change, the choices of materials available to an engineer, designer or contractor will also be affected. There will be a need increase the technical requirements and most likely, the cost of a given solution (i.e. using polymer-modified binders to replace “conventional” binders on surface dressing treatments). It will be become more and more important take a “whole life” view for maintenance solutions, by using an appropriately specified material the life of a particular treatment in a changing climate should be similar or extended to counter the reduced service life of those in current use and therefore the whole life cost could be the same or may be even cheaper than the conventional solution despite potentially having a higher initial cost.

Effective asset management planning will provide the means for authorities to understand the value and liability of their existing asset base and make the right strategic decisions, to ensure this base is exploited to its full potential and its value safeguarded for future generations.

3.5.3 Emergencies Plan and Severe Weather Events

3.5.3.1 Emergencies Plan

Local Highway Authority networks are mature and comprise an evolved interlinked combination of carriageways, footways and cycleways supplemented by a public rights of way network mainly comprising footpaths and bridleways. Although carriageways and footways are generally surfaced, some local authorities also maintain unsurfaced carriageways.

The primary objective of the transport infrastructure network is to link the centres of population including remote rural areas. A fundamental principle of network management is to provide at least one link to the edge of the network and to interface with non- publicly maintained transport links.

The effects of Climate Change will present more extensive challenges to Local Authorities to maintain their highway network without closure or catastrophic loss of parts of the network. It is probable that increased rainfall will result is a higher risk due to flooding compared with higher temperatures. Recent flooding events in Gloucester, Cockermouth and Workington indicate the temporary and more permanent consequences of loss of the network and the consequential direct effect of the general public.

The possibility of temporary closure of parts of the network due to excessive temperatures and unsafe surface course condition for use by the travelling public is also perceived. Surface dressed roads are most at risk due to this climatic condition.

It is therefore recommended that Local Highway Authorities plan for the consequences of loss of network by carrying out risk assessments for all types of surface water flooding and for parts of the network most at risk from elevated temperatures. Emphasis should be placed on safeguarding the resilience of one route where several routes exist between populated locations.

3.5.3.2 Severe Weather Events

It is very difficult to plan to mitigate for a severe weather event as part of an asset management system, however geographical areas such as river flood plains, coastal areas etc. are more susceptible to their effects and construction methods such as Sustainable Drainage Systems, Permeable Pavements etc. could be considered as a first choice design solution.

Authorities should establish, in consultation with others, including the emergency services and relevant agencies, a severe weather emergencies plan. This should contain operational plans and procedures to enable timely and effective action by the highway maintenance service to mitigate the effects on the highway network.

With the prediction that the UK can expect drier, hotter summers, milder wetter winters and more extreme rainfall events due to climate change; authorities should consider the robustness of their emergencies plans. Using tools like the *Business Continuity Management Process* (see below) to identify the potential impacts that threaten their services.

Useful Information:-

- Framework for Highway Asset Management – County Surveyors Society
- Well Maintained Highways – Code of Practice for Highway Maintenance Management – Roads Liaison Group

- Maintaining a Vital Asset
- Whole-life infrastructure asset management: good practice guide for civil infrastructure - CIRIA C677

3.6 Organisational Change to keep the public informed

3.6.1 Business Continuity Management

The main purpose of Business Continuity Management [BCM] is to ensure that the organisation/authority has a response to major disruptions that threaten its services to the public or even its survival.
Organisations have statutory and regulatory requirements either specifically for BCM or more generally for 'risk management' as part of their corporate governance requirement. An appropriate BCM plan will satisfy both the specific requirements and contribute both a response to specific risks and to the overall 'risk awareness' of an organisation. However the primary driver for BCM should always be that it is undertaken because it adds value to an organisation and the products and services it delivers rather than because of governance or regulatory considerations.

Floods in Cumbria – November 2009

"The unprecedented deluge, described by the Environment Secretary, Hilary Benn, as a "once in a thousand year event", destroyed flood defences built only four years ago and swamped scoresof homes in Cockermouth and nearby Workington".

Daily Telegraph 20th Nov 2009

Plate 3.1 Lorton Bridge, Cockermouth, Cumbria

During the flooding in West Cumbria Nov 2009 several bridges were destroyed cutting off many communities for a number of days/weeks. This extreme event not only affected the people and businesses flooded out, but the wider community in West Cumbria and beyond. With bridges washed away the highway network was unable to function throughout a wide geographical area affecting the whole infrastructure and impacting on all the authorities' services from schools to waste collection.

Damage to the highway network in West Cumbria as a result of the November 2009 flooding included the destruction of, or severe structural damage to 8 bridges, structural damage to a further 6 bridges and major carriageway repairs at 10 locations. Minor carriageway repairs were required at locations all over the County and the Rights of Way Network suffered the loss of a number of footbridges and serious damage to others. In the aftermath of the event 43 bridges were monitored until permanent repairs could be completed and Geotechnical Engineers monitored a number of features considered to be potentially instable until further investigations could take place.

3.7 Tidal and fluvial flood mapping and risks

3.7.1 Introduction

Flooding poses a major risk to the UK's built environment and infrastructure. Major floods in 2005, 2007 and more recently in 2009 have demonstrated the damage and disruption flooding can cause, with associated costs amounting to hundreds of millions of pounds.

The following section outlines key sources of flood risk in the UK, how climate change may increase this risk, and how local highways authorities can help mitigate risk to the evolved highway network through use of flood maps, screening of past flood events and use of climate change scenarios.

Links to useful resources and further information are provided at the end of the section.

3.7.2 Flood risk sources

Flood risk in the UK can arise from a number of sources including:

- **Tidal/coastal flooding**

A combination of low pressure, storm surges and high tides can cause coastal inundation – sometimes breaching existing flood defences.

- **Fluvial flooding**

This refers to flooding from rivers and streams (watercourses). It happens when a watercourse is overwhelmed by drainage/runoff from surrounding land and bursts its banks.

- **Groundwater flooding**

This occurs when groundwater levels increase and rise above ground level; it is most common where aquifers exist.

- **Flash flooding**

Prolonged, intense rainfall can sometimes overwhelm the capacity of the surrounding land, watercourses, drains/sewers etc and cause flooding to occur quickly.

3.7.3 Flooding and climate change

The link between climate change and flood risk is not a straightforward one. Furthermore, there are a number of factors in addition to climate which influence the frequency and magnitude of flood events. However, the Foresight Future Flooding (2004) (10) report for the government identified climate change as an important factor contributing to increased flood risk in the UK by 2100. Sea-level rise and the projected increase in the frequency and intensity of (mainly winter) rainfall events and storms are key climate change factors influencing this increased risk.
It is therefore considered necessary for Highways Authorities to consider flood risk both in its own right and also as part of a wider climate change/highways network risk assessment.

3.7.4 Flood risk management

Any/all of the types of flooding described above may affect the evolved highways network. Risks will, however, vary across the network depending on a number of factors including:

- location;
- local topography;
- local drainage infrastructure;
- local land use patterns;
- local climate/weather patterns (season);
- existing flood defences and management measures.

Plate 3.2 Rothersyke Cumbria –

Local road 2m from the edge of the top of slip. Many years of erosion of the toe of the slope culminated in a collapse in January 2006 re [Road is closed with diversion in place].

Plate 3.3 Wetheral, Cumbria – toe of slope eroded by the River Eden causing failure afterhigh river levels in January 2006

Coastal sections of the network (for example) will obviously be at greater risk of coastal flood (or erosion) damage; they may also be at risk from any or all of the other flood types.

Plate 3.4 B5300 Dubmill Point, Cumbria – collapse due to coastal erosion and inundation from high tides in storm conditions

It is therefore important for local authorities to understand which parts of the network are at risk from the range of flood types.

3.7.5 Flood mapping

Flood mapping is used to describe the extent and return periods of different flood types over a given area. Figure 1 shows a typical flood map. The return period refers to the time interval between the recurrences of flood events. For example, the Environment Agency national rivers flood map shows data for floods with a 1 in 100 (1%) or greater chance of occurring annually – or put another way floods with an expected return period of once every 100 years.

Figure 3.5: Example flood map

Existing flood maps (See appendix A1)

3.7.5.1 Flood mapping: local authorities

The recent Flood and Water Management Act 2010 (discussed further in section 3.8) requires key county and unitary local authorities in England and Wales to carry out comprehensive local flood/asset mapping and risk assessments. This includes risk from ordinary water courses (smaller streams and rivers), groundwater and surface run-off. Lead local authorities will co-ordinate relevant partners to produce up to date county flood-risk maps and assessments by December 2013.

As an integral part of the local drainage infrastructure the evolved (and strategic) highways network will feature in these maps and asset registers which will provide a useful resource to help manage flood risk across the network. Network operators will most likely be required to provide input into the process.

3.7.6 Previous floods: screening approach

It may be prudent for local authorities (particularly those for whom floods have been a problem in the past) to adopt a screening approach to past/current flood events on the network.

Broadly speaking this approach would entail recording and presenting basic graphical (possibly GIS) or other data relating to past flood events the significance of which was above a pre-determined threshold. A record of flood 'hot spots' could then be developed and used to identify the areas likely to be most at risk in the future. This in turn can help target maintenance and resource allocation.

The screening approach would be additional to the flood risk maps produced by national agencies or the lead local authorities under the Flood and Water Management Act 2010.

3.7.7 UKCIP Tools

The UKCP09 (7) scenarios and tools are a useful resource to help local authorities assess where flood risk may increase as a result of (for example) sea level rise and more frequent and intense precipitation events. Regional variations in climate change effects means that climate using scenarios and projections relevant to the local authority's area will be necessary.

The UKCP09 (and subsequent) climate scenarios should be used in conjunction with existing and future flood risk maps, assessments and data to help ascertain how and where climate change may exacerbate flood risk across the network.

For resources and further information (See appendix A1)

3.7.8 Summary

Flooding poses a risk to buildings and infrastructure in the UK as major floods over the last few years have demonstrated. Flood risk can arise from a number of sources; future climate change will likely increase this risk, predominantly through sea level rise and more frequent intense precipitation events.

It is important for local highway authorities to identify and manage sources of flood risk in their area. Flood mapping can be employed to show the location, extent and likelihood of flooding which may affect the evolved highways network in a given area. National flood maps are hosted by the UK environmental protection agencies. The Flood and Water Management Act 2010 requires local authorities to co-ordinate flood risk assessments and produce local flood maps. The evolved highways network will feature in these maps as part of the local drainage infrastructure.

It may also be prudent for local highways authorities to adopt an additional screening approach to record and monitor previous flood events on their part of the network. Additional tools and resources are highlighted to help local highways authorities assess flood risk and how this may increase with future climate change.

3.8 Flood and Water Management Act 2010 (9)

The following section outlines the nature and key aims of the Flood and Water Management Act 2010 (henceforth referred to as "the Act").
The Act, which applies to England and Wales, updates the approach to flood risk and water management. It is designed in part to implement recommendations made in the Pitt Review of the 2007 floods.

Key aims of the Act:

- To increase resilience and reduce flood risk
- To clarify organisational responsibility for flood risk management
- To improve drought/water shortage management
- To account for climate change risks/effects in relation to flood/water management (such as increased rainfall, sea level rise and heat waves)
- To improve water quality and promote sustainable water management

3.8.1 The Act and Highways

Local flood risk management has previously been undertaken by a variety of different bodies that assessed risk to their own part of the local drainage infrastructure. The Act requires a strategic LLFA (Lead Local Flood Authorities)-led partnership approach to conduct holistic flood risk assessments that consider all relevant assets – including the strategic and evolved highways networks. This will necessitate adoption of a flood/asset mapping approach to identify and monitor vulnerable parts of the road network within the LLFA's area. To this end evolved highways flood risk assessments will contribute to a wider local flood risk assessment and management strategy. As such, highways decision makers/technical staff will likely be required to work closely with relevant partners – both internal and external to the LLAF(Lead Local Flood Authorities) – to assess and manage flood risks.

3.8.2 Sustainable Drainage Systems (SUDS)

This is an important aspect of the Act and relates to new developments (including roads), which are required to incorporate SUDS to increase flood resilience and improve and water quality. In addition the Act requires the following:

- Introduction of National Standards in relation to (sustainable) surface water drainage system design, construction and operation; and
- A SUDS approval system to ensure that National Standards are adhered to and to allow developers to demonstrate conformity before connecting to public sewers.

3.8.3 Summary

The Flood and Water Management Act 2010 updates the approach to flood risk and water management in England and Wales. Key principle aims of the act in the context of flooding are to increase flood resilience and clarify responsibility for flood risk management.

Under the Act the Environment Agency will develop standard risk management methods, issue a national flood risk strategy and take responsibility for ‘main’ river and coastal flooding and defence.
Key local authorities will become Lead Local Flood Authorities (LLFAs) and co-ordinate relevant local partners to carry out local flood risk assessments and flood/asset mapping. Highways authorities will be involved in this process as all parts of the local drainage infrastructure – including the evolved and strategic highways networks - are included in an holistic risk assessment/flood map.
Sustainable Drainage Systems (SUDS) are required in all new developments; national standards relating to SUDS will be introduced and compliance measured.
For resources and further information (See appendix A1)

3.9 References

1. Department of Energy and Climate Change (DECC) http://www.decc.gov.uk/

2. The Climate Change Act 2008
http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1

3. The Energy Act 2008 http://www.opsi.gov.uk/acts/acts2008/ukpga_20080032_en_1

4. The Planning Act 2008 http://www.opsi.gov.uk/acts/acts2008/ukpga_20080029_en_1

5. Climate Change (Scotland) Act 2009
http://www.opsi.gov.uk/legislation/scotland/acts2009/asp_20090012_en_1

6. UK Low Carbon Transition Plan
http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx

7. UK Climate Impacts Programme (UKCIP) http://www.ukcip.org.uk/index.php

8. Foresight Future Flooding (2004) Report Available at:
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Climate Change and Evolved Pavements
Chapter 4 - Geotechnical and Drainage Aspects of Evolved Pavements

4.1 Introduction

4.1.1 Scope

This climate change project is intended to relate to “Evolved” roads which can be considered to be rural roads, estate roads and local distributor roads. It is therefore not related to management of trunk roads and motorway networks although there will be similarities in the issues facing the more heavily trafficked major roads[1 & 2]. Whilst Local Authority Highways Departments may have wider involvements the document is related to highways and so will not cover other areas such as coastal and river flood defences or desiccation of landfill clay capping layers. The information is however likely to be of interest to a range of LA engineers including highway engineers, drainage engineers and emergency planners. There may also be some interest from a legal perspective where climate change effects affect risks including landslips, , flooding and damage to bridges and walls and effects tree root propagation on buildings that may carry liability or worse still corporate manslaughter risks.

Climate change, with the expected changes to drier summers and wetter and warmer winters, will generally act to exacerbate geotechnical problems experienced by current highways rather than introduce new problems. Expected changes to drier summers and wetter and warmer winters will therefore reduce the frequency of snow related issues. Frost related issues are therefore not considered to increase as a result of climate change and so will not be considered further in this chapter.

The varied geology of Kent with stiff overconsolidated clays, soft Alluvium, weak rocks and a variety of sand and silts is a good starting point but other local authorities will have more dominant geological effects associated with other geological settings such as hard rocks, soft peat bogs, older un-engineered fills, Glacial Tills and Moraines. It is clearly important to understand the geological setting at all sites. The importance of adequate site investigations is well documented although a risk based approach can initially be developed based upon Desk Studies that embrace geological maps, memoirs and well records together with local knowledge and site specific data sources. There are numerous publications on site investigation that describe these preliminary sources of site investigation and later stages of more detailed site investigation[10, 11, 12].

The importance of engaging with experienced geotechnical engineers, ideally with local knowledge to manage future risks associated with highways related earthworks, drainage, structures and road pavement support cannot be overemphasised.

There is also an important role to be played by arboroculturists in relation to vegetation risks. Vegetation can affect the engineering performance of infrastructure earthworks through changes in slope hydrology and mechanical reinforcement by roots and therefore will form a key part of any geotechnical review related to climate change. The effects of vegetation can result in both beneficial and detrimental effects on the performance and sustainability of infrastructure earthworks, and can:

- mechanically reinforce slopes, preventing failure (reducing remedial requirements and increasing safety);
- increase seasonal slope movements (requiring additional mitigation and reducing serviceability);
- increase maintenance costs (because of increased vegetation management);
- increase risk of fire
- improve wildlife habitats; and
- increase or decrease the effects of surface water runoff during extreme rainfall events.

At all stages of managing the effects of climate change, health and safety aspects must be carefully considered through the construction phase to the after use of the site.

4.1.2 Role of Infrastructure Vegetation

The soft estate within infrastructure corridors performs a number of roles. Some of these are intentional; some are purely a function of the structure and type of vegetation involved. On ‘evolved’ roads, most vegetation has developed naturally and is generally related to the surrounding vegetation patterns and land cover.

Specific landscape functions include:-
(a) <u>Structural</u> (Root reinforcement and reduced run-off)
Herbaceous vegetation performs an important role in stabilizing topsoil on slopes, including steep verges and hedge banks. This role is particularly important on lighter more friable soils that would otherwise be washed out by heavy rain. Plant roots help to bind the soils together and thus reduce the impact of weathering due to frost and rain. The presence of vegetation slows down surface water runoff, thus reducing its potential impact on adjacent features. As ‘evolved’ roads often have slopes steeper than would be constructed today, the structural function is of even greater importance. In more shady, wooded areas, and on weak rocks such as chalk and sandstones, herbaceous vegetation cover tends to be more sparse, and the effect is less. However, roots of larger shrubs and trees can also act to bind together and stabilise some earthworks slopes.
(b) <u>Amenity</u> (Visual improvement and screening)
Roadside vegetation is an important and distinctive feature in most landscapes, especially in lowland areas where tree lined highways form an important framework within the overall pattern of the landscape. At the local scale trees, shrubs and highway hedgerows provide screening of highway users from local properties. They also contribute to the enjoyment of road users by providing visual and other sensory interest. This important function may come under pressure from stress on vegetation arising from climate change.
(c) <u>Natural Resource</u> (Wildlife habitat and filtering pollution)
Roadside vegetation of all types has an important function as a wildlife resource. It provides both habitat and corridors for movement between more widely spaced islands of habitat, such as woodlands and water bodies. This function will increase in importance as a result of climate change, with species needing to move in response to changing conditions. Vegetation within highway water courses also fulfils an important role in attenuating water flow and helping to trap solid contaminants washed from the road surface.

Roadside corridors have been described as ‘novel ecosystem’, where new combinations of species occur. They also act as habitat corridors, allowing the dispersal of seeds and the movement of plants and animals between habitats. Engineering condition (i.e. compaction) and climate (aspect) will affect species composition on engineered slopes and therefore changing the engineering conditions of engineered slopes in response to climate change and climate change itself will both have an effect on biodiversity as well as slope sustainability[66] but biodiversity and wildlife habitat is considered to be outside the scope of this report.

<u>4.2</u> <u>Impact of climate change on geotechnics</u>

4.2.1 General

The impact of drier summers and wetter winters will often relate to more extreme versions of the geotechnical effects we currently experience and so the main issues considered to date are principally increases in the following:-

- Soil Desiccation
- Surface water run-off
- Landscape stress

(a) **Soil Desiccation in summer**

- increased soil moisture loss from greater tree root growth [43]l exacerbated by dealing with increased carbon dioxide levels
- footway cracking (particularly near trees)
- edge of carriageway cracking [42]
- increased maintenance of Statutory Undertakers mains/drains
- shallow earthworks and ditch slope failures/sloughing on subsequent wetting up in winter or as a result of flash storms
- desiccation of deeper peat layers due to groundwater lowering[45]
- biodegradation of near surface peat layers (exacerbated by ploughing) [47]
- rockfalls and local spalling induced by root wedging

(b) **Surface water run-off principally in winter**

- flooding resulting in pipe surcharging and subgrade and verge softening
- flooding of flood plains, flood relief areas, road infrastructure, properties[60]
- subgrade softening/pumping/saturation[36]
- triggering of landslips/flowslides[4]
- increased pollutant loading of first flush/sewers surcharging/bypass separators
- clogging of drainage systems from increased sediment/debris loadings
- local erosion of earthworks slopes
- scour around foundations in watercourses[40]
- large scale debris (trees/cars etc) blocking culverts and other health and safety risks[76]
- subsidence (solution features/mines etc) [53]

(c) **Landscape stress**
- increased tree root propagation/root wedging
- Increased levels of CO_2 giving rise to increased plant growth by up to 50% (although this effect will decrease with time if levels remain high);
- earlier flowering and longer growing seasons in some species;
- increased frost damage when frosts occur;
- increased water stress on plants in summer, possibly acting to counteract increased growth due to other factors, and maybe leading to increased plant losses;
- increased virulence of pests and disease, including spread of alien pests from the European mainland;
- increased competition from ‘weeds’;
- increased potential for garden ‘escapes’ to become problem ‘weeds’;
- reduced effect of chemical weed control in hot, dry summers;
- lawns and grass swards will become more difficult to maintain due to the effect of drought;
- Increased risk of fire in dry vegetation during summer.

4.2.2.Ground related effects – TOO DRY

(a) **Near surface desiccation**

The shrinkability of many cohesive soils[8] can give rise to shrinkage cracks during prolonged periods of dry weather similar to those illustrated in Plates 1 with the effects more pronounced on the more highly plastic clays. This is confirmed by the increase in house subsidence claims following prolonged periods of dry weather illustrated in Plate 2[44].

Plates 1: Desiccation cracks in a clayey sandy silt and an overconsolidated clay

The effects of such desiccation will be more pronounced on shallower footway construction than on thicker road pavements as illustrated in Plates 3.

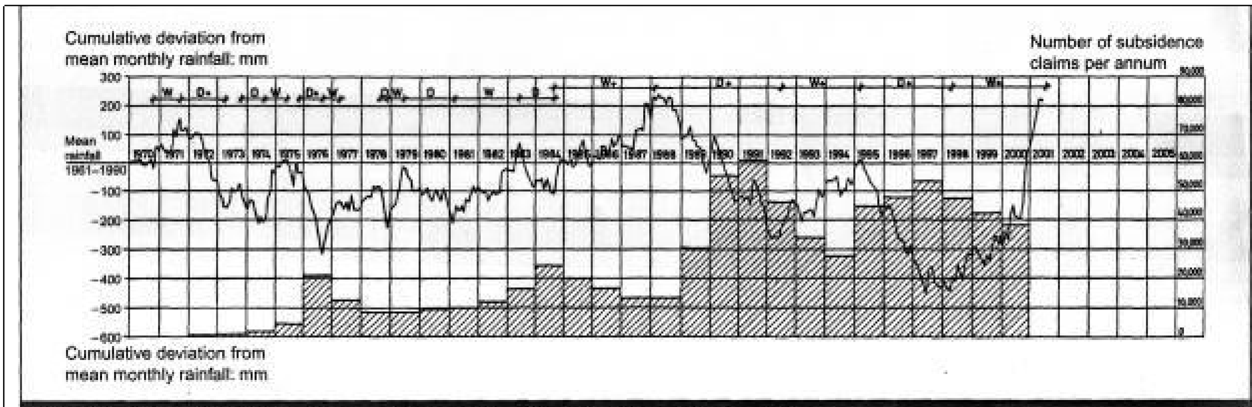


Fig. 1. Relationship between monthly rainfall and annual subsidence claims

Plate 2: Increased subsidence claims in prolonged dry periods[44]

Plates 3: Footway desiccation cracks

Vegetation type has a fundamental influence on the risk of excess slope deformation and instability. Different species provide different levels of mechanical support through root strength and spatial distribution and by extracting water over different zones of influence**[66]** from shallow rooting wildflowers and grasses to deeper rooting high water demand trees. Large mature trees provide valuable screening and aesthetic benefits. However, if such trees are classified as high water demand then the impacts of deformation due to shrinkage and swelling and consequent strain softening are likely to be significant**[66]**. Mature trees (those higher than 25m) can influence pore pressure to depths of 5m and radial distances of at least the height of the tree. Roots are generally capable of generating suctions up to the permanent wilting point, pF 4, equivalent to a suction of 1500kPa**[71]**. Conversely low water demand trees are likely to have minor impact on slope deformation, but these varieties tend to make less effective screens as water demand is in part related to evapotranspiration, which is in turn related to leaf area and thus the mass of the tree**[65]**.

Trees can help resist or aid slope instability depending on their location along a potential slip surface. The risk of excessive seasonal slope deformation is higher when high water demand trees are located close to the crest of the embankment, while the risk of slope instability is higher for shallow rooting grass covered slopes than those covered by deeper rooted trees[66]. Trees located at the toe of a potential landslip could add 10% to the factor of safety[73]. In addition, vegetation may provide a detrimental surcharge effect due to additional loading, depending on the type and position of the vegetation on the slope, which can be accompanied by an overturning moment for tall trees loaded by wind forces. Unstable or poorly anchored vegetation, particularly at the top of a steep slope may pose a significant safety hazard to the transport route below as well as hydrological effects[66] but these slope instability risks are generally near surface.

Desiccation is also undesirable in highway earthworks slopes with deep desiccation cracks shown in Plate 11[56] providing ready pathways for later rainfall to access the near surface layers of the soil with the risks of near surface instability of the saturated near surface layer of soil that is discussed in more detail in the later section relating to the impact of wetter winters.

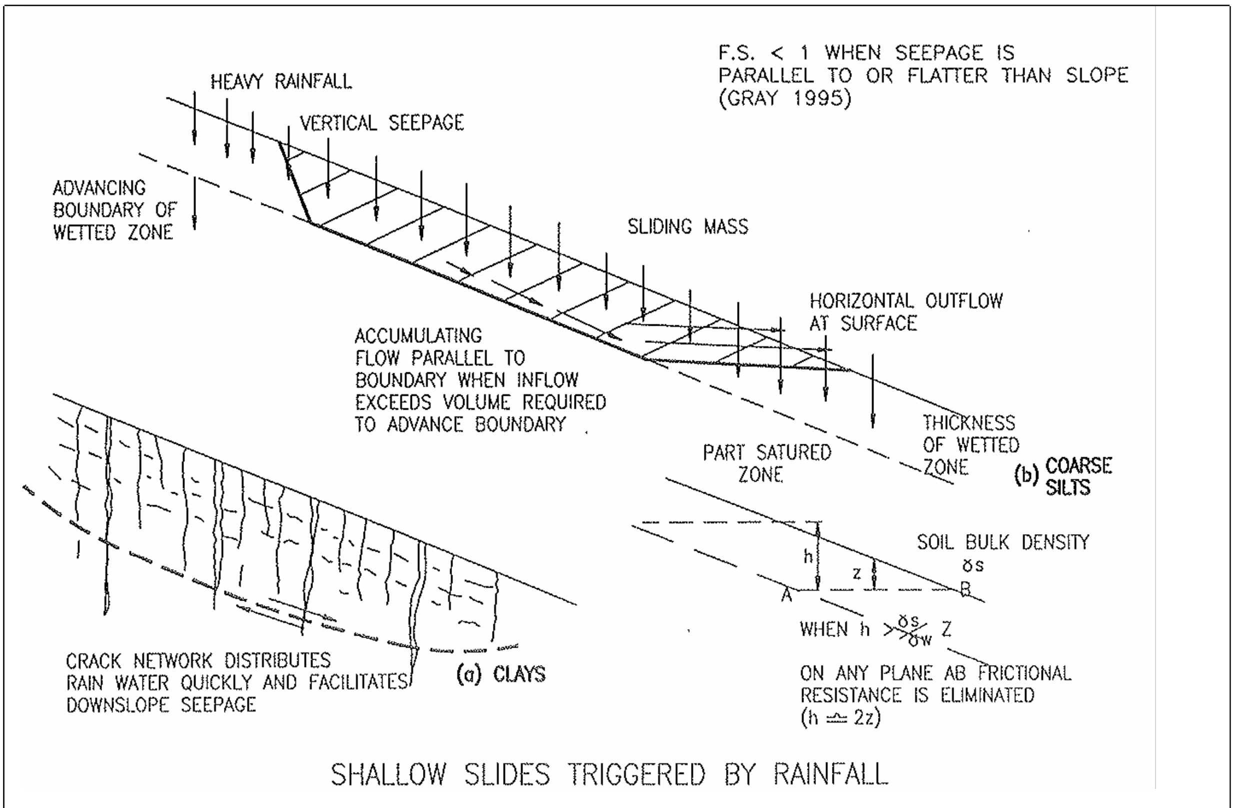


Plate 11: Desiccation pathways to shallow slope failures[56]

The hotter drier summers predicted as a result of climate change may produce higher water deficits leading to more aggressive root action with deeper penetration and wider spread. On clay soils, this will increase desiccation at lower levels, leading to deeper cracking and potential for greater water penetration in autumn/winter. This could lead to greater impact on formation levels of the highway. One solution may therefore be to use less aggressive rooting species.

The work of Freeman et al[43] has clearly shown desiccation is exacerbated by tree roots as shown by the depth and magnitude of shrinkage movements in Plate 12 next to trees on London Clay with carriageway distress caused by adjacent trees on another site shown in Plate 14. It is also interesting to note that near surface ground movements were recorded well away from the trees in Plate 13 illustrating that even grass has the potential to exacerbate desiccation effects.

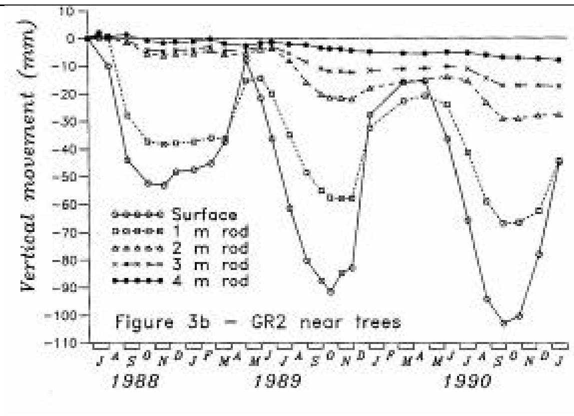
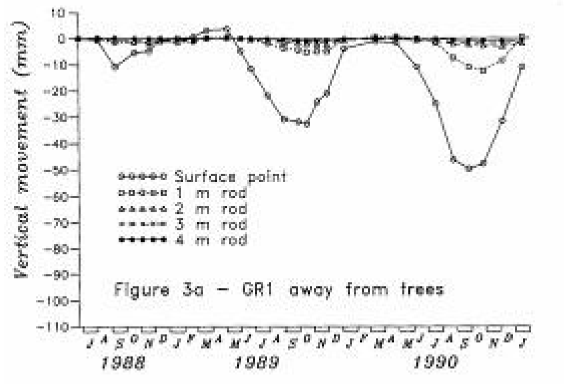
	

Plate 12: Tree desiccation potential on shrinkable clay[43]	**Plate 13: Grass desiccation potential on shrinkable clay[43]**

Plate 14: Tree root desiccation

Plate 15: Mains/drains leakage risks increased

Plate 15 also acts as a reminder that near surface desiccation increase the risk of leakage from drains and water mains which can also be affected by root propagation. Cast iron mains are particularly sensitive to ground movements and replacement with more flexible plastic pipes may need to be considered in some instances.

Moisture conditions beneath highways are often complex as shown in Plate 4[65] but provided the surfacing is sealed and the subgrade adequately drained the majority of the carriageway beneath bound highway surfacing is at an equilibrium moisture content and not affected by the seasonal changes in moisture content illustrated in Plate 5[64]. However as surface cracks appear, as a result of thermal or traffic stresses, considerable amounts of water can enter the pavement. The extent to which the subgrade and formation is affected will depend upon the permeability of the sub base, effectiveness of sub surface drainage and moisture susceptibility of subgrade soils

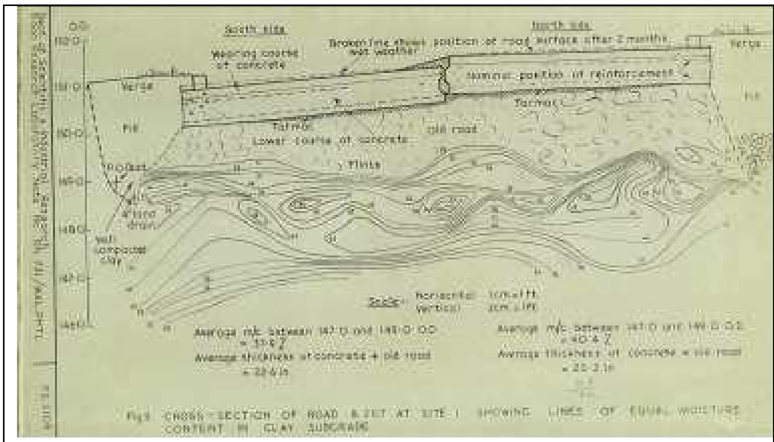


Plate 4: Moisture content profiles beneath a road[65]

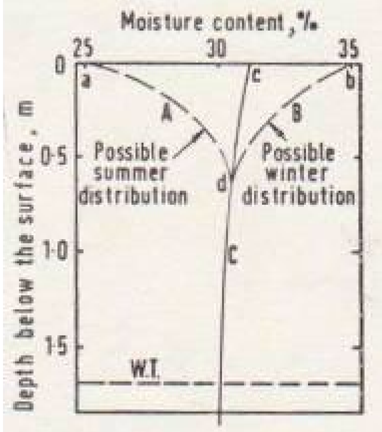


Plate 5: Zone of seasonal moisture fluctuation[64]

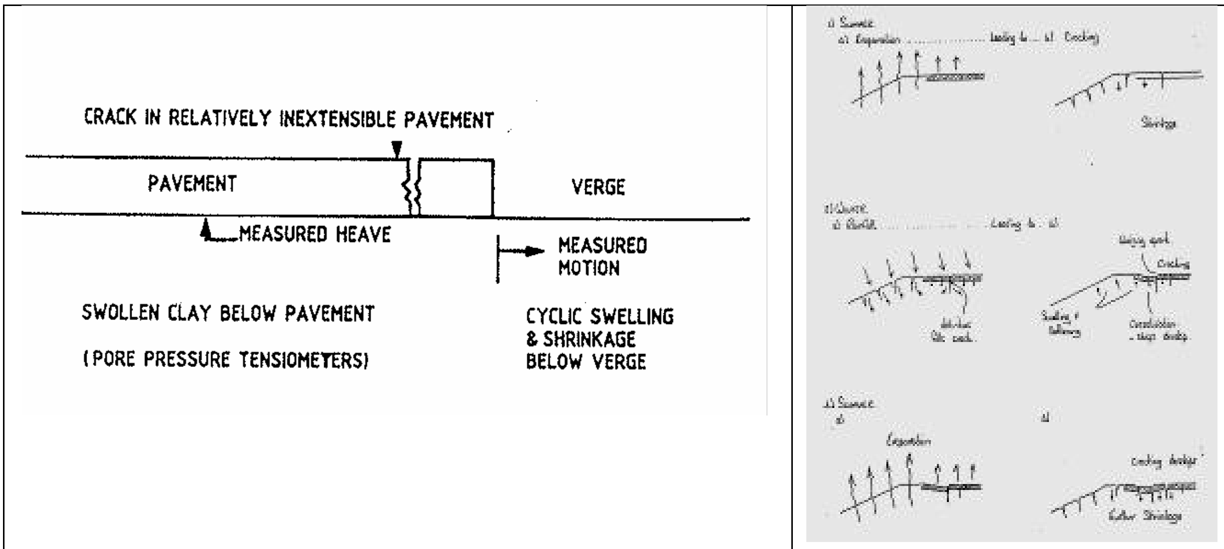
Whilst moisture conditions beneath road pavements are difficult to predict with certainty Plate 5 illustrates that the road edges and verges will be particularly vulnerable to seasonal variations in moisture and are likely to be significantly wetter than beneath the bound carriageway in the winter moths and drier in the summer months. These seasonal changes in moisture content in the verge areas can give rise to longitudinal edge cracking in more highly plastic clays as illustrated in Plates 6 to 9.

Plates 6 and 7: Longitudinal carriageway cracking on a clay soil

Plates 8 and 9: Carriageway cracking and step on clay soil

The failure mechanism producing this effect is described by Dagg and Russam[42] and is illustrated in Plate 10. The mechanism described by Dagg and Russam suggested that covering of a high plasticity clay stops evaporation occurring allowing clay to absorb moisture and swell where covered by sealed bound road pavement layers but the edge areas still experiencing shrink/swell due to seasonal effects reducing lateral restraint which together with the swelling further into the carriageway could produce a longitudinal crack. Sketches from Cambridgeshire CC[47] in Plate 10 independently suggest a similar form of pavement distress. Once swelling has occurred and equilibrium conditions have been reached then further swelling should stop although water reaching the subgrade through open cracks could have some effect. However increased depths of desiccation produced by climate change will increase the movements in the verge and so could cause further edge distress with case histories from Cambridge, Lancashire, Kent, Kenya and Australia generally supporting this view.

Plates 8 and 9 show a step across the longitudinal crack perhaps further illustrating swelling on the inner side of the carriageway at this location where it is in a deeper cutting so greater swelling might be expected from the more overconsolidated clays at depth. There is an inter-relationship with edge of carriageway drainage which also needs to be considered on a site specific basis.



Plates 10: Mechanism for longitudinal edge cracking (Dagg[42] /Cambridge CC[47])

As the plates show the problem of soil desiccation and the effects of vegetation on slopes and road construction are already apparent and will be exacerbated by the effects of climate change

Engineers planning new schemes must use a landscape expert with a brief to consider climate change when selecting planting regimes and species.They should also plan to use of less cohesive subsoils on the edges of embankments so they are protected by a granular layer as well as topsoil.

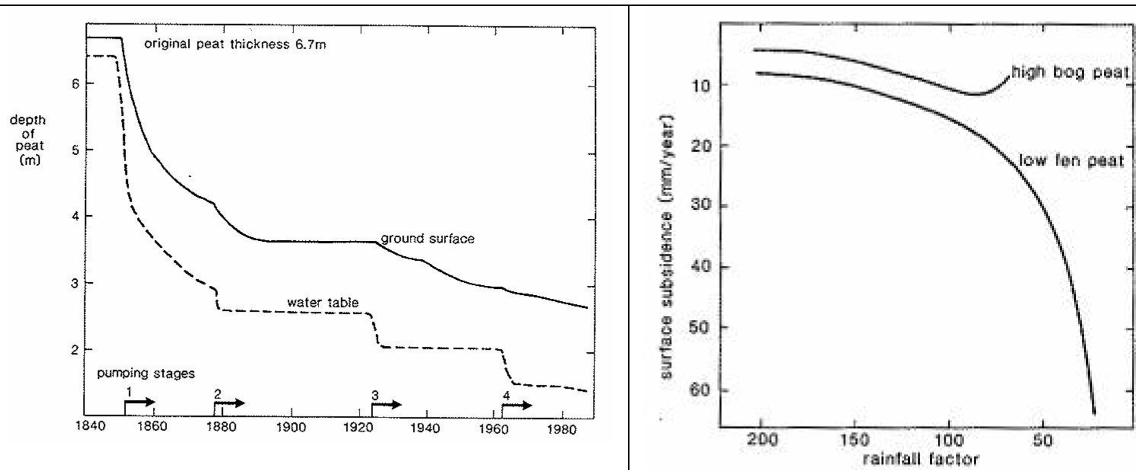
On existing schemes where these defects occur the symptom should be treated but also the vegetation changed to the use of less aggressive rooting species that will bind the surface, and not recreate the problem in the future; the use of planting pits and root barriers to contain roots should be considered.

(b) **Deeper desiccation**

Prolonged dry periods of weather can result in groundwater lowering which can result in desiccation related shrinkage cracks in peat deposits as illustrated in Plates 16. Plates 17[45] illustrate that the magnitude of movements can be much greater than the desiccation produced by near surface clay shrinkage and confirms that greater movements occur where rainfall is reduced.

Plates 16: Carriageway distress due to peat desiccation

This is a particular problem for the Moss roads in Lancashire and the peat bogs in Somerset, Norfolk and Ireland. Pavement stability is also not helped by the biodegradable nature of the surface layers of these organic soils and associated ploughing up of deeper layers which can result in lowering of the adjacent land as the materials degrade. As the fields lower the roads are then effectively being supported on an increasing height of embankment formed of similar organic materials which are vulnerable to slope instability as well as settlement. As the adjacent fields lower then the increased height of the formed road embankment within the existing highway boundary also results in steeper sideslopes that will further increase these slope stability and pavement subsidence risks[47].



Plates 17: Peat desiccation settlements related to water table and rainfall variations[45]

Engineers should consider replenishment of the water shortfall by appropriate drainage design which will be difficult to achieve and is likely to be a long term effect.
To cure the symptom, the use of tensile Geogrids has proved effective to prevent transmission of surface cracking.
The stability of critical sideslopes should be assessed and slope treatments proposed where necessary.

Increased variations of pore water pressure due to vegetation could also cause cyclic softening of the soil and provoke later slope failure due to high water pressures[66]. During the winter the suctions may not be maintained due to the higher levels of precipitation combined with low evapotranspiration principally affecting the near surface layers. Where mature, high water demand vegetation is present, some suctions will remain at depths of 3 to 4m which may help resist deeper slope instability. Removal of such vegetation will remove the winter residual suction or 'persistent pore water pressure deficit' that is aiding stability[66]. Where the suction is preserved during the winter as a remnant suction, studies have suggested the number of seasonal cycles to slope failure is greater[74].

The transient changes in pore water pressure exacerbated by the presence of high water demand vegetation will lead to seasonal cyclic loading of the soil in the embankment, which may provoke cyclically induced volumetric change or 'ratchetting' to a residual state. Physical modelling of embankments suggests that this seasonal damage is irreversible and may contribute to progressive failure. Hydrological changes will be beneficial if suctions are maintained throughout the year (likely with high water demand vegetation and intermediate permeability, such as found in silty soils), but may be detrimental if cyclic pore water pressure changes provoke progressive failure[66].

The problem may be resolved by the removal of deep rooting and high water demand trees and substitution with more appropriate species; this will require attention to PR as trees generate considerable political interest.
Alternatively root barriers may be effective but consideration should be given to the potential effect on the tree which may already be suffering from moisture deficiency.
To cure the symptom the use of high strength tensile reinforcement of carriageway layers (eg geosynthetics) may be effective if properly designed.

(c) **Increased root wedging**

Fine vegetation has a beneficial effect in binding the surface of a soil together and reducing the effects of surface erosion. The root reinforcement and desiccation effects of the dense, but small scale vegetation will generally also enhance stability as shown in Plate 20.

Thicker roots from larger species can however act to force open joints in fissured deposits below which in the case of steep cliff faces in weak rocks can reduce stability and increase weathering effects. Mature trees and heavy creepers can also topple or drag weak blocks of soil and rock from steep cliff faces and wind loading can also affect stability of the more mature vegetation.

Plate 18: Chalk fall from south facing cliff fall due to local root wedging from crest line trees

Plate 19: Long roots exposed

On chalk/rock slopes and cliffs, deeper rooting would increase fissuring at greater depth, leading to greater instability of rock faces. This would also result in increased erosion and larger pathways for water ingress along fissures, leading to greater potential for frost action and root wedging. There will be an increased need for active management of woody vegetation close to rock faces.

Experiences with the chalk fall from the south facing cliff face in Plate 18 highlighted the influence of tree root growth along the fissure planes in the Upper Chalk. Root wedging was considered to be more dominant than frost wedging for the south facing cliff in causing the toppling style failure in Plates 18 and 19. The site of Plate 19 showed that the length of some of the roots seeking moisture extended more than half of the exposed 28 metre high cliff face which was greater than might have been expected. The trees at the crest of the slope were therefore considered to be a major source of the instability.

Cyclic vegetation management of the existing vegetation is therefore recommended in conjunction with other cliff strengthening works.
Future planting at the crest of these slopes should also therefore be limited to low height shrubs with periodic removal of any self seeding larger tree species.
Warning signs and stand off zones should be considered for high risk areas

(d) **Vegetation stress/loss of vegetation**

The benefits of vegetation in enhancing slope stability are illustrated in Plate 20[71] with improved slope stability produced by vegetation with live willows used to improve slope stability from 1.2 to 1.3 at Iwade in Kent shown in Plate 21. Conversely loss of such vegetation due to increased resistance of pests, reduced available moisture content and increased fire risk will have a detrimental effect on slope stability.

It is generally acknowledged that climate change will lead to longer, warmer growing seasons with associated changes in the speed with which some plants grow. Some plant species will find it difficult in modern climatic conditions, whilst others thrive[68].

It is anticipated that the growing season will continue to be shifted by the changing climate. Research from UKCIP indicates that by the 2050's, the growing season is likely to be lengthened by a further two months. In some areas in the south of the UK, the growing season may run continuously all through the year[69]. However, it is unclear at the moment how native deciduous species may respond to this, as they may require a 'minimum' period of dormancy, governed by day length rather than temperature.

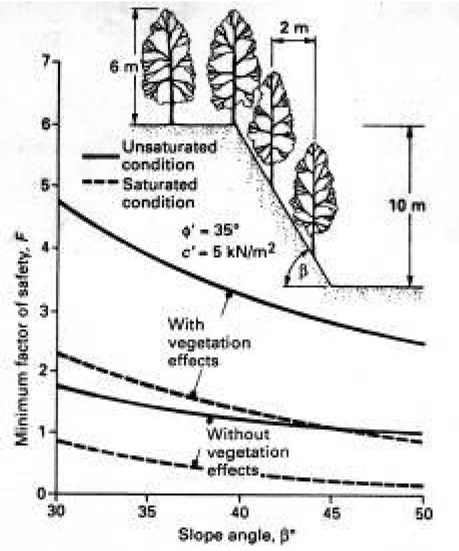


Plate 20: Enhanced slope stability with vegetation [71]

Plate 21: Live willows to improve slope stability

For new schemes the selection of more hardy plants based upon climates further south should be adopted.
It is probable that the best choice for maintenance engineers is to monitor vegetation as part of the asset management process and where the vegetation is suffering from stress to replace them with more hardy plants. As the vegetation at the road edge will be very dry the fire hazard will increase, mowing to prevent fire spreading, maintenance of fire breaks on large areas and control of gorse will all be necessary.

(e) **Increased collection of pollutants for first flush**

Plates 22a to 22c illustrate the potential for contaminants in road pavement run-off in the form of hydrocarbons, sediment or other road related contaminants. The more intense rainfall events and more frequent flash floods are likely to increase the pollutant loading particularly for first flush events following periods of prolonged dry weather. Similarly bypass separators may be bypassed more frequently by a greater frequency of intense storms.

These effects may warrant increased levels of maintenance of gulleys, grips and catchpits outfalling to sensitive watercourses and aquifer locations. These need to be identified in the Asset Management Database.
For new schemes the Environment Agency is now demanding more strenuous efforts to prevent these pollutants reaching water courses. The use of trapped gullies, catchpits, swales and ponds to trap pollutants are preferred though the use of petrol interceptors and permeable pavements may be considered in special cases.

Plate 22a: Hydrocarbons in run-off

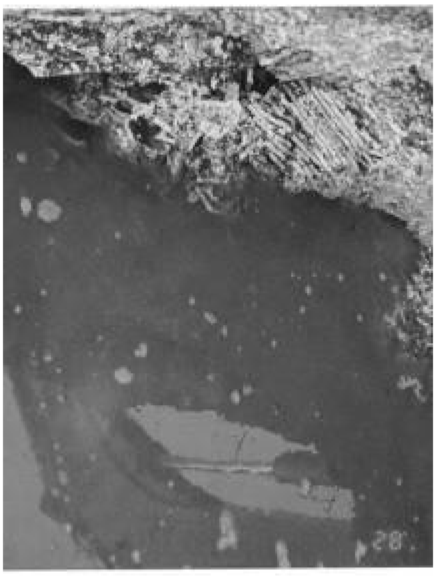


Plate 22b: Road surface showing other run off contamination

Plate 22c: Sediment in stream

4.2.3 Ground related effects – TOO WET

(a) Softening/swelling/subgrade pumping

Softening of moisture susceptible soils, principally silts and clays, is well known and is illustrated in Plate 24. As the road surface becomes liable for maintenance, surface cracking and failure of joint sealants in concrete carriageways illustrated in Plate 23 let water into the pavement structure. During the wetter winters this can lead to softening of the subgrade and mud pumping through the joints/cracks illustrated later in Plates 29 to 32.

Plate 23: Failure of joint sealants in a concrete carriageway

Moisture conditions beneath sealed and uncracked bound surfacing with adequate road pavement drainage should theoretically not be affected by such softening although clearly for both sealed and cracked roads grassed verge areas are likely to be more vulnerable to such softening if subjected to vehicle overrun as shown in Plate 25

Plate 24: Softening of Clay

Plate 25: Rutting of softened verge

The road pavement designer already needs to consider a range of potential impacts from the behaviour of the subgrade soils including:-

(a) Short term/construction subgrade strength
(b) Long term/equilibrium subgrade strength
(c) Frost susceptibility of the subgrade
(d) Frequency and treatment of subgrade soft spots/solution features/underground caves etc
(e) Differential settlement risks/need for ground improvement
(f) Suitability for subgrade soils for in-situ lime/cement stabilisation (if required)
(g) Shrinkage/swelling potential of overconsolidated clays (particularly where trees removed)

In relation to climate change, differential settlement risks, subgrade softening and shrinkage/swelling risks are the principal issues that need to be reviewed and these are invariably related to soil moisture.

Table C1 in TRRL 1132 in Plate 26[28] clearly illustrates the impact of groundwater on equilibrium subgrade strengths with lower CBR values appropriate for higher water table conditions and also for poorer construction conditions. Saturation of the subgrade due to long term surface flooding can therefore have a detrimental effect on the road pavement when trafficked, with the vehicle damage increasing with increased vehicular loads. The importance of adequate drainage to prevent road pavement damage is also reinforced by HD25/94 which states that "*It is of vital importance to keep water out of the subbase, capping and subgrade, both during construction and during the service life of the pavement*".

Equilibrium suction-index CBR values

TYPE OF SOIL	PLASTICITY INDEX	HIGH WATER TABLE						LOW WATER TABLE					
		CONSTRUCTION CONDITIONS:						CONSTRUCTION CONDITIONS:					
		POOR		AVERAGE		GOOD		POOR		AVERAGE		GOOD	
		THIN	THICK	THIN	THICK	THIN	THICK	THIN	THICK	THIN	THICK	THIN	THICK
HEAVY CLAY	70	1.5	2	2	2	2	2	1.5	2	2	2	2	2.5
	60	1.5	2	2	2	2	2.5	1.5	2	2	2	2	2.5
	50	1.5	2	2	2.5	2	2.5	2	2	2	2.5	2	2.5
	40	2	2.5	2.5	3	2.5	3	2.5	2.5	3	3	3	3.5
SILTY CLAY	30	2.5	3.5	3	4	3.5	5	3	3.5	4	4	4	6
SANDY CLAY	20	2.5	4	4	5	4.5	7	3	4	5	6	6	8
	10	1.5	3.5	3	6	3.5	7	2.5	4	4.5	7	6	>8
SILT *	-	1	1	1	1	2	2	1	1	2	2	2	2
SAND (POORLY GRADED)	-	← 20 →											
SAND (WELL GRADED)	-	← 40 →											
SANDY GRAVEL (WELL GRADED)	-	← 60 →											

* estimated assuming some probability of material saturating

Plate 26: Equilibrium CBR related to soil plasticity and groundwater conditions[28]

Brown[30] also shows the benefits of a well drained subgrade with Plate 27 showing that ingress of water increases permanent deformation of the subgrade whilst removal of water virtually halts such permanent deformation under repeated dynamic wheel loadings.

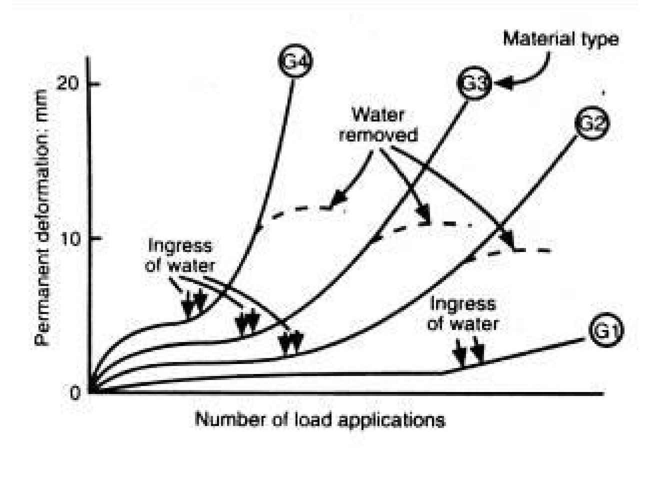


Plate 27: Increased pavement deformationswith water[30]

Plate 28: Swelling of clay due to tree removal

Tree root induced shrinkage may warrant management of vegetation to reduce the risk but Plate 28 illustrates that wholesale removal of trees can result in significant swelling induced distress as the desiccated clay absorbs moisture to move towards a new equilibrium moisture content.

Carriageway cracking and joints provide pathways for moisture to enter the lower road pavement layers and the subgrade which not only risks softening moisture susceptible subgrades but can also result in subgrade pumping under dynamic wheel loadings as described by Cedergren[36] and illustrated in Plates 29 to 32.
Where the road is very flat or subject to flooding as a result of poor drainage provision or maintenance water will very readily enter the structure thorough cracks or porous areas. This can also occur where a road is subject to occasional but prolonged flooding such as adjacent to rivers and streams or along promenades.

Plate 29: Subgrade pumping of silt

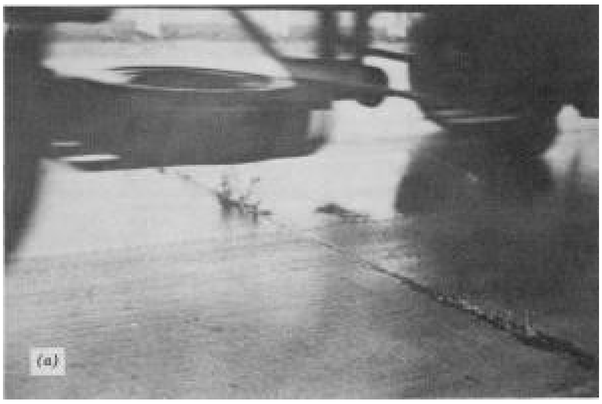
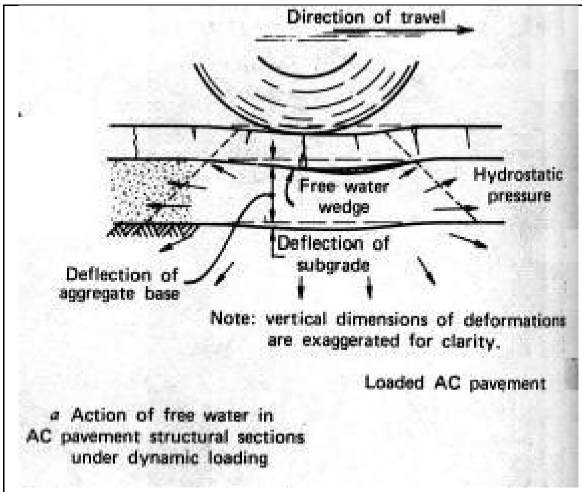
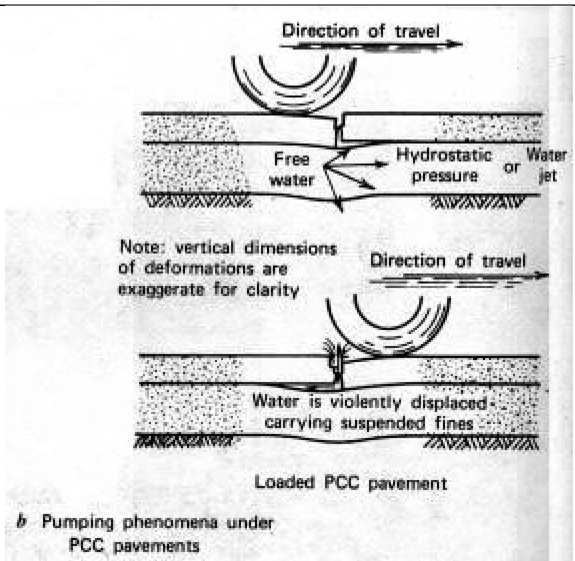


Plate 30: Subgrade pumping of water[36]





Plates 31 and 32: Subgrade pumping sketches[36]

For new works the verges must be designed anticipating occasional heavy vehicle over-run in wet conditions. Drainage works and/or stabilisation of cohesive soils should be considered.

For maintenance works routine sealing of cracks should already be a high priority and its importance will increase. Techniques include routing and resealing joints, overbanding systems, surface dressing and hot mix overlays with a Geotextile Stress Absorbing Interlayer (SAMI).

The maintenance of drainage should be prioritised to those areas subject to regular or even intermittent flooding and such areas should be considered for an impermeable HRA surface course when maintenance is required. Where carrying out improvement works is a low priority or expensive consideration should be given to temporary road closures to prevent overloading of the weakened subgrade.

(b) Washout/scour

Silts and fine sands are particularly vulnerable to washout produced by concentrations of water until vegetation becomes established as shown in Plate 33 and so loss of vegetation will risk similar features occurring.

Plate 33: Washout of fine sands

Plate 34: washout of sandy gravels

Washouts of fine sands and silts into underlying joints and fissures can also be produced by concentrations of water from soakaways as detailed in KCC's Soakaway Design Guide[37]. Coarser sands and gravels are not immune to such effects but generally require greater concentrations of water as illustrated by Plate 34 resulting from a burst water main or a flash flood. Fast flowing water in rivers can also cause undermining of gravity walls and road bridges as shown in Plates 35 and 36 so that more intense concentrations of rainfall produced by climate change may pose an increased threat to such structures.

Plate 35: Scour at toe of retaining wall

Plate 36: Bridge foundation scour[40]

The presence of trees adjacent to earthworks can produce canopy and thatch effects with drought resistant species can intercept rainwater (preventing infiltration and minimising slope erosion). In addition the uptake of water by the roots removes water from the slopes. When carrying out repairs wherever possible less erodable materials should be used.
For sensitive slopes as identified in the Geotechnical inspection consider crest drainage.
For high risk structures a catchment flood analysis should be carried out taking account of climate change predictions.

(c) Subsidence settlement

More intense rainfall will also increase the risk of collapse settlements of loosely infilled solution features and loosely infilled rock joints in cambered valleys as illustrated in Plate 37 which may be accompanied by washout of silts and sands into fissured rocks. Plate 38 shows a collapse of a manmade mine and Edmonds et al[53] note that rainfall is a major trigger for the collapse of chalk workings with unsupported roofs.

Plate 37: Collapse settlement

Plate 38: Mineworking collapse

These problems are by their nature unpredictable. Where these features are suspected the risk of occurrence may be reduced by improved carriageway drainage and possible diversion of ditches.

Area teams need to be alerted to potential at risk areas so that advance warning signs can be prepared.

(d) Shallow surface slope instability

The previously described desiccation cracks induced by prolonged periods of dry weather provide the pathway for water to readily enter and saturate the near surface soils in earthworks slopes layers. This can produce shallow sloughing of the soil similar to a flow slide as illustrated in Plates 39 and 40.


Plates 39 and 40: Shallow slope failure due to surface water run-off from clay slope

Roots will increase the shearing resistance of a slope mechanically, and this will stabilise the slope throughout the year and help to prevent erosion or failure. The amount of mechanical reinforcement provided by a root system will depend (as a minimum) on the spatial distribution of the roots ('root area ratio') and their mechanical strength but it is also likely to depend on the soil and interface properties and further root properties[66].

Wildflowers and grasses tend to be less deeply rooted than trees and shrubs, and will therefore only affect the hydrology and mechanical properties of the near-surface soil. On average grass covered slopes do not significantly influence pore pressure at depths greater than 1.5m. Grassed slopes therefore return to hydrostatic conditions more quickly than soils where a degree of tree cover is available[72].

The planting of appropriate species is likely to be effective in preventing erosion and superficial failure because of the interconnected, fibrous root system that typically will mechanically improve the top 20-30cm of the soil. These species will also have a beneficial impact on run-off and infiltration properties[66].
In the short term on new works pegged netting or even hydroseeding can be effective until the natural vegetation can take over. If possible embankment sideslopes on cohesive soils should be formed of less cohesive material, taking care to avoid deeper seated instability.

(e) Deeper seated instability

Slope instability is illustrated in Plates 41 is often triggered or aided by rainfall lubricating existing dormant slip planes at a depth below the surface, as shown on Plate 42. Davies et al[59] note the significance of rainfall in the Gault Clay adjacent to the M25 at Godstone and similarly Palmer's records [54] for the landslip at Encombe in Plate 43 show the greatest movements occurring with the heaviest rainfall so that the more intense rainfall events predicted may increase the risk of such instabilities occurring. Flow slides are similarly affected by heavy rainfall as noted by Bromhead for the coastal landslides at Beltinge[32] and by Winter et al at several sites in Scotland including the A9 at Glen Coe[4 & 5]. Water entering lateral moraines has result in flowslides carrying debris over carriageways or washing out material where such flows pass beneath the carriageway.

Failure predictions can also be related to Soil Moisture deficit (SMD) which is a measure of soil saturation defined as the amount of water per unit surface area that soil will absorb before further precipitation cannot be stored. In south east England major railway earthworks slips have correlated well with periods of low SMD [71 to 71] relating to wetter ground conditions over the last 30 years using measurements from tensiometers.

Plates 41: Examples of slope instability

Plate 42: Water lubrication of shear surface

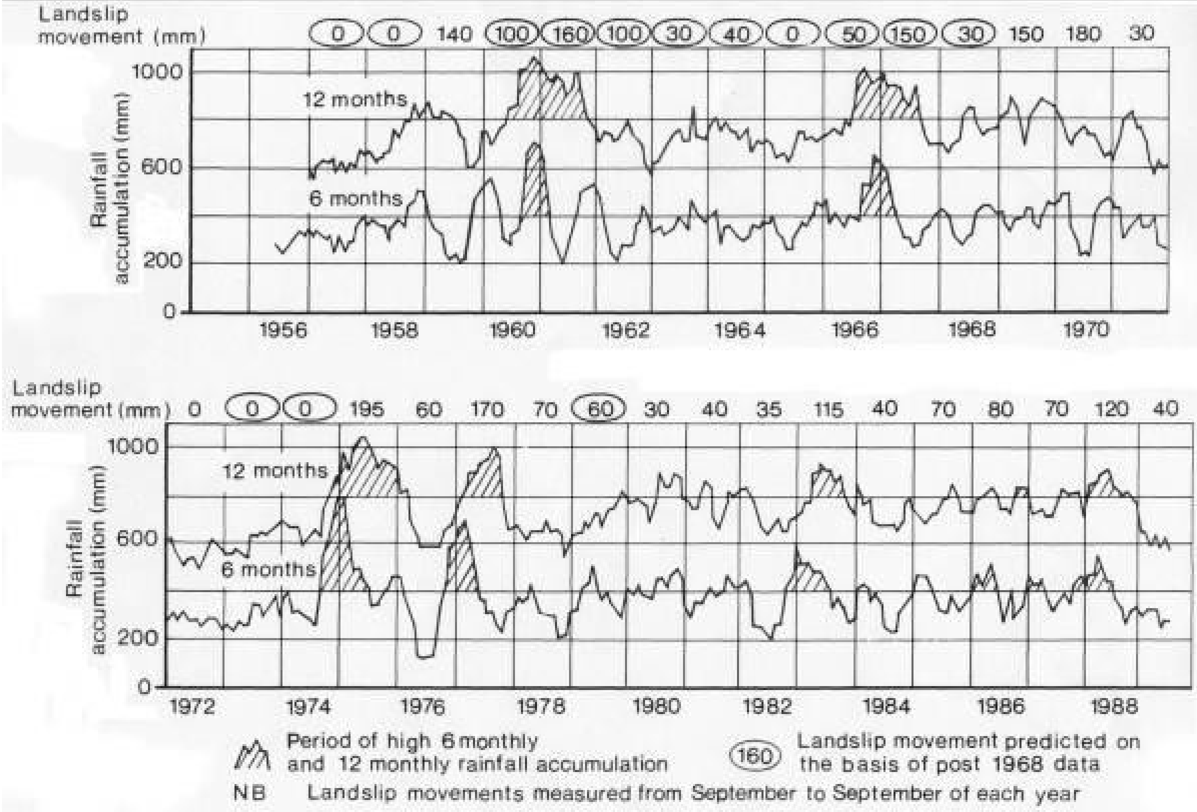


Plate 43: Records of landslipping triggered by periods of heavy rainfall[54]

The presence of potential deep seated problems can be identified by a skilled geotechnical engineer with local knowledge together with careful study of existing slope profiles. Where these exist it is essential to prevent water entering the slope by sealed crest and if required intermediate drainage to collect surface water run off (ie avoid channelling it into the slip).

After a slip has occurred treatment is expensive and can involve toe retaining structures, soil nailing, piles, replacement with granular material or geosynthetic reinforcement. Where the consequences are small, drainage works plus continual removal of slipped material may be the only option.

(f) Flooding

The risks of surface water run-off are clearly increased by more intense rainfall events in both rural and urban areas as illustrated in Plates 44 to 49. Some of these are related to the reoccurrence of springlines and nailbournes, floodplains associated with converging rivers, poorly maintained drainage systems, inadequate discharge capacity, inadequate edge drainage collection systems, surcharging of combined sewers, poorly maintained carriageway surfacing, run-off from adjacent catchments and blockages due to tree root propagation.

Plates 44: Rural flooding – reoccurrence of nailbournes and river convergence

Plates 45a/b: Urban flooding – inadequate capacity and inadequate edge collection

Plates 45c/d: Urban flooding – adjacent catchment run-off and sewer surcharging

Plate 46: Inadequate capacity of permeable paving

Plate 47: Inadequate drainage due to inadequate road sweeping

Plate 48a: Inadequate drainage due to surface rutting

Plate 48b: Inadequate drainage due toroot propagation at low point

Particularly intense rainfall run-off can carry large debris such as tree branches and even parked cars as shown in Plate 49. These can be particularly disruptive and causing blockages that are less readily cleared and so may exacerbate upstream flooding.

4

Three die as car is swept into stream during storm

TRAIL OF TRAGEDY:

Plate 49: Large scale debris carried by floodwater[76]

It is possible that flooding cannot be alleviated locally and a wide area flood study and surface water management plan is required. High risk areas need to be identified so warning signs and emergency diversion routes can be implemented and attenuation measures e.g. using drainage ditches and ponds with overflows into non-critical areas should be put in place.
Bridges and culverts need assessment for a risk of blocking with debris

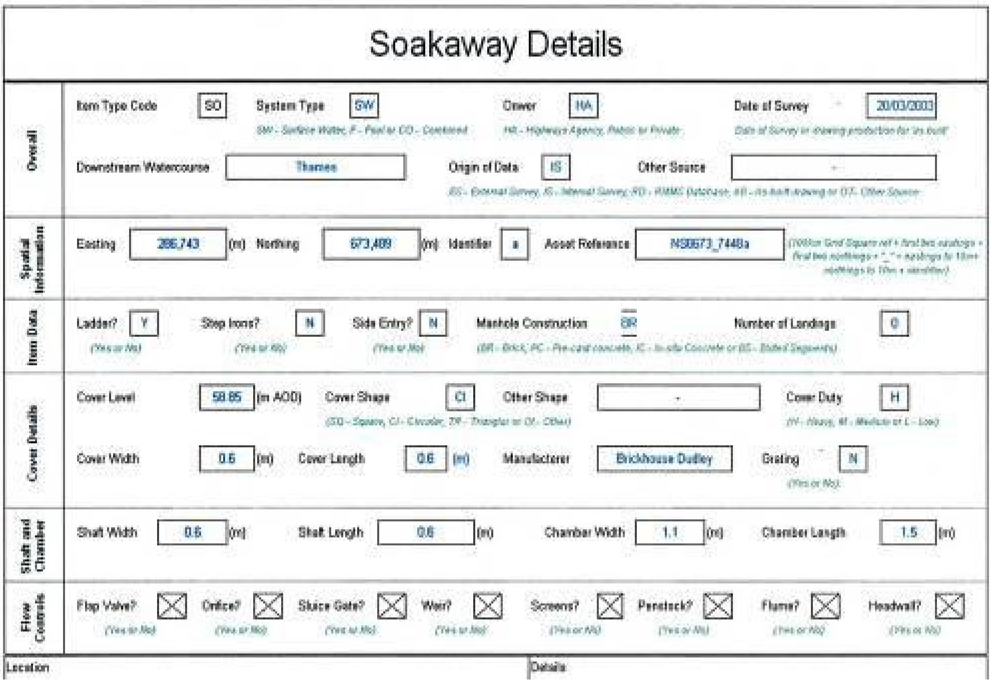
4.3 Risk Assessments

4.3.1 Inventories

Efficient asset management of infrastructure earthworks relies on reliable assessments of long-term behaviour to formulate appropriate design solutions and efficient management strategies[72]. The management of such assets requires an understanding of how different local practices (mowing, planting, felling, coppicing, manual cutting etc) can affect different aspects[66].

Management of the climate change problems identified above largely depends upon establishing the highway asset in more detail with the potential then for both proactive and reactive responses much of which are well understood by many local authorities already. The benefits of a proactive approach are confirmed by Patterson and Perry[19] in relation to earthworks slopes who suggest that planned proactive repairs of marginally stable slopes can be up to 75% cheaper than reactive approach to failed slopes with the added benefit that the proactive approach allows improved budgetary controls. Highway asset inventories of road pavement condition, earthworks, drainage and vegetation can then be used with flood risk mapping, geological mapping, topographical maps, slope aspect and other local knowledge to identify the most at risk areas and those site needing attention immediately and those likely to be at risk as a result of climate change. A process of asset management inventory and prioritised ongoing condition monitoring, should enable the implementation of targeted adaptation and mitigation measures for the geotechnical aspects proactively as the climate changes. The measures should take account of a risk assessment of the impact of failure on the infrastructure and the public.

Data management systems have been developed by the Highways Agency for the trunk road network including road pavement condition (HAPMS), Earthworks (GDMS) Drainage (DDMS) Environment (EnvIS) and Land (HAL) with associated documentation. Examples of inventories for drainage from HD41/03[17] and earthworks from HD43/04[18] are reproduced in Plates 50 and 51.



Soakaway Details

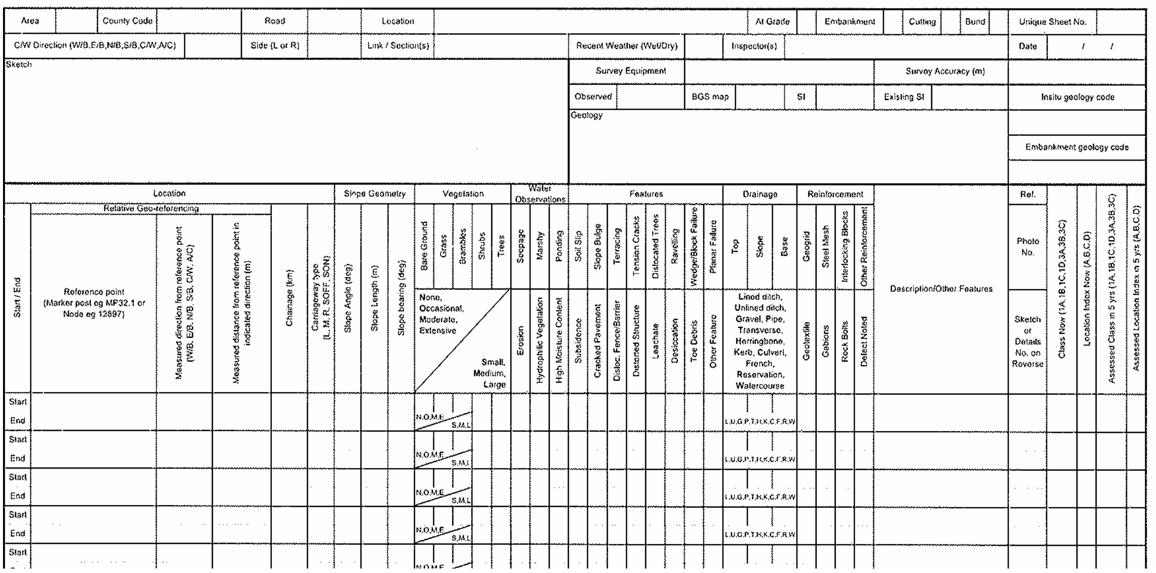
Overall	Item Type Code	SO
Overall	System Type (SW - Surface Water, F - Foul or CO - Combined)	SW
Overall	Owner (HA - Highways Agency, Public or Private)	HA
Overall	Date of Survey (Date of Survey or drawing production for 'as built')	20/03/2003
Overall	Downstream Watercourse	Thames
Overall	Origin of Data (ES - External Survey, IS - Internal Survey, RD - RMMS Database, AB - As built drawing or OT - Other Source)	IS
Overall	Other Source	-
Spatial Information	Easting (m)	286,743
Spatial Information	Northing (m)	673,489
Spatial Information	Identifier	a
Spatial Information	Asset Reference	NS8673_7448a
Item Data	Ladder? (Yes or No)	Y
Item Data	Step Irons? (Yes or No)	N
Item Data	Side Entry? (Yes or No)	N
Item Data	Manhole Construction (BR - Brick, PC - Pre-cast concrete, IC - In-situ Concrete or BS - Bolted Segments)	BR
Item Data	Number of Landings	0
Cover Details	Cover Level (m AOD)	58.85
Cover Details	Cover Shape (SQ - Square, CI - Circular, TR - Triangular or OT - Other)	CI
Cover Details	Other Shape	-
Cover Details	Cover Duty (H - Heavy, M - Medium or L - Low)	H
Cover Details	Cover Width (m)	0.6
Cover Details	Cover Length (m)	0.6
Cover Details	Manufacturer	Brickhouse Dudley
Cover Details	Grating (Yes or No)	N
Shaft and Chamber	Shaft Width (m)	0.6
Shaft and Chamber	Shaft Length (m)	0.6
Shaft and Chamber	Chamber Width (m)	1.1
Shaft and Chamber	Chamber Length (m)	1.5
Flow Controls	Flap Valve? (Yes or No)	
Flow Controls	Orifice? (Yes or No)	
Flow Controls	Sluice Gate? (Yes or No)	
Flow Controls	Weir? (Yes or No)	
Flow Controls	Screens? (Yes or No)	
Flow Controls	Penstock? (Yes or No)	
Flow Controls	Flume? (Yes or No)	
Flow Controls	Headwall? (Yes or No)	

Location | Details

Plate 50: Soakaway inventory from HD41/03[17]

Principal earthworks inspections are undertaken by HA at least every 5 years by suitably qualified geotechnical engineers combining surveys from slow moving traffic and more detailed walkovers. It is unlikely that a Local Authority needs or could afford to look at all the slopes under its jurisdiction at this frequency. It should therefore develop a plan to prioritise inspections to areas of greatest risk of failure, including the effects of climate change discussed above and to sites where the consequences of failure could be severe in terms of disruption to the public through for example flooding or diversions or expensive through frequent road maintenance.

Cyclic reviews of all earthworks drainage including subgrade drains, French drains and slope drains. must also be addressed at a frequency that reflects the consequences of failure on the public and the risk of failure given the location and geology.



Area | County Code | Road | Location | At Grade | Embankment | Cutting | Bund | Unique Sheet No.

C/W Direction (W/B,E/B,N/B,S/B,C/W,A/C) | Side (L or R) | Link / Section(s) | Recent Weather (Wet/Dry) | Inspector(s) | Date / /

Sketch | Survey Equipment | Survey Accuracy (m)

Observed | BGS map | SI | Existing SI | Insitu geology code

Geology | Embankment geology code

Location: Start / End; Relative Geo-referencing: Reference point (Marker post eg MP32.1 or Node eg 12897); Measured direction from reference point (W/B, E/B, N/B, S/B, C/W, A/C); Measured distance from reference point in indicated direction (m); Chainage (km); Carriageway type (L, M, R, SOFF, SON)

Slope Geometry: Slope Angle (deg); Slope Length (m); Slope bearing (deg)

Vegetation: Bare Ground; Grass; Brambles; Shrubs; Trees; None, Occasional, Moderate, Extensive / Small, Medium, Large

Water Observations: Seepage; Marshy; Ponding; Erosion; Hydrophilic Vegetation; High Moisture Content

Features: Soil Slip; Slope Bulge; Terracing; Tension Cracks; Dislocated Trees; Ravelling; Wedge/Block Failure; Planar Failure; Subsidence; Cracked Pavement; Disloc. Fence/Barrier; Distorted Structure; Leachate; Desiccation; Toe Debris; Other Feature

Drainage: Top; Slope; Base; Lined ditch, Unlined ditch, Gravel, Pipe, Transverse, Herringbone, Kerb, Culvert, French, Reservation, Watercourse

Reinforcement: Geogrid; Steel Mesh; Interlocking Blocks; Other Reinforcement; Geotextile; Gabions; Rock Bolts; Defect Noted

Description/Other Features

Ref.: Photo No.; Sketch or Details No. on Reverse

Class Now (1A,1B,1C,1D,3A,3B,3C); Location Index Now (A,B,C,D); Assessed Class in 5 yrs (1A,1B,1C,1D,3A,3B,3C); Assessed Location Index in 5 yrs (A,B,C,D)

Start / End — N,O,M,E / S,M,L — L,U,G,P,T,H,K,C,F,R,W

Plate 51: Earthworks inventory from HD43/04[18]

More sophisticated airborne remote sensing surveys such as the LiDAR system[19] being developed by HA may also have some uses for more sensitive, densely vegetated or poorly accessed on foot with case histories illustrating the benefits of LiDAR . Duffnell et al note Patterson's suggestion that nearly half the time for the manual principal inspections relates to obtaining the slope geometry which can readily and more extensively be obtained from LiDAR surveys without staff being exposed to the dangers of working close to live carriageways. Densely vegetated areas can be surveyed using helicopters working closer to the ground surface.

The implementation of Data management systems by Local Authorities is variable both in the systems used and the extent to which they encompass the assets comprehensively. Clearly there are economies to be made in combining asset surveys wherever possible and avoid the often current focus on single discipline data collection. For example pavement condition surveys collect some drainage data on road gulleys, drainage surveys could collect some data on vegetation features and pavement surveys identifying flat sections of carriageway provide valuable data for flood risk management. Clearly with all surveys there are issues associated with the training and subjectivity of the staff undertaking the surveys which may be complicated where different disciplines are being recorded, but surface features are recorded electronically.

The level of detail routinely required for Evolved Roads may be expected to be less than required for the higher speed and more widely used HA road network but there will be the need for greater synergy in certain sensitive locations where the loss of the road could have a significant effect locally; these need to be identified and made known to survey teams. The thoroughness of the visual surveys on the ground may similarly be less than for HA roads varying from Coarse Visual Inspections (CVI's) to Detailed Visual Inspections (DVI's) level of survey. Map based inventories have made the compilation and display of useful data much easier.

4.3.2 Surface Water Management Plans

Recent government policy development has promoted the production of surface water management plans (SWMPs)[60]. Surface water management plans (SWMPs) help to assess the risk of surface water flooding, identify options to manage risk to acceptable level, make the right investment decisions and plan the delivery of actions to manage flood risk. SWMPs will look at existing problems and inform planning decisions for new development. They therefore will register areas of the highway asset needing particular flood alleviation measures such as targeting of gulley maintenance in flood risk areas and identification of areas needing additional capacity or flood alleviation areas. They are therefore in some respects another type of asset register. A key challenge for local authorities and partners will be securing funding to deliver actions they are responsible for.

4.3.3 Risk Decision Matrices

Standard risk management tools will benefit from the data from highway inventories and SWMP's in prioritising future actions which will may well include a mixture routine maintenance, emergency planning and/pr pre-emptive remedial works. The risk management process involves assessing probability, severity and what the impacts are as illustrated in Plate 52 for the case of slope movements.

Severity/speed of movement			
	3	6	9
	2	4	6
	1	2	3
	Probability of movement		

Weightings for possible effects

Personal Injury	x 4
Damage to Property	x 3
Disruption	x 2
None	x 1

Decisions based on Risk x Weighting

1 – 9	Low risk
10 – 17	Monitor
18+	Action

Decision Matrix

Weighting						
	4	Low	Monitor	Monitor	ACTION	ACTION
	3	Low	Low	Monitor	ACTION	ACTION
	2	Low	Low	Low	Monitor	ACTION
	1	Low	Low	Low	Low	Low
		1 – 2	3	4	6	9
		Risk				

Plate 52: Geotechnical risk matrix for slope movements

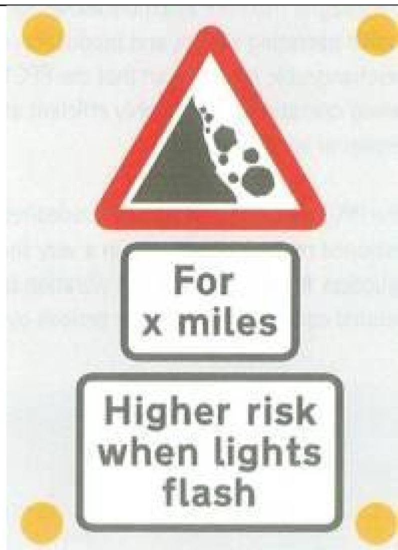
(c/o Lancashire CC)

HD22/08[24] deals with the management of geotechnical risk for new construction through a structured sequence of reporting throughout the design and construction phases.

4.3.4 Emergency planning

Information opportunities with signs and particularly Variable Message signs (VMS's) on heavily trafficked roads can be used to provide the road user with relevant local information in relation to severe weather events, flooding, rockfall risks and earthworks instability which could be expressed in relation to varying levels of likelihood of occurrence.

A wide range of temporary or permanent signs can be considered to assist in the management of climate change problems with the selection of examples shown in Plates 53 relating to carriageway subsidence, flooding and rockfalls.



Plates 53: Temporary Usage of Road Signs

For flooding in particular, emergency planning has a role to play (signs, designated routes to minimise flood damage, identifying flood alleviation fields/car parks etc). Roads themselves may play a part management of these floods and may be required as streams/causeways transferring water to appropriate outfall locations.

4.3.5 Inspection/Maintenance strategies

Routine maintenance plays an important part (eg preventing ruts channelling water away from drainage, gullies blocked with leaves/snow related grit, blocked grips from road edge to ditches, etc) as shown in Plates 54 although clearly additional capital works will be needed in some areas.



Plate 54A: Leaf blockages

Plates 54B and 54C: Snow grit blockage

Pre-emptive clearance of detritus from drainage channels, gulleys, ditches and watercourses in known areas of flooding in advance of predicted heavy rainfall will help reduce flooding incidents. Similarly other maintenance interventions including grit removal following periods of snow management and leaf removal following autumn leaf falls will also reduce the incidences of flooding in high risk areas. This requires knowledge of where such flooding occurs so that these can be targeted. The Environment Agency flood mapping supplemented for principal roads by SCANNER data can be a useful aid together with local knowledge from staff. Cyclic maintenance of earthworks drainage must also be addressed including subgrade drains, French drains and slope drains.

Increased growing seasons for vegetation will lead to greater frequencies for hedge trimming, tree crowning and grass cutting in manage loss of visibility and increased desiccation risks.

For cliff face stability two formal cycles of maintenance might therefore be considered in ensuring adequate management of vegetation induced root wedging which whilst will vary on a site specific basis might perhaps be as follows:-

- Two yearly maintenance – de-vegetation comprising pruning of trees/shrubs along the crest the cliffs and strimming of lighter vegetation. The vegetation controls will need to be confirmed in discussion with arboroculturists.
- Four yearly maintenance – As (a) but include clearing out of any rock traps, releasing debris collected by any meshing and any repairs to shotcrete facing and bolt head plates.

4.4 Future Management Recommendations

4.4.1 Drainage

(a) Quantity

Design storm parameters used in surface water drainage design need to be reviewed and where appropriate revised to allow for predicted climate change effects. This is usually managed by the use of more onerous storm return periods to take account of more frequent greater intensities of heavy rainfall expected as a result of climate change, with often an additional climate change uplift factor to take account of future increases due to further climate change effects. The additional uplift factor takes account of the fact that current design rainfall events are based on historical rainfall events that may not be correctly reflect future rainfall effects enhanced by climate changes.

This has already been addressed by many Local Authorities as illustrated by Kent County Council in their 2007 “Kent Design – Making it happen” [16] which includes the following:-

- The system must be capable of accepting without surcharge a storm frequency of once every 2 years except for sites where consequences of flooding affect existing properties adjacent to new development, where a frequency of once every 5 years will need to be applied.

- The system must be capable of containing a storm frequency of once every 5 years without flooding except for sites where consequences of flooding affect existing properties adjacent to new development, where a frequency of once every 30 years will need to be applied.

- A further assessment will be required to determine the flood path of a 1 in 100 year event. The flood path or flood storage area should not affect the operation of the highway or adjacent property

Retrospective application of these increased design standards to existing drainage systems is not practicable although an understanding of flood paths and the implications of flash flooding should be considered. A legal view on the risks of flooding from drainage systems designed to previous lesser standards may also be needed.

Similarly Soil Moisture Deficit assessments of soil saturation should be revisited to assess whether more water is shed by the soil within the catchment area is greater than the 15% to 50% values often used in the design of drainage systems.

Flooding is not the only drainage risk that needs to be considered at the design stage with Kent Design identifying the need to consider 5No principal drainage risks of flooding, subsidence, contamination, siltation and maintenance liability.

Directing water away from critical areas may be an effective way of managing flood risk. Plates 55 show flooding of an underpass that is managed by the use of a speed bump to channel upslope flows of water away further downslope and away from the underpass. Similarly water could be channelled away from carriageways into flood alleviation areas which could be open fields or car parking areas with some infiltration drainage to eventually drain the car park.

Plates 55: Underpass flooding removed by road ramp

Increased capacity of edge drainage systems may also be considered with Plates 56 and a wide variety of grate sizes could be considered to remove the surface water run-off away from the carriageway surface. To further encourage water to enter such surface gratings speed bumps to hold back flows of water or grated troughs could perhaps be considered for particularly sensitive areas.

Plates 56: Kerb grate drainage systems

Linear kerb drainage systems may provide more opportunities of removing water from the carriageway surface and are often favoured for particularly flat sections of carriageway. However the ability to maintain such systems, joint leakage and impact damage of such systems can affect the suitability of such systems.

Plates 57: Linear kerb drainage channels

Controls for large debris such as tree trunks and cars shown to be transported by some recent flooding events may also need to be considered including catch fences systems near to rivers, grilles on culverts and flood alleviation areas. Vulnerable sites will presumably be identified during the development of Surface water management plans (SWMP's).

(b) Quality

Regular maintenance of trapped gullies, catchpits, soakaways and petrol interceptors will improve the contaminant retention capabilities of drainage systems. Alarm systems for petrol interceptors and rapid response to pollution incidents will also be beneficial in this respect.

Vegetative systems including sediment retention of swales and the breakdown of hydrocarbons in reed beds can also be considered the design stage[39] but are often less easy to retrofit into an urban area.

4.4.2 Earthworks

(a) Road pavement subsidence

Pre-emptive Risk Management techniques should be considered including:-
(a) reducing vehicular loadings (long term prohibition or short term when more vulnerable)
(b) use the maintenance strategy to optimise pavement options for keeping water out by surface dressing or enhanced drainage and correcting the defect by overlay, overlay with geogrids/geotextiles or full depth reconstruction as required
(c) Identify designated emergency routes for flooding/subgrade saturation risks particularly HGV designated routes
(d) Manage tree root propagation risks by cyclic maintenance, localised root barriers, selective replanting with more appropriate vegetation, bituminous reinforcement in overlays and increased pipe flexibility.
(e) Manage verge softening from vehicle over-run with hardened verges, warning posts/barriers, enhanced verge falls

Maintaining equilibrium moisture contents in highway verges to reduce the risk of edge cracking would appear to be unrealistic either requiring deep construction of non-moisture susceptible materials or the provision of a barrier to prevent loss of moisture during the drier summer months. Deep construction is likely to be unsustainable and the use of an impermeable barrier would provide a barrier to moisture migration that could result in verge softening with any leakage of such a barrier also resulting in concentrations of water locally softening deeper layers of soil. Design engineers therefore may have to accept that soft verges will pertain in winter and consider erecting suitable signs and providing kerb edging to minimise inadvertent overrun. The provision of suitable edge drainage on both sides of the carriageway such as a fin drain or traditional french drain should help to prevent moisture changes affecting the carriageway itself.

In relation to subsidence risk local knowledge is invaluable and there is also some guidance on the suitability of strata for soakaway discharges provided in published documents such as KCC's Soakaway Design Guide[37]. Subsidence risks include:-

(a) Washout/piping of fine grained soils
(b) Activation of solution features
(c) Collapse settlements of poorly controlled Made Ground
(d) Tree root desiccation of clay soils
(e) Triggering adjacent landslips
(f) Collapse of mineworkings
(g) Long term creep settlements of organic soils
(h) Sulphate heave
(i) Frost heave

Drainage improvements embracing near surface SUDs infiltration[37 and 39] systems therefore need to assess the suitability of a site for them in relation to such subsidence risks, in addition to undertaking appropriate assessments of soakage potential of the ground in relation to depth, lateral extent and soil strata. Infiltration tests must also use realistic heads of water and follow specified test procedures notably in relation to repeated tests to mimic reductions in soakage caused by future saturation and clogging by detritus. Most of the permeable pavement systems have no provision for maintenance.

At the design stage geosynthetics can assist in managing some of the settlement risks notably with the use appropriately designed geotextile filter fabrics to control piping, fabrics to form root barriers and geogrid reinforcement to even out differential settlements. Reconditioning cracked carriageways suffering from post construction distress is can include reinforced asphalt solutions which can be facilitated using a variety of products including those shown in Plates 58 to 61. Guidance from the respective manufacturers suggests some can provide assistance resisting the reoccurrence of thermally related reflective cracking. To resist the previously described clay and peat desiccation failure modes, their design needs to consider the potentially higher tensile resistance needed. NCE articles relating to drought damage to roads in 2003 referred to geogrids tearing on the A1073 between Peterborough and Spalding[61 & 62] to illustrate the need to assess this loading condition. Workmanship issues can also affect the performance of some of the available products and future reconditioning options may be restricted by the presence of certain pavement reinforcing options. Future reinstatement of these membranes by Statutory Undertakers plant also need

to be considered including assigning such roads as Special Engineering Difficulty (SED) status. A digitised SED inventory accessible to development control officers, STATS co-ordination teams and road space licensing officers may be helpful as an additional readily available highway asset register in this respect.
As an alternative for concrete slab paved roads cracking and seating is very effective followed by an asphalt overlay designed for the traffic and the foundation condition created For weaker concrete and asphalt paved roads, in-situ recycling with cement and/or foam bitumen can be used to reconstruct the pavement without exposing the potentially weak subgrade.

Plate 58: Steel mesh reinforcement[49]

Plate 59: Glass fibre reinforced mesh[50]

Plate 60: Stress absorbing membrane[52]

Plate 61: Polypropylene grid reinforcement[51]

(b) Slope issues
A wide range of methods are available to stabilise marginally stable or failed cutting and embankment slopes as described by many authors[55 to 58] with typical solutions as follows:-
(a) Vegetation for control of near surface erosion and sloughing
(b) Vegetation management for deeper seated desiccation and root wedging
(c) Soil nailing

(d) Reinforced soil using geosynthetics
(e) Counterfort drains/buttressing
(f) Crest drainage
(g) Other slope drainage systems
(h) Low height retaining walls

Proactive treatments prior to failure are more cost effective than reactive solutions for less stable slopes which should encourage greater funding of earthworks inventories. Pre-emptive risk management making use of earthworks/vegetation inventories and cyclic maintenance should be undertaken to identify the main at risk locations.

Slope drainage can retard or eliminate slope movements provided permeable pipes and open joints do not channel water into sensitive areas. The importance of the longer term maintenance of such systems should also not be overlooked.

4.4.3 Vegetation

A structured risk assessment is required to manage the conflicts between slope stability and vegetation. Identifying high risk sites relating to different potential failure mechanisms is the first step.

There are two key areas in which vegetation may be detrimental to soil slopes:

- Steep cutting slopes where vegetation may fall on infrastructure. Removal of trees in these scenarios is a key risk management measure, however removal of rootballs and stumps should also be considered.
- Removal of vegetation from plastic clay embankments can result in ultimate failure of the embankment, it is imperative that removal should not be carried out without understanding the site-specific risks.

When vegetation on a large scale is cleared from an area of a slope, there is a gradual reduction in soil strength due to the loss of evapotranspiration effects and root decay over time]. Studies have shown that the original reinforcement is lost in 4 to15 years following clearance. Failure does not normally occur immediately after felling but typically takes a few years to occur as the stability gradually decreases as soils moisture deficits are lost, and roots decay and lose strength[73].

If the site is considered to be high risk, vegetation should not be removed without making an assessment of the capability of the embankment to withstand the increased pore water pressures that are likely to arise from vegetation removal. If stability analysis shows that it cannot withstand such changes in pore water pressures while maintaining a satisfactory factor of safety, then additional remedial measures will need to be provided in parallel with vegetation removal[66]. For vegetation management selective progressive replanting of more vulnerable trees with more tolerant species may be considered as illustrated in Plates 62 and 63 where the use of planting pits and root barriers are recommended.

Plate 62: Removing footway distress trees

Plate 63: Replacement trees

National Indicator 188 (NI 188) is designed to help local authorities assess and address the risks and opportunities presented by a changing climate, as well as provide a tool for measuring preparedness and has a three-year life span, from April 2008 to March 2011.

4.5 Summary of Potential Problems and Recommendations

The following is a summary of potential problems resulting from the effects of climate change on geotechnics, and possible solutions. It should be noted that there are a number of conflicts arising from these, and each situation will need to be assessed individually. All of these risks can be managed with the aid of appropriate earthworks, landscape, drainage and road pavement condition inventories.

4.5.1 Hotter Drier Summers

- High water deficits leading to more aggressive root action with deeper penetration and wider spread. On clay soils, this will increase desiccation at lower levels, leading to deeper cracking and potential for greater water penetration in autumn/winter. Possible greater impact on formation levels of highway.
  Recommendation – use less aggressive rooting species, less cohesive subsoils, surface binding roots. However, deeper rooting species may help slope stability by mechanical effects. May need to carry out more active vegetation management to remove problem species close to road, Limit growth by regular crowning/pruning and if appropriate selective replacement with lower water demand species. Edge root barriers and geosynthetic reinforcement of carriageway materials.

- Increased biodegradation of near surface peat layers adjacent to carriageways accelerated by ploughing that can increase embankment heights and steeper embankment sideslopes.
  Recommendation – discourage ploughing close to road edges and use of slope reinforcement techniques where slopes become too high or steep.

- High water deficits leading to desiccation of deeper peat layers.
  Recommendation – consider replenishment drainage designs and use of tensile grids in road pavement layers to limit surface cracking.

- On chalk/rock, deeper rooting will increase fissuring at greater depth, leading to greater instability of rock faces. Also increased erosion and larger pathways for water ingress along fissures, leading to greater potential for frost action.
  Recommendation: Active management of woody vegetation close to rock faces – removal/control of larger /more aggressive species. Warning signs and stand off zones for high risk areas.

- High water deficits leading to more aggressive tree root action – deeper penetration, wider spread. Increased desiccation of shrinkable clay soils will lead to increase in damage to highway structures and possibly adjacent privately owned property.
  Recommendation - May require more removal of ‘high risk’ trees, and replacement of these with varieties with lower water demand or use of root barriers. Important trees may need specialist intervention to mitigate adverse impacts, e.g. by artificially limiting root spread.

- Increased drought leading to vegetation death, especially on south/south-west facing slopes on light soils. Potential for increased fire risk with consequent hazard to users and damage/ loss of structural vegetation.
  Recommendation - May require the use of more drought tolerant varieties in extreme circumstances. However, on evolved highway verges the vegetation mix may evolve naturally in response to this. May need increased management input to reduce the amount of dead vegetation – increased cutting of grass areas/firebreaks. More active management of flammable woody vegetation, especially gorse and fire breaks if appropriate.

- Increased drought leading to vegetation death, especially on slopes on clay soils. Potential for increased slippage in following wet seasons without stabilising effect of roots (estimated 10% increase in factor of safety with vegetation).
  Recommendation - May require the use of more drought tolerant varieties in extreme circumstances or increased engineering intervention to stabilise earthworks.

- Increasing water stress leading to decline and death of significant woody vegetation, such as hedgerows, providing wider function eg screening of roads.
  Recommendation - May need replanting with more drought tolerant species.

- More severe drought events may have detrimental effects on existing ditches and other SUDS installations such as swales and flood alleviation areas, with decline and death of aquatic plants crucial to the functioning of the watercourse. Loss of vegetation in ditches, swales and lagoons would lead to reduced filtering effect and increased first flush pollution, also potentially reduction in flow attenuation.
  Recommendation - Replanting of aquatic suitable vegetation may be required, but difficult to source and establish later in summer. Plant mixes in lagoons need to be carefully considered. Avoid monospecific solutions.

Pollutants shed on the highway surface will be washed away less frequently and therefore the pollutant loadings on first flush will increase.
Recommendation - Regular emptying of catchpits and trapped gulley pots and for sensitive sites consider investment in pollution control measures, particularly vegetative systems such as swales and ponds although the use of petrol interceptors and permeable pavements may be considered in special cases.

4.5.2 Warmer Wetter Winters

- Increase in severity and frequency of flood events may have increased detrimental impact locally and further downstream from existing drainage outfalls.
  Recommendation - Advance warning signs and designated emergency routes where roads closed when being used as temporary rivers. Existing drainage systems may need enhancement with additional attenuation/storage measures, requiring more land or changes within existing highways landscape. Additional land take may lead to loss of habitat/impact on protected species/impact on local landscape.

- Increased flood leading to localised softening, subgrade pumping and washout of earthworks and vegetation. Large debris carried in floodwaters can impact on downstream culverts and watercourses. Possible instability in large trees and risk to public.
  Recommendation – Improve carriageway drainage, divert water away from carriageways, identify flood relief areas and repair carriageway cracking and joint sealants. Advance warning signs and designated emergency routes where roads being used as temporary rivers to limit subgrade damage. Increased frequency of highway tree inspections required during wet winters. Debris catch fences and grilles.

- Increased surface scour events leading to localised washout of earthworks and surface vegetation – increased silting of watercourses.
  Recommendation - Use of more robust vegetation on at risk areas. Increased frequency of ditch cleaning. Redesign of drainage system to cope with increased silting. Ensure adequate topsoil thickness and vegetation cover with near surface root reinforcement and consider need for crest drainage. Soil reinforcement solutions may require removal of woody vegetation and knock on effects associated with this.

- Moisture changes beneath carriageways producing edge cracking and uneven road surface and tree root propagation affecting adjacent structures and services. Concentrations of uncontrolled run-off risks washout, activation of solution features and inundation settlements/ collapses.
  Recommendation – Improved carriageway drainage, diverting flows away from sensitive areas, prompt repairs of joints/cracks (possibly with geosynthetic reinforcement) and consider root barriers where tree root desiccation is expected.

- Increased flood leading to raised water table and more prolonged inundation causing shallow slope surface instability, decline or death of woody vegetation. Safety impact of more dead trees and aesthetic impact of loss of linear vegetation screens.
  Recommendation – Near surface rooting species to bind surface together. Will require increased tree safety inspection effort and action. May require replanting of important screens with more tolerant aquatic species, although these may not necessarily be able to withstand more frequent or severe summer drought events.

- Intense rainfall events leading to raised water table and more prolonged inundation causing deeper slope instability, decline or death of woody vegetation. Safety impact of more dead trees and aesthetic impact of loss of linear vegetation screens.
  Recommendation – Use and maintenance of crest drainage and slope drainage such as counterfort drains. Warning signs for know problem areas. Near surface rooting species to bind surface together. Will require increased tree safety inspection effort and action to ensure vegetation benefits realised

- Increased flood leading to raised water table and more prolonged inundation causing death or decline of SUDS vegetation. Loss of vegetation in swales and lagoons leading to reduced filtering effect and increased first flush pollution and potential reduction in flow attenuation.
  Recommendation - Replanting of aquatics may be required. Plant mixes in lagoons need to be carefully considered. Avoid monospecific solutions such as pure Phragmites.

- Pollutants shed on the highway surface washed into local watercourses and aquifers.
  Recommendation - Improved carriageway drainage, regular emptying of catchpits and trapped gulley pots and for sensitive sites consider investment in pollution control measures, particularly vegetative systems such as swales and ponds although the use of petrol interceptors and permeable pavements may be considered in special cases.

- Large debris such as trees and cars carried in fast flowing floodwaters blocking watercourses and culverts and risks to people caught up in such events.
  Recommendation - Grilles on culverts and catch fences near watercourses and the use of advance warning signs and designated emergency routes where roads being used as temporary rivers.

4.6 Further Research

The above discussion illustrates that there is a wide variety of research opportunities notably in developing asset inventories, providing confidence in the use of alternative road pavement reinforcing membranes, flood risk management and control of soil desiccation.

It is not possible at present to quantify the consequences of climate change reliably enough to enable the prediction of the behaviour of long-term infrastructure earthworks to enable the design of appropriate solutions and efficient asset management strategies. Many research groups are working on aspects of the problem.

The relationship between climate and pore pressure regimes in slopes is complex and currently is not fully understood. Key processes include interactions between vegetation and climate (type of vegetation and growth patterns), and between the vegetation and soil (moisture removal leading to soil desiccation and cracking, and formation of zones of increased permeability) [72].

Research opportunities appear to exist with a range of organisations including the following:-

(a) Highways Agency dialogue
(b) University studies (eg BIONICS)
(c) Railways experiences
(d) European experiences in similar climatic regions
(e) European funding

A wealth of experience currently exists with a number of highly experienced Local Authority highway engineers who have already established ways of managing some of these climate change related issues together with an understanding of the shortcomings of some techniques. This can be supplemented using experiences from current regions elsewhere in the world with more temperate climates that may mirror future climate change in the UK which for south east England could include the Dordogne area of France and perhaps even Florida in the USA.

4.7 Conclusions

It is not possible at present to fully quantify the consequences of climate change reliably enough to enable the prediction of the behaviour of long-term infrastructure earthworks to enable the design of appropriate solutions with absolute certainty they will be required. However efficient asset management strategies are required not only for this aspect but for effective management of the network generally.

The fact of climate change is not in doubt it is the speed of change and consequences that are variable. It is believed that the speed of climate changes, will not permit the vegetation to adapt naturally and planned replanting with new species will be required. Knowledge of appropriate species will be required.

As the climate changes the implementation of adaptation and mitigation measures for the geotechnical aspects proactively would appear to be possible.

A wealth of experience currently exists with a number of highly experienced Local Authority highway engineers who have already established ways of managing some of these climate change related issues together with an understanding of the shortcomings of some techniques. This can be supplemented using experiences from current regions elsewhere in the world with more temperate climates that may mirror future climate change in the UK which for south east England could include the Dordogne area of France and perhaps even Florida in the USA whilst for northern counties the future climate may be similar to perhaps Dunkirk in France or even Kent/Cornwall now.

A process of asset management inventory and prioritised ongoing condition monitoring, should enable the implementation of targeted adaptation and mitigation measures for the geotechnical aspects proactively as the climate changes. The measures should take account of a risk assessment of the impact of failure on the infrastructure and the public.

Managing future climate change can be managed for new developments by appropriate and robust design, construction and maintenance taking account of the effect of climate change. Management of the potentially increased maintenance requirements for new and existing infrastructure will require further research, funding and development of intervention strategies that are either proactive or reactive with earthworks, drainage and landscape inventories including their condition a key part of the management process.

Often faced with an almost impossible task of modelling the behaviour of in-situ soils and engineered fills to climate change the geotechnical engineer must combine industry good practice with available case history data from more temperate climates in the world which with the vital ingredient of experience and appropriate inventories can provide confidence to clients that the risks posed by the ground and surface water run-off have been adequately managed.

Future climate change can be managed for new developments by appropriate and robust design, construction and maintenance, taking account of the effects of climate change. Management of the potentially increased maintenance requirements for existing infrastructure will require intervention strategies that are either proactive based upon comprehensive asset management databases or reactive, with the latter preferred and giving better value for money. Implementing this process will provide confidence to clients that the risks posed by the geotechnical and surface water changes have been adequately managed and appropriate responses are in place as suggested in table 1.

Problem	Key features	Suggested Actions to mitigate
1. Hotter and Drier	Summer issue	Identify critical soils and rock features Identify roads at risk Identify adjacent properties at risk Inventories to manage risks
(a) Near surface desiccation.	Present in many cohesive soils	Use of less aggressive rooting surface binding species Use of less cohesive subsoils Planting pits
(b).Deeper desiccation	Caused by tree roots	Remove deep rooting and high water demand trees Root barriers and geosynthetic reinforcement of carriageway layers
	Desiccation of peat layers	Replenishment drainage design Use of Tensile grids for surface cracking Slope treatments for overstep slopes
(c) Increased root wedging	Caused by tree roots	Regular crowning of crest trees Use of lower water demand trees Warning signs and stand off zones
(d) Vegetation stress/loss of vegetation	Lack of retained moisture Combustion	Use of more hardy plants Control of gorse and use of fire breaks
(e) Increased collection of pollutants for first flush	Contamination of watercourses	Maintain catchpits and gullies Use of vegetative treatment areas

2. Colder and Wetter	Winter issue	Identify critical soils and rock features Identify roads at risk Identify adjacent properties at risk Identify downstream flood risks Inventories to manage risks
(a) Softening, swelling and subgrade pumping	Access of water to moisture sensitive subgrade soils	Improved carriageway drainage Diverting flows away from carriageways Repair of carriageway cracking Road closures when flooded and designated emergency routes
(b) Washout/scour	Erosion of material from sideslope run-off particularly where vegetation not established or has died	Use of surface binding vegetation Repairs with less erodable material Consider crest drainage Use more drought resistant species
(c) Subsidence settlement	Irregular road surfaces Inundation settlement Washout Tree root propagation Activation of solution features	Advance warning signs Improved carriageway drainage Divert flows to less sensitive areas Root barriers and lower water demand trees
(d) Shallow surface slope instability	Near surface saturation Water filled desiccation cracks Ditch instability,	Use of near surface rooting species Less cohesive subsoils Use of aquatic suitable planting
(e) Deep seated instability	Deeper desiccation cracks More intense storms	Crest and slope drainage Vegetation management Advance warning signs
(f) Flooding	Surface water run-off from carriageways and adjacent	Improved carriageway drainage

	fields and upstream catchments	Diverting flows away from carriageways Provide flood alleviation areas Repair of carriageway cracking Advance warning signs Road closures and emergency routes Ploughing fields transversely across slopes and at ends of polythene lined growing tunnels
(g) Contamination of run-off	Pollution of watercourses Blockages from larger floodwater debris such as cars and trees	Improved carriageway drainage Maintain catchpits and gullies Use of vegetative treatment areas Grilles and catch fences

TABLE 1: **Summary of effects of climate change on geotechnics**

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Climate Change and Evolved Pavements Chapter 5 - Pavements and Materials Aspects

Abstract
The effects of climate change are likely to reduce the performance of many existing pavements which consequently will increase highway maintenance costs unless adaption and mitigation measures are adopted to counteract these effects.
A risk management approach is recommended to adapt and mitigate risks with the utilisation of experienced staff with skills in highway maintenance and highway materials.
Climate change problems have been identified and solutions suggested for consideration.
Practical guidance has been provided on material selection and remediation within additional appendices.
As the effects of climate change will impact across all aspects of pavement engineering, further research and guidance is required in future.

5.1 Introduction

5.1.1 General

This report relates to the effect of climate change on the evolved highway network. The evolved network, which can account for a very large part of the typical local highway authority network, generally comprises minor highways which have not been designed or constructed to modern standards.

5.1.2 Climate Change

The effects of climate change will reduce the performance and design life of pavements and will accelerate existing deterioration modes. The most relevant expected changes to the climate as indicated by UK Climate Impacts Programme (UKCIP) (1) have been reviewed in Chapter 3 and are in summary as follows:-

- Wetter and milder winters
- Drier and hotter summers
- More extreme rainfall events and storms
- Rising sea levels

As cold weather (frost/snow/ice) issues are not considered to increase due to climate change, these issues are not considered further (although winter 2009/2010 was considered to be coldest for some thirty years).

5.1.3 Highway Pavement Types

Highway pavements within a local highway authority network can be subdivided into three generic types as follows:-

- Asphalt pavements which include flexible and flexible composite. These pavements deflect and deform under loading and can be damaged by extremes of temperature or by prolonged static loading. Asphalt pavements are relatively easy to construct and repair.

- Rigid pavements which include rigid and rigid composite and utilise pavement quality concrete. These pavements deflect slightly but do not deform under loading. Most local authority rigid pavements have joints as they were constructed in bays or strips with these joints required to accommodate thermal movements.
- Modular pavements which are constructed with modular components laid on either a rigid or flexible base. Modular elements include slabs, blocks or natural stone setts.

A small number of unsurfaced pavements may also be utilised by local highway authorities for minor vehicular use and also for cycleways and footways.

5.1.4 Fundamental Requirements

The design of pavements indentifies fundamental requirements for the layers in the pavement and is summarised as follows:-

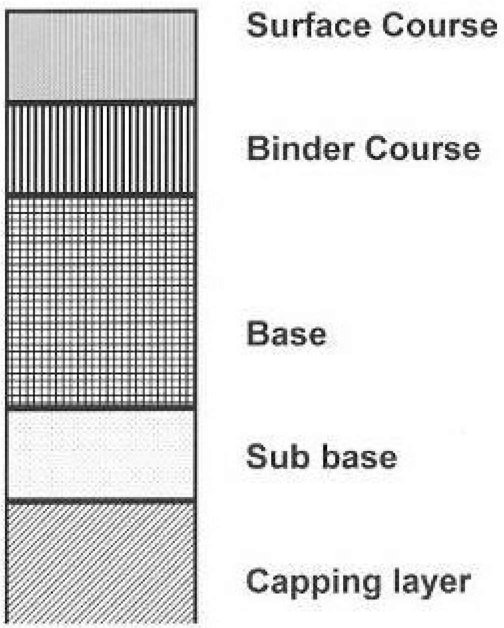

Figure 5.1

Capping Layer (which provides a short term working platform and longer term contribution to the structure)

- Strength (stiffness)
- Stability (low plasticity)
- Durability

Sub base (regulated platform of consistent strength for subsequent construction and protects the formation from ingress of water.

- Strength(stiffness)
- Stability (frost heave)
- Durability
- Permeability

Base and Binder Course (main structural layer whose purpose is to spread stresses induced by repeated loading over the foundation and to withstand internal stresses without deformation or excessive cracking)

- Stiffness
- Deformation resistance
- Fatigue resistance
- Workability
- (Impermeability)

Surface Course (the running surface which seals the construction and provides a smooth ride, skid resistance and some resistance to wear)

- Deformation resistance
- Fatigue resistance
- Skid resistance
- Riding quality
- Workability
- Impermeability
- (noise reduction)
- (spray reduction)

It is important to consider these functional requirements since performance will be impaired due to climate change effects. Adaption/mitigation measures will be required and it will be preferable to utilise end result specifications to define the performance level required for highway materials.

5.2 Impact of Climate Change on Pavements and Materials

5.2.1 General

Traditionally, climate has in the past had a significant influence on pavement construction and maintenance. This climatic influence is one of the primary factors affecting the performance of highway pavements. Other influential factors which interact with climate are as follows:-

- Pavement characteristics (materials, structure and condition)
- Drainage
- Underlying geology
- Topography
- Traffic Loading

Climate change will not introduce new consequences for the pavement but may increase the magnitude of existing deterioration modes or induce premature failure.
There are three fundamental pavement types utilised within local authority highway networks:-

- Asphalt
- Rigid
- Modular

The typical local authority highway network comprises mainly asphalt pavements. However, there are several general issues regarding climate change that can be appraised in relation to all three generic pavement types derived from TRL Published Project Report PPR 184 (2)

5.2.1.1 Materials and Construction Practice

It is clearly important that to maximise the value for money from expenditure on highway construction and maintenance that practitioners utilise the current best practice guidance. Many documents are available in the public domain and it is not intended to list these documents in detail.
One recent document is highlighted for reference as it provides practical technical guidance for the design and construction of asphalt pavements –"Best Practice Guide for the Durability of Asphalt Pavements" by Nicholls et al (3). Application of this report is recommended to practitioners to assist with mitigating the effects of climate change.
To adapt to the effects of higher temperatures and increased rainfall and to mitigate these effects, it is essential that all highway construction and maintenance achieves the highest quality to provide the longest functional life and be resilient to climatic changes.
The utilisation of performance specifications is recommended to counteract the effects of climate change, whereby the characteristics of the pavement material are defined to meet in-service requirements. The performance requirement can vary from a minimum "no requirement" to a stated maximum and is not necessarily a high performance. The use of the traditional recipe/method specification is currently planned for phased deletion from British Standards in future and therefore this type of specification is now no longer recommended.

5.2.1.2 Lack of Effective Drainage

Increased rainfall mainly during the winter months but also the intensity of downpours even during the summer months has highlighted many deficiencies with existing highway drainage. It is therefore important that local highway authorities possess a definitive inventory of drainage assets and that existing drainage is maintained in a fully functional condition. Highway drainage should be prioritised as part of highway maintenance strategy to ensure that resources are sufficient to achieve objectives.
Additional drainage provision may be difficult to deliver against a backcloth of public service budget constraints. However it may be necessary to prioritise new expenditure to provide a safe and secure highway network that is not subject to continual closure due to flooding and the damaging effects of inundation.

5.2.1.3 Maintaining Pavements in a Good Condition and the Surface Sealed

Highway maintenance engineers are aware that a pavement in good condition with a sealed surface remains an aspiration for good future performance. The effects of climate change additionally contribute to the desired need for a pavement in good condition.

Both past and predicted expenditure on highway maintenance result in the above statement remaining an aspiration but not a reality in many instances. However, it is clearly apparent that well maintained highway pavements will assist the resilience of the highway network to deterioration from climate change.

Traditionally, highway maintenance engineers had employed resurfacing or surface treatments to keep pavements sealed to prevent ingress of water. These techniques will be in more future demand to mitigate the effects of climate change.

5.2.1.4 Pavement Strength and Integrity

Evolved pavements are generally very thin in construction and often comprise low grade materials that pre-date modern specifications. The base, sub-base and any capping layer is unbound in nature and of poor quality when compared with modern materials.

Stiffer pavement foundation layers are recommended in future as cement and hydraulically bound materials will provide better performance (deformation resistance and water deterioration resistance).

In situations where minor highways/evolved pavements are reconstructed, this option can be considered and will provide long term benefit. However, funding may be very limited for this type of activity in practice.

Appendix 3 provides further technical advice on this issue.

5.2.1.5 Pavement Solar Gain

As highway pavements absorb heat from solar radiation and these higher temperatures have a detrimental effect on pavement structural performance, it would be desirable to take action to reduce this solar gain. Asphalt pavements due to their black colour constitute the greatest problem. Research is continuing in this respect and it is recommended that local highway authorities monitor progress and implement measures in the future that will assist this issue.

Research has also been carried by Sheffield Hallam University on behalf of UK Roads Liaison Group/UK Lighting Board to investigate road surface reflectivity as this factor has an input into street lighting design (4).

Porous or permeable pavements would appear to contradict the tradition of well sealed pavements. However, there are several benefits that can accrue from permitting water to permeate through pavement layers. The cooling effect would reduce the effects of solar gain. In addition, the Flood and Water Management Act 2010(5 requires local highway authorities to utilise SUDS to increase flood resilience and improve water quality. It is therefore recommended that local highway authorities monitor the development of national standards and consider the implementation of SUDS at selected locations on their highway network.

Appendix 5 provides further advice on this issue.

Hotter and Drier Summers

5.2.2 Asphalt Pavements

The following review is derived and developed from TRL Published Project Report PPR 184

- **Asphalt Deformation and Binder Softening**
  As bitumen is thermoplastic, deformation or rutting of asphalt becomes progressively greater at higher temperatures when the binder softens. Deformation is also greater at higher traffic loading and lower speeds (in the case of evolved roads lower speeds are more relevant but not heavy traffic loadings).
  Appraisal of a typical highway network should identify the parts of the network at most risk from deformation. Risk assessments should consider factors including the following:-

  - Pavement layer thicknesses – thinner layers are at more risk
  - Material type – some materials are more prone to deformation
  - Topography – South and South West facing slopes with shelter from prevailing winds endure increased solar gain
  - Traffic – channelized and slow moving traffic result in more deformation
  - External - shelter from surrounding buildings/walls/trees etc

  For new highway construction including maintenance, local highway authorities should consider the selection of appropriate deformation resistant asphalt materials. End result specifications which include the selection of deformation resistance levels of performance for definition in contract specifications are preferred. In the case of recipe materials, careful asphalt mixture selection including binder grade is recommended. If end result compaction is not specified, considerable care is recommended to ensure the insitu asphalt is of adequate compacted density. Appendix 3 provides technical advice including recommendations on asphalt surfacings, binder and base layers.

- **Loss of Surface Texture**
  Higher temperatures soften binders which has the effect of reducing surface texture. This is predominantly an issue for surface treatments and in particular surface dressing where lower binder grades are used in bitumen emulsion formulations compared with asphalt mixtures. The evolved highway network in rural areas is often surface dressed and therefore this is considered to be substantial issue for local highway authorities.
  Appendix 4 provides technical advice to assist in adaptation to the effects of climate change for surface treatments.
  For new surface dressing designs it is recommended that in addition to using Road Note 39 6th edition (6), that risk assessment of the highway network may result in enhancement in the selection of binder grade and/or aggregate to offset the detrimental effects of higher temperatures.
  In the case of existing highways that have lost surface texture, an advice note is included for the treatment or remediation of “melted” surfaces.

- **More Rapid Ageing of Binder**
  Bitumen hardens with age. Read and Whiteoak (2003) (7) provide an overview of this process.
  Asphalt is known to harden during the storage and manufacture of the material followed by further hardening during the in-service life. An increase in temperature due to climate change will increase the rate of asphalt/binder hardening. Higher insitu air voids within the asphalt will also increase the rate of asphalt/binder hardening.
  The effect of binder hardening within thin evolved pavements is to render the asphalt more brittle and decrease the ability of the pavement to flex under traffic loads and therefore the asphalt will be prone to cracking.
  Observations have shown that the majority of cracking on the heavily trafficked trunk road network initiate at the top and propagate downwards (Nunn,1989; Nesnas and Nunn,2006) (8).
  Adaption recommendations are to construct and maintain highway pavements with well compacted asphalt and to maintain the surface in a sealed condition. Modified binders will assist to resist the cracking problem but at additional cost. Modified surface dressing binders will help to counteract cracking (including reflective cracking) of pavements and provide a more elastic surface seal.

- **Contribution to the Heat Island Effect**
  As discussed in paragraph 5.2.1.4 Pavement Solar Gain, asphalt pavements absorb considerable quantities of heat from solar radiation. With increasing temperatures as a result of climate change this situation will become more prevalent in future.
  The principle of cooler pavements has been reviewed within TRL Published Project Report PPR 184. (2) This type of paving technology is claimed not to require new materials.
  Three options that have been previously studied to date are as follows:-

  1. Increased surface reflectance which reduces solar radiation absorbed by the pavement.
  The use of light coloured surfacing would greatly assist surface reflectance.
  Concrete or “whitetopping” is preferable to black bitumen in asphalt.
  The use of light coloured aggregate for surface dressing was appraised but considered to be difficult to align with current procurement and technical specifications.
  Light coloured aggregate and/or asphalt with modified colour can be considered but the increased cost for minor evolved highways was concluded to be an obstacle to promotion.
  Local availability of light aggregates across the UK was considered to be poor and also light coloured aggregates did not generally provide adequate frictional and abrasion properties that are specified for surface courses.
  The use of light buff coloured calcined bauxite for high friction surfacings was considered advantageous to reduce solar gain.

  2. Increased permeability, which cools the pavement through evaporation of water.
  It is initially apparent that the principle of permitting water permeation through a pavement structure is contrary to traditional highway engineering expertise that is

based on maximisation of in-service performance by keeping the pavement sealed to prevent ingress of water (surface treatments are a good example).
The cooling effect of the water percolation through the pavement reduces the retained heat which in turn lessens the heat island effect.
The concept of porous or permeable pavements reduces surface water run-off and is promoted by SUDS initiatives. The Flooding and Water Management Act 2010(5) introduces sustainable drainage and the development of appropriate national standards.

3. A composite pavement structure for noise reduction has been found to emit lower levels of heat at night.

Within Appendix 5, the first two options above are reviewed with recommendations. Option 3 is considered to require further research at this stage.
These newer design concepts should be considered for further research and development with a view to implementation trials in the future.

5.2.3 Asphalt – Insitu Recycling
The following review is derived from Design Manual for Roads and Bridges Vol 7 HD 35/04(11) and the Specification for Highway Works(8). More recent publications are Road Note 43(12) and TRL Published Project Report 468(13)

- **Clay Shrinkage and Swelling**
  Cohesive clay soil is susceptible to volumetric change due to changes in water content. Shrinkage in dry weather and swelling in wet weather is the result of this process which can be summarised as ground movement or pavement movement if within the pavement structure. Climate change with a decrease of rainfall in the summer and an increase in rainfall and water content in the winter will create greater risk from volumetric change.
  To avoid this risk, it is recommended that this issue should be appraised at the design stage by testing of recycled material samples after immersion in water for evidence of shrinkage and swelling with any associated cracking. However, the risk remains of ground movement below the recycled pavement with more extreme climatic conditions.
  Further information and advice is contained in Appendix 3.

- **Binder grade may require increase**
  An increase in summer temperature due to climate change will result in an increased risk from deformation or rutting. The deformation resistance of samples will require to be checked for adequate performance at the design stage. It is possible that the binder grade may have to be increased compared with past practice, to provide adequate deformation resistance.
  Further information and advice is contained in Appendix 3.

- **Durability due to the effects of water**
  An increase in rainfall resulting from climate change and ingress of water into the pavement structure will demand a material with adequate durability to cyclic changes of water and temperature.

It is recommended that the components and the composite material are assessed for durability by appropriate testing.
Further information and advice is contained in Appendix 3.

- **Sub-grade- requirement for lime/cement stabilisation**
  Water sensitive sub-grades may require to be stabilised by the addition of lime or cement to improve their resistance to deterioration due to water ingress. Design guidance may require reappraisal to ensure the adequacy of insitu recycling pavements in future.
  Further information and advice is contained in Appendix 3.

- **Binder stripping of recycled aggregate**
  Reclaimed aggregate from existing pavements may be more susceptible to binder stripping with increased rainfall due to climate change. Older sources of aggregate supply may include acidic rock types i.e. granite and quartzite that may offer poor binder/ aggregate affinity.
  It is recommended that both reclaimed and new aggregates are appraised for binder/aggregate affinity.
  Further information and advice is contained in Appendix 3.

- **Free Draining Materials more suitable for Unbound Material**
  When free draining materials are encountered as part of the layer to be recycled, these materials are generally deficient in fine material. Alternative use of this free draining material as an unbound material can be considered.
  Further information and advice is contained in Appendix 3.

- **Frost Heave potential due to more water present**
  The potential supply of water resulting from climate change within insitu recycled pavements necessitates the need for frost heave testing for the composite pavement material as part of the design process.
  Further information and advice is contained in Appendix 3.

- **Lack of Waterproofing**
  The risk of increased water penetration into in-situ recycled pavements due to climate change suggests that measures should be taken to render the pavement structure impermeable. The use of surface treatments and/or bond coats will assist this objective.

5.2.4 Rigid Pavements

The following review is derived from TRL Published Project Report PPR 184 (2)

- **Defective Joints**
  Most rigid pavements maintained by local highway authorities are jointed and are either unreinforced or reinforced concrete pavements. Joints are required for construction and thermal expansion reasons but have proved to be difficult to maintain in adequate condition to fulfil the design requirements. The increase

temperatures resulting from climate change will result in lower functional life particularly for joint seals.
It is therefore recommended that local highway authorities:-

- Inspect and monitor the condition of joint seals or a regular frequency.
- Replace defective joint seals to ensure that sealants are adequately bonded and adhering to the concrete slabs at the joint detail and are ductile to expand as a result of future higher temperatures. The utilisation of upgraded joint sealant may be considered to provide improved future performance.

Further technical advice is provided in Appendix 6.

- **Concrete Expansion**
  Increased temperatures will result in an increase in the volumetric dimensions of concrete slabs. Closure of expansion joints may result in compression failure or "blow ups". Inadequately designed concrete slabs and poorly maintained joints with poor load transfer efficiency will be at more risk from failure. Adaption measures are as follows:-

  - For new construction or replacement of slabs, the use of concrete containing aggregate with a low coefficient of expansion is considered desirable to offset this problem.
  - Construction of concrete pavements with a greater gap width can also be considered for new or replacement slabs.

- **Concrete Construction**
  The following considerations are recommended for concrete construction:-

  - At high temperatures, concrete mixes may require to be re-evaluated for workability characteristics and the curing arrangements including the curing time. This may well require the use of selected additives to modify the basic concrete mix design.
  - Restrict concrete paving at times of very high temperature.

- **Asphalt Surface Course**
  Many rigid pavements have been overlain by an asphalt surface course. As asphalt has a greater solar compared with rigid concrete, this principle is more problematic at higher temperatures. The following recommendation can be considered for new construction:-
  - Use of exposed aggregate open textured concrete surface course.

5.2.5 Modular Pavements

The following review is derived from TRL Published Project Report PPR 184 (2)

- **Element Expansion**
  At higher temperatures slab elements will warp and expand with an increased range of expansion and contraction.
  It is recommended that to mitigate these effects that smaller dimension elemental slabs are utilised in practice.

Further technical detail and advice is contained in Appendix 7.

- **Joint Width**
  To offset higher temperatures and expansion, the joint width can be increased to accommodate increased movement.

5.2.6 Footways and Cycleways
Local highway authorities maintain large networks of footways and an increasing length of cycleway. Many of these pavements have evolved over the passage of time. These pavements are thinner in construction thickness compared with carriageways
The following review is derived from the Design Manual for Roads and Bridges Vol 7 HD 39/01(14) and HD 40/01(15)

- **Damage by Vegetation**
  Narrow, thin pavements are vulnerable to damage by vegetation and the effects of climate change are likely to accelerate this process with a longer and more extensive growing season. Previous experience with reductions in highway maintenance expenditure on footways illustrates the decline in condition due to the climate and vegetation.
  Recommended actions to mitigate against these effects are as follows:-

    - Operate highway maintenance procedures to cut back vegetation including additional grass cutting and weed killing of verges and channels.
    - Keep paved areas free of vegetation or cut vegetation to avoid a slip hazard.
    - Avoid locating footways close to large trees to avoid deformation and subsidence.

  Further information is contained in Appendix 9

- **Desiccation Cracking**
  Clay and moisture susceptible sub grade materials are particularly prone to desiccation cracking and should be avoided if possible. Pavement drainage will also assist to mitigate the problem.
  Further information is contained in Appendix 9.

- **Asphalt Age Hardening**
  To counteract age hardening due to increased temperatures, it is preferable to utilise asphalt with the following characteristics as asphalts with thin binder films and high air void levels are most at risk.:-

    - Dense grading and close texture
    - Adequate binder content
    - A high level of compaction (preferably an end result compaction specification or carefully monitored method compaction)

Further information is contained in Appendix 9.

- **Asphalt Deformation**
  Increased temperatures may also result in pavement deformation or rutting.
  Mitigation recommendations are as follows:-

- Select an asphalt type with good deformation resistant properties
- Higher grade binders (low penetration values) have a greater resistance to deformation.
- A high level of compaction (preferably an end result compaction specification or carefully monitored method compaction)

Further information is contained in Appendix 9.

<u>Milder and Wetter Winters</u>

5.2.7 Asphalt Pavements

The following review is derived and developed from TRL Published Project Report PPR 184

- **Bitumen Stripping**
  Water can under certain conditions break down the adhesion and cohesion between aggregate and binder in an asphalt mixture. This often occurs when water enters a highway pavement and is trapped between two layers at an interface. Hydraulic pressure from traffic scours the binder from the aggregate.
  The highway industry and the Specification for Highway Works(9) has no current requirement to check the affinity of the binder to the aggregate and this issue has been controlled in the past in an informal manner.
  Increased rainfall may increase the incidence of binder stripping and therefore local highway authorities should be aware of the potential danger.
  Several recommendations are presented in Appendix 3 to prevent this problem.

- **Lack of Bond between Layers with poor Waterproofing**
  The presence of voids at layer interfaces combined with lack of bond and adhesion between layers has in the past been detrimental to pavement performance. Increase rainfall penetration as a result of climate change will contribute to this problem. A fundamental need for improved waterproofing exists at layer interfaces.
  The use of bond coats at layer interfaces will greatly assist to mitigate this deficiency. Compared with traditional tack coats, bond coats utilise of higher binder spread rate and a modified binder which provides enhanced benefits and are now preferred in the current draft BS 594987; 2010(10).
  Appendix 3 provides additional information on the use of bond coats.

- **Asphalt Permeability**
  Thin evolved pavements often constructed with low grade materials tend to be relatively permeable to surface water. Increased rainfall penetration again will make matters worse.
  Local highway authorities should consider several options to reduce the permeability of these highways during the maintenance process as follows:-

  During resurfacing or reconstruction, utilise asphalt materials with low permeability.
  Dense, well graded asphalt mixtures are preferred.
  Selected asphalt mixtures should be designed with sufficient binder and not be lean.
  Asphalt should be adequately compacted to a high compacted density with low air voids preferably using an end result specification.
  Ensure the number of joints is minimised and effectively sealed.
  Cracked asphalt or open joints within existing pavements should be effectively sealed.
  Surface treatment to seal the pavement remains as best practice.
  Advice regarding best practice for the construction of asphalt joints is contained in Appendix 3.

- **Permeable Pavements**
  As discussed in paragraph 5.2.2.4, the concept of designing a pavement that deliberately permits water to permeate through the structure is gaining recent attention as an alternative approach whereby surface water is allowed to naturally drain through the pavement to the formation. The Flooding and Water Management Act 2010(5) identifies the key benefits of a reduction in surface water runoff and improvement in water quality. Local highway authorities will wish to consider the design life and maintenance profile for these pavements and the locations where benefit would accrue. The future publication of national design and specification standards will be beneficial for implementation.
  Further advice is included in Appendix 5.

- **Lack of Waterproofing**
  This defect has been traditionally addressed by the use of surface treatments. In rural areas surface dressing has been a popular choice and has offered good value for money. Evolved pavements should continue to be sealed in this manner to counteract climate change and to waterproof the pavement structure. However surface dressing design requires to be re-appraised and adapted as discussed in Appendix 4

5.2.8 Rigid Pavements

The following review is derived from TRL Published Project Report PPR 184 (2)

- **Defective Joints**
  As with paragraph 5.3.2.1, defective joints that are not adequately sealed will permit water permeation through the pavement structure. Corrosion of reinforcement and erosion of the sub-base/sub grade support layer are undesirable consequences. The following recommendations are listed:-
    - Inspect and monitor the condition of joint seals on a regular frequency.
    - Replace defective joint seals to ensure that sealants are adequately bonded and adhering to the concrete slabs at the joint detail and are ductile to expand as a result of future higher temperatures. The utilisation of upgraded joint sealant may be considered to provide improved future performance.

  Further technical advice is provided in Appendix 6.

- **Asphalt Surface Course**
  As with paragraph 5.2.3.4, the use of exposed aggregate open graded concrete surface course is recommended for drainage purposes as it is less likely to clogging compared with an asphalt surfacing.
- **Concrete Construction**
  During periods of heavy rain concrete paving should be suspended as water damage to the fresh concrete could result.

- **Concrete Air Entrainment**
  The use of high strength pavement quality concrete and predicted less cold temperatures with a reduction in freeze/thaw cycles due to climate change now negates the traditional need for air entrained concrete.

5.2.9 Modular Pavements

The following review is derived from TRL Published Project Report PPR 184 (2)
Milder Wetter

- **Drainage Damage**
  Increased rainfall and water ingress through joints and bedding sand will drain into the sub-base and subgrade reducing the pavements load bearing efficiency. Deformation under traffic loading is a consequence.
  To reduce this effect, rather than utilising a design with sealed joints which will contribute to surface runoff, that consideration be given to the use of a porous foundation. The use of a sub-base with increased permeability should be considered with a coarse graded (free draining) type 3 sub-base as an option.
  The addition of a geotextile layer at the underside of the sand bedding layer can prevent erosion of this layer.
  The use of modular pavements in locations prone to regular flooding should be reviewed with the use of an alternative pavement design preferred due to the potential risk of premature failure.

- **Bedding Sand Integrity**
  As discussed in paragraph 5.2.4.3, the use of a geotextile layer at the underside of the sand bedding layer can prevent erosion of the layer as a result of extensive water migration. The use of a porous sub-base may have additional benefit.

5.2.10 Unsurfaced Pavements

- **Increased Water Damage**
  Increased rainfall due to climate change will result in increased erosion and scour with unsurfaced pavements.
  The use of unbound materials with good permeability characteristics is desirable to permit water to permeate to the pavement formation. Drainage features to assist water runoff would also be beneficial.
  Stiffer cement and other hydraulically bound mixtures may have merit in selected locations where enhanced performance and durability are important design considerations.
  Further information is contained in Appendix 8.

5.2.11 Footways and Cycleways

Local highway authorities maintain large networks of footways and an increasing length of cycleway. Many of these pavements have evolved over the passage of time. These pavements are thinner in construction thickness compared with carriageways
The following review is derived from the Design Manual for Roads and Bridges Vol 7 HD 39/01(14) and HD 40/01(15)

- **Freeze/Thaw Cycles**
  Although climate change predictions do not indicate freeze/thaw will become more acute, the thin structure of footways and cycleways will be prone to deterioration due to this regime as there will be greater quantities of water present.

It is therefore important to ensure that these pavements are constructed with both asphalt and sub-base materials that contain durable and frost resistant aggregates.

- **Foundation Weakening**
  Additional weakening of the pavement may occur from water entering the foundation layers. As climate change will increase the potential quantities of water entering the pavement structure, it is important that foundation layers be designed for adequate thickness and should be well compacted to achieve maximum stiffness.

- **Binder Stripping**
  Additional and more intense rainfall will have the effect of increasing the potential for binder being stripped from the aggregate. Footway and cycleway pavements are particularly at risk due to a range of factors of which the pavement thickness and traditional choice of asphalt materials are major issues. Layer interfaces and joints have been found to be the locations of most risk from binder stripping.
  To mitigate against binder stripping, the following recommendations are listed:-
    - Select an aggregate with good binder affinity
    - Select a binder with good water resistant properties
    - Specify a higher binder grade
    - Consider the use of hydrated lime as a proportion of the filler if concern regarding binder and/or aggregate.
    - Surface treatment to seal surface and prevent water ingress.

5.3 RECOMMENDATIONS - BLACKTOP

- Specify the highest penetration bitumen grade (lowest penetration value) that can be practically laid and compacted to meet the specification requirements for carriageways, footways and cycleways.

- The preferred bitumen paving grade for hot rolled asphalt surface course is 40/60.

- For lightly trafficked evolved highways, hot rolled asphalt surface course recipe Clause 910 may be adequate but the use of design Clause 911 or performance - related Clause 943 may be more appropriate on sites with higher risk to higher temperature deformation concern is considered to be a potential future issue.

- High stone content asphalt surface course has many benefits to resist higher temperature deformation concerns but consider the low resultant texture depth dis-benefit.

- For thin surface course systems, apply the principles of the Best Practice Guidelines for Surfacing to ensure the surfacing is resilient to withstand the rigors of future climate change and also ensure the use of a product with BBA HAPAS Roads and Bridges certification for type approval.

- Apply the principles of the "Best Practice Guidelines for the Durability of Asphalt Pavements" to ensure stone mastic asphalt surfacing is resilient to withstand the rigors of future climate change and also ensure the use of a product with BBA HAPAS Roads and Bridges certification for type approval. 40/60 pen grade bitumen is preferred for deformation resistance.

- Specify a dense/close of fine graded asphalt concrete. Ensure that the mixture is resistant to binder stripping. Use a high viscosity/ low penetration grade binder that can be successfully constructed on site. Apply the "Best Practice Guide for the Durability of Asphalt Pavements".

- Specify SHW Clause 924 high friction surfacing with a BBA HAPAS Roads and Bridges certificate for type approval. Select the appropriate class of product to accord with use and ensure that material laid in cooler and inclement conditions adheres and is bonded to the substrate. The light buff coloured calcined bauxite will assist to reduce asphalt pavement temperature during hotter summer months.

- Consider the use of Grouted Asphalt (Macadam) in limited selected locations to resist abnormal design requirements. Benefits also include resistance to the effects of climate change in addition to hydrocarbon fuel spillage resistance.

- Dense base and binder course asphalt concrete have traditionally been used for structural strengthening on highways. To adapt to climate change, use of Clause 929 material is recommended with deformation/ wheel tracking type approval appraisal and compaction control which can be monitored on site.

- For climate change adaption, ensure that the specification for stone mastic asphalt binder/base clearly describes the required technical parameters and type approval information is provided by the supplier (Compaction and deformation resistance are both important)

- Despite the benefits (particularly deformation resistance) from using EME 2 on major highways, it is not recommended that this material is used on the minor evolved highway network meantime until publication of future national guidance. Recent proprietary asphalt materials with less stiff binder including polymer modification offer an alternative option.

- Cement and hydraulically bound base and sub-base would provide a stronger more durable structure and foundation for evolved pavements. However the opportunities to implement this material may be limited. Recycled options offer reduced aggregate supply and sustainability benefits.

- Apply the best practice for transverse and longitudinal joints – refer to the Specification for Highway Works and Road Note 42 "Best Practice Guide for the Durability of Asphalt Pavements".

- Use bond coats to reduce voids at layer interfaces, promote adhesion and to waterproof asphalt pavements as required by Draft BS 594987(2010)

- Appraise binder and aggregate for asphalt mixtures for susceptibility to stripping and use binders with good water resistant properties. Use higher viscosity (lower penetration) bitumen binders and hydrated lime as filler to promote binder/aggregate affinity.

- To provide continuing resistance to freeze thaw risk due to increased presence of water, appraise frost heave potential and durability.

- When consider remedial works to asphalt pavements which include insitu recycling of existing materials, climate change adaption will require further consideration at the design stage of the effects of higher temperatures and higher rainfall.

- As the effects of climate change will be detrimental to patching performance, it is important to apply specifications and use materials with resistance to the higher temperatures and increased rainfall expected in future.

- Appraise proprietary, thermosetting, resin based emergency patching materials and ensure that the performance is suitable for the anticipated temperature range and thickness of application.

RECOMMENDATIONS - SURFACE TREATMENTS

- Micro- surfacing including slurry surfacing can be effectively used to maintain evolved pavements by sealing and waterproofing the existing structure in conjunction with improvements in other properties. The waterproofing function should assist resistance to increased rainfall as a result of climate change.
- Consider phasing out the use of unmodified bitumen emulsion binders and using only modified binders for enhanced performance and to counteract increased temperatures.
- Consider increasing the binder grade of modified bitumen emulsion at high risk sites.
- Consider a reduction in the use of surface dressings using single size aggregates by increasing the use of racked in surface dressings or by the use of graded aggregates at high risk sites.
- Use the guidance note to rectify surface dressings with excess binder at the surface (bleeding or fatting) and have melted during hot weather.

RECOMMENDATIONS - HEAT ISLAND EFFECT

- It may be difficult to specify (as colour is out with technical specifications for aggregates) and use pale colour aggregates and also to meet other technical requirements despite the validity of the principle. Increased cost and carbon footprint may discourage this option.
- Monitor developments of national standards for SUDS and applicability to the local authority highway network
- Consider the option of designing porous pavements in selected locations where benefits will accrue from reduced surface run-off. The design and maintenance will require careful consideration since there is currently limited research/development and experience with these pavements.

RECOMMENDATIONS - CONCRETE

- Consider a range of options to improve performance of rigid pavements and counteract the effects of climate change. Adaption measures can include the use of more frequent joint seal replacement, improved grade sealants, use of low coefficient of expansion aggregate and restrictions on construction during periods of high temperatures.
- Asphalt overlays will exacerbate the thermal strain within rigid pavements due to increased temperature as a result of climate change. Consider proprietary systems (e.g. asphalt reinforcement) to improve performance and resilience to climate change

RECOMMENDATIONS - MODULAR PAVEMENTS

- To adapt modular pavement designs for climate change, consider the use of smaller elemental slabs or blocks. Enlarged joints may also be desirable.

RECOMMENDATIONS - UNSURFACED PAVEMENTS

- Climate change with increased rainfall will require unbound layers with improved drainage characteristics for unsurfaced pavements. Consider alternative pavement type if location prone to flooding.

RECOMMENDATIONS – FOOTWAYS AND CYCLEWAYS

- Use dense well compacted asphalt concrete with 100/150 pen grade bitumen binder for new footways and maintenance of footways. The use of 40/60 pen grade bitumen binder can be considered at domestic vehicular crossings to improve performance.

- To adapt to the effects of climate change and maximise modular and rigid footway performance, apply the best practice recommendations of DMRB Vol 7 HD 39 and 40.

5.4 Risk Management

5.4.1 Background

General recommendations suggest that Local Highway Authorities should prepare a risk assessment with the full engagement of members and staff as a result of climate change. This is likely to include reviewing existing highway maintenance strategy, policy and plans in the light of risks posed by climate change. (Managing Pavements in a Changing Climate- Department of Transport (16))

A further two recommendations (Managing Pavements in a changing climate – Department of Transport (16)) to assist with risk management associated with climate change are as follows:-

Undertake a sustainability audit of highway maintenance and management plans ensuring that practices used to adapt to climate change are not in themselves contributing to climate change.

Record and monitor weather effects on the local highway authority network and share the lessons learnt with other local authorities. Compiling a local climate impacts profile (LCIP) can assist with this. (UKCIP User Forum 2007- http://www.ukcip.org.uk (2)).

An example or case study of a climate change risk management process is published by The 3 Counties Alliance Partnership (17). A list of action plan activities is included within the literature review within Appendix 2. Each local highway authority will have different potential risks identified as a result of climate change which will depend on the detail of the individual highway network.

5.4.2 Highway Inventory

The development of Transport Asset Management Plans during the past ten years has encouraged local highway authorities to collect inventory data covering the range of assets associated with the public highway network. This inventory should of assistance in the determination of which asset groups are at risk from climate change and the locations of high priority risk. Interaction between risks associated with highway asset groups is also significant and should be considered. Geographic information systems can be utilised to collect inventory data regarding South/South West exposure and gradient where high temperatures present greatest risk. Additional inventory items (pavement type/surface type) may also be of assistance during the climate change risk management process to provide sufficient detail to provide higher confidence risk assessment.

5.4.3 Inspection/Condition Assessment

Local highway authorities currently operate many types of inspection and condition assessment of the highway infrastructure as part of generic pavement management systems. These systems are utilised to maintain the highway network in a safe condition for the user and to monitor and prioritise highway maintenance works and range from visual safety inspections to detailed technical measurements of the pavement condition by SCANNER.

The effects of climate change can be appraised using existing systems, albeit the type and frequency of assessment will be lower on minor and evolved pavements. Initial assessment may illustrate the defects that have developed whilst adaptive measures can be monitored to check if success is realised.

An example is loss of surface texture, where measurement of texture depth on a network basis can determine locations of defective texture depth and highlight high risk locations due to a range of influential factors. Comparisons with data from earlier surveys will assist the prediction of trends e.g. SCANNER and Coarse Visual Inspection can provide valuable information regarding change in rut depth.

5.5 Summary of Potential Problems and Solutions

The effect of climate change on highway pavements and in particular minor highways and evolved pavements is to reduce the in-service performance of these pavements. Without adaption and mitigation, highway pavements will cost more to maintain to prescribed levels of service.

It is therefore recommended that local highway authorities carry out a risk management process to re-appraise highway maintenance with an objective of change to current practice. This change should focus on addressing any perceived reduction in pavement performance with emphasis on whole of term accountancy practice.

The following is a summary of the potential problems resulting from the effects of climate change on pavements and suggested actions or solutions to mitigate. Additional advice and recommendations are contained within accompanying appendices 3-9. Several conflicts are apparent notably the traditional principle of sealing the pavement structure which is very important with increased potential rainfall and the newer concept of porous or permeable pavements which encourage the passage of water through the pavement for sustainability reasons of reduced surface runoff and the cooling effect of water permeation. It is apparent that local highway authorities need to consider the risk on an individual basis and on the merit of the particular location on the highway network.

Mitigation of climate change effects on pavements and materials

General

PROBLEM	**Key Features**	**Suggested Actions to Mitigate**
(a)Materials and construction practice	Best practice	Apply current guidance (Road Note 42 for Asphalt Pavements)
(b)Lack of effective drainage	Surface flooding and pavement damage	Existing drainage adequately maintained Additional drainage provision
(c)Maintain pavements in good condition and the surface sealed	Poorly maintained pavements – deformed and cracked	Requires adequate finance and pavement management systems
(d)Pavement strength and integrity	Problems with low strength and unbound layers	Consider the use of stronger hydraulically bound foundations
(e)Pavement solar gain	High surface temperatures	Consider increasing surface reflectance to reduce temperatures Consider permeable pavements which would cool the pavement and align with SUDS principles

Table 5.1

Asphalt/Flexible Pavements

PROBLEM	Key Features	Suggested Actions to Mitigate
1.Hotter and Drier	Summer Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a)Asphalt deformation and binder softening	Rutting of asphalt layers at higher temperatures	Select deformation resistant material type and specify deformation resistance Specify appropriate binder grade Specify high level of compaction Specify modified binder
(b) Loss of Surface Texture	Predominantly surface treatment issue	Ensure adequate design Specify modified binder For Surface Dressing remediation refer to advice note
(c) More rapid age hardening of binder	Increased cracking potential	Ensure asphalt has a high level of compaction. Specify modified binder
(d) Contribution to heat island effect	Asphalt heat absorption	Lighter colour surfacing Porous/permeable pavements
(e) High Friction Surface Colour	Calcined bauxite	Use light buff colour
2. Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk

		Develop pavement inventories and carry out risk assessments to manage potential risks
(a) (a) Bitumen stripping	Predominantly surface course issue	Select aggregate with good binder affinity Use binders with good water resistant properties Specify higher binder grade Consider use of hydrated lime filler if poor binder affinity Surface treatment to seal surface
(b) (b) Lack of bond between layers with poor waterproofing	Improved adhesion and waterproofing	Specify bond coats at layer interfaces
(c) (c) Asphalt Permeability	Render more impermeable	Select appropriate material type Ensure satisfactory mixture design with adequate binder Specify high level of compaction Minimise joints and ensure sealed Seal cracked surface courses Surface treatment to maintain seal
(d) (d) Permeable pavements	SUDS promoted design Encourage water to drain through pavement cooling pavement with reduced surface run-off	Consider suitable locations Assess design life
(e) (e) Lack of waterproofing	Cracks, poor joints	Surface Dressing

Table 5.2

Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for asphalt surfacing, binder and base layers, insitu recycling and patching within Appendix 3
Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for surface treatments within Appendix 4.
Additional more detailed recommendation and suggested actions to mitigate the effects of climate change and the heat island effect within Appendix 5

Asphalt- Insitu Recycling

PROBLEM	**Key Issues**	**Suggested Action to Mitigate**
1.Hotter and Drier	Summer Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a)Clay shrinkage and swelling	Ground movement	Further design appraisal and testing to take account of shrinkage/swelling potential
(b)Binder grade may require increase	Deformation or rutting	Deformation resistance testing required
2.Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a)Durability due to effects of water	Potential water damage	Assess durability of components and composite material
(b)Sub grade – requirement for lime/cement stabilisation	Sub grade improvement of water susceptible soils required	Assess sub grade characteristics as part of ground investigation
(c)Binder stripping of recycled aggregate	Both recycled and new aggregate should be resistant to binder stripping	Appraise binder and aggregate. Carry out binder /aggregate affinity tests

(d)Free draining materials more suitable for unbound material	Alternative use	Assess from ground investigation for alternative use
(e)Frost heave potential due to more water present	Additional potential	Frost heave testing
(f)Lack of waterproofing	Water ingress	Surface Treatment or bond coat to seal pavement

Table 5.3

Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for asphalt surfacing, binder and base layers, insitu recycling and patching within Appendix 3

Rigid Pavements

PROBLEM	Key Features	Suggested Actions to Mitigate
1.Hotter and Drier	Summer Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a) (a) Defective Joints	Joint integrity	Maintain joint seals Upgrade joint seal composition
(b)Concrete expansion	Thermal movement	Use low coefficient of expansion course aggregate Wider gap width
(c)Concrete construction	Concrete workability and curing	Modify concrete mix design to ensure adequate workability and curing time Restrict concrete paving at high temperatures
(d)Asphalt surface course	Asphalt solar absorption	Use exposed aggregate concrete surface course
(e) Asphalt overlays	Reflective cracking potential	Use proprietary systems
2. Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a) Defective Joints	Joint integrity	Maintain joint seals
(b) Asphalt	Asphalt solar absorption	Use exposed aggregate concrete

surface course		surface course as less likely to clogging
(c) Concrete construction	Rain damage	Restrict paving during heavy rain
(d) Concrete air entrainment	Resistance to freeze thaw	Not considered necessary

Table 5.4
Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for rigid pavements within Appendix 6

Modular Pavements

PROBLEM	Key Features	Suggested Actions to mitigate
1.Hotter and Drier	Summer Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a)Element expansion	Joint compression	Replace large slabs with small elements/blocks
(b)Joint Width	Joint compression	Use concrete block paving with enlarged joints
2. Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a)Drainage damage	Foundation permeability	Lay on a porous foundation
(b)Bedding sand integrity	Bedding sand washout	Use geotextile under bedding sand

Table 5.5
Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for modular pavements within Appendix 7

Unsurfaced Pavements

PROBLEM	Key Issues	Suggested Actions to Mitigate
Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
(a) Increased water damage	Erosion and Scour	Use porous granular layer
(b) Weak foundations	Deformation	Use Cement/Hydraulically Bound Recycled Material

Table 5.6
Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for unsurfaced pavements within Appendix 8

Footways and Cycleways

PROBLEM	Key Issues	Suggested Actions to Mitigate
Hotter and Drier	Summer Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
Damage by vegetation	More growth Change in surface condition Tree roots	Keep vegetation under control Slip hazard Structural deformation/subsidence
Desiccation cracking	Shrinkage cracking Tree roots	Reject moisture susceptible materials, provide good drainage, avoid large trees
Asphalt age hardening	Cracking	Use dense asphalt Ensure adequate binder content Ensure that asphalt is well compacted
Asphalt Deformation	Rutting	Select deformation resistant material type Specify appropriate binder grade Specify high level of compaction
Milder and Wetter	Winter Issue	Identify relevant pavement and materials issues Identify parts of highway network at risk Develop pavement inventories and carry out risk assessments to manage potential risks
Freeze/thaw cycles	Results in surface	Use aggregate with adequate

	deterioration	durability and frost resistance
Foundation weakening	Water ingress and erosion	Ensure adequate thickness, well compacted sub-base
Binder stripping	Prevalent in warm, moist conditions	Select aggregate with good binder affinity Use binders with good water resistant properties Specify higher binder grade Consider use of hydrated lime filler if poor binder affinity Surface Treatment to seal surface

Table 5.7
Additional more detailed recommendations and suggested actions to mitigate the effects of climate change for footways and cycleways within Appendix 9

5.6 Further Research

5.6.1 General

Countless potential exists for research to improve the performance of highway pavements subject to increased temperatures and rainfall predicted to occur as a result of climate change. Past research tends to focus on heavily trafficked highway pavements with greater investment and perceived increased benefits. Unfortunately research on minor and evolved highway pavements is limited
Past local highway authority strategy for these minor highways has been greatly influenced by a limited budget and has resulted in the use of low cost techniques employed to maintain the highway pavement in a safe condition to fulfil legislative requirements. Surface treatment to seal the existing surface has been the most popular and successful previous treatment. Additional benefits accrue from re-texturing the surface.

5.6.2 Design Guides and Materials Specifications

Design guides for processes and treatments would benefit from review to appraise changes required to adapt to climate change. Examples of guidance are as follows but not exhaustive:-

(a) Design Guide for Surface Dressing - Road Note 39 6th edition (5)
(b) A guide to the use and specification of cold recycled materials for the maintenance of road pavements – TRL 611(18)

Recommendations for the selection and use of materials are based on past practice. With the impending changes due to climate change, these recommendations may require to be updated.

National, regional and local specifications/notes for guidance require to be considered. In the case of the application of European specifications, assistance can helpful from warmer and wetter climates –typically France and Germany.
One specification and notes for guidance update that would be particularly of assistance to benefit from an update for climate change and the performance of minor highways/evolved pavements is the New Roads and Streetworks Act 1991, HAUC Specification for Reinstatements and Openings in the Highway (19). This would also ensure that in future, work on the highway by statutory undertakers, was also resilient to climate change.

5.6.3 SUDS/ Porous or Permeable Pavements
Recent flash flooding in many parts of the country, culminating in the Flooding and Water Management Act 2010 (5) has led to mounting pressure to reduce the extent and impermeability of hardened surfacing including highway pavements. Porous or permeable pavements have been promoted as part of a more sustainable approach to drainage.
Local highway authorities have previously aligned with the principle of sealing highway pavements will have some concern regarding the design life and maintenance profile for such pavements. Further research and national guidance would be desirable to assist with possible implementation.

5.6.4. Heat Island Effect
Ooms Avenhorn (20) has developed an energy from asphalt system to harness the solar energy from asphalt for use in property with reversal of the energy flow in winter and summer. Although high in sustainability benefit, research on the cost benefit in the UK is required for this option.
Published Project Report TRL PPR 184 (2) identified an option with a composite pavement structure comprising rubber surfacing over conventional rigid concrete slabs with noise reduction and night time temperature benefits. Further research and cost evaluation is required prior to pilot trials.
Kubo et al 2006 (21) promote the concept of heat shield whereby pavements are coated with hollow ceramic particles and special pigment to control the absorption of incoming solar radiation. Further research and cost evaluation is required prior to pilot trials.

5.7 Conclusions

5.7.1 The predictions of climate change including hotter and drier summers and milder and wetter winters including more severe rainfall events are considered conclusive and result in a high risk those highway pavements (particularly minor/evolved pavements) in- service performance will decline leading to a lower functional life from new and maintained construction.
It is therefore important that local highway authorities adopt a risk management approach to identify the key issues affecting their highway network as a result of climate change.
Adaption and mitigation will require changes to current practice commencing with strategy, policy and plans, and culminating with technical changes to pavement material selection and construction. In short, the complete highway maintenance process requires to be re-appraised with a view to improved in-service performance.

5.7.2 With current budgetary pressures, it is important to deliver lowest whole life cost. Without change, whole life cost will increase due to lower performance as climate change takes effect. Adaption and mitigation changes require redressing this upward trend by improving functional life. Some changes will however, involve an increased initial cost i.e. change binder to a modified binder as improved performance materials will be required to resist higher temperatures or rainfall. Justification of increased initial cost offset by lower whole life cost will be required in some situations.

5.7.3 Many proposed adaption and mitigation changes have been proposed by Department for Transport within their publication “Maintaining Pavements in a Changing Climate” (Reference). These changes have been retained and extended within this report. More extensive advice has been included within appendices which include a series of recommendations.

5.7.4 A summary of problems, key issues and suggested actions to mitigate these problems is provided in paragraph 5.4.
Existing highway maintenance systems re-appraised for climate change by a risk management approach is recommended to local highway authorities.
The selection of materials based on end result specifications with defined levels of performance is preferred where possible.
Careful consideration of the characteristics of material types is required to maximise performance
As previous, best construction practice is important to maximise performance.
The principles of best value and best practice generally apply.
The majority of advice relates to existing materials and processes. However there are several newer design and construction options recommended for further consideration. Further research and development may be required in this respect. The option of SUDS and porous or permeable pavements is currently receiving considerable attention due to recent legislation - the Flooding and Water Management Act 2010.

5.7.5 Expertise exists within many local highway authorities, with staff experienced in highway maintenance and highway materials, to assist with risk management and adaption/mitigation of existing systems, to refine/ re-appraise and to produce system improvements to deliver improved performance more resilient to the rigors of climate change. Local highway authorities can also consider working in partnership with neighbouring authorities and/or external providers.

5.7.6 The Department for Transport and the UK Roads Liaison Group would appreciate and benefit from feedback on adaption and mitigation of climate change due to the influence on the condition of the national highway network. The Department for Transport is currently developing reporting mechanisms for impact of any maintenance backlog possibly via the Local Transport Plan. Sharing of experience and lessons learned through ADEPT would clearly be beneficial.

5.8 References

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Climate Change and Evolved Pavements

Appendix A1

Detailed Background

A1.1 Background to UK Climate Impacts Programme (UKCIP) 2009 climate change projections (7)

The following section provides some background information on global climate change, the UKCIP climate projections and their use. It then highlights recent trends in temperature and precipitation in the UK and presents some of the UKCP09 projections for change.

A1.1.1 Global Climate Change

According to the Intergovernmental Panel on Climate Change (IPCC) global climate warming is now beyond doubt. Global average surface temperature has increased by about 1°C since the industrial revolution; eleven of the twelve years from 1995 to 2006 were among the twelve warmest years since global records began (IPCC, 2007). The IPCC suggest most of this warming over the last 60 years is “very likely” a result of greenhouse gas (GHG) emissions from human activity. Furthermore, because of the inertia of the climate system, some further climate warming (caused by past emissions) will be unavoidable – even if current emissions are significantly reduced. Therefore, whilst strategies to mitigate climate change are essential, adapting to a changing climate is now also a key issue both globally and in the UK.

A1.1.2 UK Climate Impacts Programme

The UK Climate Impacts Programme has been established to help a range of sectors understand the potential impacts of climate change and formulate strategies for adaptation. UKCIP works closely with the Met Office Hadley Centre and other scientific bodies. Together they present scenarios for climate change in the UK in a user-friendly format. UKCIP have released scenarios previously in 1998 and 2002; the latest scenarios are known collectively as UK Climate Projections (UKCP09).

A1.1.3 UKCP09 projections

The projections are created primarily by the Hadley Centre’s global and regional climate models and are based on each of the IPCC’s three ‘emissions scenarios’. These describe how polluting global society may be in terms of greenhouse gas emissions over the 21st Century. In the UKCP09 projections the emissions scenarios are presented as ‘low’, ‘medium’ and ‘high’. Broadly speaking, climate change projections based on a high emissions scenario show greater change than those for a low emissions scenario – particularly over longer timescales. This is due to the increased climate forcing effect of higher volumes of greenhouse gases in the atmosphere.

Rather than being presented in a report format (like previous scenarios) the UKCP09 projections are accessible via a dynamic web tool. In addition to the three emissions scenarios projections are made for different “time-slices” (representing different periods of the 21st Century) and for 16 administrative regions across the UK (at a spatial resolution of 25km) allowing users to view and customise local/regional climate data over different timescales. This is important as climate change impacts are not uniform across the UK and are characterised by geographical and temporal variations. The 2009 projections also come with probabilities attached (a new feature) - which can help with probabilistic risk assessments.

Users can access different aspects of climate change information via the UKCP09 web tool:

- **Key findings** – includes probabilistic projections for key climate variables (temperature and precipitation) for three time slices and emissions scenarios, for both the UK and 16 administrative regions;

- **Published material** – a series of reports discussing (for example) the rationale and methodology behind the UKCP09 projections, and pre-prepared maps to provide an indication of the range and depth of climate data available;

- **Customisable output** – this comprises a 'user interface' allowing users to produce customised maps, graphs and figures showing changes to a range of climate variables to a high spatial and temporal resolution, and access the raw data used in the projections.

Some of the changes in key climate variables are presented in the following section of the report. **It is recommended that local authorities use the UKCP09 web tool in conjunction with this study to gain a more detailed understanding of potential climatechange impacts on the evolved highway network at a local level.**

A1.1.4 Sources of uncertainty in the climate projections

There are significant uncertainties inherent in climate change projections (Murphy *et al*, 2009). It is important to understand the nature of these uncertainties when using climate projections as a basis for decision making and forward planning in relation to the evolved highway network. This is especially so if capital investment is to be made based on descriptions of future climate.
In the UKCIP09 projections uncertainty is broadly separated into three categories: 1) uncertainty regarding natural variability of climate; 2) uncertainty inherent in modelling climate change; and 3) uncertainty surrounding future greenhouse gas emissions.

A1.1.4.1 Uncertainty regarding natural variability

Even in the absence of the external forcing effect of greenhouse gases from human activity climate will vary over different geographic scales and time periods. There are two principle causes of this variability:

i. Natural internal variability – this describes the "chaotic nature" of the climate system. At some points it may act to reinforce the effects of manmade climate change enhancing the changes; other times it may act against, leading to smaller changes overall. Uncertainty regarding natural internal variability is accounted for and quantified in the UKCP09 probabilistic projections;
ii. (Natural) external factors, mainly changes in solar radiation and aerosol particles from volcanic eruptions. Neither of these can be accurately forecasted, therefore this uncertainty remains.

A1.1.4.2 Climate modelling uncertainty

There are gaps in the knowledge of the behaviour of the climate system as a whole. Furthermore, it is not yet possible to create models which perfectly represent climate. Because of this, modelling necessarily includes some "subjective judgement" which differs between modellers/models. Therefore different climate models will produce different outputs even when based on the same emissions scenario. In the UKCP09 scenarios uncertainties in the projections are quantified in a probabilistic manner. This gives users an idea of the relative likelihood of a change occurring in the future. This goes some way to addressing modelling uncertainty; however, some will remain due to the subjective ‘human’ element within the process.

A1.1.4.3 Future emissions

Quite how polluting society is over the next fifty years in terms of GHG emissions depends on a range of socio-economic factors relating to economic development, population, politics and technological choice. These are all complex, interconnected issues; predicting how they will pan out in reality is fraught with difficulty. The IPCC emissions scenarios are “storylines” which make assumptions about these choices (and there is some further uncertainty inherent in their development). Of the three scenarios (high, medium and low emissions) one is no more or less likely to occur than another. Neither are all three equally probable. Until roughly the early-middle of the 21st Century climate warming is relatively stable and consistent for all three scenarios. This is because of the inertia of the climate system and the effects of GHG’s already emitted. This means a slightly higher degree of confidence can be attached to changes over the short – medium term. After that time the projections begin to diverge due to uncertainty over emissions. Again, emissions uncertainty is accounted for to some extent in UKCP09 via probabilistic projections for each emissions scenario. But it is impossible to state definitively which future scenario is most likely to occur. Therefore UKCP09 recommends that projections for all three emissions scenarios are taken into account when planning adaptation responses.

Consideration is given to dealing with risk and uncertainty in relation to climate projections in practical terms in Section 1.2. However, it is important for users to be aware that whilst uncertainty is inherent in future climate change projections, the climate models used for UKCP09 projections are capable of robustly representing current climate and the major processes that will influence climate change throughout the 21st Century. The existence of uncertainty does not cast doubt on whether climate change is happening should not be a basis for inaction. Moreover, as climate modelling techniques improve so confidence in the projections increases.

1.2 Recent trends in UK climate

The UKCIP report The Climate of the UK and Recent Trends (Jenkins *et al*, 2008) describes how UK climate (temperature and precipitation) has been observed to change recently.

1.2.1 Temperature

The Central England Temperature (CET) records show CET has risen by approximately 1°C since the 1980s (this has also been the case in Wales). This is “a more rapid rise than that of the global average land-surface temperature over the same period and considerably faster than that of the global mean temperature” (Jenkins *et al*, 2008 p. 10). The report suggests this increase “likely” to have been influenced by man-made GHG emissions and their warming effect. Of the fifteen warmest years on CET record, ten have been since 1989, whilst five were too early to have been influenced by human induced climate change – which highlights the effects of natural variability of climate.

In Northern Ireland and Scotland annual mean temperature has increased by about 0.8°C since the 1980s – though this is not definitively attributed to man-made climate change.

1.2.2 Precipitation

Overall, there has been little change in average annual rainfall over England and Wales (for which the longest records exist) since records began. Although variable, there seems to have been a general shift in the distribution of rainfall towards drier summers and wetter winters – though winter rainfall has shown little change for around 50 years. Heavy winter precipitation events have increased across the UK; the opposite is true for in summer for the UK with the exception of Northern Scotland and Northeast England.

A1.2.3 Future changes in temperature and precipitation

The tables below show UKCP09 probabilistic projections for mean summer temperature and winter precipitation, for four regions of the UK (South East England, North West England, Northern Scotland and Northern Ireland). These regions were chosen as they are considered broadly representative of changes across the UK. To understand local and regional changes (and projections for other climate variables) in more detail users should access the UKCP09 projections directly. Changes are shown here for the 2050s time-slice (representing 2040 to 2069/the middle part of the 21st Century) and the three emissions scenarios.

Mean Summer Temperature	**Table A1.1: Change in mean summer temperature (°C) 2050's**											
Emissions Scenario	**South East England**			**North West England**			**Northern Scotland**			**Northern Ireland**		
	Probability Level											
	10%	**50%**	**90%**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**
Low	**1.4**	**2.6**	**4.3**	**1.1**	**2.4**	**3.8**	**0.9**	**1.9**	**3.1**	**0.8**	**1.9**	**3.2**
Medium	**1.3**	**2.8**	**4.6**	**1.2**	**2.6**	**4.1**	**0.9**	**2.0**	**3.4**	**1.0**	**2.2**	**3.5**
High	**1.4**	**3.1**	**5.2**	**1.5**	**3.0**	**4.7**	**1.1**	**2.4**	**3.9**	**1.1**	**2.4**	**4.0**

Mean Winter Precipitation	**Table A1.2: Change in mean winter precipitation (%) 2050's**											
Emissions Scenario	**South East England**			**North West England**			**Northern Scotland**			**Northern Ireland**		
	Probability Level											
	10%	**50%**	**90%**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**	**10%**	**50%**	**90%**
Low	**+1**	**+13**	**+30**	**-1**	**+8**	**+20**	**-1**	**+8**	**+20**	**-1**	**+6**	**+14**
Medium	**+2**	**+16**	**+36**	**+3**	**+13**	**+26**	**+3**	**+13**	**+24**	**+2**	**+9**	**+19**
High	**+3**	**+19**	**+40**	**+3**	**+13**	**+27**	**+3**	**+13**	**+26**	**+2**	**+9**	**+19**

The probability levels represent the likelihood of changes occurring beyond certain thresholds, based on an holistic understanding of climate science (including behaviour of current climate) and expert judgement. To illustrate, table 1 shows that under the low emissions scenario the evidence suggests there is a 10% likelihood the temperature change will be less than 1°C (i.e. it is highly unlikely to be less). There is a 90% likelihood it will be less than 3.8°C (i.e. it is highly likely to be less). The central estimate (2.3°C: 50% likelihood) is relatively the most likely - but this doesn't mean it should be regarded as having "special significance". It is important that the range of uncertainty represented by the probability levels is accounted for when using them in climate change adaptation strategies.

A1.3 The Climate Change Act 2008 (2)

The Climate Change Act 2008 makes specific provision for the potential impacts of climate change and the UK's adaptive capacity. Part 4 of the Act (Impact of and adaptation to climate change) requires the Secretary of State to assess the risks posed to the UK by climate change every five years. Following each risk assessment the Government must publish details of the proposed adaptive measures. Part 4 also gives the Secretary of State power to advise and guide public authorities on climate change risk assessment and adaptation.

In terms of the UK road network, the Highways Agency - or an appropriate body - will be invited to report on climate change risks and adaptation strategies. Their report will take into account the outcomes of studies such as this one which considers the effects of climate change on evolved pavements. Their report will then contribute to the Secretary of State's five-yearly climate change impact assessment. Figure A1.1 shows the potential reporting hierarchy under the Climate Change Act 2008.

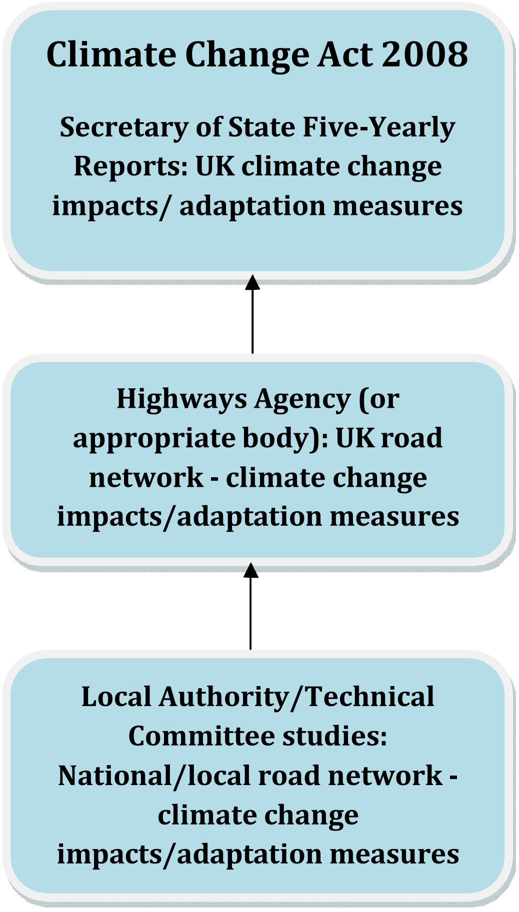


Figure A1.1: *Shows the likely reporting hierarchy for climate change impacts and adaptation measures for UK road network under the Climate Change Act 2008*

A1.4.1 The UK Low Carbon Transition Plan (6)

The UK Low Carbon Transition Plan
The UK Low Carbon Transition Plan plots how the UK will meet the 34 percent cut in emissions on 1990 levels by 2020, set out in the budget. We have already reduced emissions by 21 percent – equivalent to cutting emissions entirely from four cities the size of London.
Transforming the country into a cleaner, greener and more prosperous place to live is at the heart of our economic plans for 'building Britain's future' and ensuring the UK is ready to take advantage of the opportunities ahead.
By 2020:

- More than 1.2 million people will be in green jobs.
- 7 million homes will have benefited from whole house makeovers, and more than 1.5 million households will be supported to produce their own clean energy.
- Around 40 percent of electricity will be from low-carbon sources, from renewables, nuclear and clean coal.
- We will be importing half the amount of gas that we otherwise would.
- The average new car will emit 40 percent less carbon than now.

A1.4.2 Low Carbon Industrial Strategy

The UK Low Carbon Industrial Strategy was launched on 15 July 2009 with the core objective of ensuring that British businesses and workers are equipped to maximise the economic opportunities and minimise the costs of the transition to a low carbon economy. Building on the framework for supporting British business set out in *Building Britain's Future: New Industry, New Jobs*, its ambition is to ensure that the transition to low carbon is a source of quality jobs and business savings in Britain: from our rapidly developing civil nuclear industry and renewable energy sector, to energy saving in our smallest SMEs..
In March 2009 the Government launched *Low Carbon Industrial Strategy: A Vision*, settingout key areas for the Strategy to target. This was followed in April 2009 with ambitious investment and policy plans set out in *Investing in a Low Carbon Britain*.
The *UK Low Carbon Industrial Strategy* now develops and brings together these strands of work into a single strategy for seizing the industrial benefits of the transition to low carbon in Britain in the years ahead.
The Strategy is supported by the economic analysis put forward in BIS Economics Paper No. 1, *Towards a Low Carbon Economy: economic analysis and evidence for a low carbonindustrial strategy*

A1.4.3 Highway Agency PatnerNET – Climate Change

Climate Change Mitigation

Mitigation - how we can minimise our contribution towards the causes of climate change and support the UK Government's targets on greenhouse gas reductions. We need to take positive action to assist the Government in meeting its greenhouse gas emission reduction targets and climate change commitments. The Highways Agency has direct control over the construction, maintenance and operation of the strategic road network and we need to drive this towards a low carbon future.

Carbon Accounting Framework

The Highways Agency is a UK leader in the construction sector, and as such needs to lead by example, and provide its supply chain with the tools necessary to measure greenhouse gas emissions, and provide the incentives to actively manage, and reduce these, wherever possible. However, before the Highways Agency can set about implementing new measures to reduce its emissions it is first necessary to establish and quantify current greenhouse gas emission levels. To achieve this, data will be gathered from across the Agency and their supply chain to populate the HA Carbon Calculation Framework.

HA Carbon Calculation Methodology

The Highways Agency has developed a carbon calculation methodology, so the business and supply chain have a consistent and transparent methodology for collecting and calculating their carbon emissions. This data will be used to calculate an annual carbon footprint for the Highways Agency, including maintenance, construction and operational (office and travel) activities.

The web site includes:-

- MAC HA Carbon Calculation Spreadsheet and Instruction manual
- DBFO HA Carbon Calculation Spreadsheet and Instruction manual
- Major Projects HA Carbon Calculation Spreadsheet and Instruction manual
- HA Carbon Calculation Explanatory Report

A1.4.4 Transport Scotland's Carbon Management System

Transport Scotland is currently running a six month pilot for a carbon calculator for transport schemes. This scheme will encourage the use of materials with the lowest lifetime carbon impact.

This carbon calculator tool will be known as the carbon management system (CMS) allowing input of information about the pavement, the materials available and the transport and energy use on site. The predicted embodied carbon in the CMS report will be used to estimate the whole life carbon emissions of pavements, allowing project and structural maintenance decisions to be based not just on the immediate footprint of road construction but on its lifetime emissions profile.

It is hoped that in addition to providing an emissions reporting tool, the CMS is being developed with additional functionality to provide a carbon efficiency tool for projects. This will allow the CMS to be deployed through the life of projects as a means of providing information about carbon emissions with the aim of minimising carbon emissions across the life cycle of the asset. For example by using the tool to consider the embodied carbon

implications of design options, alternative materials specifications or infrastructure durability, project can be designed with lower carbon footprints.
Transport Scotland expects that carbon reporting will become a mandatory activity across all projects within a few years.

A1.4.5 Asphalt Pavement Embodied Carbon Tool (asPECT)

The asPECT (asphalt Pavement Embodied Carbon Tool) calculator is being created alongside the *Protocol for the Calculation of Life Cycle Greenhouse Gases Generated by Asphalt used in Highways*[1] and the supporting guidance document[2]. The protocol, guidanceand calculator together constitute the first three deliverables of the asphalt Pavement Embodied Carbon Tool (asPECT).

The asPECT calculator software is an execution of the protocol which enables the user to calculate the CO_2e emissions associated with individual asphalt products and applications. asPECT is designed to be used at the company level, to gather information on materials used, transport and mixing plant characteristics in order to make product and project level CO_2e assessments. The overall CO_2e emission figures generated can be broken down in detail to give per tonne figures for each life cycle step and mixture in the project.
The asPECT protocol provides a clear set of rules, implemented in the accompanying calculation tool, to be used by producers of road materials, designers and contractors to calculate carbon dioxide equivalent (CO_2e) emissions associated with different bitumen bound mixtures. This will fulfil the following functions:

- Assessment of the potential greenhouse gas (GHG) emissions of different alternatives at the procurement stage.
- Accounting of GHG emissions during and after construction.

This protocol represents the first phase of a larger project aimed at developing an industry standard for the calculation of the environmental impacts of building and maintaining a road structure, from souring raw materials and laying mixtures to reconstruction through regular maintenance interventions. The protocol considers all emissions which contribute to climate change from sources including energy use, combustion process, chemical reactions, service provision and delivery.
This project is part of the 2008-11 Collaborative Research Programme. Collaborative research is a joint initiative of the Highways Agency, Minerals Products Association (MPA), Refined Bitumen Association (RBA) and TRL. Recognising the importance of sustainability issues for industry as a whole, the project team and focus group set out to create a 'sustainability management system' for the highways sector. The initial focus of the project is to create a standardised method of measuring the contribution to climate change which highway products and applications make and to achieve endorsement from the sector in doing so.
The protocol is endorsed by the Highways Agency, MPA, RBA and CSS (County Surveyor's Society).
The asPECT protocol covers Asphalt mixture and application.

Asphalt mixture

The CO_2e content of an individual asphalt mixture shall be calculated as the summation of the following elements:

- The combination of the cradle to gate and transport CO_2e from each of the constituent materials and ancillary materials (Consumables used in the manufacture of the final product).
- CO_2e arising from energy involved in producing the asphalt at the mixing plant, other than that involved in heating and drying, but including energy for site offices etc..
- CO_2e arising from the process of heating and drying the mixture and its constituent materials.

Asphalt application

In addition to the CO_2e content of an asphalt mixture, the following elements shall be included in the calculation to determine the CO_2e content of given asphalt applications:

- CO_2e arising from transporting the asphalt material to site.
- CO_2e associated with laying and compacting the material at the construction site and site related activities (i.e. mobilising labour to site, cutting joints etc...).

The asPECT Protocol – Excludes

- The manufacture, installation and maintenance of fixed plant.
- The manufacture and maintenance of mobile plant.
- Corporate off site and laboratory overheads.

The Appendix to the asPECT Protocol Includes:

A. Converting grid electricity consumption to CO_2 equivalents.
B. Converting fuel consumption to CO_2 equivalents.
C. GHGs resulting from the use of explosives.
D. Default cradle to gate CO_2e data for various constituents.
E. Pre-combustion factors for fuels.
F. Data quality assessment.
G. Converting between mass, volume and energy.
H. Updates to the protocol.

A1.5 Climate change risk assessment

A1.5.1 Introduction

The following section considers the approach to assessing the risks posed by climate change to local authorities and the evolved highways network.
There are significant sources of uncertainty surrounding future climate change and its impacts. It is important for local authorities to address and manage risk in such a way that reflects this uncertainty. Previously risk has generally been assessed on the basis of past climate, using (for example) extreme weather events as reference points for assessing the magnitude of possible future events. Although this approach is still important it is now also necessary to consider future scenarios for which there may be no precedent.

A1.5.2 Aims

The aim is not to prescribe a method, but to provide broad guidance to help authorities develop a consistent approach to assessing climate change risks.
Authorities may have a comprehensive risk framework already in place; the approach described here could be adapted to fit in line with the authorities' requirements. The authorities' approach should, however, generally incorporate the key elements highlighted.
It is important for decision makers to be aware that climate change risk assessment need not be carried out in isolation of other perceived risks to the highway network. The UKCIP risk report recommends climate and non-climate risks are assessed together. Doing so would enable an understanding of the potential interaction of climate and non-climate risks and contribute to a more holistic risk overview.
Links to useful resources and further reading to help local authorities develop robust climate change risk frameworks are provided at the end of this section.

A1.5.3 Risk assessment: Key stages

There are key stages to any risk assessment which apply also to assessing climate change risks. These stages are shown in figure A1.2 and discussed in more detail below.

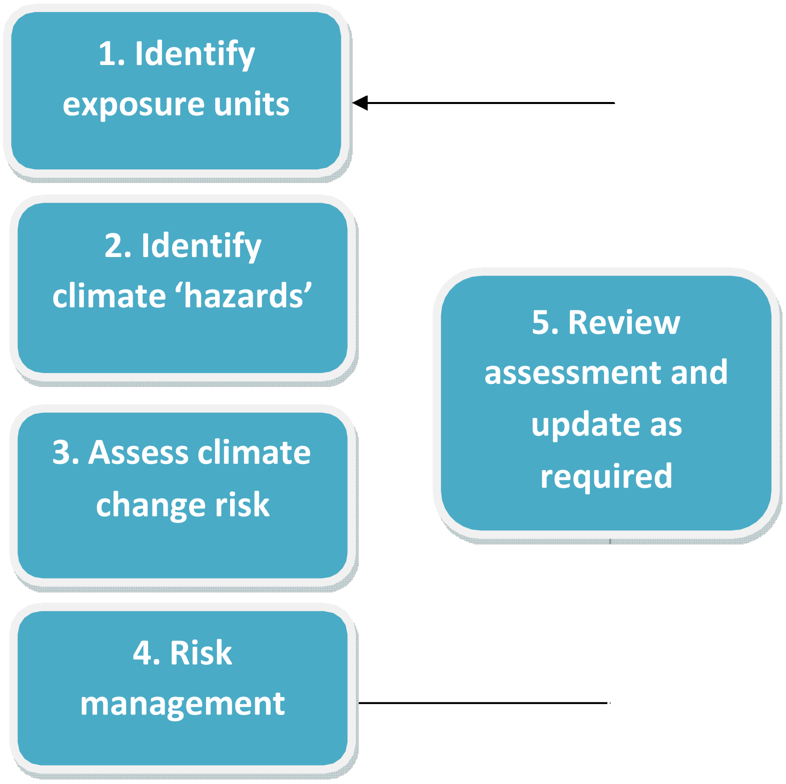


Figure A1.2: Key stages in a climate change risk assessment.

1. Identify "exposure units"

The exposure units will be the aspects of the evolved highway network that are currently affected and/or likely to be affected by future climate change. This may refer to physical characteristics such as pavement surfaces or street furniture. It may also refer to non-material entities such as network management policies or specific design criteria. Moreover, it may only be certain aspects of the exposure unit that are sensitive to climate. At all events the exposure unit will be in some respect climate-sensitive and will generally be identified by highways decision-makers and appropriate technical staff (and those carrying out the risk assessment).

The UKCP risk report recommends establishing a frame of reference (using 'endpoints') within which the robustness of the entity (or those aspects that are vulnerable to climate) can be gauged. For example, an entity may be designed to cope with a 1 in X year climatic event. Such endpoints will help create a context within which the risk from future climate change can be better understood.

2. Identify climate 'hazards'

These are the climate variables that may affect the exposure unit. An understanding of the influence of past climate on the exposure unit is important to help decide which variables are most important. However, it would be necessary also to identify the range of climate

variables whose future change may present additional risk (or, indeed, opportunity – such as a potential reduction in winter service requirements resulting from milder winters).
The UKCP09 projections are a key resource to aid this process. Use of their customisable output features is recommended to help local authorities understand how climate change risk may develop in their own respective contexts. This is important as climate change is characterised by regional variations across the UK. The future climate in parts of the UK may be similar to the current climate of some areas of Europe (known as a 'climate analogue'). UK highways authorities should consider investigating climate analogues and liaising with their (relevant) European counterparts. Thepractices and approaches to risk employed by authorities in analogous climates could aid UK authorities' risk assessments. This approach is recommended in the Highways Agency'sclimate change adaptation strategy.

3. Assess the climate change risk
An understanding of how the climate 'hazards' identified in stage 2 are projected to change and how the changes will impact on the exposure unit(s), including some measure of the likely severity of the impacts, will be necessary.
The UKCP09 scenarios go some way to quantifying the uncertainty inherent in predicting climate change via probabilistic projections. The projections don't give the probabilities of specific aspects of climate change actually occurring. Rather they present the probabilities of change occurring within certain ranges. The probabilities can help decision makers/those assessing risk to quantify uncertainty in their risk assessments. The robustness and value of risk assessments undoubtedly increases where uncertainty can be measured to some degree – particularly where they are used as a basis for allocating costs.
The probability of the climate change hazard having the forecasted impact on the exposure unit could also be quantified. This may require expert judgement from network operators/technicians, but may also involve research and the use of data/empirical evidence and consultation.
This approach is employed in the 3CAP (8) climate change study, where both the probability and likely severity of impacts are given a score (that contribute to an overall risk score). This enables risk to be categorised and resources to be allocated accordingly.
Local authorities may have their own approach to scoring in risk assessments which may be adapted to assess climate change risk. However, the scoring process should be as accurate as possible and based on robust data (empirical where possible) and/or expert judgement.

4. Risk management
To some extent risk management would be considered during each of the previous stages, as an understanding of the likely risks is developed. However, at this stage a formal risk management strategy should be formulated, and should generally include:

- Assessment of the ability and requirement of the local authority to influence/mitigate the risk;
- Identification and appraisal of options to mitigate risk (these are by default climate change adaptation strategies);
- Decision making and implementation of appropriate options.

There are different approaches to risk management; selecting the most appropriate will depend on the nature of the risk/exposure unit and the requirements of decision makers and stakeholders. The UK Climate Impacts Programme provides useful resources to help local authorities assess and manage climate change risk.

5. Review assessment and update as required
Monitoring both the risk and the performance of risk management strategies is an ongoing process. Once a decision has been made and a strategy implemented continual review will be necessary to ensure the objectives are being met. New climate change scenarios should be reviewed in the context of the risk assessment as they become available.

Key resources and further reading:

- The UK Climate Impacts Programme Risk Framework provides a number of useful resources to help organisations develop approaches to assessing climate change risks:

  http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=62&Itemid=9

- UKCP09 climate change scenarios:

  http://www.ukcip.org.uk/

- The Highways Agency has developed a climate change adaptation framework (which broadly incorporates the elements discussed here) and be found at:

  http://www.highways.gov.uk/aboutus/24180.aspx

- The Three Counties Alliance (3CAP) (8) report on the effects of climate change on highways network policies and standards includes a detailed climate change risk assessment and offers useful information for other local authorities:

  http://www.leics.gov.uk/climate_change_adaptations.pdf

A1.5.4 Summary
Climate change presents risks to local authorities and the evolved highways network; these risks must be assessed and managed. This section presents a broad framework within which authorities can develop a consistent approach to assessing climate change risk in the context of their own situation.
There are five key stages within the framework:

6. Identify ‘exposure units’;
7. Identify climate ‘hazards’;
8. Assess climate change risk;
9. Employ risk management; and
10. Review assessment and update as required (ongoing).

Carrying out a climate change risk assessment will that incorporates these elements allow local authorities to formulate appropriate adaptation strategies. Resources could then be allocated to the areas/operations considered to be most at risk. This in turn could help minimise future risk to the network, posed by an uncertain climate future

A1.6 Existing flood maps

The following UK agencies host flood maps which can be accessed by the public:

- The **Environment Agency** hosts a flood map for **England and Wales** showing a range of flood data relating to rivers and sea flooding. Layers include:
    - Extent of river and sea flooding with a 1% and 0.5% or greater chance respectively of occurring in a given year;
    - Extreme flooding extent (floods with a 0.1% or greater chance of occurring); and
    - Flood defences.

Available at: http://www.environmentagency.gov.uk/homeandleisure/floods/default.aspx

- The **Scottish Environment Protection Agency (SEPA)** hosts a flood map showing the extent of river and sea flooding with a 0.5% (1 in 200) or greater chance of occurring in any given year.

Available at: http://www.sepa.org.uk/flooding/flood_map.aspx

- The **Northern Ireland Rivers Agency** hosts a strategic flood map with layers showing the extent of historical and present day river and coastal flooding. It also has a climate change layer showing modelled data, incorporating the projected effects of climate change to the year 2030.

Available at: http://www.riversagencyni.gov.uk/index/stategic-flood-maps.htm

In each of the above maps flood data are overlaid onto OS-type maps that are at a high enough resolution to show most/all of the evolved highways network. As such they are a useful existing resource to help network operators understand which parts of their network are at risk from tidal and fluvial flooding and their use is recommended.

UKCIP Tools

The UKCP09 scenarios and tools are a useful resource to help local authorities assess where flood risk may increase as a result of (for example) sea level rise and more frequent and intense precipitation events. Regional variations in climate change effects means that climate using scenarios and projections relevant to the local authority's area will be necessary.

The UKCP09 (and subsequent) climate scenarios should be used in conjunction with existing and future flood risk maps, assessments and data to help ascertain how and where climate change may exacerbate flood risk across the network.

Resources and further information

- UKCP09 climate change scenarios:

  http://www.ukcip.org.uk/

- Climate adaptation resource for advisors (CLARA):

http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=531&Itemid=498

- Flood Risk Management Research Consortium (FRMRC):

http://www.floodrisk.org.uk/

- Northern Ireland Environment Agency (NIEA):

http://www.ni-environment.gov.uk/

- Planning Policy Statement 25 (Government policy on new development and flood risk):

http://www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicystatements/pps25/

A1.7 Flood and Water Management Act 2010 (11)

The following section outlines the nature and key aims of the Flood and Water Management Act 2010 (henceforth referred to as "the Act").
The Act, which applies to England and Wales, updates the approach to flood risk and water management. It is designed in part to implement recommendations made in the Pitt Review of the 2007 floods.

A1.7.1 Key aims of the Act:

To increase resilience and reduce flood risk

- To clarify organisational responsibility for flood risk management
- To improve drought/water shortage management
- To account for climate change risks/effects in relation to flood/water management (such as increased rainfall, sea level rise and heat waves)
- To improve water quality and promote sustainable water management

Part one of the Act aims to strengthen and consolidate the UK's approach to flood risk management - including all potential sources of flooding (not the case previously) and coastal erosion. The Act recognises that flooding and coastal erosion cannot easily be prevented and approaches that focus more on addressing the consequences are required.

A1.7.2 Climate change

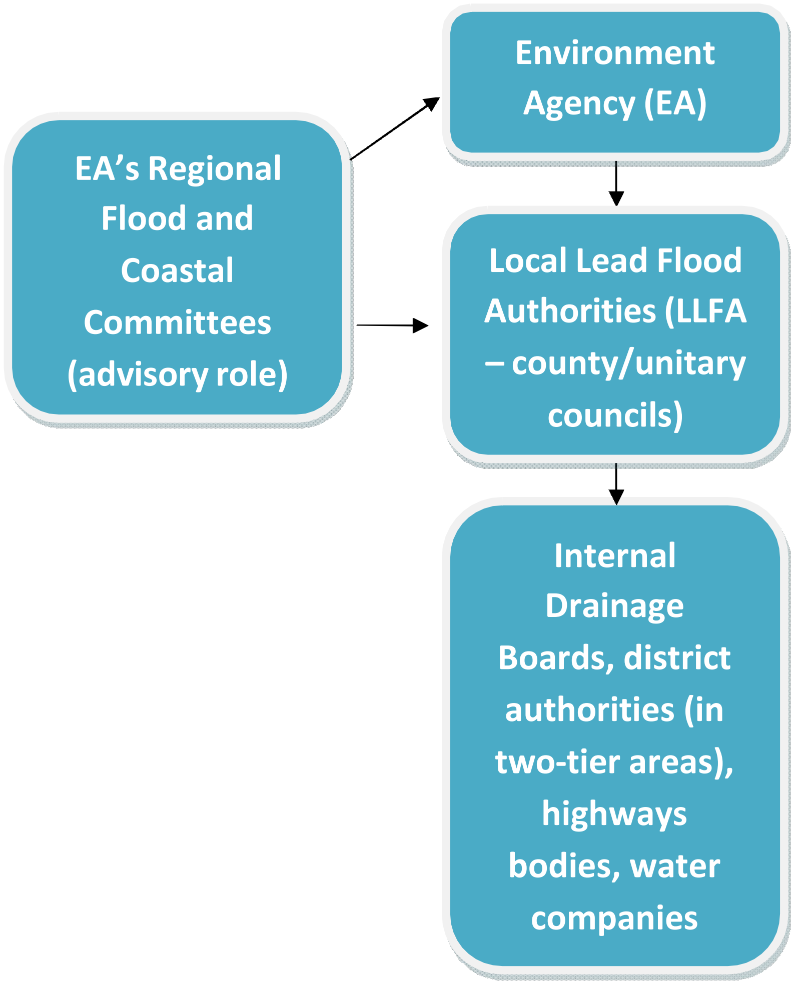
The Act does not deal explicitly with climate change adaptation per se; this is covered in the Climate Change Act 2008. Rather it provides a framework within which a range of flood risks – including those from climate change – can be managed. This includes issues such as planning guidelines for new development in areas prone to flood risk and making buildings and assets (such as the evolved highways network) more flood resilient. The Act recognises the need for long-term flood risk assessment, using tools such as the UKCP09 (and subsequent) climate projections.

A1.7.3 Roles and responsibilities

A key purpose of the Act is to clarify responsibilities in the context of flood risk management with an aim to improve national flood resilience. Under the Act the Environment Agency (EA) will take a strategic flood risk overview role, developing standard risk management methods and issuing a national flood risk strategy. It also has responsibility for 'main' river (or 'critical ordinary watercourses') and coastal flood defence.
Key county councils and unitary local authorities will become Lead Local Flood Authorities (LLFA's) under the Act. They will have responsibility for co-ordinating relevant partners in the management of flood risks from ordinary water courses, groundwater sources and surface run-off, employing strategies recommended by the EA. Key LLFA responsibilities include:

- Holistic local flood risk assessments and flood/asset mapping
- A more comprehensive approach to drainage and flood risk management
- Drainage from the evolved highways network (as is the current situation)

Figure A1.3 below shows the national flood and risk management structure under the Act:



A1.7.4 The Act and highways

Local flood risk management has previously been undertaken by a variety of different bodies that assessed risk to their own part of the local drainage infrastructure. The Act requires a strategic LLFA-led partnership approach to conduct holistic flood risk assessments that consider all relevant assets – including the strategic and evolved highways networks. This will necessitate adoption of a flood/asset mapping approach to identify and monitor vulnerable parts of the road network within the LLFA's area. To this end evolved highways flood risk assessments will contribute to a wider local flood risk assessment and management strategy. As such, highways decision makers/technical staff will likely be required to work closely with relevant partners – both internal and external to the LLAF – to assess and manage flood risks.

A1.7.5 Resources and further information

- Draft Flood and Water Management Bill:

http://www.official-documents.gov.uk/document/cm75/7582/7582.pdf

- Defra: Flood and Water Management Act 2010:

http://www.defra.gov.uk/environment/flooding/policy/fwmb/

A1.7.6 Summary

The Flood and Water Management Act 2010 updates the approach to flood risk and water management in England and Wales. Key principle aims of the act in the context of flooding are to increase flood resilience and clarify responsibility for flood risk management.

Under the Act the Environment Agency will develop standard risk management methods, issue a national flood risk strategy and take responsibility for ‘main’ river and coastal flooding and defence.

Key local authorities will become Lead Local Flood Authorities (LLFAs) and co-ordinate relevant local partners to carry out local flood risk assessments and flood/asset mapping.

Highways authorities will be involved in this process as all parts of the local drainage infrastructure – including the evolved and strategic highways networks – are included in an holistic risk assessment/flood map.

Sustainable Drainage Systems (SUDS) are required in all new developments; national standards relating to SUDS will be introduced and compliance measured.

A1.8 Overview of Recent Publications

A1.8.1 Well Maintained Highways: Code of Practice for Highway Maintenance Management.(July 2005)
(http://www.ukroadsliaisongroup.org/pdfs/p03_well_maintained_highways.pdf)
Climate Change is covered in section 14.1 and highlights the implications of climate change for highway maintenance. Case studies are included to illustrate potential problems. In 2009 the Department for Transport issued an update to the Code of Practice.
In the update the DfT recognised that climate change is having a considerable impact on the highway network and commissioned a research project to investigate the implications of the changing climate for highway maintenance. In June 2008 Maintaining Pavements in a Changing Climate was published by the DfT (See A1.8.2 below).
Well Maintained Highways: Code of Practice for Highway Maintenance (Complementary Guidance dated 14 May 2009 – subject to update)
http://www.ukroadsliaisongroup.org/pdfs/Well%20maintained%20highways%20October%20 2009%20v3.pdf
Section 15.15 Climate Change
http://www.tsoshop.co.uk
A1.8.2 Maintaining Pavements in a Changing Climate (June 2008)
Published by the Department for Transport
http://www.tsoshop.co.uk
Purpose and scope of guidance
This document identifies:

- climate parameters that affect pavement condition and maintenance need; how those climate parameters may change to 2050;
- the potential effects of those changes on pavements condition and maintenance need;
- other factors that influence that effect; and potential mitigation actions, including adaptive maintenance.

The scope of this guidance includes:

- the implications of climate change on the maintenance of carriageways and footways, including reconstruction activities; and
- drainage, in so far as inadequate drainage is a prime cause of deterioration of the pavement.

The guidance draws upon existing technical knowledge of the effects of extremes of weather in the UK on pavements that might be indicative of the future norm and also overseas climatic analogues.

A1.8.3 Scottish Road Network Climate Change Study & Scottish Road Network Landslides Study
Published by the Scottish Executive
http://www.transportscotland.gov.uk/road/climate-change-and-the-roads

Following three major landslides in August 2004, the Scottish Government commissioned a study into potential trends in climate change in Scotland and how these might affect the road network. The Scottish Rod Network Climate Change Study was subsequently published in June 2005 and presented a series of 28 recommendations for the design and operation of the road network. A further report, Progress On Recommendations, was published in October 2008 detailing how the recommendations made in the Climate Change Study have progressed in the intervening period. These reports may be downloaded from the above address. An associated study into the risk factors associated with landslides and their potential effects on the trunk road network was also instigated at that time. The Scottish Road Network Landslides Study: Implementation report was published in March 2009. This is also available as a summary report. The main and summary reports can be downloaded from the above address.

A1.8.4 Published Project Report PPR 184 (October 2008)

The effects of climate change on highway pavements and how to minimise them:Technical report

Published by the TRL Ltd for the Department for Transport

http://www.tsoshop.co.uk

The Department for Transport commissioned TRL to improve the understanding among local highways engineers of the implications of the predicted change in climate. This document provides the detailed technical information which is the basis for guidance document *Maintaining Pavements in a Changing Climate* (See below).

PPR 184 is a technical report and describes the impact climate has on the different types of pavement; asphalt, concrete, modular and unbound. It also discusses the vulnerability of a pavement to climate depending on factors such as pavement type and condition, but also on geography, geology, topography and traffic loads.

The report discusses how pavement performance and vulnerability could be affected by climate change scenarios predicted for the UK in the 2050s, the possible impact of those changes and potential maintenance requirements. Where possible the report gives recommendations on maintenance treatments and materials that may prove cost-effective in the changing climate. This includes changed deterioration patterns of pavements and the impact of extreme weather events, such as flooding and drought.

Case studies are given to illustrate the affects of extreme weather events on pavements.

A1.8.5 Published Project Report PPR 233 (June 2008)

Sustainable Choice of Materials for Highway Works

A Guide for Local Authority Highway Engineers

Published by TRL Ltd for UK Roads Liaison Group and the Department for Transport

http://www.trl.co.uk/online_store/reports_publications/trl_reports/cat_sustainability/report_Sustainable_choice_of_materials_for_highway_works_A_guide_for_Local_Authority_highway_engineers.htm

This document provides a detailed description of how to make sustainable choices in the selection of materials and methods for Local Authority highway works, including maintenance and new construction. The main focus of this document is on maintenance activities for road pavements and footways. However, the advice is equally applicable to new construction.

The document is intended to be applicable throughout the United Kingdom. Case studies are given throughout the document to illustrate specific materials, methods or issues.

A1.9 References

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Climate Change and Evolved Pavements

Appendix A2

Questionnaire

Appendix A2
CSS Climate Change – Questionnaire for Local Highway Authorities

A2.1 Introduction
During December 2009 a questionnaire was sent out to all the local highway Authorities in England, Wales, Scotland and The Roads Service Northern Ireland, with a request to respond by the 28th February 2010. 19 Authorities responded and their responses to 10 out of the 11 questions are summarised in section A2.2.
The response to Question 11 which took the form of a list of 22 potential climate change consequences which were currently causing the most concern with the effect on the highway network – is summarised in tables A2.3.1 & A2.3.2.
Each response to question 11 was scored in order of importance (1 = Highest Concern, 5 = Lowest Concern).
From the scores obtained from the 19 Authorities who responded to the questionnaire, the following lists the top 5 climate change consequences which gave the most concern:-

1. Asphalt deformation and binder softening resulting in loss of surface integrity.
2. More rapid pothole deterioration
3. Surface water ponding
4. Fatting or bleeding of surface treatments.
5. Surcharge of drainage systems.

A full list of the 22 potential climate change consequences can be found on page A2.8.
The scoring in the tables A2.3.1 & A2.3.2 represents our assessment of the responses to Q11 and is not a scientific survey.

A2.2 Summary of Questionnaire Responses

Q1. Has your organisation considered any changes to your strategic or operational plans to reflect climate change? (12 out of 19 responded to this question)
There is a general move by authorities to change their specifications for pavement and drainage design. Some authorities encourage the use of recycled materials as a first choice maintenance option: however all authorities are increasing their specification requirements for pavement materials, particularly in surface course / surface dressing materials (i.e. stopping the use of high penetration or non modified binders).
Highway drainage is particular concern, with many authorities carrying out risk assessments, identifying potential problem areas and targeting these areas for more maintenance or redesign/reconstruction of the of drainage systems.
The response to the risk of damage of highway foundations and earthworks due climate change depends on the geology/topography of the particular authority, with some authorities using a standard approach to foundation design and others have carried out risk assessments, identifying "high risk" areas and are developing location specific design solutions. Some authorities also inspect and assess embankment slopes following extreme periods of rainfall.
The concerns expressed about landscaping are the need for increased maintenance (grass cutting, tree and hedge trimming etc...) and the selection of more suitable plant species to possibly help to counter the effects of climate change (i.e. provide shade in exposed areas, slower growing grass etc..) from sustainable sources.

Q2**.** Has your organisation considered any changes to your capital or revenue budget allocations to reflect climate change? (10 out of 19 responded to this question)
With budget restraints of recent years and the high likelihood of future pressures on local government funding. The authorities are not anticipating extra funding to mitigate the effects of climate change and have looked to other ways of funding projects:-

- "Invest to save" borrowing to accelerate maintenance programmes in order mitigate the need for more expensive reconstruction in the future.
- External funding for projects – This has been particularly successful with drainage/flooding and coastal defence projects.
- Diverting funds by changing design practices and specifications.
- Diverting funds by using more recycling schemes.
- Building up a reserve fund to deal with extreme weather events.

Q3. Of any recent changes implemented to counter climate change, which do you consider to date have demonstrated success at meeting your objectives? (9 out of 19 responded to this question)
Generally the response from the authorities is that it is too early to tell if any changes implemented to counter climate change have been successful.
Some feedback was given on:-

- The use of polymer modified binders has helped with the durability of surface dressing.
- The restriction on the use of high penetration bitumen in asphalt concrete has reduced problems with deformation.

- The use of reinforcement grids to control cracking arising out of volume changes due moisture susceptible sub-grades.
- The use of external funding sources has permitted development of schemes to resolve local surface water and coastal flooding problems.

Q4. Has your organisation reviewed pavement designs, specifications and working practices further to concerns regarding climate change? (11 out of 19 responded to this question)
Most of the authorities who responded to the questionnaire carryout some form of review of pavement designs, specifications and working practices on a regular basis and from the responses they are considering concerns with regard to climate change as part of their reviews.
For example:-

- Phasing out the use 190 pen binder materials for footway surface courses in anticipation of the future higher temperature deformation risks.
- The increased use of recycled materials to reduce the carbon footprint of schemes.
- The use of polymer modified binders has helped with the durability of surface dressing.
- The use of 50 pen binders in all carriageway binder courses unless there are exceptional circumstances to justify using a softer binder.
- Design reconstruction schemes taking measures to reduce their depth and therefore the volumes excavated, reducing waste and the use of virgin materials.
- Moving towards the use of wheel tracking requirements to specify deformation resistance values in anticipation of increasing surface temperatures.
- Control of air void contents on all construction layers to reduce their permeability.
- The use of soil stabilisation techniques, geotextiles and reinforcing grids to limit the effects of soil shrinkage.
- Selection of surface course materials on overlay schemes to reduce the reflective cracking induced by lower layers (including cracking caused by clay shrinkage in the foundation layer), thus reducing ingress of water into the road structure.

Q5. Has your organisation carried out a risk assessment of your existing maintenance and management strategies further to climate change? (7 out of 19 responded to this question)
Many authorities are part of council wide assessments and as such are subject to general strategies like reducing carbon emissions (i.e. use of electrically powered trucks), recycling and reducing waste.
However where more specific assessments have been carried out the main concerns are:-

- Increased risk of softening of road surface and higher UV levels affecting the health of outdoor workers. Both the result of hotter, drier summers.
- Wetter winters creating problems in highway drainage “hotspots” and increasing the incidence of water ingress into the pavement structure, inducing binder stripping, foundation heave etc...
- The migration of tar from lower layers up to the surface on “evolved” roads.

Q6. Has your organisation carried out a sustainability audit of maintenance and management plans to ensure that the carbon footprint is as low as practicable and that current practices are not contributing to climate change? (8 out of 19 responded to this question)

As with Q5 most authorities are part of council wide audit schemes which concentrate on reducing carbon emissions, set targets for reducing waste and increasing recycling. Some authorities have looked at the feasibility of carbon calculators for construction purposes.

Q7. Has your organisation recorded past weather effects on the local authority highway network and operate a Local Climate Impacts Profile as recommended by UKCIP? (4 out of 19 responded to this question)
With only 4 responses to this question it is very difficult to draw any conclusion. However out of the 4 responses received, all relate to maintaining records of flooding and other extreme weather events. Only 1 authority then used this data to change their winter maintenance plan.

Q8. Has your organisation prepared or is currently preparing a Surface Water Management Plan in response to the draft Flood and Water Management Bill. (16 out of 19 responded to this question - 10 giving details)
Most authorities are developing SWMP in conjunction with other agencies and councils within their geographical areas. This is to provide co-ordinated management and delivery of flood risk and drainage management functions of all relevant organisations across their areas. Developing flood risk maps and priority areas where surface water management will be required in extreme weather events.

Q9. Have you been able to develop a mechanism to report the effects of climate on your maintenance backlog via your Local Transport Plan? (4 out of 19 responded to this question)
With only 4 responses to this question it is very difficult to draw any conclusion.
An asset management approach is adopted by the authorities, who did respond, monitoring their network condition and over time assessing the impact of climate change on the pavement asset. This information can then be used to manage the maintenance needs of the pavement network.

Q10. Has your organisation developed SUDS as highway drainage for projects including adoptable highways? (14 out of 19 responded to this question)
Authorities are using SUDS in many areas for highway construction from use in new housing developments (with adoption under Section 38 Agreements) to major works schemes. With specifications and design guidance, designers, developers etc.. are encouraged to consider using SUDS as a first choice solution in favourable site locations.
Many authorities have incorporated the selection of SUDS into their Surface Water Management Plan (SWMP), developing SUDS requirements applicable to local circumstances and conditions.
As with the SWMP many authorities are working closely with other agencies in their areas to achieve a sustainable design for a particular project.

A2.3 Summary table of Respondents – Climate Change Consequence Concerns (Question 11 [Q11]).

A2.3.1 Summary Table of Respondents Climate Change Consequence Concerns (Question 11)

Issue No.	Score (1 = Highest Concern 5 = Lowest Concern)												
	A	B	C	D	E	F	G	H	I	J	K	L	Score
1	3	3		5	3		2					1	3
2		4		5	3		3					1	3
3		4		5	4		4					3	4
4	4	2		5	1		1		1		3	1	1.5
5	1	3		4	2		3					1	2.5
6	5	2		4	1	3	1		2		4	2	2
7		4		5	4		4					2	4
8		3		5	5		4					5	5
9		4		5	5		4					5	5
10		3		5	5		4					4	4
11		4		5	5		4					4	4
12		4		5	5		4					4	4
13		4		5	4		5					4	4
14		4		5	3		4	5				3	4
15	1	3		4	4		3					2	3
16	2	2		2	1	1	1	1	3		2	1	1.5
17		3		4	4		2		4			3	3.5
18		3		3	3		2				5	3	3
19		2		2	3	2	1	2	5		1	1	2
20		3		3	3		2					2	3
21		5		4	3		3	3				3	3
22		3		5	3		1	4				2	3
Remarks			No Response							No Response			

A2.3.2 Summary Table of Respondents Climate Change Consequence Concerns (Question 11)

Issue No.	Score (1 = Highest Concern 5 = Lowest Concern)												
	M	N	O	P	Q	R	S					Page 1 Score	Score
1			5	1	1	1						3	1
2				5		2						3	3
3						3						4	3.5
4		3										1.5	2.25
5			4	2	3							2.5	2.75
6	1	2	3	4	5		1					2	2
7		5				5						4	5
8							4					5	4.5
9												5	5
10												4	4
11												4	4
12												4	4
13												4	4
14					2							4	3
15												3	3
16	2	4	1		4		2					1.5	2
17	5											3.5	4.25
18				3		4						3	3
19	3		2				3					2	2.5
20	4	1										3	3
21												3	3
22												3	3
Remarks													

The scoring in the tables A2.3.1 & A2.3.2 above represents our assessment of the responses to Q11 and is not a scientific survey

Key

Issue No.	Item 11 - CSS Climate Change - Questionnaire for Local Highway Authorities 11. Which of the following potential climate change consequences is currently causing you concern with the effect on your highway network:-	
1	i.	Asphalt deformation and binder softening resulting in loss of surface integrity
2	ii.	Loss of surface texture
3	iii.	Accelerated polishing of surfacing
4	iv.	Fatting or bleeding of surface treatments
5	v.	More rapid aging of asphalt resulting in fretting and cracking
6	vi.	More rapid pothole deterioration
7	vii.	Footway cracking
8	viii.	Concrete pavement joint problems including compression failures
9	ix.	Warping of concrete
10	x.	Surface damage during paving
11	xi.	Workability and curing problems with concrete mixtures
12	xii.	Erosion of modular pavement jointing and bedding sand
13	xiii.	Expansion, cracking and spalling problems with modular pavement larger slabs
14	xiv.	Increase in differential settlement resulting in trip hazards
15	xv.	Bitumen stripping from surface course aggregate
16	xvi.	Surface water ponding
17	xvii.	Weakening of pavement foundations
18	xviii.	Subsidence and cracking
19	xix.	Surcharge of drainage systems
20	xx.	Increased problems with pavements on poor formations
21	xxi.	Embankment and cutting instability
22	xxii.	River and coastal inundation

Each Authority was assigned a letter identifier.

Climate Change and Evolved Pavements

Appendix A3

Asphalt Surfacing/Binder and Base Layers/In-situ Recycling/Patching

Appendix A3 Asphalt Surfacings/Binder and Base Layers/ In-situ Recycling/Patching

Asphalt Binder Grade Selection

1. Asphalt - General

It is recommended that to offset poorer potential future performance due to higher temperatures that the binder grade should be selected to increase the binder viscosity (reduce the penetration in numerical terms) compared with more traditional recommendations. Other changes to the composition to improve performance i.e. the addition of a polymer modified binder will incur increased cost which may be difficult to support in the case of the evolved highway network.
Machine lay binder grades should preferably be as follows:-
30/45, 40/60, 70/100, 100/150 (160/220 for fine graded asphalt surface course)

RECOMMENDATION 1

Specify the highest penetration bitumen grade (lowest penetration value) that can be practically laid and compacted to meet the specification requirements for carriageways, footways and cycleways.

2. Hot Rolled Asphalt

Binder 40/60 is the preferred grade. The following grades are also suitable:- 30/45, 70/100.

RECOMMENDATION 2

The preferred bitumen paving grade for hot rolled asphalt surface course is 40/60.

3. Hot Rolled Asphalt with Pre-coated Chippings

Plate A3.1 Hot Rolled Asphalt (Deformation in Wheeltracks)

Until the early 1990’s the most widely used surface course material on flexible pavements was hot rolled asphalt (HRA – Typically 14mm 30% stone content) with a surface layer of 20mm pre-coated chippings to resist polishing, this provided and maintained a high level of skid resistance. HRA usually has low air voids content which minimises binder ageing and hardening. In order to accept and retain the pre-coated chippings the asphalt consists of a bituminous mortar in which the larger aggregate particles are suspended in a finer material (usually sand) and not connected with each other. The deformation resistance of this material depends on the properties of the binder and fine aggregate interaction rather than the interlocking of course aggregate.

<u>Advantages of Hot Rolled Asphalt</u>

1. HRA provides a dense impervious layer
2. Weather resistant durable surface
3. Resistant to cracking
4. Resistant to erosion
5. Small amount of flexible under foundation movement
6. Provides a skid resistant surface

<u>Disadvantages of Hot Rolled Asphalt</u>

1. Problems with embedment of chippings
2. Deformation under load
3. High degree of solar radiation absorption and heat retention
4. Requires a larger working area to lay than “Thin Surfacing” for example and also needs a skilled workforce.
5. High Surface noise.

The move towards “thin surface courses” in recent years has increased the risk of moisture entering the road structure; this has resulted in problems relating to water ingress. With warmer wetter winters this may be more of a problem in the future.
Hot rolled asphalt has traditionally proved to be durable and relatively impermeable surface course. The issues that have led the Highways Agency to prefer Thin Surfacing which are relevant to heavily trafficked high speed traffic are as follows:-

1. Deformation (rutting) of surface course.
2. Noise levels.

Both of these problems are more prevalent with the low stone content option with the addition of pre-coated chippings.
Hot Rolled Asphalt Surface Course can provide a suitable choice for the local highway authority network and can provide a relatively good level of impermeability which will be beneficial in wetter conditions due to climate change. The deformation resistance of hot rolled asphalt surface course should be considered due to the detrimental effect of increased temperatures.
The HA SHW contains three options for Hot Rolled Asphalt Surface course:-

1. Clause 910 Hot Rolled Asphalt Surface Course(Recipe Mixtures)

This clause in intended for lightly trafficked use and where there is local knowledge of the successful performance of this material. There are no coarse fine aggregate grades or are there any high stone content options available within this clause.

2. Clause 911 Hot Rolled Asphalt Surface Course(Design Mixtures)

Changes have been effected via BS EN 13108-4 with the Marshall design method now contained in BS 594987 for the design binder content.
Coarse and fine aggregate and high stone content options are available. High stone content mixtures (HRA 55/10 or HRA 55/14) provide an option providing an unchipped surfacing which is easier to lay (pre-coated chippings not required) and with good deformation properties but the surface texture is low and generally unsuitable for high speed roads without additional surface treatment.
The standard bitumen grade is 40/60.

3. Clause 943 Hot Rolled Asphalt Surface Course and Binder Course (Performance - Related Design Mixtures)
This specification is intended for use on heavily trafficked roads where deformation resistance is important. Only HRA 35/14F option is available and three rut resistance (wheel tracking) categories are available.
Refer to the “Guidance on Specifying Hot Rolled Asphalt (Surface Course) to BE EN 13108 Part 4 dated March 2010 from CSS/MPA for assistance with the selection of rut resistance (wheel tracking) categories.

In conclusion, hot rolled asphalt surface course may provide a suitable surfacing option for local highway authorities and provide proven durability and good resistance to water penetration from wetter conditions. Care must be exercised to ensure that the future life will not be compromised by poor deformation properties (build up of rutting in the wheel tracks). This requires careful specification and monitoring of design and performance related parameters.
The potential use of hot rolled asphalt with pre-coated chippings on thin evolved highways may be limited due to cost and performance issues. Ensure that the pavement and formation provide adequate stiffness for the use of this surface course as low stiffness pavements surfaced with hot rolled asphalt with pre-coated chippings will have a propensity for fatigue cracking.

Plates A3.2 & A3.3 Hot rolled asphalt laying process with sufficient access for a tractor to reload the chipper hopper throughout the surfacing process.

Chipper to uniformly spread the “pre-coated chippings”

RECOMMENDATION 3
For lightly trafficked evolved highways, hot rolled asphalt surface course recipe Clause 910 may be adequate but the use of design Clause 911 or performance - related Clause 943 may be more appropriate on sites with higher risk to higher temperature deformation concern is considered to be a potential future issue.

4. High Stone Content Asphalt

A variant of HRA 30/14 has been used for many years on trunk roads and motorways with a surface dressing treatment and in areas of low speed with no surface treatment. This HRA has a nominal stone content of 55% with no added coated chippings. Although with this level of coarse aggregate there is some aggregate interlock, the material still depends primarily on the sand/filler/binder mortar for its stiffness. Nevertheless, a 55/14 mixture will typically have a stability about twice that of a 30/14 mixture made with the same constituents.
DMRB Vol 7 HD37/99 (reference) provides useful information for Hot Rolled Asphalt selection.

Traditional HRA is more susceptible to deformation than other surface treatments. The gap graded mixtures of HRA relies on the interlock of the sand fines for deformation resistance. This along with the high degree of solar absorption and heat retention will mean that the traditional 30/14HRA will be less suitable for high speed roads.
The use of high stone content HRA on high speed roads requires a surface dressing treatment straightaway making the process expensive and means the carriageway is restricted due to resurfacing for relatively long time.
There is still a place for high stone content HRA on low speed roads which are subjected to low loads i.e. urban and rural networks. The high stone content along with modified binders could mitigate the effects of higher surface temperatures due to climate change and increase the resistance to deformation under load, without losing any of the advantages of HRA.
<u>Benefits of High Stone HRA with Modified Binders</u>

1. Relatively long life and low maintenance.
2. Good water resistant qualities – protects underlying structure
3. Flexibility under foundation movement.
4. Resistant to erosion.

Many local highway authorities have a long successful tradition using high stone content hot rolled asphalt surface course. Care should be exercised to ensure that the pavement structure has adequate stiffness and that the surface texture design is fit for purpose.

RECOMMENDATION 4
High stone content asphalt surface course has many benefits to resist higher temperature deformation concerns but consider the low resultant texture depth dis-benefit.

5. Thin Surface Course Systems

Thin surface course is a proprietary bituminous material manufactured to a performance specification which requires a British Board of Agrément HAPAS Roads and Bridges certificate.

The mix constituents should provide a high level of performance which should counteract the predicted effects of climate change if appropriately specified. Highways Agency requires a Level 3 wheel tracking requirement for their network unless otherwise specified. Local highway authorities should be cautious regarding the specification of Level 1 wheel tracking requirement unless in very lightly trafficked locations.
The hydraulic conductivity or permeability of thin surface course is greater than traditional hot rolled asphalt surface course. It is therefore essential that a bond coat is applied prior to surfacing which is generally part of the system package. The incorporation of a dense, impermeable binder course will also assist the performance of the highway pavement by preventing water ingress through very thin evolved pavement structures.
It is recommended that local highway authorities adopt the principles of “Best Practice Guidelines for Surfacing” June 2006 published at www.roadscodes.org for application to negatively textured surfaces.
As with hot rolled asphalt surface course, cost and performance issues may reduce the potential use of this surface course on the minor highways of the evolved network.

RECOMMENDATION 5
For thin surface course systems, apply the principles of the Best Practice Guidelines for Surfacing to ensure the surfacing is resilient to withstand the rigors of future climate change and also ensure the use of a product with BBA HAPAS Roads and Bridges certification for type approval.

6. Stone Mastic Asphalt

Useful information:-
BS EN 13108 – 5 includes generic SMA surface courses.
PD 6691 – Guidance to BS EN 13108 - 5
DMRB HD37/99
SHW 937 & NG

<u>DMRB HD37/99</u>

Stone Mastic Asphalt (SMA) has proved to be durable and resistant to age hardening as a consequence of its low void content and thick binder film. As a result it is resistant to premature cracking, ravelling and moisture damage. Other advantages claimed for the material are its ability to shape an uneven or rutted surface, because the majority of the compaction is carried out by the paver and there is little further compression under rolling. It is necessary to limit the void content to ensure adequate durability. However, if the void content is too low, deformation can occur resulting in a loss of surface texture.

It should be noted that the Highways Agency (HA) SHW includes Clause 937 for SMA Binder Course and Regulating Course. HA policy is to use Thin Surface Course Systems (Clause 942) as a proprietary surfacing rather than generic materials to BS EN 13108-5 because of concerns about retention of texture depth.

Advantages of Stone Mastic Asphalt Surface Course

1. Weather resistant durable surface
2. Resistant to ageing – higher binder film and lower voids reduces oxidation of the binder
3. Resistant to deformation – due to the aggregate skeleton
4. Deformation resistant
5. Easy to lay – within a lane by small gang.
6. Good skid resistance (Once binder is removed from aggregate) – Maximises the properties of the aggregate.
7. Low road noise and a reduction of spray.
8. Reduced rolling resistance.

Disadvantages of Stone Mastic Asphalt Surface Course

1. Poor early life skid resistance – Requires treatment to address this i.e. gritting.
2. Suffers from a reputation for being difficult to lay.
3. Poor workmanship leads to early life failure.
4. The design of the material is critical – Factors to consider are, location and weather, type of aggregate (grading/shape) and binder, thickness of layer – If any of these parameters change, then the design may need to change.
5. Difficult to lay by hand – Should be avoided.
6. Difficult to patch
7. High cost of production

SMA offers potential help to local highway authorities to meet the challenge of climate change. With warmer drier summer there will be an increased rate of ageing and warmer, wetter winters increasing the potential for water to penetrate the road structure, SMA may be less susceptible to binder stripping or rutting compared with asphalt concrete. SMA with appropriate design and supervision of construction could provide a sustainable way of surfacing the local highway networks. The negative texture of SMA will also reduce spray and rolling resistance of vehicles improving ride quality and fuel consumption (Reducing the carbon footprint).
SMA systems certified under the BBA HAPAS Roads and Bridges Certification scheme, should give local highway authorities confidence in the material performance.

For SMA Binder Course and Regulating Course, improved performance for machine lay material will result from the use of lower penetration grade and the use of polymer modified binders. The 100/150 pen grade bitumen binder is the least preferred to offer resistance to deformation.
Wheel tracking classification shall be chosen from the recommendations in BSI PD 6691 to ensure that the material will not deform on site.
Overall, this surface course has similarities with thin surface course systems and therefore similar guidelines apply in practice. Both surface courses offer some benefits to resist the effects of hotter summers with increased rate of aging and warmer and wetter winters

leading to more deterioration. This is due to the thicker binder film thickness, better bitumen/aggregate adhesion, less propensity for binder stripping and lower insitu air voids.

RECOMMENDATION 6
Apply the principles of the Best Practice Guidelines for the Durability of Asphalt Pavements to ensure stone mastic asphalt surfacing is resilient to withstand the rigors of future climate change and also ensure the use of a product with BBA HAPAS Roads and Bridges certification for type approval.

7. Asphalt Concrete

Asphalt concrete surface course (previously known as coated macadam) has a long history of successful use mainly on lightly trafficked highways and evolved pavements.
Typical current use is identified in the Specification for Highway Works under the following clauses:-

Clause 909 6 mm Dense Asphalt Concrete Surface Course (6 mm upper sieve size)
Clause 912 Close Graded Asphalt Concrete Surface Course (10/ 14 mm upper sieve size)
Clause 914 Fine Graded Asphalt Concrete Surface Course (4 mm upper sieve size)
Clause 916 Open Graded Asphalt Concrete Surface Course (10/14 mm upper sieve size)

Asphalt concrete surface courses have traditionally comprised well graded aggregate with relatively low binder content compared with other generic asphalt materials.

Open graded asphalt concrete will have a lower stiffness and be more permeable to water infiltration and will therefore exhibit lower overall performance compared with dense/ close of fine graded options.

Adaption and mitigation against the effects of climate change (higher temperatures and higher rainfall) can include the following options:-

- Ensure binder grade selected is as high viscosity (low penetration value) as possible from the selected list.
- High binder content will be more resistant to stripping.
- Use aggregate with good binder affinity.
- Consider the use of modified binders for high risk locations.
- Ensure adequate compaction of layer.
- Ensure that joints and interlayer bonding is specification compliant.

RECOMMENDATION 7
Specify a dense/close of fine graded asphalt concrete. Ensure that the mixture is resistant to binder stripping. Use a high viscosity/ low penetration grade binder that can be successfully constructed on site. Apply the “Best Practice Guide for the Durability of Asphalt Pavements”.

8. High Friction Surfacing

Plates A3.4 & A3.5 High Friction Surfacing - Used at the approach to junctions, crossings and on bends

The combination of high quality binder and small sized dense chippings results in this type of surfacing being less at risk from higher temperatures and wetter conditions. The thermosetting binders used in some products will be particularly resistant to high temperature problems.

Calcined bauxite aggregate is available with several different colours. The light buff coloured calcined bauxite will assist to reduce asphalt pavement temperature during hotter summer months.

RECOMMENDATION 8
Specify SHW Clause 924 high friction surfacing with a BBA HAPAS Roads and Bridges certificate for type approval. Select the appropriate class of product to accord with use and ensure that material laid in cooler and inclement conditions adheres and is bonded to the substrate. The light buff coloured calcined bauxite will assist to reduce asphalt pavement temperature during hotter summer months.

9. Grouted Macadams

Grouted macadams are proprietary products; they are not controlled by a British Standard but are the subject to a BBA HAPAS Roads and Bridges certificate for type approval. Grouted macadams are available in two variants, cementitious grouted macadams and asphaltic grouted macadams.

9.1 Cementitious grouted macadams – are used in areas where loading is particularly heavy or concentrated, where there is likely to be spillages of aggressive materials or in areas that require high surface rigidity.

Typical uses include:-

- container handling and storage areas and docks
- vehicle maintenance and refuelling areas
- runway thresholds and areas subjected to jet blast
- areas used by tracked vehicles
- bus lanes
- industrial areas and mooring
- roundabouts
- car parks.

9.2 Asphaltic grouted macadams – evolved from the long-term use of cementitious grouted macadams. The essential difference between asphaltic and cementitious grouted macadams is the nature of the grout which, in the former, is based on bitumen rather than cement. Manufacturers claim that the materials, when laid, improve flexibility and resistance to permanent deformation whilst, via increased bitumen content, possessing increased resistance to oxidisation leading to longer life. The material is marketed as a carriageway surface course and is particularly suited to use on airfields.

9.3 Laying grouted macadams – There are two stages in laying these materials. The first stage is to lay a single layer of open textured coated macadam designed with a controlled void content. A resin/cementitious grout or asphaltic grout is then vibrated into this 'receiving coat', filling the voids and sealing the surface. The resulting product, in the case of the cementitious grouted macadam, exhibits properties that lie between those of a flexible asphaltic layer and one constructed of rigid concrete.

Grouted macadams may be laid onto any existing clean, sound and level surface. A layer of regulating course is normally required over an irregular surface.

When laying over existing concrete, all joints should be inspected and any loose joint compound removed. Where edges have spalled, these should first be treated with a suitable material such as fine graded asphalt or bituminous sealant before the application of the receiving coat. For new construction, grouted macadams should be considered as an alternative surface course.

Grouted macadams are generally laid at a nominal thickness of 40mm but this may be varied to suit the particular application. The thickness of this layer and the necessary void content controls the aggregate size used in the receiving course. The design of the traditional matrix can be altered to produce a range of material strengths suitable for use from general carriageways to heavy industrial areas.

The type of coarse aggregate used is governed by the application. However, it is essential to use an aggregate that is hard and durable. Thus, if polishing of the aggregate is not a consideration then macadams containing carboniferous limestone can be successfully used. However, in locations where severe abrasion is likely, igneous rock sources would produce a superior material.

Normally 100/150 penetration grade bitumen is used as the binder, although 160/220 penetration grade bitumen may be used where ambient temperatures so warrant. Use of a softer bitumen will assist where the material is laid by hand. Conversely, the use of a harder grade of bitumen such as 40/60 pen may be adopted in areas where high ambient temperatures occur.

Summary
A relativity expensive process; however there are many benefits to using these materials, particularly when considering the effects of climate change.

<u>Benefits</u>

1. Provides an impervious surface
2. High resistance to deformation
3. Easy to change the colour of the material – reducing the effect of solar radiation with the integration of UV stable colours and possibly reduce the number of street lights required in a given area – Brighter surface colour less light absorption (Reduced carbon footprint)
4. Does not oxidise
5. Can be overlaid on flexible or rigid road surfaces.
6. Can be used to extend the life of existing carriageway.

<u>Drawbacks</u>

1. Relativity expensive
2. Only as good as the material it's laid on.

RECOMMENDATION 9
Consider the use of Grouted Asphalt (Macadam) in limited selected locations to resist abnormal design requirements. Benefits also include resistance to the effects of climate change in addition to hydrocarbon fuel spillage resistance.

10. Hot Rolled Asphalt (Binder/Base)

It is considered that this material is unlikely to be considered for use on minor evolved highways.

A drawback is that this material is not generally subject to a performance compaction specification unless specifically incorporated into the construction contract. Although the material has good waterproofing qualities, a combination of high binder content and method compaction renders the material more prone to deformation.

Asphalt Concrete (Binder/Base)
The guidance for asphalt concrete surface course applies to the binder and base materials –

Clause 906 Dense Base and Binder Course Asphalt Concrete with Paving Grade Bitumen (Recipe Mixtures)
Clause 929 Dense Base and Binder Course Asphalt Concrete (Design Mixtures)

Type approval for compaction and deformation resistance for Base and Binder courses. Useful information:-

1. BS EN 13108-1 Bituminous mixtures – Material specifications – Part 1:Asphalt Concrete
2. BS EN 13108-20 Bituminous mixtures – Material specifications – Part 20:Type Testing
3. PD 6691:2007 Guidance on the use of BS EN 13108 Bituminous mixtures – Material specifications
4. SHW – Volume 1 – Clause 906 & 929
5. SHW – Volume 2 – Notes for Guidance Clause 906 & 929
6. TRL – Road Note 42 – Best practice guide for durability of asphalt pavements
7. BS 594987 – Asphalt for roads and other paved areas – Specification for transport, laying and compaction and type testing protocols

Summer surface temperatures of 60°C and ambient temperatures >30°C are not unknown in the south of England, and with the impact of climate change, these temperatures (and higher) could be more common across the U.K.

The base and binder course layers are the main load spreading layers in a flexible pavement; however the resistance to rutting (deformation) of AC materials is dependent on road temperature as well as traffic load. At high temperatures AC materials become more susceptible to deformation, and rutting is more likely, particularly on highly trafficked roads and at low traffic speeds.

With the move towards performance specifications, care must be taken to ensure that requirements for durability are not overlooked and take into account local knowledge of materials and/or site conditions.

A durable pavement can be achieved by good compaction control during construction and a material resistant to deformation. These properties can be monitored by checking the material compaction during construction by density testing and assessing the material's resistance to permanent deformation by taking samples for wheeltracking, both in accordance with BS594987, however this type of testing is only suitable for large projects and for most contracts, the information from the "Type Test Report", supported by CE marking, should be sufficient to demonstrate that a particular AC mixture is suitable for a project.

It is the responsibility of the asphalt producer to provide verification of the requirements of PD 6691 Annex B, for each AC mixture in the form of a Type Test Report, in accordance with BS EN 13108-20.

Destructive Testing (TRL Road Note 42)
"When checking the actual properties of the asphalt as achieved on site, the extent of destructive testing should be limited with a balance between the information gained by suchtesting and the damage to the pavement caused by it, even with good quality back-filling.
There is no point in proving that the construction was perfectly constructed if the testingregime has developed a series of weak spots".

RECOMMENDATION 10
Dense base and binder course asphalt concrete have traditionally been used for structural strengthening on highways. To adapt to climate change, use of Clause 929 material is recommended with deformation/ wheel tracking type approval appraisal and compaction control which can be monitored on site.

11. Stone Mastic Asphalt(Binder/Base)

It should be noted that the HA SHW includes Clause 937 for SMA Binder Course and Regulating Course. HA policy is to use Thin Surface Course Systems (Clause 942) as a proprietary surfacing. BS EN 13108 -5 and BSI PD 6691 include options for a generic stone mastic asphalt surface course.
In consideration of climate changes in terms of higher temperatures and wetter summers, local highway authorities require to maximise the performance of their surfacing and therefore the use of thin surface course systems is preferred compared with stone mastic asphalt surface course due to the formers composition and BBA HAPAS Roads and Bridges Certification.
For SMA Binder Course and Regulating Course, improved performance for machine lay material will result from the use of lower penetration grade and the use of polymer modified binders. The 100/150 pen grade bitumen binder is the least preferred to offer resistance to deformation.
Wheel tracking classification shall be chosen from the recommendations in BSI PD 6691 to ensure that the material will not deform on site.

RECOMMENDATION 11
For climate change adaption, ensure that the specification for stone mastic asphalt binder/base clearly describes the required technical parameters and type approval information is provided by the supplier (Compaction and deformation resistance are both important)

12. EME 2 (Binder/base)

"Impermeable binder course (high binder content/low air voids) – EME 2"
With the effects of wetter, milder winters, extreme rainfall events and also drier warmer summers, due to global warming there will be a requirement to specify more impermeable and durable base and binder courses.

EME 2 “Enrobé à module elevé class 2” is a high binder content/low air voids flexible paving material which as the following properties:-

1. Resistance to deformation
2. Durable and Impermeable to water
3. Good load spreading ability

EME2 requires a range of “Hard grade binders” (typical 10/20 and 15/25 Pen) and the Specification for Highway Works recommends using EME2 with foundations of class 3 or 4 only – Minimum foundation stiffness of 120Mpa. (HD26/06) – This is to resist the compactive efforts needed to obtain the reduced air voids it is possible to achieve with EME2.

The requirement for stiff pavement foundations would limit the use of EME2 to “new build” or reconstruction works.

Most maintenance on county roads would not be able to utilise EME2 as most sites would not meet the foundation stiffness requirements. (Typically foundation stiffness’s would be class 1 or 2 at best).

(Could use Polymer Modified Binder to replace the “Hard grade binders” keeping EME2’s “Fine” PSD and relatively “High” binder contents)?

The Highways Agency SHW and DMRB provide limited guidance on the use of EME 2 Base and Binder Course Asphalt Concrete. It is clear however, that the intention of Highways Agency is to use the new EME 2 asphalt concrete on heavily trafficked roads and also roads with a stiff foundation (and base). DMRB Volume 7 HD 26/06 requires a Class 3 or 4 foundation (generally a bound sub-base) or a Class 2 foundation with a surface stiffness of 120 MPa at time of construction. A lower design traffic flow of 10 msa is indicated for a Class 3 foundation for the use of EME 2.

It is concluded that a well designed highway pavement design for a heavily trafficked road ensures that the flexible pavement includes a combination of relatively stiff layers. The use of one (or more) stiff layer within a pavement structure of other layers of less stiff characteristics may result in problems with excessive deflection and resultant strain resulting in fatigue cracking failure.

The typical local authority highway network comprises mainly evolved pavements with many comprising a thin structure and often with a poor quality foundation. These pavements are not heavily trafficked and generally do not have Class 3 or 4 foundations nor bound materials within the sub-base.

It is concluded that EME 2 is recommended at present for use by local authorities on principal and other more heavily trafficked highways where there is modern designed pavement structure containing a stiff foundation. On other parts of the local authority network, it is recommended that EME 2 is not used meantime but future relaxation for use on thin pavements with less stiff foundations may be forthcoming if adequate compaction levels can be consistently achieved on site.

It is therefore unlikely that Local highway authorities will consider using EME 2 on the minor evolved highway network for the present.

RECOMMENDATION 12
Despite the benefits (particularly deformation resistance) from using EME 2 on major highways, it is not recommended that this material is used on the minor evolved highway network meantime until publication of future national guidance. Recent proprietary asphalt materials with less stiff binder including polymer modification offer an alternative option.

13. Cement and other Hydraulically Bound Mixtures

Cement and other hydraulically bound mixtures are intended for use as base or sub-base within flexible composite pavements with the most commonly used option being that of cement bound granular mixture (CBGM) –previously cement bound material (CBM).

These materials have not extensively been used within the evolved part of a local authority highway network in the past. This is considered to be due to the thin pavement structures that have been utilised and the cost of providing such materials in comparison to granular materials. PPR 184 (reference) recommends the use of stronger pavements which are more resistant to degradation due to moisture to assist with mitigation against the effects of climate change.

Hotter drier summers will increase the temperature of the CBGM both during curing and in service. This will have the effect of increasing the potential for shrinkage cracking in the CBGM with refection through overlying asphalt. Modern design incorporates pre-cracking of the CBGM to offset this problem but older pavements will be susceptible to greater thermal movement. The use of slow curing hydraulic binders also assists with the reduction in shrinkage crack potential.

Milder wetter winters present less risk to cement and other hydraulically bound mixtures as these materials are higher strength and bound by binder. However the cost of providing these mixtures within evolved and minor highways is likely to be expensive and unviable Additionally, there is limited scope to reconstruct evolved pavements with current/future budget funding.

The use of the existing pavement aggregate or other recycled aggregate is a further option for consideration to reduce primary aggregate costs and provide a more sustainable solution.

RECOMMENDATION 13
Cement and hydraulically bound base and sub-base would provide a stronger more durable structure and foundation for evolved pavements. However the opportunities to implement this material may be limited. Recycled options offer reduced aggregate supply and sustainability benefits.

14. Joints in Bituminous Bound Materials

With the effects of wetter, milder winters, extreme rainfall events and drier warmer summers, due to climate change there will be a need to control the construction of longitudinal and horizontal joints because, however a joint in a bituminous layer is constructed, it will always be the weakest part of the pavement, possibly allowing ingress of water and/or surface break up.
Therefore it is good practice, wherever possible, to:-

1 Minimise the number of cold joints by, for example, using wide screeds and / or paving in echelon.
2 Locate joints in low stress areas in the pavement – Outside the wheel track zone.
3 Offset joints by at least 300mm from the parallel joints in layer beneath.
4 Locate the joints in the surface course to coincide with either the lane edges or the lane marking.
5 Ensure air voids are controlled at the edges of base and binder courses (Particularly difficult at the unsupported edge).
6 Apply a binder to all faces of cold upstanding edges, including previously laid asphalts, against which hot bituminous mixtures are to be laid.
7 Within 24 hours of the joint being formed a sealant shall be applied to the top surface of all base and binder course joints.
8 Maintain all joint seals throughout the life of the pavement structure.

Plate A3.6 Joint located next to lane marking – Not sealed and showing signs of fretting.

RECOMMENDATION 14
Apply the best practice for transverse and longitudinal joints – refer to the Specification for Highway Works and Road Note 42 “Best Practice Guide for the Durability of Asphalt Pavements”.

15. Bond Coats, Tack Coats and other Bituminous Sprays

Plate A3.7 Tack Coat

Wheels of material delivery wagons have removed tack coat in wheeltracks – reducing the potential for a bond between layers.

With the effects of wetter, milder winters and extreme rainfall events due to climate change, it will be increasingly important to prevent the ingress of water between layers of pavement construction.

Bond coats and tack coats are used to promote the development of a homogeneouspavement structure and prevent ingress of water.

Traditionally a tack coat using K1-40 or K1-60 emulsion has been used to add a little extra binder to an existing surface and is often adequate to initiate adhesion between layers only; therefore a bond coat is more suitable and is therefore the preferred option. Ref Draft BS 594987:2010

Bond coats generally have a higher binder content containing modifiers and are usually used at a higher rate of spread.

This promotes: -
1. Improved adhesion
2. Some waterproofing capability

It is particularly important to prevent water ingress below porous or permeable materials.

RECOMMENDATION 15
Use bond coats to reduce voids at layer interfaces, promote adhesion and to waterproof asphalt pavements.

Bituminous Sprays may be used to seal and protect:-

1. Earthworks
2. Recycled materials
3. Drainage Media
4. Cementitious materials (Including cement – stabilised soil).

The primary purpose of bituminous sprays is not necessarily to promote bond with an overlay, but to limit the evaporation or ingress of water and in cementitious materials, to facilitate proper curing.

Workmanship – It is important when using these materials:-

1. To obtain an even rate of spread – Use of sprayers– It is very difficult to obtain an even rate of spread of binder with a hand lance.
2. Loosening of coating when driven or walked over – Use of “non-tack” bond coats or cover with small (3mm) aggregate.
3. Completeness of break – Emulsions need reasonable good weather conditions if they are to break before construction traffic is to run on the sprayed surface. Emulsions will not break in the rain, break slowly in high humidity (above 80%) and will form ice if the surface temperature is below freezing – Emulsion should not be used in these conditions.
4. Pick –up – Even if the emulsion is fully broken, it is still possible for construction traffic to “pick-up” sticky binder – This could be a problem with thicker binder films – If there is significant loose of binder, it may necessary to use a polymer modified emulsion.

With the effects of wetter, milder winters and extreme rainfall events due to climate change, the ingress of water can have the following impacts on the materials and structure of asphalt pavements:

16. Binder Stripping

This is a mechanical failure of the asphalt pavement system – Water enters the pavement and become trapped between two layers of asphalt – The asphalt may then fail as a consequence of repeated hydraulic pressures caused by traffic loading physically scouring the binder from the aggregate – This action is so aggressive that all asphalt will probably fail – Some aggregates are more susceptible to binder stripping than others.

Binder stripping:-

1. Tends to begin at the base of the susceptible asphalt layer and is usually well advanced before there are any visible signs on the surface.
2. Leads to localised areas of deterioration and eventually total disintegration of the asphalt layer forming potholes.
3. Less viscous binders are more prone to stripping.
4. Stripping is accelerated by warm moist conditions.

To avoid these problems:-

1. Water should be prevented from penetrating the road surface.
2. Voids between asphalt layers should be minimised with the use of a “Bond Coat or similar”.
3. Joints in asphalt layers should be constructed to the highest possible standards.
4. Water that does penetrate the pavement should be drained as quickly as .possible (By design).
5. Areas who have a supply of susceptible aggregates should consider treatment with some form of anti stripping agent (Hydrated lime for example) before coating with binder – This should be done as a matter of course.
6. Consider using polymer modified binders to improve binder viscosity without losing other properties (i.e. resistance to deformation).

RECOMMENDATION 16
Appraise binder and aggregate for asphalt mixtures for susceptibility to stripping and use binders with good water resistant properties. Use higher viscosity (lower penetration) bitumen binders and hydrated lime as filler to promote binder/aggregate affinity.

17. Freeze Thaw

If water penetrates and is retained in the pavement structure it becomes susceptible to the action of the freeze-thaw cycles. With climate change it is anticipated that the U.K will have wetter, milder winter, however there will still be colder events (Just not as frequent) – This may increase the effects of freeze – thaw cycles (More water about to freeze – milder during the day – freezing at night etc...).
The freeze – thaw process generates tensile stress in the pavement structure and can create cracks, which propagate through the structure with each freeze – thaw cycle. The vulnerability of the pavement depends on the characteristics of material, such as its condition and the permeability. In addition, frost heave freezing draws up water from the sub-base increasing the amount of water in the pavement. Freezing of a pavement takes place from the surface downwards, drawing water up from lower levels. Layers of ice form causing the road to expand upwards, i.e. "heave".
Freeze-thaw is less of a problem where winter conditions are such that the ground remains frozen or does not freeze at all.
Frost heave will occur if the construction material absorbs water, so good drainage helps to prevent frost heave.

RECOMMENDATION 17
To provide continuing resistance to freeze thaw risk due to increased presence of water, appraise frost heave potential and durability.

18. In-situ and Exsitu Recycling

Plates A3.8 & A3.9 Recycled material used as binder course

References and useful information:-

1. Road Note RN43 – Best practice guide for recycling into surface course
2. PPR 468 – Enhanced levels of reclaimed asphalt in surfacing materials – a case study evaluating carbon dioxide emissions.

Local Authorities are responsible for a wide range of highway, from heavily trafficked principal highways to very lightly trafficked rural lanes and suburban housing estate highways. While the busiest highways and most new highways built in the last thirty years are likely to have been designed and built to high standards, many other highways on the network will have evolved over the years through the addition of successive layers of asphalt. These highways have always posed a challenge to highway engineers when designing maintenance schemes, particularly when trying to recycle existing pavement materials. The effect of climate change is another factor to consider in the design process. With the effects of wetter, milder winters, extreme rainfall events and also drier warmer summers, due to global warming there will be a requirement to specify more impermeable and durable pavement constructions. It is also required to consider the opposite scenario of permeable pavements and SUDS.

Recycling Processes Covered by the SHW

SHW Clause	Recycling Process
614, 615, 643	Lime and cement stabilisation for capping
713 to 716	Saw cut and seal, crack and seat (concrete and HBM)
902	Reclaimed bituminous materials in hot asphalt
926	In-situ recycling: the remix and repave processes
947, 948	Cold recycled bitumen bound material

Issues to considered when selecting recycled materials with regard to Climate Change

Climate Change	Possible Design Considerations
Hotter Drier summers	• Clay shrinkage and swelling causing ground movement –may required increased stabilisation • Selection of bitumen more critical – softer grades may no longer be suitable
Milder Wetter winters	• How durable is cold recycled pavement material if there is more moisture present? • Lime/cement stabilisation of subgrade. • Adhesion of bitumen to recycled aggregates – compared to primary aggregates. Some aggregates are susceptible to binder stripping (i.e. acidic aggregates – granite & quartzite). • Free draining materials may be more suitable for unbound materials – Possible fines reduction?
	• Frost heave less frequent – However more moisture about to freeze.

References- Specification for Highway Works and Design Manual for Roads and Bridges Volume 7 HD 35/04 “Conservation and the Use of Secondary and Recycled Materials” for details.

RECOMMENDATION 18
When consider remedial works to asphalt pavements which include in-situ recycling of existing materials, climate change adaption will require further consideration at the design stage of the effects of higher temperatures and higher rainfall.

19. Potholes and Depressions and Patching

Plate A3.10 Pothole with deterioration of both surface and binder courses. Progressive peripheral deterioration.

References – 1. CSS Report No 3/8 April 1989 2. HA SHW Clause 946 May 2009 3. NRSWA Specification for the Reinstatement of Openings in Roads April 2003.

The market position some twenty years ago was one where the suppliers of deferred set macadams (asphalt) were focussed to fulfil workability and storage requirements with little emphasis on long term performance.

Four recommendations were outlined in CSS Report No 3/8 1989 to assist local highway authorities as follows:-

1. Do not use cut back or any volatile dilutents in dense or close graded mixes.
2. Wherever possible, avoid the use of deferred set binders in base course (binder course) and roadbase (base) layers.
3. Do not use deferred set macadams in pre-surface dressing patching immediately before surface dressing.
4. Recommendations to use a medium textured grading for macadams in accordance with the SW Counties Regional Specification for Bituminous Materials.

During the past twenty years, developments have occurred with cold lay bitumen emulsions and also with modified bitumen technology.

The NRSWA HAUC Specification does not permit deferred set macadams to be used in permanent reinstatements with restriction to temporary use. In application of the principle of uniform specification standards applied between highway authorities and utilities, it is recommended that deferred set materials are not used by local highway authorities for permanent long term use on the public highway.

The NRSWA HAUC Specification has developed the concept of Permanent Cold Lay Surfacing Materials and these materials are approved for use via the British Board of Agreement HAPAS Roads and Bridges system. There are currently many approved products and the cold binder carbon footprint offers advantages compared with conventional hot lay materials.

The HA SHW Clause 946 Patching and Repairs to Potholes and Depressions (Including Emergency Patching) provides the basis for a permanent patch with defined performance requirements. Unfortunately at the time of review, there are no approved products on the market.

Alternatively, proprietary in-situ recycling repair systems incorporating infra red heating are available on the market together with approval to the British Board of Agreement HAPAS Roads and Bridges system.

With the future predictions for higher temperatures and wetter conditions, it is vitally important that any patching of an asphalt pavement is considered from a maximisation of performance perspective and a whole life costing approach. The use of high workability but low performance deferred set or depot grade asphalt materials will exhibit even lower performance in future years. It is therefore recommended that “permanent” asphalt materials are selected and preferred together with the support of the British Board of Agreement HAPAS Roads and Bridges certification system.

Plate A3.11 Pre-patching with low grade binder asphalt resulting in surface dressing bleeding.

RECOMMENDATION 19
As the effects of climate change will be detrimental to patching performance, it is important to apply specifications and use materials with resistance to the higher temperatures and increased rainfall expected in future.

20. Emergency Patching

The Highways Agency has developed guidance (Interim Advice Note 01/07 Amendment No 1) and a specification (SHW Clause 946) for emergency patching material. With the increased demands of climate change, the need for a high performance patching material to safeguard against higher temperatures and increased rainfall is essential if such materials are to provide reasonable performance and value for money. In the interim period until several BBA HAPAS Roads and Bridges certified materials are available, it is recommended that appraisal of independent certification of proprietary, thermosetting, resin based emergency patching materials is conducted to ensure that the potential performance is satisfactory

RECOMMENDATION 20
Appraise proprietary, thermosetting, resin based emergency patching materials and ensure that the performance is suitable for the anticipated temperature range and thickness of application.

Climate Change and Evolved Pavements

Appendix A4

Surface Treatments

Appendix A4 Surface Treatments

1. Micro-Surfacing and Slurry Surfacing

Plates A4.1 & A4.2 Slurry surfacing

Micro- surfacing and slurry surfacings are mixtures of aggregates and plain or polymer modified bitumen emulsions, which may contain fibre additives. Slurry surfacings range in thickness from about 2 mm to 8 mm and micro-surfacings from about 10 to 20 mm. Slurry surfacings are suitable for footways; areas that are trafficked only occasionally and at low speeds; and for traffic delineation. Micro-surfacings are targeted at all roads, including high speed roads carrying significant traffic volumes, and in consequence require appropriate levels of skid resistance and texture retention. Both materials permit only limited surface regulation when laid in one pass. If greater surface regulation is necessary, an initial pass may be made to fill in surface irregularities, such as minor rutting, followed by a second pass to provide the complete overlay.

<u>Benefits</u>

1. Slurry Seal could be used to replace Surface Dressing on “Estate Roads” – The finished surface is cleaner (No chippings or binder pick-up) – It is less likely to “tear up” with the action power steering from large 4 x 4 type vehicles. These problems with surface dressed “Estate Roads” are more likely with higher surface temperatures predicted in the future.
2. Tyre noise is relatively low because slurry surfacings have low or fairly low macro-texture (Making it a possible choice for low speed residential areas). Micro-surfacings with a higher texture may be less quiet.
3. Slurry and micro-surfacings may be used on road surfaces that have undergone a number of reinstatements, or significant patching, in order to provide a more uniform overall appearance and provide a sealed more water resistant surface. Slurry and micro-surfacings can be used on surfaces that are fretting, and on those showing early signs of ravelling, to halt further deterioration. Coloured aggregates or mixtures may be used for delineating traffic calming measures etc...
4. Micro – surfacing improves the profile of the underlying surface; particularly in the transverse direction, there is also some improvement of ride quality.

Limitations

1. There are currently no slurry surfacings that can maintain adequate surface texture for high speed roads for more than a few weeks; therefore these materials should not be used on high speed roads.
2. Slurry surfacing does not improve the profile, either transverse or longitudinal, of the existing surface, so defects of this nature should be reduced to acceptable levels before their use.
3. Laying slurry and micro-surfacings, particularly the thicker varieties, is relatively slow and the material must be left to break and stabilise prior to opening to traffic. In good weather conditions, warm with low humidity, this will take about half an hour, but in less satisfactory conditions it may take an hour or more. Where more than one layer is used however, traffic may use each layer as it becomes sufficiently stable.
4. Slurry surfacings do not increase the load bearing capacity of the pavement structure. Thicker microsurfacings may add to the structural strength of the pavement, but any claims made by a system proprietor should be confirmed by the BBA HAPAS certificate.
5. Although slurry and micro-surfacings arrest surface deterioration, most products are permeable to a greater or lesser extent. They should not be assumed to be entirely waterproof.
6. Slurry and micro-surfacings with emulsion binders are sensitive to high humidity and wet weather during construction. If heavy rain occurs before the emulsion has broken the surface may be washed away, or if there is a frost within the first 24 hours, then the surfacing may be disrupted.

Micro- surfacing and slurry surfacing with BBA HAPAS Roads and Bridge Certificates shall only be laid by approved contractors.

RECOMMENDATION 1

Micro- surfacing including slurry surfacing can be effectively used to maintain evolved pavements by sealing and waterproofing the existing structure in conjunction with improvements in other properties. The waterproofing function should assist resistance to increased rainfall as a result of climate change.

2. Surface Dressing Design

Plate A4.3 Surface Dressing – Sprayercarrying out "quartering" operation

Plate A4.4 Surface Dressing – Sprayer withchipper behind

Summer surface temperatures of 60°C and ambient temperatures >30°C are not unknown in the south of England, and with the impact of climate change, these temperatures (and higher) are likely to be more common across the country. At these temperatures the Surface Dressing binder becomes a liquid – These will be extreme events: however the average summer ambient temperature in 2020 could increase by 2°C (UKCIP02) with a greater impact on surface temperature.

Current U.K average ambient summer temperature is about 15°C

Table A4.1 Ideal pavement temperature range for surface dressing application (Road Note 39 6th Edition) Bitumen Emulsion states:-

Binder Grade	Minimum Temperature °C	Maximum Temperature °C	
		Traffic Cats A to E	Traffic Cats F to G
Unmodified	10	30	35
Intermediate grade	10	35	40
Premium or Super-Premium grade	As for intermediate grade emulsions unless otherwise advised by the supplier		

Temperatures quoted are for "Rising or stable movement" see table 14.3 RN 39 for full details.

As can be seen above the surface temperatures in an "extreme event" at 60°C plus, will be greater than the maximum recommended in table 14.3, in this case the surface dressing operation would need to suspended until surface temperatures come down below the maximums – A change in working patterns may be required (i.e. early mornings starts).

If the average summer ambient temperature increases due to climate change, it could be prudent to change the design of the modified binders (Intermediate and premium grades) to raise both the minimum and maximum working temperatures.

The use of unmodified binder would be less flexible and with low Cohesion (see table NG 9/8), the practicalities of continuing to use “Conventional” binder grades would need to be examined.

Table A4.2 NG 9/8 SHW: (08/08) Vialit Pendulum Test

Binder Grade	Minimum Peak Binder Cohesion Joules/cm²	Class in BS EN 13808
Super - Premium	1.4	6
Premium	1.2	5
Intermediate	1.0	4
Conventional	0.5 over a minimum temperature range of 15°C	3

(08/08) The Vialit pendulum test should be carried out in accordance with Clause 957. The minimum binder cohesion at peak measured using the Vialit Pendulum for three grades of binder are given in Table NG 9/8. Guidance as to the choice of binder is given in Road Note 39 and British Standards Published Document PD 6689.

Benefits which may be obtained by the use of modified binders in surface dressing include:

1. Improved adhesion to aggregates.
2. Increased cohesion, giving better chipping retention in the early life.
3. Reduced hardening or ageing in service, giving longer life to surface.
4. Reduced temperature susceptibility throughout service temperature range.
5. Reduced susceptibility to bleeding at high ambient temperatures.

<u>Selection of Polymer-Modified Emulsions in Surface Dressing</u>

Some of the benefits of using Polymer-modified emulsions are listed above. If the design guidance in Road Note 39 is followed the choice of the “Conventional” binder grade will be limited to all but a few sites and with the varying weather conditions that have occurred in recent years (and the potential for greater variation in the future due to climate change) provides further support for only using polymer-modified binders.

Consideration of an increase in the binder grade at locations of high risk to increased temperature should also be considered.

A local highway authority reports the successful changes to surface dressing practice to provide improved tolerance in both hot and cold conditions in addition to providing better resistance to intense agricultural activity during the warmer months. These changes are to replace the traditional single size aggregates (6mm and 10mm) with graded aggregates (8mm all-in and 12mm all-in).

<u>End Product Performance Specifications</u>

In the case of surface dressing the Contractor has responsibility for performance during the guarantee period; this may be for only two years, whereas the life of surface dressing may be in excess of eight years. It is imperative that the Overseeing Organisation has data to ensure that modifiers used successfully in the past, where durability has been confirmed in practice, are identified, so that they may be used again with confidence.

The end-performance tests currently available cannot fully predict durability and it is inevitable that some material component control will be part of specifications for some years to come. Polymer modified binders will require rheological identification, cohesion testing to determine low temperature performance and tests to determine resistance to ageing, so that performance limits may be determined for future specifications.

A polymer modified binder for surface dressing may have a very high cohesion value and perform well in laboratory tests, but exhibit poor adhesion to chippings in practice, under realistic weather and traffic conditions. Therefore a balance has to be struck. The approach adopted is to encourage innovation by allowing the use of proprietary products with BBA HAPAS certification. The scheme includes monitoring and surveillance which will provide assurance on the performance of the various products and systems.

Binder performance tests will not guarantee the performance of all binder/aggregate combinations, but can provide a useful indication of mixtures that are likely to be satisfactory.

RECOMMENDATION 2
Consider phasing out the use of unmodified bitumen emulsion binders and using only modified binders for enhanced performance and to counteract increased temperatures.

RECOMMENDATION 3
Consider increasing the binder grade of modified bitumen emulsion at high risk sites.

RECOMMENDATION 4
Consider a reduction in the use of surface dressings using single size aggregates by increasing the use of racked in surface dressings or by the use of graded aggregates at high risk sites.

3. Guidance Note on the treatment of "melted" Surface Dressed roads

The problem

Surface Dressing has been a most effective sealer, dust suppressant and skid resistance enhancement treatment for over 70 years.

It has been widely used across the networks of local highway authorities.

The treatment has been carried out repeatedly and there may be 10mm – 30mm of bound material built up overlying the original unbound aggregate road metal.

Summer surface temperatures of 60°C and ambient temperatures >30°C are not unknown in the south of England, and with the impact of climate change, these temperatures (and higher) are likely to be more common across the country. At these temperatures the Surface Dressing binder becomes a liquid.

Rural traffic loads have increased with the increase in weight of private and commercial vehicles.

Plate A4.5

As a result fatting up of the surface occurs leading to

- Poor skid resistance in the dry and possibly dangerous levels when wet.
- Pick up of binder on car and cycle tyres and by pedestrians.
- Surface deformation in the wheel tracks which hold water – this may not always be present if the traffic levels are low.

The binder may be bitumen with the addition of a light oil flux, bitumen cut-back with creosote or tar. The last two are no longer used but may exist within the bound layers; they are carcinogenic and treated as hazardous waste. Any volatile materials can be trapped within the overlays by subsequent treatments.

The scale of the potential problem is very large with 50,000 km of road at risk in UK.

Identification of the problem

The problems will be easy to see by visual inspection by machine surveys by SCANNER and SCRIM, by public complaint or from accident records.

Possible remedial works

Remedial works can be categorised into three each with strengths and weakness as follows.

1. Remove excess binder from the surface

Table A4.3

Treatment	Benefits	Additional benefits	Disadvantages
Remove excess binder from the surface with water jetting	• Provides a short term safe surface • Can treat just areas affected • Reactive so only does those areas that really need it		• Repeated applications will be necessary at alternate summers so overall cost is high £1.50/m² per application. • If deformation also present treats only the surface layer. •

4. Treat melted layers

Table A4.4

Treatment	Benefits	Additional benefits	Disadvantages
Repeated application of grit reactively	• Makes the existing open graded mixture more dense and like an asphalt concrete • Uses winter equipment that is available • Reactive so only does those areas that really	No other action required as a consequence	• Repeated applications will be necessary possibly within the season so overall cost is high £1.00/m² per application. • May not be successful in solving the problem • May not restore enough

	need it		texture depth to make the road safe.
Sandwich Dressing (a layer of stone placed in the soft areas and compacted prior to a single/racked-in dressing with intermediate binder over the whole road	• Stone stabilises the soft areas preventing further deformation • Finished road has uniform appearance	Seals whole road surface Designed in accordance with RN 39	• Possible longitudinal ridges which may be difficult for motorcyclists • Needs special sectioned chip spreader just to cover wheel tracks • EO cost on a surface dressing £1.50/m².
Retread: Pulverise the top [75mm] of material and add lime/cement/bitumen emulsion and recompact. Surface dress with hard emulsion binder	• Solves the problem provided HGV volumes are low	Solves rutting, cracking and poor profile at the same time	• Cost £12/m² • Areas not requiring treatment are done for practicality increasing cost. • Road markings need reinstating

5. Cover Melted Layers

Table A4.5

Treatment	Benefits	Additional benefits	Disadvantages
Microasphalt in two layers incorporating fibres	• Resolves skid resistance and any deformation issues • Very speedy • Cost £4/m² • Not subject to H&S issues	• Transverse profile benefit • Some longitudinal profile benefit • Some crack sealing	• Does not reduce temperatures in the lower layers so any deformation will continue. Alight colour may be beneficial • Bleeding through of the binder below possible

			• Areas not requiring treatment are done for practicality increasing cost • Road markings need reinstatement
Thin surface course overlay 35mm thick	• Resolves skid resistance, any deformation and some cracking issues	• Transverse and longitudinal profile benefit • Some structural strength improvement • Reduced peak temperatures in lower layers • Quiet surface provided	• Costly £8/m² • May suffer from fatigue cracking and delamination where high points in exiting surface make the layer too thin. This may be resolved by increasing the nominal thickness at greater cost • Drainage, verge and road marking work also required • Site investigation necessary to see if road needs structural strength improvement (visible cracking) • Road markings need reinstatement

6. Remove soft material and replace with hot mix

Table A4.6

Treatment	Benefits	Additional benefits	Disadvantages
Thin surface course inlay with binder course	• Resolves skid resistance and any deformation issues • All poor material likely to be removed	• Transverse and longitudinal profile benefit • Structural strength improvement (if required) • Quiet surface provided	• Costly £15/m² • Drainage, verge and road marking work also required • Possible H & S issues with removed material

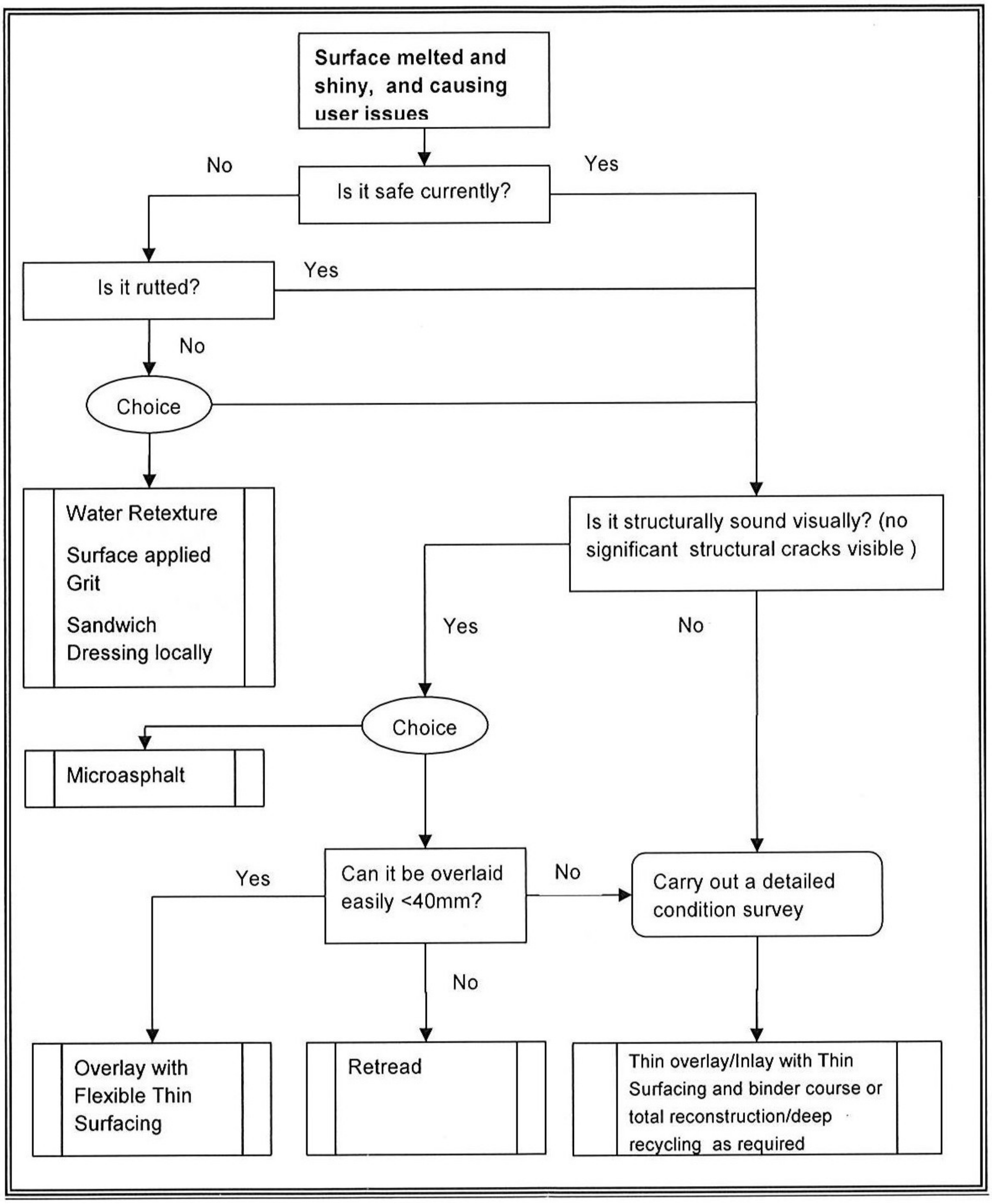


Figure A4.1

NB Costs at 2009 price datum.

The external assistance and contribution of consultant, Professor Ian D Walsh with this advice note is acknowledged.

RECOMMENDATION 5

Use the guidance note to rectify surface dressings with excess binder at the surface (bleeding or fatting) and have melted during hot weather.

Climate Change and Evolved Pavements

Appendix A5

Detailed Background

Appendix A5 Heat Island Effect

1. Use of pale coloured aggregate

A CSS workshop on climate change suggested the use of pale/light coloured aggregates for road surfaces to increase surface reflectance and reduce the damaging effects of increased temperatures.
Lighter colour surfaces including aggregates improve reflection from the highway surface for sunlight, daylight and also street lighting during the hours of darkness.
Parts of the highway network where most benefit would be attained are as follows:-

- Traffic -Heavily trafficked, channelised highways
- Environment -Built up areas (and also with street lighting)
- Exposure -South and South West facing gradients
- Structure/Materials - Highways with thin construction and surfacings with known potential for heat damage.

Both the binder and aggregate can be considered for lighter colour.

- Clear binder with light pigment (Tarmac Mastertint or equivalent)
- Light colour aggregate (coarse aggregate or surface applied chippings)

The most cost effective option is considered to be the use a light coloured aggregate for surface treatment in a surface dressing.

Cost/Sustainability implications:-

Initial cost would be higher but whole life cost could be justified if improved performance over the longer term.

Increased transport costs and carbon footprint from transporting aggregate from further distance.

Other Issues:-

Consider improvement of other material performance characteristics – e.g. deformation resistance/ chipping embedment etc.

The UK Roads Liaison Group/UK Lighting Board have carried our research at Sheffield Hallam University –"The Effect of Pavement Material on Road Lighting Performance" 2005 by Fotios et al. Road surface reflectivity has an input into lighting design and darker surfaces due to aggregate colour and increased bitumen contents results in increased lighting costs.

In the case of lighter aggregates, require to consider colour in addition to technical material properties

The local availability of light coloured aggregates was considered to be poor across most the UK. Light coloured aggregates also had the disadvantage of not generally providing adequate technical characteristics.

BS EN 13043 “Aggregates for bituminous mixtures and surface treatments for roads. Airfields and other trafficked areas” does not contain any reference to colour or reflectance. There may be procurement difficulties in the selection of aggregate on the basis of an additional parameter. Also selection on the basis of colour can be very subjective.

Road Surface Solar Absorption and Reflectance

Road surfaces absorb and reflect solar radiation and contribute to the general “heat island effect”.

With the expected rise in temperature due to global warming, the review will focus on current practice and mitigation measures to contain this problem.

Surface reflectance is also an issue for street lighting design.

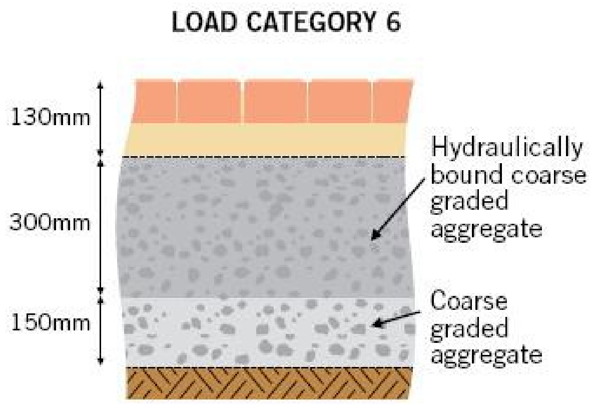
Factors/Variables:- Carriageways/ footways/ cycle-ways
Flexible/ rigid/ modular construction
Surface course types
Materials – binders (bitumen and hydraulic)
aggregates
other

RECOMMENDATION 1
It may be difficult to specify (as colour is out with technical specifications for aggregates) and use pale colour aggregates and also to meet other technical requirements despite the validity of the principle. Increased cost and carbon footprint may discourage this option.

2. Porous Pavements and SUDS

Plates A5.1 & A5.2 School Car paved with Permeable Paving/ Sustainable

Drainage Systems (SUDS)



Key:

Geotextile
(upper geotextile optional)

Figure A5.1

With the effects of wetter, milder winters, extreme rainfall events, due to global warming there will be a requirement to manage water more effectively particularly in locations next to rivers or on flood plans. This could be achieved by designing more permeable pavements i.e. “concrete block permeable paving” or other “Sustainable Drainage Systems (SUDS)”managing the increase in rainfall and moving the water away from carriageway. Locations were this could be used are housing estates built on flood plans.

Useful information:-

1. BS 7533 –13:2009 – Pavements constructed with clay, natural stone or concrete pavers: Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers.
2. The SUDS Manual CIRIA 2007
3. Permeable Pavements Guide to the Design, Construction and Maintenance of Concrete Block Permeable Pavements Edition 5.
4. Permeable Paving – Guidance for Achieving Successful Local Authority Adoption of Permeable Pavements.

SUDS can mitigate many of the adverse effects of urban stormwater runoff by:-

- Reducing runoff rates, thus reducing the risk of downstream flooding.
- Reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality.
- Encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment.
- Reducing pollutant concentrations in stormwater, thus protecting the quality of the receiving water body.
- Reducing the volume of surface water runoff discharging to combined sewer systems, thus reducing discharges of polluted water to watercourses via Combined Sewer Overflow (CSO) spills.

SUDS Maintenance

1. Permeability will decrease with age due to the build-up of detritus in the jointing material – pavements need sweeping regularly. If pavements become clog – use of jet washer and suction sweeper can be used.
2. Soil and other fine materials must be prevented from contaminating the pavement surface.
3. Depressions rutting and cracked or broken blocks are detrimental to structural performance of the pavement and can be a hazard to users – Will need the appropriate corrective action.
4. With climate change the longer growing season of vegetation would require more control – If not controlled the vegetation growth could damage the pavement, present slip hazards to pedestrians and in the case of tree roots in time of drought, seeking water, undermine pavement foundations.

Recent legislation with the introduction of the Flooding and Water Management Act 2010, include SUDS and propose the future development of national standards for design and specification accompanied with an approval system.

Design functional life and highway maintenance costs are prime considerations for local highway authorities for these pavement types.

Proprietary systems should be appraised and evaluated for applicability.

RECOMMENDATION 2
Monitor developments of national standards for SUDS and applicability to the local authority highway network

RECOMMENDATION 3
Consider the option of designing porous pavements in selected locations where benefits will accrue from reduced surface run-off. The design and maintenance will require careful consideration since there is currently limited research/development and experience with these pavements.

Climate Change and Evolved Pavements

Appendix A6

Rigid Pavements

Appendix A6 Rigid Pavements

Unreinforced Rigid Concrete and Jointed Reinforced Concrete Pavements

Plates A6.1 & A6.2 Typical concrete pavement on a trunk road – Well maintained. Typical concrete pavement on estate or industrial estate roads – Poorly maintained and repaired with poor joints and areas cracking

The proportion of concrete pavements on local highway authority networks is relatively small with a concentration in South East England where there is a shortfall of crushed rock aggregate and more abundant supply of sands and gravels.

Many local highway authority concrete pavements were constructed during the period after the Second World War and have subsequently been overlain with an asphalt surface course.

Few new concrete pavements have been constructed for addition to the local highway authority network other than for specific localised purposes. Modern concrete pavements have generally been constructed for Motorways/Dual Carriageways or for private industrial access roads and hardstandings.

The following recommendations further to the publication of TRL PPR 184 are as follows:-

Ensure properly maintained joint seals.
Most local highway authority concrete pavements are either unreinforced or reinforced concrete pavements with transverse joints at 5 metres to 25 metres centres. The joints are the weakest part of the design and require continuous monitoring (the concrete slabs generally are less problematic to maintain). It is important to ensure that the joints continue to perform satisfactorily and perform the intended function including keeping detritus and water (including de-icing salt) out of the joint. The joint sealant has an important part to play in the success of the joint performance. Joint sealants require regular maintenance to remain watertight.

Upgrade Joint Seal Composition.
The life expectancy of most joint seals is short compared with that of the concrete pavement, since they tend to harden and become brittle with age. Consequently, joint seals have to be replaced regularly, and a guide to the main types, relative life and usage is given in Table 3.1 of DMRB HD 32/94.

With the predicted effects of climate change resulting in increased temperatures and higher rainfall, it would be prudent to improve the performance of joint seal materials. This can be achieved by a more regular maintenance process of raking out the old joint seal and topping up with new material. DMRB Vol 7 HD 32/94 and The Concrete Pavement Maintenance Manual by Highways Agency and Britpave, 2001 provide guidance on joint seals.

The two most common coarse aggregate types used in UK for concrete pavements are:-

- Quartz gravel
- Limestone

When incorporated into concrete, limestone aggregate provides higher strength properties and lower thermal movement than gravel. Research indicates that the lower thermal movement of concrete comprising limestone aggregate was beneficial to overall concrete pavement performance.

It is therefore recommended that the DMRB Vol 7 HD 26/06 requirement for a thermal expansion less than 10x10-6 per C for higher strength 28 day flexural strength of 5.5 MPa is used for all concrete pavements. Note that this requirement is generic and relates to aggregate properties rather than the type or source of aggregate. Modify the concrete mixture to ensure adequate workability and curing time.

With higher expected future temperatures the concrete pavement mixture design will require to be carefully designed to ensure that the mix has sufficient workability for placement and compaction. Curing times will become shorter and therefore mixture modification to a slower curing regime may be considered.

Concrete paving during high summer temperatures will result in large joint gaps during the winter which in turn will create increased strain for joint fillers and seal materials. In order to minimise this potential problem, concreting during hot summer months would be undesirable and specification restrictions will be required in future.

Compression failures/ Concrete “pop-ups”

Higher anticipated summer temperatures coupled with other defects will increase the frequency of compression failures at joints in concrete pavements. To avoid the problem, it is important to design jointed pavements with sufficient joints to accommodate anticipated movement. Construction of the concrete pavement to the specification requirements to avoid other defects is essential. The use of exposed aggregate as a surface course for concrete pavements is encouraged due to the benefits of low noise and reduced solar gain.

The traditional requirement for air entrained pavement quality concrete to resist frost damage due to freeze/ thaw cycles is considered to be less necessary in a climate with increased temperatures and with fewer frost occurrences. Air bubbles in the fresh concrete have been incorporated to accommodate the increased volume expansion of ice.

It is concluded that due to the combination of increased pavement quality concrete strength over time and higher temperatures, that the risk of frost damage in the future is limited and that air entrainment could be deleted from specifications.

Joints in Concrete Pavements

Plate A6.3 Spalling of concrete at edge of joint.

Plate A6.4 Holes in the bitumen sealant in joint

Placement of joints is critical to the construction of concrete pavements – See SHW Series 1000 for full details.

The life expectancy of most joint seals is short compared with that of concrete pavements, since they tend to become hard and brittle with age.

Joint seals have to be replaced regularly throughout the life of the concrete pavement – A guide of the main types, relative life and usage can be found in HD32/94 Table 3.1.

Defective joint seals allow silt, grit, stones and water to enter between the slabs and infiltrate the lower levels of the pavement. An accumulation of detritus can prevent the joint closing and lead to spalling of concrete or, if several slabs are affected, “blow – up” expansion type slab compression failures – This effect may be more common if “heat wave” events are become more frequent. Ingress of water into the joint can lead to softening of subbase or subgrade and corrosion of steel dowels and tie bars, especially in the presence of de-icing salt.

The presence of water is also a contributory factor in the disruptive alkali-silica reaction, which can occur within concrete composed of certain reactive aggregates.

Types of hot applied joint sealants (BS EN 14188-1:2004 – Table 1 & [part] Table 2

Material	Type	Softening Point °C	Penetration mm
Elastic – high extension	N1	≥85	40 to 130
Normal – low extension	N2	≥85	40 to 100
High extension fuel-resistant	F1	≥85	40 to 130
Low extension fuel-resistant	F2	≥75	40 to 100

The softening points of all the hot applied joint sealants (as can be seen from the table above) would indicate that these materials would be suitable for all but the most extreme (heat wave) rises in surface temperature due to climate change. These materials become hard and brittle with age, this process would be accelerated if high surface temperatures become more common, thus increasing the need for timely joint maintenance throughout the life of the concrete pavement.

Types of cold applied joint sealants (BS 5212-1:1990)

Material	Type	Compliance Criteria to BS 5212-1	Hand or machine applied
Normal	N	Clause 5 (Except 5.9 & 5.10)	Either or both
Fuel resistant	F	Clause 5 (Except 5.10)	“
Flame and fuel resistant	FB	Clause 5	“

SHW Clause 1017 Joint Seals recommends:-

Hot – applied Sealants shall be Type N1 or Type F conforming to BS EN 14188-1.Cold – applied Sealants shall be Type N conforming to BS 5212-1 – except that Type F shall be used for lay-bys and hardstandings.

Asphalt Overlays
A large number of local highway authority rigid pavements are overlain with asphalt. The effects of climate change with hotter summers will exacerbate the thermal strain problem

normally associated with rigid pavements. Reflection cracking at joint locations may be a significant issue in future. It is therefore recommended that proprietary systems are appraised to provide improved performance at these locations e.g. asphalt reinforcement.

RECOMMENDATION 1

Consider a range of options to improve performance of rigid pavements and counteract the effects of climate change. Adaption measures can include the use of more frequent joint seal replacement, improved grade sealants, use of low coefficient of expansion aggregate and restrictions on construction during periods of high temperatures.

RECOMMENDATION 2

Asphalt overlays will exacerbate the thermal strain within rigid pavements due to increased temperature as a result of climate change. Consider proprietary systems (e.g. asphalt reinforcement) to improve performance and resilience to climate change

Climate Change and Evolved Pavements

Appendix A7

Modular Pavements

Appendix A7 Modular Pavements

Plate A7.1 Modular pavement in Keswick Town Centre

With the effects of wetter, milder winters, extreme rainfall events and drier warmer summers, due to climate change there will be a need to allow for this “weathering “when designing modular pavements.

References and useful Information:-

1. BS 7533 Parts 1 to 13 – Design guidance and codes of practice for laying/construction of modular pavements.
2. The SUDS Manual CIRIA 2007

Cause of Deterioration	Result	Remarks/Hazard
Effects of wetter, milder winters	1 Weakening/Erosion of the foundation and sub-grade 2 Freeze/Thaw cycle 3 Removal of jointing material (Washing out)	1 Foundations developing voids – leading loss of structural support. 2 Although with milder winters, freeze events will become less frequent – when there is a ground frost there will be more water about to freeze – thus still causing surface deterioration. The freeze/thaw cycle can also draw water up from sub-base. 3 The removal of jointing material will allow the paving modules to move horizontally and vertically – thus traffic loads will be carried by individual blocks – Opening-up of the joints will allow water into the bedding layers.
Effects of drier,	1 Slab warp	1 The top surface of a slab will expand more than the underneath,

warmer summers	2 Surface heating and cooling, causing expansion and contraction.	causing the slab to became concave – The larger the slab the more pronounced the concaving – slabs bedded on sand less susceptible – slabs bedded on concrete could crack. 2 Edges of slab curl up – Could crack if loaded – Could cause trip hazards.
Damage by Vegetation	1 Longer growing seasons – more growth of vegetation (More of a problem on footways)	1 Vegetation ingress accelerates deterioration of pavement structure. 2 Slip hazard to pedestrians

Possible causes of Deterioration to Modular Pavements due to Climate Change

Plate A7.2 Limited repair options once modular pavements fail

Factors to consider when designing a Modular Pavement:-

1. The available sub grade – The structural strength of a modular pavement is dependent on the foundation (Sub grade / Sub-base) – Care should be exercised in the interpretation of site investigation data as the strength of soils is a function of their moisture content, the in-service strength may be much lower in soils than the recorded values in the site investigation. Care should also be exercised in using CBR values measured in summer as artificially high figures may be obtained due to the dryness of the sub grade – The effects of drier summers could have a greater affect in artificially increasing the CBR value. – Wetter winters could also have a great affect on moisture susceptible materials – Once the pavement is constructed it becomes increasingly important to exclude water.
2. Selection of size and type of paver units– Pavers with a larger exposed surface area will be more susceptible to surface temperature variations increasing the “wrap” affect on the paver – Other factors could be location – is the pavement south facing – is the area to be paved enclosed (Less cooling down during extremely warm periods)

3. Expansion and contraction – Increasing incidents of “blow-up” where no or little allowance for the expansion of pavers under hot conditions has been made – this could cause spalling – particularly if the pavers do not have chamfered edges.
4. Maintenance: -
    a. Cleaning and sweeping – Care should be exercised when using suction sweepers or high-pressure jetting – avoid removing jointing material – if this happens and with wetter winters the ingress of water could be more likely – Causing a reduced load bearing capacity and increasing the liability of deformation of the pavement structure, leading to movement of the surface modules, resulting in cracking and spalling.
    b. Moss, Lichens and Algae etc.. – Likely under trees, heavily shaded or areas with an inadequate fall – With longer growing seasons more cleaning/chemical treats may be required – Surfaces will need to withstand increased treatments (i.e. to avoid leaching out of colour pigments in some concrete products).
    c. For permeable modular pavements see notes on “Sustainable Drainage Systems” (SUDS).
5. In locations that are at risk from flooding, it is recommended that an alternative pavement design type is considered.

RECOMMENDATION 1

To adapt modular pavement designs for climate change, consider the use of smaller elemental slabs or blocks. Enlarged joints may also be desirable. Consider alternative pavement type if flooding is very likely.

Climate Change and Evolved Pavements

Appendix A8

Unsurfaced Pavements

Appendix 8 Unsurfaced Pavements

In rural areas, local highway authorities may be required to maintain generally old, historic highways which have not been developed and improved to a surfaced standard. As these highways do not attract revenue funding from central government for their upkeep, it is important to keep maintenance treatments and costs within a basic, minimalistic approach.

Higher temperatures will not be detrimental to performance but wetter conditions pose a greater hazard. It is therefore recommended that the following options be considered:-

1. Conventional longitudinal ditches with soakaway or positive outfall.
2. When reconstructing unsurfaced roads use of a coarse graded (free draining) type 3 sub-base with consideration of extension of this layer to provide drainage continuity with the longitudinal ditches.
3. Take measures to prevent surface water scour by preventing highways that are lower than the surrounding area from damage.
4. Consider the use of stabilisation techniques to use cement or other hydraulically bound material to construct a pavement with improved performance in locations of greater public use where a bound surface may be beneficial. The reuse of the existing pavement materials with the addition of processed sub grade material can form a stabilised pavement with significant characteristics that will be more resilient to the effects of climate change.

RECOMMENDATION 1
Climate change with increased rainfall will require unbound layers with improved drainage characteristics for unsurfaced pavements.

RECOMMENDATION 2
Consider stabilisation techniques for selected locations where beneficial.

Climate Change and Evolved Pavements

Appendix A9

Footway and Cycleways

Appendix A9 Footways and Cycleways

The effects of climate change with higher temperatures and rainfall are likely to result in a relative worsening of footway condition due to the climatic conditions.
Most local highway authorities have extensive footway networks particularly in built up areas. These pavements are considerably thinner in construction thickness compared with carriageways and are more prone to climatic change damage. Although pedestrian loading is lightweight, vehicle over-run is an increasing problem in congested areas. The heat gain and shelter in built up areas exacerbates the predicted higher temperatures resulting from climate change.

(a) Flexible Footways
Specify the highest bitumen grade or viscosity (lower penetration numeric's) that can be laid and compacted satisfactorily (bitumen grade 100-150 is specified in the following examples). Avoid the use of low viscosity binders including deferred set or cut back bitumen as these materials will be prone to higher temperature defects.
To minimise future binder stripping as a result of higher rainfall, ensure that sufficient binder is adhering to the aggregate. This problem will be more acute with asphalt concrete materials and with aggregates with poor binder affinity.
Recommended surface course materials are as follows:-
Hot Rolled Asphalt - HRA 15/10F Surf 100/150 PSV 50 AAV 16% or
Asphalt Concrete (previously dense macadam) AC 6 dense surf 100/150 PSV 50 AAV 16%
Slurry surfacing is currently one of the most popular highway maintenance surface treatments to arrest surface fretting and to seal the surface from water ingress. The HA SHW clause 918 provides a recommended specification format with the emphasis on a two year performance assessed against standard defects.

(b) Rigid Footways
With higher predicted temperatures and increased rainfall, greater care is required with joint design and maintenance to ensure that the pavement performance is realised. Avoidance of construction in hot summer weather would be advantageous.

(c) Modular Footways
The use of smaller element slabs or blocks with larger joints (not too large as to cause a safety hazard) should be considered to offset the predicted effects of climate change.

Typical footway defects are as follows:-

- **Trip**
- **Pothole**
- **Rocking slab or block**
- **Open joint**
- **Depression**
- **Crowning**
- **Tree root damage**

It is therefore important that footway safety inspections for flexible, rigid and modular footways recognise the potential for additional deterioration due to climate change and to identify the sections of footway most at risk due to existing less resilient construction.

The effects of climate on flexible and rigid footways

Flexible or rigid footways experience some of the same type of problems as flexible or rigid road pavements.

Possible Causes of Deterioration due to Climate Change

Cause of Deterioration	Result	Hazard
Damage by Vegetation	Longer growing seasons – More growth of vegetation	1. Vegetation accelerates deterioration of the footways. 2. Slip hazard to pedestrians 3. In times of drought tree roots seek water causing deformation of surface and/or subsidence in lower unbound layers
Desiccation Cracking	Reflective Cracking	1. Clay shrinkage causing ground movement. 2. In times of drought tree roots seek water causing deformation of surface and/or subsidence in lower unbound layers
Effects of Temperature on Bituminous Surfaces	1. Age Hardening and Cracking 2. Rutting	1. Age hardening results in brittle binder which can crack the surface due to thermal stresses and strains (Higher surface temperatures, oxidation and UV radiation) 2. Rutting – At high surface temperatures the typical surface course used in footways are more susceptible to deformation.
Effects of Water	1. Freeze/Thaw cycles 2. Weakening/Erosion of the foundation and sub-grade 3. Binder stripping on bituminous material	1. Freeze/Thaw cycles – causes surface deterioration and draws water up from subbase increasing the amount of water in pavement. 2. Weakening of the foundation/Erosion and sub-grade – Leading to voiding and decreasing structural support. 3. Binder stripping – Leading to localised areas of deterioration – Stripping is accelerated during warm moist conditions.

Poor Design and/or Poor Construction	1. Inadequate thickness. 2. Edge restraint. 3. Poor drainage. 4. Frost protection.	1. Unable to withstand the loadings to which it is subjected. 2. Edge restraint – Unable to achieve adequate compaction of the materials during construction. 3. Poor drainage – see effects of water. 4. Frost protection – Layer thicknesses are insufficient to provide protection to frost susceptible sub-grade.

With the increased incidents of litigation following pedestrian injury accidents, the primary objective of footway maintenance is to keep footways safe for pedestrians. This needs to be achieved by ensuring that overall expenditure is both justified and cost-effective in terms of present and future maintenance of footways.

Material Selection

Although the thinner construction of footway layers result in a lower thermal mass and heat and cool more quickly, in urban areas the heat from buildings can keep the footway surfacing warmer than carriageways. With higher surface temperatures anticipated due to climate change, the surface course of footways will be affected more and more. (See “Effect of temperature” in table above).

Footway Foundations

To perform satisfactorily, a footway must be constructed on an adequate foundation. A soft subgrade provides insufficient support for compaction of the layers above, which may subsequently deteriorate rapidly. For road pavement construction the subgrade is conventionally assessed in terms of its California Bearing Ratio [CBR] (Methods for measuring CBR are described in IAN 73/06) and as footways are associated with road pavements it is convenient to use the same measure.

Footway Surfacing

Bituminous Construction (Flexible Footways)
Flexible surfacing for footways and paved areas shall utilise the following materials:

Layer	**Clause**	**Material** **BS EN 13108-1**	**Binder Grade**	**Thickness (mm)** **BS 594987**	**Special Requirements**
Surface Course	909	AC 6 dense surf	100/150 pen	20 - 30	Min PSV: 50 Nominal Size: 6mm
Binder Course	906	AC 20 dense bin	100/150 pen	50 - 100	Nominal Size: 20mm

One local highway authority utilises 100/150 pen binder grade for both surfacing and binder course with the option to use 40/60 pen grade bitumen binder at domestic vehicular crossings to provide a higher quality pavement with improved deformation characteristics. A high compaction level is important and an end result monitoring process is recommended.

Summer surface temperatures of 60°C and ambient temperatures >30°C are not unknown in the south of England, and with the impact of climate change, these temperatures (and higher) are likely to be more common across the country. With this in mind, great care should be exercised in specifying material – particular in urban areas.
Please see PD6691 “Guidance on the use of BSEN 13108 Bituminous mixtures – Material specifications Annex B – Asphalt concrete” for guidance on selection of materials and use of flux.

RECOMMENDATION 1
Use dense well compacted asphalt concrete with 100/150 pen grade bitumen binder for new footways and maintenance of footways. The use of 40/60 pen grade bitumen binder can be considered at domestic vehicular crossings to improve performance.

<u>Modular and Concrete Surfacing (Rigid Footways)</u>

Plate A9.1 Modular footway in Keswick Town Centre

Less susceptible to the effects of higher surface temperatures (however large slabs can wrap – turn up at the edges) the ingress of water and the subsequent damage to the unbound layers would be one of the main cause of failure, however, problems with vegetation and poor construction are also common.

<u>Cracking of both Flexible and Rigid Footways</u>

Reflective Cracking (Desiccation Cracking)

Clay shrinkage causing ground movement and tree roots draining water – These can be avoided by:-

- Investigation of the in-situ ground conditions – Rejecting moisture susceptible materials.

- Keep the footway structure well drained during its service life.
- Avoiding locating the footway near large trees – On new developments, treesshould be selected for having deep rather than spreading roots and allows sufficient space for root growth.

Mosaic cracking (crazing) of a bituminous surface may be the result of excessive deflections due to lack of support from underlying materials (possible caused by wateringress washing out support), or to embrittlement of the bituminous material.

Cracking of modular paving may be due to the foundation layers providing insufficient support. The larger and thinner the flags, the larger the warping and traffic induced stresses. Note that a stabilised bed will not provide adequate support to a warped flag –Warping may be caused by high surface temperatures.

Cracks in concrete footways may be due to insufficient thickness of slab, shrinkage, lowconcrete strength or inadequate compaction, loss of support and settlement, natural weathering, temperature changes and freeze/thaw cycles. If the cracked concrete is providing adequate load spreading to the underlying foundation the cracking can be considered as surface deterioration, otherwise reconstruction is required.

The effects itemised above will be magnified if:-

- Pedestrian – only footways are “overrun” by vehicles, over-stressing surfacing andfoundations.
- Poor reinstatement of trenches by “Statutory Undertakers”.
- Poor maintenance – allowing ingress of water etc...

Reference - HD 39 & 40 Design Manual for Roads and Bridges – Footway Design &Footway Maintenance.

RECOMMENDATION 2
To adapt to the effects of climate change and maximise modular and rigid footway performance, apply the best practice recommendations of DMRB Vol 7 HD 39 and 40.