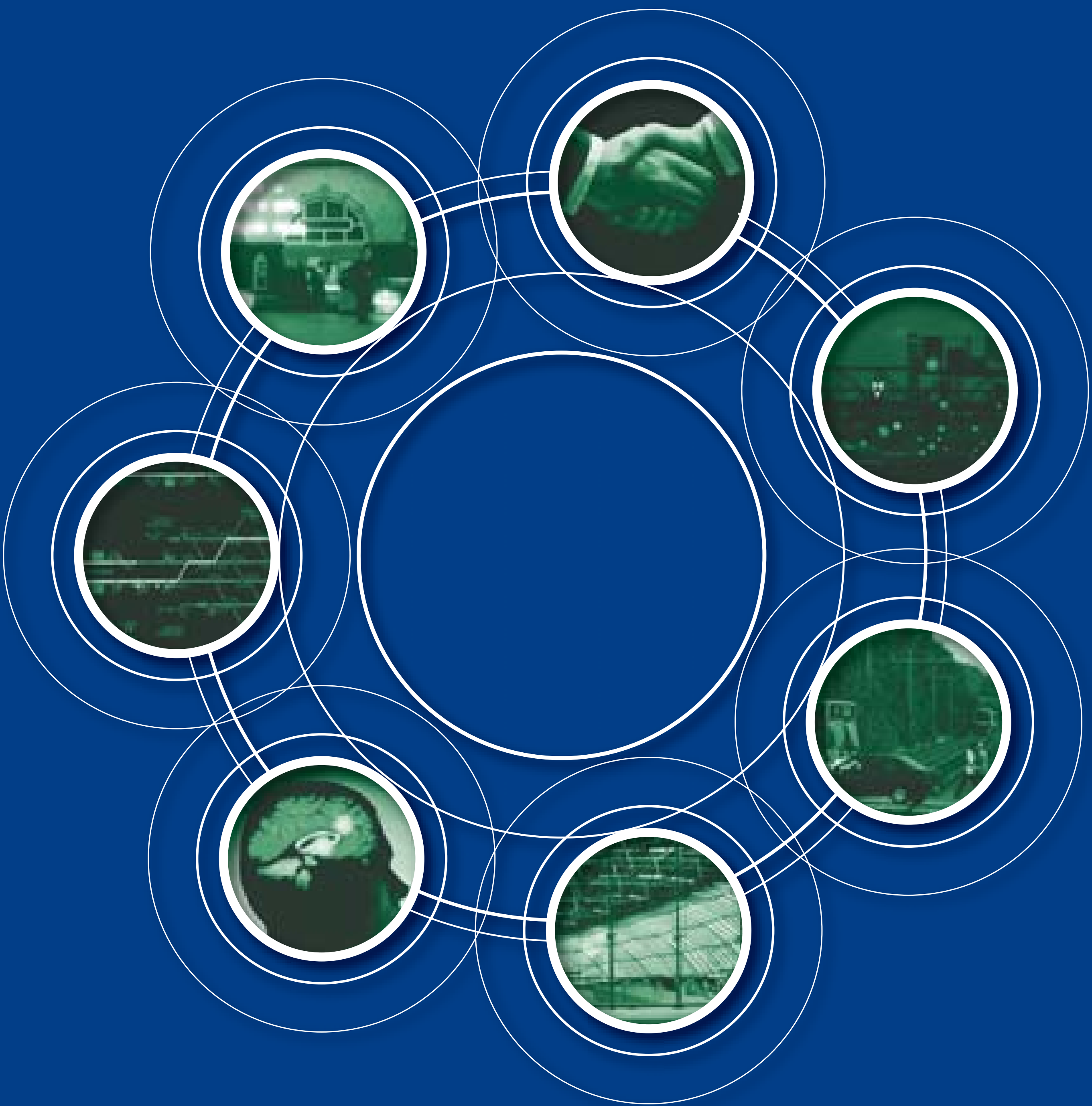
Rail Safety & Standards Board

Research Programme

# Engineering

## Safety implications of weather, climate and climate change



**Rail Safety and Standards Board's (RSSB's) response to the report by AEA Technology entitled 'Safety implications of weather, climate and climate change' April 2003**

## 1. Purpose

The purpose of this paper is to outline RSSB's response to the attached report, and to summarise the proposed future actions to be taken by RSSB.

## 2. Brief

The report was commissioned by RSSB as part of the Rail Safety Research Programme and was prepared by AEA Technology plc. The overall aim of the research is to help Railway Group members understand better the implications that climate change may have on their activities. The research was designed to:

- Identify the current status of knowledge concerning climate change impacts on railway safety, and gaps in that knowledge.
- Define what work is required to fill those gaps.
- Specify what work is needed to determine how the railway industry should respond to the threats associated with climate change.

## 3. Content of the Report

The report covers the following:

- A robust summary of current information and research, highlighting the development of global, regional and local climate research.
- Current documentation and databases within Network Rail and RSSB.
- A qualitative assessment of the effect of predicted climate change scenarios on railway infrastructure.

It lists individuals, organisations, websites, reports and databases concerned with climate change and weather. This is a valuable set of references.

## 4. RSSB response

4.1 While there is uncertainty about climate change, RSSB considers that the United Kingdom Climate Impacts Programme (UKCIP) provides an acceptable set of assumptions for present purposes. These are for the decade of 2080 *ie* within the design life expectancy of much of the present infrastructure. The main predictions are:

- Average temperature to rise by at least 1-2ºC.
- Precipitation to reduce 5-15% overall but with higher winter rainfall and lower summer rainfall and possibly more extreme hourly rainfall.
- Average wind speed to rise between 4% and 10%, but with possible increase in the number of severe events.
- Sea level to rise between 20-60cm depending upon emission scenario and northwest southeast tilt.

4.2 The report contains valuable qualitative information on the likely effects. It is considered that the main types of infrastructure vulnerable to the changes are:

- track (extreme temperature)
- earthworks (extreme precipitation)
- drainage (extreme precipitation)
- overhead line equipment (extreme wind)
- coastal and estuarial infrastructure (protection/defence) (sea level rise).

The report findings will enable future work to be more focused.

4.3 It is noted that an enormous amount of work is being undertaken by many organisations into weather, climate and climate change so that it is difficult to identify specific gaps in knowledge with respect to railway infrastructure. The following, however, are the main 'gaps' identified:

- Uncertainty in future predictions (the uncertainty varies between weather elements).
- The likely increase in the frequency and intensity of extreme weather events.
- Work directly related to the railway sector.
- The likely effects of the rise in sea level, which are predicted to be substantial and exacerbated in some areas by the effects of the continuing northwest/ southeast UK land tilt and storm surges (but alleviated in other areas).

It should be noted that individual railway localities may be disproportionately affected by climate change. These will need systematic identification.

4.4 Although the report is largely qualitative, reference is made to the quantitative assessment of weather related precursors to hazardous events contained in RSSB's Safety Risk Model (Appendix 3) and the database of delays based on the daily log reports. The results of a pilot study are contained in Appendix 8. It is considered that this information will also be of significant benefit in developing a more quantitative assessment of the future effect on safety performance on railway infrastructure. (See 5.2 below.) Readers should see also the Annex to this paper, on Delays and Safety.

4.5 The brief did not include reference to weather forecasting per se and its effect on railway safety. Weather forecasting and climate change are related topics. If we have three times as many storms in the future, but can predict them with accuracy, we may suffer less loss than we do today.

4.6 Similarly the brief did not include reference to sustainability issues. The way these are addressed might reduce the predicted climate changes.

## 5. Recommendations for future action

5.1 Railway infrastructure and vehicles are generally robust, but the safety performance of train operations can be affected by extreme weather. Although the risk is low generally, it is considered not low enough to be negligible, especially if the number and intensity of extreme weather events increases. It is considered that further research would be justified as set out below.

5.2 Organisationally there should be more formal links between RSSB and the relevant government/research organisations (for example the Environment Agency, and the Department for the Environment, Fisheries and Rural Affairs,) to maintain an up-to-date review of current work and thinking at a national level. There is the potential advantage that RSSB could exert greater influence on such work and thinking. Links should also be strengthened with those concerned with reducing green house gas emissions related to the railway, and other sustainability matters. RSSB could provide a focus for information on climate change matters for Railway Group members (RGMs).

5.3 It is considered that the most valuable way forward is to begin quantifying the changes to safety risk and traffic delay that are likely to result from extreme weather events. This should take into account:

- Different types of infrastructure and how widespread they are (for example, track, drainage, overhead electrification equipment).
- Historical numerical data on delays caused by weather related incidents.
- Current values used in the RSSB risk model for weather related precursors to hazardous events and the predicted consequential harm to people.
- Best available quantitative estimates of likely changes to extreme events based on current industry intervention levels (air temperature, flood level, wind gust speed).

The combining of delays and direct safety risk (safety performance) could be based on the methods and model being developed for assessing the effect of vandalism on railway safety performance. The vandalism research programme is being managed by RSSB on behalf of the railway industry.

5.4 Specific research projects related to climate change should be initiated to:

- Understand better the effects of climate change on trackside vegetation.
- Identify more clearly how railway locations are most likely to be affected by the rise in sea level.

Consideration could also be given to addressing how the railway industry could best help in mitigating the predicted climate change, possibly in conjunction with other transport undertakings.

5.5 It is considered that the proposals contained in 5.2 and 5.3 would be the most effective way to forward the research, by providing a more quantitative assessment of the likely effects of climate change on safety performance and by gaining more detailed knowledge in specific areas.

In the longer term there may be ways in which the railway industry might help in mitigating the predicted climate changes through addressing sustainability issues.

The results of this further work could, for example, help RGMs in determining how existing assets would be most effectively managed, whether revised design standards for new assets would be beneficial, and how operational measures might best be adapted.

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AEAT/RAIR/76148/R03/005 Issue 2

# Safety Implications of Weather, Climate and Climate Change: Final Report

April 2003

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# Safety Implications of Weather, Climate and Climate Change: Final Report

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# Executive Summary

Some safety hazards on the railway are identified as being weather and climate related and the onset of climate change has the potential to increase the system's susceptibility to weather related hazards. Against this background, research into climate change impacts on the railway system is being undertaken under the Rail Safety and Standards Board Research Programme by AEA Technology. The objectives of the work are:

- To identify the current status of knowledge concerning climate change impacts on railway safety and gaps in that knowledge;
- To define what work is required to fill those gaps;
- To specify what work is needed to determine how the railway industry should respond to the threats associated with climate change.

From the work carried out to date, it is evident that it is the occurrence of extreme events that presents the main risks to the safety of the railway system. New items of infrastructure will need to be planned to provide design functionality throughout their life, accommodating increased extremes, for example through the application of appropriate design standards. Management regimes may also need to be adapted to address the change in circumstances.

Our review of the status of the available information on climate change itself identified the following:

- ***Global level research.*** The work undertaken by the IPCC provides a sound technical basis for the assessment of climate change impacts, albeit that there is considerable uncertainty in future predictions. It is expected that on-going research will lead to an improvement in the quality of that understanding and the associated predictions over the coming years.
- ***UK National level research.*** The work programme of UKCIP provides a more detailed assessment of the likely extent of climate change in the UK. Focusing on the decade of the 2080s, this work has provided quantitative estimates, in the form of expected ranges of outcomes, for various climatic features. Whilst recognising the limited scenarios considered and the inherent uncertainty in the associated climate change predictions, the available information provides a basis for evaluating the potential significance of the identified anticipated changes to climate and weather. Work is ongoing and again it can be expected that this will lead to improved quality of technical understanding and climate change impact predictions.
- ***UK Regional and Sectoral research.*** Regional and sectoral studies have identified what the anticipated changes in weather and climate are likely to mean locally, having regard to local economic, geographical and social conditions. In this context, potential impacts on the railway system in the UK have been identified. At present, little or no detailed work seems to have been undertaken that seeks to quantify these sector specific impacts and evaluate their practical

significance. Current research has not identified the magnitude or frequency of occurrence of adverse impacts. There are plans for further work on various aspects of climate change impacts on the built environment but, at present, this does not include any work directly addressing the railway sector.

In general, we find that the available information should provide a sound basis for the assessment of identified impacts but recognise that, at present, there is limited quantitative information on the magnitude or frequency of impacts. Further work in this area should support prioritised proactive planning and the identification of appropriate remediation measures.

As far as knowledge of weather related hazards to the railway system, we identify a wide variety of data sources of relevance to the current study, derived from historical incidents and the need to manage the current situation, as follows:

- Industry knowledge and operating experience. There would appear to be a considerable body of knowledge within the industry that responds to weather related safety and operational impacts on the railway. Expertise has developed according to local needs and knowledge is apparently uncoordinated. The knowledge and expertise should provide a solid technical basis for addressing climate change impacts but accessing it may require significant effort.
- Industry data systems. Data systems such as those supporting the System Risk Model and the SMIS and TRUST data bases hold considerable amounts of information that might be employed to determine which weather related precursor events make a significant contribution to system risk and hence those that would be seen to be priorities for future research activities in respect of climate change;
- Climate change studies. Studies of climate change impacts on the built environment provide a body of generally qualitative information concerning possible hazards and associated risks to the railway system. It is recognised that there is considerable uncertainty concerning the significance of climate change impacts on specific features of the system.

Taken together with the identified information on climate change impacts, we recognise a substantial body of relevant information that should support the development of a cost-effective response by the railway industry to the potential threats associated with climate change.

Drawing on this information a series of risk scenarios can be identified, associated with various weather factors: Rain; Hail; Snow/Sleet/Ice; Fog; Wind; Temperature (High / Low); Lightning; Insolation; Sea; Vegetation. These scenarios have been assessed, against factors reflecting the risk likelihood (current baseline risk; system vulnerability to change; anticipated extent of climate change) and risk impact (consequence, extent of exposure, system adaptability). The basic assessment process undertaken on the basis of this structure involved the following steps:

- Develop an initial characterisation of each of the risk scenarios in terms of the identified factors;
- On the basis of that characterisation, identify priority risk scenarios requiring actions by the Rail Safety and Standards Board to address them;

- For the identified priority risk scenarios, identify information needs and other actions appropriate to the risks and their significance.

The following primary conclusions are drawn in respect of the various climate factors:
- ***Excess rain.*** This is already identified as a significant risk scenario in respect of scour, slope failure and flooding (the last scenario resulting track circuit failure as well as more generally causing disruption). Anticipated increase in and more intense winter rainfall and extreme events at other times of the year are expected to increase the risk. The primary initial research requirement is for better characterisation of the risk, in terms of the vulnerability of the railway systems and the likely future occurrence of significant extreme weather events.
- ***Reduced rain.*** The reduced summer rainfall and increased summer temperatures may lead to settlement of structures and the associated risk merits further characterisation.
- ***Hail.*** Not considered likely to be a major issue but the likely extent of climate change in respect of hail is uncertain and the possibility of more severe events merits further evaluation.
- ***Snow/sleet/ice/(low temperature).*** The anticipated reduction in incidence of relevant events associated with these climate factors means that no risk mitigation response is required. There may be a benefit in determining whether there may be sufficient reduction in the future occurrence of events such that resources currently employed to address associated risks might be re-allocated.
- ***Wind.*** The anticipated increased incidence of high winds could be significant if it reaches threshold levels at which this impacts on the railway, for example through overhead line damage, impact on vehicle stability and tree-fall, etc. Better characterisation of the understanding of extreme wind events and the associated risk is required.
- ***Temperature.*** The anticipated increased incidence of extremes in temperature could be significant if it reaches threshold levels at which this impacts on the railway, for example through potential rail buckling or overheating of equipment. Better characterisation of the associated risk is required.
- ***Lightning.*** Not considered likely to be a major issue but the associated electromagnetic interference could have implications for increased risk. The likely extent of climate change in respect of lightning is uncertain and the possibility of more severe events merits further evaluation.
- ***Insolation.*** Although identified as a contributory factor in some accidents due to glare, the relatively modest increase should not be significant and should be managed by measures already identified (appropriate positioning of signals). (Note that any influence increased insolation has on rail temperature is assumed to be covered under the extreme temperature scenario discussed earlier).
- ***Sea.*** The increased risk of flooding events, arising from the average rise in sea level and weather related factors such as increased wave heights and storm and tidal surges, merits better characterisation. Current measures for managing this hazard, e.g. flood defences and procedural measures to address severe events, may not be reliable in the future. Risk characterisation will need to consider the increased risk to those areas currently identified as vulnerable and the increase in the areas at risk.
- ***Vegetation.*** Various risks associated with vegetation are identified, including leaf-fall related risks and fallen trees. Current efforts (in particular within Network

Rail) directed towards vegetation management are expected to be able to address these risks but may need to adapt with time to new growing conditions. Requirements for additional work, for example as part of future climate change related safety research may be limited. There may, however, be scope for supporting research outside the current Network Rail programmes, for example looking at the introduction of new species designed for a specific function within the infrastructure.

Against this general background, more specific research requirements have been identified in respect of relevant risk scenarios.

As regards the structure of a future research programme to address these research needs, we identify distinct aspects to the requirements as follows:

- Involvement of the rail industry in UK climate change impact research programmes, to direct research efforts to areas of specific interest to rail safety, having regard to the need to improve the general climate modelling capability and develop a general understanding of impacts on the built environment;
- Extension of and integration with existing rail safety research and hazard management programmes to meet future requirements in respect of climate change, where these complement climate change related safety management needs: e.g. Network Rail's programmes relating to the bridge scour, slope failure and flooding and elements of the Rail Safety and Standards Board's research programme that address relevant hazards such as wind.
- Development of specific new research efforts where necessary, typically involving more detailed and quantitative characterisation of the risk scenario, with subsequent evaluation of risk mitigation requirements.
- Joint research with other interested infrastructure managers who are involved with common structure types e.g. bridges over water, sea defences, overhead lines.

An effective programme to meet the identified research requirements will require interdisciplinary inputs from a range of organisations both within and outside the railway industry and coordination of existing and new research projects. Organisations to be involved will include the following:

- UKCIP and the associated climate change research organisations, with railway industry representation steering the direction of effort towards areas of practical importance to the industry;
- Network Rail, providing support in particular in respect of on-going technical programmes that address current weather-related hazards and relevant information systems (TRUST);
- The Rail Safety and Standards Board, with interests relating to potential links to existing climate-related safety research, the initiation of new research projects, safety related information systems (e.g. SMIS) and standards;
- Rail industry contractors providing appropriate technical expertise;
- EPSRC Climate Change research programme members, The Railway Research Centre and Rail Research UK.

Preliminary proposals for an on-going work programme have been made to address the identified technical requirements and to integrate the efforts of these different organisations, involving the following initial work packages:

- A programme to coordinate links with between the rail industry and climate change impacts research;
- Work to provide for the systematic identification of complementary programmes already underway within the rail industry and their future support roles;
- Hazard theme related technical research programmes:
    - Excess rain related impacts, covering different aspects of flooding, scour; drainage, slope instability; tunnel collapse;
    - Settlement arising from reduced moisture;
    - Wind related impacts;
    - Impacts arising from extreme temperatures;
    - Sea related impacts.
- Information systems related activities.

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# 1 Introduction

Some safety hazards on the railway are identified as being weather and climate related. The IPCC and other respected bodies have reported that the climate is already changing and that a significant proportion of that change arises from man-made greenhouse gas emissions. The onset of climate change is predicted to have impacts on weather conditions that include the increased frequency of extreme weather events to which the railway is particularly susceptible and which may pose an increased level of catastrophic risk. Some work on these issues has been undertaken in recent years, but gaps in knowledge remain. Against this background, research into climate change impacts on the railway system has been undertaken under the Rail Safety and Standards Board Research Programme by AEA Technology, on behalf of the Rail Safety and Standards Board. The objectives of the work are:

- To identify the current status of knowledge concerning climate change impacts on railway safety and gaps in that knowledge;
- To define what work is required to fill those gaps;
- To specify what work is needed to determine how the railway industry should respond to the threats associated with climate change.

This report provides an account of the findings of this work programme. We begin by providing some background information on the general context within which climate change research is currently being undertaken. The status of that climate change specific research is then reviewed. This is followed by a broader account of potential safety related impacts of weather and climate on the railway. That account addresses first the effect of weather and climate on the safety of the railways and second the issue of climate change itself, the associated impacts and the safety implications for railway operations.

Drawing on the basic information that has been gathered, primary hazards to the railway are then assessed, future research needs are identified and outline proposals are made for a programme to address these needs.

# 2 General Context for Climate Change Research

The UK climate and associated weather patterns are understood to be changing and are expected to continue to change over the next century. These changes are expected to arise as a result of increased concentrations of greenhouse gases in the atmosphere, which absorb heat radiation emitted from the surface and re-emit some of it back down to the earth, thus reducing the amount of heat escaping in to space. A warmer atmosphere is expected to change weather patterns as well as move climatic regions. Accurate assessment of likely impacts on weather systems and climate is more difficult than prediction of increases in average global temperature. Whether or not such changes arise primarily from human activity, there is evidence from recent records that global temperatures are rising and that weather patterns are changing. Whatever the cause, this is an issue that merits attention.

Researchers[1] have argued that all human society is fundamentally adaptive. At a simple level, migration is used as a climate change adaptation technique. However, growing global populations and increased pressures on resources from economic growth mean that future adaptation responses will have to be more complex if they are to meet the objective of maintaining a stable modern industrialised society.

It is worth noting that many adaptation responses may occur unconsciously as economic capital is replaced under natural replacement rates with new capital more suited to current climatic conditions. This can have feed back effects that may worsen the situation, for example the retro-fitting of air conditioning on buildings as a response to increased average temperatures may precipitate further use of energy and subsequent carbon dioxide emissions which may in turn further increase average temperatures. Careful and planned adaptation management should be able to avoid such unwanted effects.

Careful management of major infrastructure, both existing and planned, is also required. Items with service lives of 50 years or more are likely to experience climate change within their lifetimes. Climate change impact planning for new items of infrastructure may help to ensure that they continue to provide designed functionality throughout their life. Existing infrastructure projects can be assessed in a similar way which will help infrastructure managers to plan maintenance, modification or, in extreme cases, replacement.

Current climate change research is focused on three distinct areas:

- **Mitigation** – research into possible ways of reducing the effects of climate change. This might include the development and implementation of replacement or alternative fossil fuel sources of energy or encouraging consumers to use fossil fuels more efficiently. Both of these approaches will result in reduced green house gas emissions per unit of economic or social activity.

[1] Adger et al. (2002) Adaptation to Climate Change: Setting the Agenda for Development Policy and Research

- **Adaptation** – research examining ways of coping with the expected effects of climate change. It is understood that rising concentrations of greenhouse gases in the earth's atmosphere have already had an impact on global climate and weather patterns[2] and that even if emissions were to be stabilised in the next few years the impacts of this rise are expected to be felt up until 2050. Adaptation research aims to evaluate the likely changes that we will need to make to our daily living patterns in order to avoid increased risk from weather or climate related changes. Work in this area includes assessments of improved building codes designed to withstand expected weather conditions over the next 50 years, and an examination of expected agricultural patterns and crop yields against future changes in climate.
- **Vulnerability** – research examining the relative vulnerabilities of the earth's varied ecosystems to the potential effects of climate change. Vulnerability is a function of the adaptive capacity of an area or region. For example, an area may be exposed to significant climate change but, if it has a high degree of adaptive capacity, it may not be significantly vulnerable. Conversely, some areas may be exposed to relatively low levels of climate change only but, if the area's adaptive capacity is small, the area will be vulnerable. High levels of vulnerability tend to occur where ecosystems are already at critical capacity levels, for example the Ganges delta, or some Pacific islands.

The understanding of these sciences is still relatively undeveloped; the existence of climate change has only become widely recognised over the past ten years, in part due to the efforts of the Intergovernmental Panel on Climate Change (IPCC). This is an international group of scientists looking at the earth's environment and monitoring, analysing and explaining observed changes to weather patterns and climate. Their three main areas of focus are:

- The scientific basis for change
- Impacts, Adaptation and Vulnerability
- Mitigation

Scientists from all IPCC member countries contribute to these groups and are seeking to establish a common understanding of the magnitude and knock-on effects of climate change and potential responses to it.

### The Timescale of Change

The general consensus amongst the scientific communities is that changes in weather and climate to 2050 are immutable, regardless of any changes to global greenhouse gas emissions profiles that may occur in future. Atmospheric circulation and composition have long response times, which means that there will be significant post-industrial revolution emissions remaining in the atmosphere to make a degree of climate change inevitable, whatever actions to reduce emissions are taken. Most scenarios currently being developed look to 2080 as a planning horizon, as it is believed that mitigation actions taken today may be able to impact on atmospheric greenhouse gas concentrations at this time and thus allow more effective control over future changes in the climate.

[2] IPCC (2001) WG1 – Climate Change: the scientific basis, Switzerland (available from www.ipcc.ch)

# 3 Climate Change and Associated Impacts

## 3.1 INTRODUCTION

Despite the relatively immature state of the science of climate change a considerable body of work has been undertaken that seeks to evaluate what the likely future concentrations of greenhouse gases will be, what impact increased greenhouse gas concentrations will have on weather systems, and what impacts changed weather systems will have on the natural environment.

A common feature of much of this work is the level of uncertainty incorporated into the models and calculations developed by the scientific communities engaged in this work. This means that many projections and predictions must be considered as a range of possible outcomes. Planning a response in the light of these projections is fraught with difficulty in that there are significant risks of under and/or over responding.

This review of research looks at the following levels of analysis:

- Global
- National
- Regional
- Sectoral

It is based on interview and discussion with a number of contacts, as summarised in Appendix 1 and review of written documents. A reference list of documents is presented in Appendix 2.

## 3.2 GLOBAL CLIMATE CHANGE IMPACTS RESEARCH

The key actor in promoting global climate change impacts research is the Intergovernmental Panel on Climate Change (IPCC), based in Switzerland. The IPCC comprises scientists from all the nations that have agreed to take part in the United Nations Framework Convention on Climate Change (UNFCCC). Their work is informed by modelling carried out by the Hadley Centre of the UK Met Office, the Max Planck Institute in Germany and NOAA (National Oceanic and Atmospheric Administration) in Washington DC, in the USA.

Key outputs from the IPCC include those from Working Groups (WG) I – III, as follows:

- WG I "Climate Change 2001: The Scientific Basis"
- WG II "Climate Change 2001: Impacts, Adaptation and Vulnerability"
- WG III "Climate Change 2001: Mitigation"
- "Climate Change 2001: Synthesis Report"

It should be noted that current efforts of the IPCC are focused on transforming qualitative assessments of global climate change impacts into quantitative assessments on likely impacts. A recent (June 2002) IPCC conference on extreme weather events noted that:

> *"[Because of] the large variety of projects funded by the European Commission, national institutions and other agencies, progress in quantifying changing climate statistics and impacts is expected. The intrinsic uncertainties may be better quantified when cascading information through a chain of global models, regional climate models and specific impact models. The relative uncertainty is expected to be larger for precipitation and wind than for temperature extremes, but the improvement may be larger for wind and precipitation."*
>
> *IPCC Workshop on Changes in Extreme Weather and Climate Events*
>
> *Beijing, China 11 – 13 June, 2002*

IPCC Third Assessment Reports (TAR) focus on identifying impacts qualitatively and they are not yet able to identify sub-continental impacts. Examples of their projections include[3] the impacts summarised in Table 1 below.

**Table 1: Example Generic Global Climate Impact Projections**

| Vulnerable Sector | Impacts |
|---|---|
| Water resources | Peak stream flow will move from spring to winter in many areas where snowfall is currently a major component of the water balance. |
| | Climate change challenges existing water resource management practice by introducing increased uncertainty. |
| Human settlements, energy and industry | Extreme weather events (storm, heat, drought) may increase mortality rates. |
| | Physical urban infrastructure may be more vulnerable to extreme weather events. |
| Agriculture and food security | Agricultural capacities may change. |
| | Incomes from agriculture are likely to increase in developed countries, but decrease in less developed countries. |

The IPCC hopes that the Fourth Assessment Reports (4AR) will improve the quantification of much of this research. Communications with the UK IPCC technical support office suggest that this improved information will be available during 2006, and will allow regional analysis to a greater depth than is now possible.

## 3.3 NATIONAL CLIMATE CHANGE IMPACTS RESEARCH

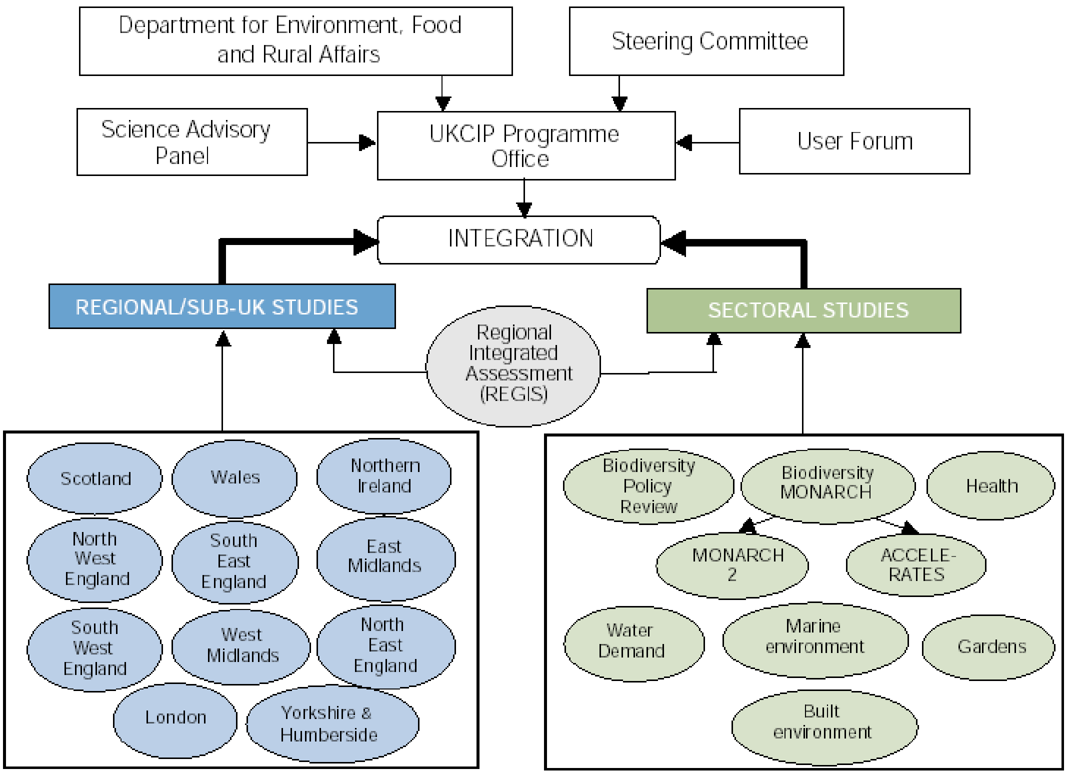
The United Kingdom Climate Impacts Programme (UKCIP) was set up in 1997 to help UK organisations assess the possible risks they face from climate change.

[3] All examples taken from Climate Change 2001, Impacts, Adaptation and Vulnerability, the Third Assessment Report of Working Group II, IPCC, Switzerland.

Through collaboration between the private, public and academic sectors, UKCIP has been able to produce a number of national, sectoral and regional studies into the potential impacts of climate change on the United Kingdom economy.

UKCIP is funded by central government and acts as a facilitator between the research communities and other interested bodies. It does not commission research but acts as a 'dating agency' matching funding to appropriate research contractors. (See Figure 1 for a summary of relationships between the parties involved.) For this reason their work programme is ongoing. The work programme includes a series of regional studies that cover Scotland, Wales, Northern Ireland, the North West, South East, East Midlands, Yorkshire and Humber and London. Sectoral studies cover impacts of climate change on nature conservation (MONARCH), health, and gardens. Work in progress is looking at impacts of climate change on water demands, the marine environment and the built environment. The studies are discussed further in the subsequent sections.

**Figure 1:Relationship of UKCIP to funders, stakeholders and central government.** (Taken from the UK's Third Communication to the United Nations Framework Convention on Climate Change.)




The UKCIP national scenarios (developed in 1998 and revised in 2002) are the recognised 'industry standard' for detailed climate change impacts forecasting for the UK. They present impacts as a range of outcomes that are dependent on a range of possible future emissions profiles and the uncertainty inherent in forward prediction. These scenarios were developed from data provided by the Met Office Hadley Centre's global and regional climate models which are also used in IPCC analysis.

UKCIP also present information on actual changes in weather and climate based on data collected over the past 150 years. They suggest that the changes described in Table 2 have already occurred to British climate and weather patterns.

The global climate system has a high inertia, which means that emissions made over the past 200 years will continue to affect the climate, even if emissions were to be significantly reduced from now into the future. In selecting the data for their headline scenario projections UKCIP recognise this and focus on 2080, on the assumption that the majority of climate features for 2050 are already decided.

UKCIP suggest that, even if future emissions were to fall below today's emissions rates, future warming could be as much as four times that experienced over the past century, and if the emissions rate increases to approximately four times today's level, then warming rates could increase to eight times the levels seen in the last century.

**Table 2: Recorded changes in UK weather and climate 1900 – present[4]:**

| Feature | Impact | Comments |
|---|---|---|
| Temperature | +1°C | The 1990's were the warmest decade on record, with twice as many summer days exceeding 25° C in 1990's than in the first half of century, The thermal growing season is now longer. |
| Precipitation | - | Winters have been getting wetter, with increased incidence of high intensity precipitation. Summers have been getting dryer. |
| Sea Level | +1mm pa | Accounting for natural land movements |
| Storm frequency | - | Although storm frequency has increased over the past decade, this is not unprecedented in the historic record. |

The ranges of climate and weather change indicated by UKCIP, according to scenarios showing low, medium low, medium-high, and high $CO_2$ concentrations in the atmosphere by 2080, are summarised in Table 3.

[4] Taken from UKCIP02 projections: Climate Change Scenarios for the UK (2002), UKCIP, Oxford.

**Table 3: UKCIP02 climate impact projections for 2080**

| Feature | Low estimate | High estimate | Comments |
|---|---|---|---|
| Temperature rise per decade | 0.1 – 0.3 °C | 0.3 – 0.5 °C | There is significant regional variation in warming patterns, most notably between the south east (+4 °C) and the north west (+1-2 °C). |
| Diurnal range in temperature | Not quantified | Not quantified | Winter diurnal ranges are expected to shorten; summer ranges are expected to lengthen. This is linked to cloud cover. Together with the average temperature rise, these changes imply a reduced frequency and intensity of frost / freezing. |
| Insolation | +10 $W/m^2$ | +30 $W/m^2$ | In spring, summer and autumn, cloud cover is expected to reduce in the south and centre of the UK. This will lead to increased sunshine. |
| Precipitation | -5% overall | -10 - 15% overall | Winter precipitation is expected to increase by between 5-15% (low emission scenario) and as much as 30% under the high emission scenario. In summer, rainfall is expected to decrease by 20% (low emission scenario) to 40% (high emission scenario). Both winter and summer changes are expected to be more pronounced in the south east. High intensity precipitation events (rainstorms and the like) will become more frequent. |
| Snowfall | -50% | -90% | Snowfall is closely linked to altitude, but the model does predict significantly decreased levels of snowfall for all areas, with long sequences of snowless winters becoming common. |
| Relative Humidity | -1% (winter) | -8% (summer) | Overall reductions in relative humidity mask regional variations in scale. Reductions greater than those indicated here are expected in some areas and under some scenarios. |
| Fog | N/A | -20% (winter) | Modelling that relates relative humidity to weather patterns suggests that there may be 20% fewer winter fog days in the 2080's. |
| Average windspeed | +4% | +10% | Windspeeds are not expected to change dramatically across the UK. Projected changes do not exceed windspeeds already found in the windiest parts of the UK. The exception is the south coast of England where moderate increases are predicted in winter. An increased frequency and strength of gales in the summer and winter is anticipated. |
| Soil moisture | -20% (Summer) | -40% (Summer) | Soil moistures are expected to reduce in all areas, under all scenarios during the summer months. In winter, increases of up to 10% are expected in Scotland, Northern Ireland and Northern England. Southern and central England is expected to see a decrease in soil moisture as increased temperature and reduced humidity increase evaporation rates. |

In addition to these identified impacts on weather and climate, significant impacts on sea levels are also anticipated, as follows:

- There will be a significant reduction in the return period for certain high-tide levels for some parts of the UK coast.
- The sea level around the UK will rise as a result of global warming. It will also continue to change due to isostatic adjustment. By the 2050s, the combination of the two might lead to a rise in average sea level of about 41 cm in East Anglia and about 21 cm in the west of Scotland.

## 3.4 REGIONAL CLIMATE CHANGE IMPACTS RESEARCH

The regional studies published by UKCIP take the national impacts projections and apply them to local climatic and socio-economic situations, providing two key outputs:

- Assessment of local climate change impacts: local weather data is assessed using the national impacts projections to generate local climate change impacts.
- Identification of impacts in accordance with local economic, geographical and social conditions: this allows more detailed understanding of what changes in weather and climate patterns actually mean to the day-to-day activity of towns and villages.

The regional studies also examine particular sectors identifying the impacts and magnitudes that are specific to local circumstances. The transport sector is identified as a sector worthy of comment in all current regional studies. Three of the studies are reviewed briefly here.

**Study 1: London's Warming**

The report from the Greater London Authority recognises that climate change impacts could impinge on the functionality of the capital's transport networks. The intensive rainfall event of August 7th, 2002 is identified as being typical of expected weather patterns under a future weather regime where climate has changed. During this particular event, over 25 mm of rain fell in a 30 minute period during the evening rush hour. The intensity of the rainfall meant that London's sewerage system was unable to remove surface water fast enough and flooding ensued. This was particularly disruptive to London's transport system where 5 mainline Rail stations were closed, and a number of Underground stations, including Chalk Farm, Kentish Town and Belsize park were closed due to flooding. Other impacts identified in the report include:

- Increased incidence of rail buckling through extreme temperatures[5];
- Reduced occurrence of icing of railway line points;
- Reduced incidence of snowfall induced delay.

[5] The project team notes that, although the London's Warming report identifies this possibility, this issue can be managed and is indeed managed effectively, both in the UK and other countries where more extreme temperatures than those encountered in the UK occur.

**Study 2: The Potential impacts of Climate Change in the East Midlands**
This report also identifies buckled rails and increased incidence of flooding as being the main challenges to the railway system. It identified warmer winters being likely to benefit the system. It suggests that there may be increased risk of diesel locomotives overheating. It also recognises that there may be increased demands for air conditioning and increased subsidence of land through drying of soils. Less frequent, more intense rainfall is identified as being likely to make embankments and cuttings more prone to landslip.

**Study 3: Wales: Changing Climate, Changing Choices**
The report recognises that severe weather conditions are more likely to present disruption than overall changes in average climate. Extreme temperature, rainfall and wind events could all cause track buckling, flooding and blockage episodes. Sea level rise is expected to cause inundation at some points along the Welsh coast line (where many railways are sited to utilise the relatively flat terrain) and possibly increased corrosion rates. Increased intensity of rainfall is also cited as presenting increased risks to static railway infrastructure such as bridges (through increased scour), stations and platforms (flooding) and embankments (landslip).

The Welsh report does suggest that warmer winters may reduce the frequency of snowfalls preventing service, and that warmer summers and climate change mitigation policies may increase consumer demands on the rail system, as tourism increases and substitute transport methods are made less attractive.

## 3.5 SECTORAL CLIMATE CHANGE IMPACTS RESEARCH

It is UKCIP's intention to carry out further research into impacts of climate change on the built environment. However, neither funders nor researchers have yet been tasked with looking at the rail system in detail. This is despite the availability of some £2M of funding from the Engineering and Physical Science Research Council (EPSRC) for research into these impacts. The EPSRC will be letting research contracts into the evaluation of the UKCIP 02 scenarios against the following areas of impacts research:

- Climate change and the electricity supply industry;
- Sustainable urban drainage;
- Climate change and the built environment;
- Climate change and historic buildings;
- Climate change risk assessment;
- Refining climate scenarios: the impact on cities.

Communications with the EPSRC have indicated that they are extremely interested in developing further work concerning the impacts of climate change on transport infrastructure, and would welcome dialogue with interested stakeholders and potential co-funders. (We note that Network Rail has already had some involvement.)

### 3.5.1 Impacts on The Built Environment and Transport Infrastructure

Other research has been identified that investigates the impacts of climate change on individual sectors. None have been identified which look specifically at the rail network but some work has been identified which treats the rail sector in conjunction with other transport or built environment related work.

The Construction Research and Innovation Strategy panel (CRISP) have funded work examining the state of research into climate change impacts for the transport and infrastructure sectors of the construction industry, which consider the relevant issues for the railway sector. The work looks in some detail at impacts of climate change on the following areas of railway operation:

- Rail tracks;
- Subgrade and ballast;
- Drainage systems;
- Earthworks;
- Lighting Columns, signs and gantries;
- Signalling systems;
- Points and other lineside equipment;
- Overhead lines.

For each item the review assesses which impacts will be of importance and makes some indications as to what would be the likely problems encountered if climate and weather were to change. For example, the literature suggests that the stability of track ballast could be reduced if moisture contents of the substrate were to increase, thus increasing pore water pressures in soils, leading to gradual or possibly catastrophic collapse.

Interestingly, the authors note that the design process upon which infrastructure provision is based is a ‘semi-empirical’ process: i.e. experience is used to inform the process, with knowledge of failures being incorporated into the design model to prevent such failures occurring in the future. This process, balanced against design criteria formulated from current projections of likely climate impacts, could help deliver design standards for new railway infrastructure which will be better prepared for expected climate change impacts.

Further work undertaken by CRISP[6] has considered the construction industry as a whole and the need for it to change both its operations and product range if the built environment is to provide both a product which services the needs of customers and a safe, secure and durable environment.

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[6] Lowe, R. (2001) A review of Recent and Current Initiatives on Climate Change and its impact on the Built Environment, A research report for the Construction Research and Innovation Strategy Panel (CRISP)

Whilst this work has identified which risks are expected under various climate change scenarios, and which elements of transport infrastructure are likely to be affected and how, there does not seem to have been an integrated effort to decipher what this means for investors in the system.  As such there appear to be gaps in the collective knowledge as to what actually needs to be done about expected climate change impacts.

The key information source identified in this context is the CRISP report, as described above.  Reflecting the considerable interest in climate change issues, there are a significant number of references of possible relevance.  However, review of a range of sources (see Appendix 4) has failed to identify any information of any real substance beyond that in the CRISP report.  The available information is generally qualitative, recognising the hazards and potential risks, and it is recognised that there is considerable uncertainty concerning the significance of climate change impacts on specific features of the UK's transport infrastructure.  Information derived from these sources is described in the following section.

### 3.5.2 Future Research Needs

Findings from the CRISP report suggest that it is difficult to assess the combined effects of a number of changes on the built environment, for example rainfall, temperature and the frequency of storms. To date little work has been done on assessing the impact, alone or combined, of the various anticipated changes in weather conditions within specific geographic settings.

Analysis indicates that the infrastructure of the transport and utility sectors across the UK is most vulnerable to an increase in annual precipitation, high intensity rainfall events and an increase in wind strength. Their effects are compounded at particular locations, for example, at exposed headlands, on floodplains and in coastal regions. This suggests that further work should be directed, as a matter of priority, to the design of drains (to various structures), to the construction of better insulated structures, and to the influence of wind forces on bridges, towers, pylons etc.

The report goes on to suggest areas deserving further investigation:

ANALYSIS OF PAST WEATHER DATA

- To be able to prepare for the impact of future weather and climate change, it will be necessary to carry out an analysis of past weather-related events, which requires not only relevant archived meteorological data, but also records of the effects on the infrastructure. However, there might be a lack of data of such events and/or their effects, and such events might become more extreme and occur more frequently.

WIND

- The effects of wind and sea level induced changes on long-shore drift and cliff erosion, and the implications these have for coastlines, coastal defences and the built environment located close to the coast are potentially significant.  Similarly, the effect of higher winds, storm or tidal surges, and high tides on such features may be important.

- The combination of higher wind speed and more frequent high intensity precipitation events (rainstorms and the like) will increase the incidence of driving rain. Thus the design of facades, windows etc to buildings might need to be changed to prevent rain penetration, and measures taken to improve the insulation of existing buildings.

- The susceptibility of lighting columns, cooling towers, and overhead cables and their supports to changes in wind loading should be reviewed. (Changes might have to be made to current methods of the design, inspection and maintenance of such structures.)

FLOOD PLAINS AND COASTAL AREAS

- A detailed review of the likely impact of climate change on the infrastructure in particularly vulnerable areas, for example in coastal areas and floodplains should be undertaken. Particular attention should be given to the robustness and durability of drainage and flood defence systems.

- More demanding regulations should be developed and imposed for construction works on floodplains and in coastal areas; these should be based on the flood maps issued by the Environment Agency for England and Wales.

LIGHTNING STRIKES

- The likely effects of an increase in lightning strikes on various components of the transport and utility infrastructures should be investigated in historical records.

TEMPERATURE CHANGES

- The combined effects of changes in the temperature and precipitation in winter months on the incidence of icy conditions on road and rail networks should be investigated.

STORM PROFILES

- The storm profiles currently adopted in design should be reviewed in the light of predicted climate changes. Specifically, (a) the appropriateness of storm return periods of 1 in 1 year and 1 in 5 year periods currently employed as a basis for design standards, (b) the duration of storm events and (c) the likelihood and effects of closely spaced storms. This review should cover the design of the drains to roads, permanent way, earthworks, retaining walls etc. (Note in general that the intensity of the storm with a given return may increase and design standards may therefore need to be revised if they are to accommodate the more extreme nature of the event associated with any given return period.)

STRUCTURES

- The design of foundations, buried and earth retaining structures should be reviewed in the light of the likely changes in (a) soil moisture content, (b) the depth and intensity of cracking of soils in summer and (c) the depth of penetration of frost.

CONSTRUCTION MATERIALS

- The effects of climate change on the durability of construction materials and products should be reviewed. This might then require research into the development and use of more durable materials.

RISK ASSESSMENT

- An examination should be made of the opportunities for including an assessment of the consequences of climate change (including impact, vulnerability and adaptation) on decision making processes, risk management, sustainable development initiatives and similar issues for the construction industry.

- The relation between weather conditions and accident rates should be reviewed, and used to predict the likely change in the accident rate resulting from a change in climate. The implications this has for accident reduction targets should be explored.

## 3.6 DATA ASSESSMENT AND SUMMARY

The review of information on climate change and impacts has identified a number of key data sources, as summarised in Appendix 1. Although we identify a significant amount of literature on the subject, much of this is fairly general and of limited value to the current studies. We therefore anticipate that future work will build on a fairly manageable data set.

Relevant work has been undertaken at a global level, at a UK national level, at a UK regional level and at the sectoral level within the UK. Some work has been directed towards impacts on transport infrastructure including rail systems.

Our assessment of the status of the available information is as follows:

- ***Global level research.*** The work undertaken by the IPCC provides a sound technical basis for the assessment of climate change impacts, albeit that there is considerable uncertainty in future predictions. It is expected that on-going research will lead to an improvement in the quality of that understanding and the associated predictions over the coming years.
- ***UK National level research.*** The work programme of UKCIP provides a more detailed assessment of the likely extent of climate change in the UK. Focusing on the 2080s, this work has provided quantitative estimates, in the form of expected ranges of outcomes, for various climatic features. Whilst recognising the limited scenarios considered and the inherent uncertainty in the associated climate change predictions, the available information provides a basis for evaluating the potential significance of the identified anticipated changes to climate and weather. Work is ongoing and again it can be expected that this will lead to improved quality of technical understanding and climate change impact predictions, including reducing and managing uncertainty.
- ***UK Regional and Sectoral research.*** Regional and sectoral studies have identified what the anticipated changes in weather and climate are likely to mean locally, having regard to local economic, geographical and social conditions. In

this context, potential impacts on the railway system in the UK have been identified. At present, little or no detailed work seems to have been undertaken that seeks to quantify these sector specific impacts and evaluate their practical significance. Current research has not identified systematically the magnitude or frequency of occurrence of adverse impacts, although there are some quantitative estimates of changes in extremes provided in Chapter 5 of the UKCIP02 report. There are plans for further work on various aspects of climate change impacts on the built environment but, at present, this does not include any work directly addressing the railway sector.

A summary of expected changes in weather and climate and their associated impacts on the railway system is provided in Table 4 below.

**Table 4: Summary of expected climate changes and potential impacts**

| Expected change | Impact of variable on the railway system |
|---|---|
| Increased average temperature | Increased subsidence |
| Increased frequency of extreme temperature episodes | Increased incidence of rail buckling, increased staff and customer heat stress. Overheating of equipment both on infrastructure and trains. |
| Increased insolation | Increased incidence of glare. (Link to extreme temperature.) |
| Decreased average rainfall | Increased subsidence |
| Increased rainfall intensity and winter rainfall | Increased incidence of washout, flooding and scour |
| Reduced frequency of snowfall | Reduced number of blockage incidence, improved safety on platforms |
| Reduced frost incidence | Reduced icing of rails, points and overhead cables and extended growing season (see also impact under increased average wind speed) |
| Reduced incidence of fog | Reduced need for speed restrictions |
| Increased frequency and intensity of storms | Increased incidence of washout, flooding, increased incidence of fallen trees blocking tracks, reduced safety for staff and customers at stations and on platforms. |
| Increased average wind speed. | Changes to annual patterns of leaf fall, but note also that first frost related changes in growing season can be expected to have an impact |
| Increased sea level | Increased rate of inundation in vulnerable areas, increased area considered vulnerable, increased corrosion of track, points and signals and overhead line equipment in vulnerable areas |

In general, we find that the available information should provide a sound basis for the assessment of identified impacts but recognise that, at present, there is limited quantitative information on the magnitude or frequency of impacts. Further work in this area should enable prioritised proactive planning and remediation measures to be identified.

Whilst identifying the current limitations in understanding of impact significance, we note that some studies do attempt to identify which effects will be most pressing in a regional context. For instance, whilst the Welsh report acknowledges that increased gust speed and frequency could pose problems for overhead power cables, it recognises that within Wales this will not be a problem, as all train power is provided through diesel engines. However, it notes that Welsh links with other parts of the UK may be affected by this impact.

The need to discern the effects of climate change from changes in frequency and intensity of extreme weather patterns is clear. It has been suggested that the railway system could adapt to the average changes identified but, as is the case under current climate systems, it is the occurrence of extreme events that present the main risks to the operation and safety of the railway system.

Greater understanding of both the frequency and intensity of extreme weather events under future climate change scenarios is needed to allow accurate planning and remediation. (See comment about Chapter 5 of UKCIP02 report, under “UK Regional and Sectoral research”.) A tailored analysis of changes in extreme events with impacts on the railway is certainly required.

An important finding during discussions with the Consultees is their interest in the development of focused programmes of ongoing practical research into this area. Several of the contacts that were established would be interested in developing a dialogue with the Rail Safety and Standards Board with regard to accessing data held by them and the development of future research programmes.

# 4 Weather and Climate Effects on Safety on the Railway

## 4.1 BACKGROUND

Weather and climate impacts are a known phenomenon on the railway and knowledge derived from past and current experience provides a basis for identification of impacts in the context of this study. Key impacts on the railway system already apparent, outside any consideration of climate change related issues, include: rain leading to flooding risk or structural instability; wind leading to instability of train motion or damage to infrastructure; excessive heat and cold impacts on the track. The objective of the work described in this section of the report is to identify the full range of impacts that should be addressed in the context of future climate change and to identify information sources that may be of use in further studies. For the current purposes we focus on physical impacts on the railway system but recognise other less direct impacts on the railway such as human factor related issues linked to climate and weather. The latter types of impact are outside the scope of the current study.

## 4.2 REVIEW OF DATA SOURCES

Various railway industry sources have been reviewed to support the identification of weather and climate impacts on the railway, including for example, Railway Group Standards relating to management of weather impacts, the SMIS and TRUST data reporting systems, together with discussion with industry representatives and technical experts within AEA Technology Rail and information in the public domain (e.g. on the world wide web). Drawing on the information gathered from these sources and from the review of climate change impacts presented in the previous section, a list of impacts has been drawn up

### 4.2.1 Railway Group Standards

Railway Group Standards reveal a number of recognised weather related safety issues for which there is a current requirement for management action:

- GO/RT 3411: Exceptional Weather Conditions – Managing the Risks;
- GC/RT 5143: Scour and Flooding – Managing the Risk;
- GC/RT5123: Safe Asset Management – Coastal and Estuarial Defences;
- GO/RT3208: Arrangements Concerning The Non Operation of Track Circuits During Leaf Fall Contamination Period.

The first of these identifies a number of hazards as follows:

- Exceptionally hot weather – high rail temperatures;
- Cold weather:
    - Snow build up;
    - Point operation;
    - Ice build up, e.g. in tunnels and on overhead lines;
    - Ingress of snow into fixed equipment;
    - Impact of extreme conditions on vehicle traction;
- Flood:
- Other specific issues not covered elsewhere:
    - Sea conditions / coastal tide surge;
    - Very dry weather – Steam locomotive operation.

The Standards themselves do not provide any specific information concerning the hazards but identify responsibilities and broad requirements for management actions. We understand that there will be specific expertise within Network Rail in addressing these hazards and it can be expected that this expertise will vary between regions, according to local needs. At this stage in the study, we have not sought to investigate this data source in any detail. However, some further consideration of the issues raised has arisen in the context of interviews with representatives from the rail industry, as discussed below.

### 4.2.2 Interviews with Industry Representatives

Industry representatives interviewed during the current phase of the study include: Julie Gregory, Weather Strategy Manager, Great Western Region; Jonathan Ellis, Innovation Manager, SRA; Michele Francis, Head of Environment, Network Rail HQ. Other contact names with knowledge of specialist aspects that could be followed up have been identified. The objective of the interviews was to consider, quite broadly, the range of potentially relevant weather and climate related impacts on safety on the railway though, not surprisingly given the context in which the interviews were held, the interviews often involved a significant focus more specifically on climate change issues.

A number of key weather related hazards of general concern were identified, though not systematically and comprehensively, and these include:

- Precipitation - embankment stability (a big concern for Scotland/North West Region)
- Wind - OHLE, tree stability
- Bridge Scour
- Track - Track Circuits
- Hot Weather - rail buckling

As regards future climate change impacts there is concern that in the future there will be more frequent and more extreme severe weather episodes. Particular concerns raised were:

- The knock on effects of adverse weather, such as those experienced in 2002 in London. In a short space of time a large amount of rainfall caused major disruption on the infrastructure. Trains were stopped in tunnels due to flooding and passengers had to be evacuated. There are also identified safety concerns relating to trackside/maintenance workers in restoring the system. Other issues, relating to this event were the large number of Signals Passes at Danger (SPAD) events that occurred during this month. There were a large number of trees uprooted and the leaf fall that normally happens steadily during October and November was concentrated into a very short period. In addition, due to the high winds, the distribution of leaf fall was spread over a much greater area and affected locations not normally associated with adhesion problems. Following major clear-up operations throughout the weekend, services recommenced, but there was an exceptionally high incidence of category A SPADs associated with reduced adhesion under braking caused by poor railhead conditions.
- The long term effects of weather on the infrastructure. The impacts are uncertain. Bridges etc that were built during the Victorian era are already subject to weather conditions that are different from those for which they were intended. Some structures are also listed buildings, such that there are limitations to the extent to which major structural changes might be made.

In general, the approach to addressing current weather related hazards is based on knowledge of existing problems in particular locations, and specific reports have been produced to address some of these (eg in coastal areas, such as the Teignmouth Cliffs protocol to address sea defences and tunnel flooding risks at Chipping Sodbury).

We are advised that Scotland Region have undertaken some research looking at wind and rainfall algorithms, assessing whether correlations exist between historic railway delay data and historic weather data.

Each year each of the Regions currently produce seasonal preparedness documents (for autumn, winter and summer) as well as receiving weather forecasts daily from the Met Office. They also implement the requirements of the Rule Book, Network Rail Procedures and Region specific procedures in relation to operations during adverse weather.

The winter preparedness reports have a requirement for reference to 4 day forecasts with immediate actions based on current day forecasts. Hazards covered by the report are:

| HAZARDS | CRITERIA |
|---|---|
| Frost | Air temperature is expected to fall below 0°C at any point during the 24 hour period. |
| Low temperatures | Air temperature is expected to fall below -5°C during the 24 hour period. |
| Ice day | Air temperature is not expected to rise above 0°C at any point during the 24 hour period i.e. it will remain below freezing all day. |
| Snow | Snow is expected. Includes details on depth, drifting, adhesion code. |
| Freezing rain | Rain is expected to fall onto surfaces already below freezing and freeze on contact with them, resulting in widespread icing. |
| Freezing fog | Fog is expected to form with air temperatures below freezing so fog droplets freeze on contact with surfaces and structures. |
| Heavy rain | Rainfall forecast during the periods is expected to exceed 25mm. |
| Gales | Wind speeds are expected to reach gale force: mean speed of at least 39mph and/or gusts reaching 49mph. |
| Thunderstorm | Lightning is expected during the period. |

Other hazards that the report highlights are chemicals that might be used to treat the infrastructure. It also highlights the risks associated with removal of icicles from tunnels, bridges and overhead line equipment.

Whilst the winter preparedness reporting requirements and the identified location and problem specific responses reveal significant efforts are being directed towards some weather related hazards, it was suggested that Network Rail funding was not specifically focused on weather issues. The potential benefits of a more coherent approach are recognised and Mr Amar Rehal, Safety Risk Manager, Strategic Safety Policy, Safety & Operations is looking into the development of a reliable model for the impact of weather related effects on the railway.

Recognising the anticipated weather and climate changes, it was suggested that, in the future, it would be more beneficial to refer to future predictions of weather and climate rather than rely on the use of historical data.

As far as involvement in climate change research initiatives is concerned, Network Rail Great Western Region are members of UKCIP, but are not well represented in other specific weather and climate change areas. Network Rail had some input into the CRISP report but would like to see future UKCIP effort directed towards production of a more reliable weather and climate impact model for the railway system.

It was the view of interviewees that an official body, with the power of enforcement, should take the lead in driving forward and implementing the issues that will impact on the rail industry. It was thought that, without this lead, progress would be limited. More generally the possible role for a weather bureau/centre specific to the rail industry for forecasting impacts was identified together with further coordination through the definition of standards.

Internal research being carried out at present is generally being driven forward by means of a "bottom up" approach. Any research produced in this manner is not easily retrievable and usually takes place once projects are underway, rather in the early planning stages. It was felt that there may be benefit to be gained from top management initiatives and a more coordinated approach across the industry.

In addition to expertise within Network Rail, we identify bodies of expertise in weather related hazards to railway operations within technical support organisations such as AEA Technololgy Rail and have made some preliminary enquiries of these sources.

In summary, we identify significant technical expertise within the railway industry in hazards associated with extreme weather, based on current operating experience and designed to meet local needs identified on the basis of historical incidents. There is a recognised concern that more frequent and severe extreme weather episodes may arise in future due to climate change. The current body of technical expertise in weather related hazards should provide a sound basis upon which to develop an effective response. However, the knowledge base appears to be somewhat scattered across the industry and significant effort may be required to gain access to it. In order to deliver an effective response to climate change, it is felt that enhanced coordination of activities in future may be of significant benefit.

### 4.2.3 Rail Safety and Standards Board and Network Rail Information Systems

There are a number of sources of data within the Rail Safety and Standards Board and Network Rail that capture data relating to weather related incidents. These include: TRUST, SMIS and the Safety Risk Model. All of these data sources provide details of the same types of events with each providing a different perspective. We review each of these in turn and then consider the potential for their application in climate change related research.

#### 4.2.3.1 Safety Risk Model

The Safety Risk model is an independently validated model of the risk presented by current operation of Network Rail Controlled Infrastructure. The risk information contained in this model relates to the system wide risk on Network Rail Controlled Infrastructure (RCI) covering all running lines, rolling stock types, locations and stations currently in use. Non-RCI related risk associated with yards, sidings, depots, station concourse areas, station car parks and on train incidents is not included.

The Rail Safety and Standards Board is the custodian of data from the Risk Profile Bulletin and SRM and maintains an annual update.

The risk information is used by Railway Group members to provide information for use in their risk assessments and for judging how the risk relating to their operations compares with and contributes to the system wide risk.

The SRM is designed to take full account of both the high frequency low consequence type events (events occurring routinely for which there is significant quantity of recorded data) and the low frequency high consequence events (events occurring rarely for which there is little recorded data).

The Safety Risk Model (SRM) utilises data derived from a number of sources including:

- Fatalities database (derived from SMIS)
- Major Injuries database (derived from SMIS)
- SPAD analysis (derived from SMIS)
- Train fires database
- RAILDATA (broken rails database)
- AEA derailment database
- GEOGIS
- FRAME (S&T database)
- HMRI database/annual reports
- Generic failure and reliability data sources.
- And most notably, the safety management information system (SMIS).

The SRM provides a quantification of risk resulting from identified hazardous events. These hazardous events are a combination of precursors that influence the occurrence of the event. For example HET 9 – Collision with Buffer Stops has 21 precursor failures ranging from brake failures to driver misjudgement.

Data available from the Safety Risk Model includes:

- Hazardous events;
- Event Precursors;
- Frequency of Events and Precursors;
- Severity of Events and Precursors;
- Risk Contribution.

The SRM uses the equivalent fatality measure for quantifying the severity of incidents on the railway. One Equivalent Fatality represents:

- One actual fatality or
- Ten major injuries or
- 200 Minor injuries.

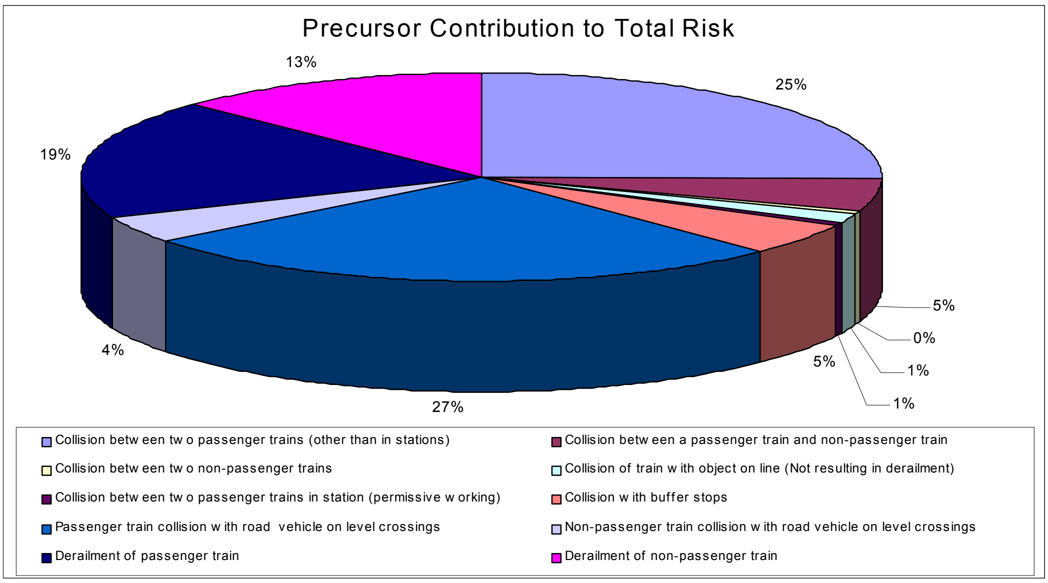
An analysis has been conducted of the data in the SRM to assess the contribution to system risk from ‘weather related’ cause precursors across Network Rail controlled infrastructure (RCI). The breakdown includes passenger and freight trains but, as these two types of activity differ, further analysis may need to be undertaken to fully understand any particular issues that are unique to the activities concerned.

We identify a number of weather related precursors. Analysis based on these precursors has identified a number of weather related hazardous events. The climate related issues identified are mainly associated with the hazardous event, signal passed at danger (SPAD). SPAD related incidents present the greatest overall contribution to the industry's risk (excluding trespasser fatalities). The preliminary results of this analysis are summarised in Appendix 3, which provides further information on the range of precursor events considered and their contributions to different hazardous event types. The outcome of this preliminary analysis is summarised in Figure 2.

As shown in Figure 2, the main hazardous events (HE) identified, where risk contribution arises from weather related issues, are:

- Passenger Train Derailment;
- Freight Train Derailment;
- Collision between two passenger trains;
- Collision of passenger train with road vehicle on level crossing;

**Figure 2 Precursor Contribution to Total Network Risk**




It should be noted that Figure 2 shows the distribution of the weather related precursor contributors as a proportion of the total contribution these precursor groups make (5 equivalent fatalities per annum). The total network risk is 137 equivalent fatalities per annum. The significance of weather related events can therefore be judged against their relative contribution to the total network risk. This will enable priority areas to be identified. At this stage in the work programme a limited amount of analysis only has been performed but it has indicated the role that this information source should be able to play in directing future research activities.

#### 4.2.3.2 Safety Management Information System (SMIS)

SMIS is the key data capture tool for safety related incidents that occur on the railway network. SMIS is a network wide database administered by the Rail Safety and Standards Board.

Railway Group Standards mandate the use of SMIS and, as a result, all railway group members have a nominated representative with responsibility for inputting information about specified incidents. The database ensures consistent data capture by the use of mandatory fields that prevent the incident being “closed” without their completion.

As detailed previously, SMIS forms a key input into the safety risk model detailed above. SMIS, however, could be of benefit to the study in that details of individual events can be analysed. Information can be obtained on:

- Location;
- Time;
- Infrastructure/Vehicle Description;
- Underlying Causes;
- Narratives of the event;
- Remedial Action Taken.

Within SMIS, weather conditions are captured under a variety of events and causal factors. The principal *event* categories identified by the research team are:

- Flooding of infrastructure (4600 events since 1/1/1990);
- Damage to Infrastructure due to objects blown onto the overhead line (4353 events since 1/1/1990);
- Environmental (1 event identified since 1/1/1990).

Due to time constraints, the considerable length of time taken by SMIS to generate reports and computer system failures encountered during our initial analysis work, a limited assessment only has been undertaken at the present time. However, we recognise that further interrogations of SMIS should be able to reveal the numbers of events for which weather specific cause categories contribute to incidents e.g. fog, heavy rain, snow, wind etc. This information should aid identification of priority areas and help direct future research efforts. The narrative available in some SMIS reports should also help the development of a better technical understanding of the identified weather related precursor events.

In evaluating data derived from SMIS a number of risks were determined that related to the hazards presented by adverse weather conditions:

- Signals Passed at Danger;
- Derailment;
- Collisions between train and road vehicle.

Note that the similarity between SMIS hazards and the precursor events detailed in the SRM are due to the commonality of source data and provides a degree of validation to the study team's observations thus far.

#### 4.2.3.3 TRUST

TRUST contains the information used to attribute delay minutes and fines payable by the company(s) that cause delays on the network. When delays occur, information captured in TRUST is used by TRUST delay assistants, within each Network Rail Region, Train Operating Companies (TOCs) and Infrastructure Maintenance Companies (IMCs), to determine which party caused the delay and what cost they therefore incur. PALADIN provides a source of historical delay information. TRUST and PALADIN data can provide a clear link to delays caused by weather related causes.

On the basis of discussions with TRUST experts it was been determined that the TRUST data would be able to provide information on weather related incidents where these have led to delays. There are a number of codes used by TRUST to identify weather related problems. Although TRUST is designed for analysis of delays on the network it represents a wider base of data on weather related incidents that could be used to inform the current study. Some further consideration of TRUST data is presented in Section 7 of this report.

## 4.3 ACCOUNT OF IDENTIFIED IMPACTS

On the basis of the information sources described in the previous sections and our own hazard review, a set of potentially relevant weather related hazards that may need to be addressed in any response to climate change have been identified and are summarised below. We start by presenting an account of the weather features to which the railway system may be sensitive and the nature of those sensitivities. Next we identify the vulnerabilities of different elements of the railway system to those weather features. Finally we review identified adaptation strategies that might be adopted to address climate change and areas for further research.

### 4.3.1 Weather Features and Sensitivities

According to a 2001 report issued by the Intergovernmental Panel on Climate Change (IPCC), rail transport is the most tolerant sector to climate change. However, for the UK, analysis suggests that, overall, the rail sector may exhibit some significant sensitivities to the weather and climate change.

Identified sensitivities are summarised below, with information on thresholds of significance and mitigation methods where these have been identified.

***Exceptionally hot weather***

- Air temperature – high rail temperatures in excess of the maximum for which the track is designed (e.g. ≥ 36°C for some parts of the system) – managed generally

by differential speed limits – also managed locally by differential speed limits at a lower critical rail temperature for sections of track that are less than full strength
- Increased temperatures throughout the year – increased vegetation mass due to longer growing season – increased level of leaf fall - low adhesion - ineffective braking - (skid, loss of traction, wheel spin), signals passed at danger – vegetation management

***Cold weather***
- Low temperature – Points frozen in one position, derailment - point heaters
- Low temperature – diesel engine starting systems ineffective – minus 10°C – operational arrangements to maintain running
- Very low temperature – brittle fracture of rail and steel structures – minus 20°C beyond design levels – derailment, collision – adequate drainage, condition monitoring

***Rain/Flood***
- Delay to services due to speed restrictions (flood warnings, engineering solutions)
- Stranded or suspended rail services (electric supply issues)
- Sea condition/coastal tide levels
- Rain – degradation of the track formation – beyond design levels – improve drainage, use pumped systems
- Wet rails – small amounts – exacerbation of rolling contact fatigue on rails and wheels – railhead and wheel conditioning
- Precipitation – flooded tunnels – beyond design levels – drowned passengers – flood gates, pumping systems
- Precipitation – cutting and embankment collapse – beyond design levels – derailment, collision – adequate drainage, condition monitoring
- Precipitation –collapse of shallow mine workings– beyond remaining resistance – derailment, collision – adequate drainage, condition monitoring
- Track circuit failure arising from flooding

***Ice/Snow***
- Snow – drifts block lines, trains stranded - monitor forecasts, snowploughs, contingency planning
- Ice/snow - poor adhesion, ineffective braking (skid, loss of traction, wheel spin), signals passed at danger
- Ice/snow – dead load in excess of strength of structure – station roof damage – design, condition monitoring
- Powdered snow – ingestion into vehicle and trackside equipment – loss of function, traction or signalling – selection and design of intakes and equipment

***Fog***
- Patchy fog – signals passed at danger, collision - visibility reduced below signal sighting distance – temporary speed restrictions, monitor forecasts, driver briefing

***Wind***

- Increased wind speeds - flying debris - vehicle and line-side damage (exclude debris) – clear line-side, wind fences
- Increased wind speeds or gusts- passenger rail vehicles overturning – 40 m/s – vehicle design, speed restrictions – wind fences
- Increased wind speeds or gusts- freight vehicles overturning – 30 m/s – vehicle design, speed restrictions – wind fences
- Increased wind speeds or gusts- overhead line out of alignment, torn down by pantographs – 30 m/s – spacing of overhead line supports
- Increased wind speeds or gusts- damage to station roofs and exacerbated by pressures generated by increased pressures due to higher train speeds – 30 m/s – building design to resist, monitoring
- Increased wind speeds or gusts- trees blown across the line, derailment – 25 m/s – clear line-side of vulnerable trees
- Increased wind speeds or gusts – sea waves the overtop sea defences – 25 m/s stranded trains – design sea defences and train systems

***Vegetation***

- Leaf fall - low adhesion - ineffective braking - (skid, loss of traction, wheel spin), signals passed at danger
- Longer growing season – visual obstruction
- Loss of vegetation – embankment instability

***Lightning***

- Lightings strike to signalling system – disruption to train movements – strikes to electronic systems – power systems vulnerability – system design to resist surges

***Soil Moisture***

- Drought – settlement of permanent way – movement outside design limits. – monitoring
- Excessive moisture and increased pore pressure – cutting and embankment collapse – beyond design levels – derailment, collision – adequate drainage, condition monitoring

### 4.3.2 Railway System Vulnerabilities

For the UK, the identified climate scenarios (UKCIP, 1998) indicate that there will be an increase in the incidence and severity of extreme weather events, for example precipitation and wind. This will increase disruption of the transport network through, for example, the closure of bridges in high winds, the loss of overhead power lines to trains, blockage of roads and permanent way by fallen trees, floods and snow drifts. The supply industries will also be similarly affected, but to a lesser extent. It would, therefore, seem necessary to draw up contingency plans to cope with more frequent severance of transport routes and service.

Areas of the rail infrastructure vulnerable to weather and climate include:

- Highways, platforms
- Bridges, viaducts, aqueducts
- Earthworks / Embankments
- Drainage systems
- Tunnels
- Ballast/subgrades
- Trees and vegetation
- Lighting columns, signs and gantries
- Permanent way, underground and tram lines
- Buildings
- Points/line-side equipment
- Timber and telegraph poles
- Overhead cables
- Signalling systems
- Boundary structures

A more detailed description of how the infrastructure is affected is given below.

***Bridges, viaducts and aqueducts***

UK bridges are built with a designed service life of 120 years. It is therefore necessary to take a reasonably far sighted view of climate change problems that might arise.

An increase in the magnitude and severity of flooding will, in turn, increase the potential for scour around the foundations of a bridge: as has been shown in the UK and elsewhere, this can lead to collapse of the structure and the loss of life.

The stresses induced by the higher wind speeds and wider annual temperature ranges will need to be taken into account in both the design and assessment of structures. The effects of temperature affect, amongst other things, the amount of movement required at bearings, expansion joints and the like, and the stress relief required from the backfill to an integral bridge.

An increase in the incidence of high wind speeds may lead to the more frequent closure of some structures, and alternative routes might need to be considered.

***Tunnels***
An increase in precipitation may increase the risk of failure of cuttings and retaining walls located around tunnel portals. Some consideration has been given to the likely effects of climate change on the tunnel network of London Underground (2001).

***Track, Points and other line-side equipment***

Work has been undertaken by Network Rail to identify the lengths of track that are vulnerable to the vagaries of weather. Track owners and operators should be able to pinpoint lengths of track prone to flooding and sliding and may have first hand experience of the disruption to services generated by leaf mulch and fallen trees.

Problems of poor traction will be met in icy conditions and also where flooding occurs, particularly where conductor rails are present. Given that milder winters will also be wetter, it is not known whether the incidence of such problems will increase or not. However, warmer summers might lead to some increase in rail buckling.

At present, it is not clear whether milder winters with fewer frosts will reduce the incidence of frozen points or the icing of other line-side equipment. Furthermore, it is also unclear whether point failures will increase with an increase in snow fall.

Points are particularly sensitive to lightning. There might therefore be a need to improve the robustness of the equipment and/or install more lightning conductors at strategic points alongside the track. There is clearly a benefit to be gained from further research on these issues.

Reliable prediction of climate change is required for the planning and design of new rail infrastructure, whether for train, tube or tram systems. Such predictions might affect the selection and implementation of new technology. For example, the construction of new high-speed tracks, the upgrading of existing tracks, and the introduction of new rolling stock - perhaps based on a tilting or magnetic levitation system.

***Subgrade and ballast***
An increase in annual precipitation poses particular problems regarding the performance of subgrade and ballast. As strength and stiffness of the materials reduces, there is a risk of degradation of bearing capacity or generation of wet spot problems under the live loads applied by passing traffic.

***Drainage systems***
Designs of drains are currently based upon historical data rather than predictions of likely weather conditions. There is therefore a need to consider the impact to drainage due to predicted increases in annual precipitation and higher ground water and river levels.

***Embankments / Earthworks***
Hotter, drier summers will increase the seasonal shrinkage of cohesive soils and also more noticeably of organic soils, such as the outcrops of peat shrinkage in East Anglia. As a result, deeper cracks in cohesive soils may be generated, although

structure foundations (e.g. piles or rafts) may address the risk at some locations at least. It is, therefore, possible that works will be required to reduce the likelihood and severity of problems associated with subsidence.

Studies have shown that the incidence of earthwork failure increases following a prolonged period of wet weather. This is because the build up of pore water pressures following wet weather increases the disturbing force on the soil and also reduces its shear strength. The generation of deeper cracks will allow water to penetrate further into a slope, and so earthwork failures might be triggered by heavy rainfall following a prolonged period of hot dry weather.

***Lighting columns, signs and gantries***
Higher wind speeds will increase the loading on signs and gantries, thus the structural detail of the panels and fixings might have to be reviewed in the light of climate change. Higher overturning forces developed on signs and gantries will reduce the stability of their foundations.

The stability of foundations might also be reduced by the softening of the ground brought about by an increase in precipitation. It may be necessary to review the design requirements for the foundations to signs and gantries. It may also be necessary to assess the positioning of signs and gantries with respect to their visibility, as a result of any changes in the incidence of fog. The stability and visibility of temporary signs should also be addressed: the current requirements for these differ from those required of permanent structures. The operation of signs can be detrimentally affected by a combination of wet and cold weather. Climate change might, therefore, lead to an increase in the icing-up of signs. The loss of signage, particularly those warning of poor visibility, icy surfaces and accidents, might increase the likelihood of accidents. Such issues should be investigated through regional risk assessments.

***Signalling systems***
At present, the UK rail network is prone to disruption through lightning strikes - signals seem to be particularly at risk.

***Overhead lines:***

- Warmer Temperatures
  An increase in summer temperature will increase the sag of overhead power cables, where there are no balancing weights to take up the thermal expansion. This may reduce the clearance between adjacent cables and between cables and other structures, such as buildings, trees and passing vehicles.

  The risks posed by an increase in temperature and wind may need to be assessed. An increase in temperature might also reduce the capacity of overhead power lines, but milder winters might reduce the incidence of their icing-up. Iced overhead lines can damage the pantograph of trains and may create a particular problem for the rail industry, depending on the geographical location.

- High winds
  An increase in the frequency and strength of high winds may increase the incidence of dewirements, and the amount of damage generated by such eventsresulting from the snagging of overhead lines with the pantograph.

- Storms
  Stormier weather could increase the incidence of damage to overhead lines by fallen trees and by wind-blown debris. It might be necessary to review the strength of supporting brackets and fixings to power cables. To date, little consideration has been given to the effect of climate change on the stability of structures that support overhead cables. However, because of their form of construction, pylons are unlikely to be particularly vulnerable to the effects of climate change.

***River and coastal defences***
According to an IPCC (2001) report, the risks and hazards of river flooding will increase across much of Europe. However, for the UK, the most important impacts of climate change will be associated with a rise in sea level: these include an increase in the incidence and severity of flooding of coastal areas and an increase in coastal erosion, FOE (2000).

This is confirmed by the findings of UKCIP studies; which predict a substantial increase in the likelihood of flooding, erosion and loss of wetland - all of which have implications for the rail infrastructure.

The predictions of a study for the Southeast of England include (a) an increase in the frequency of overtopping of coastal defences, and (b) an increase in the incidence of river flooding during the winter months.

Some improvements in flood defences may have to be made along some lengths of coastline and selected reaches of the major watercourses. Further initiatives/improvements are required in flood forecasting and warning systems.

***Pipes, culverts and sewers***
Road pavements and the permanent way are more prone to flooding (than elsewhere) and the traffic on them imposes live loads on the ground. Thus, pipes and cables installed in the vicinity of roads and the permanent way might be more at risk from some of the foregoing mechanisms.

***Boundary structures***
Boundary structures which include fences, noise barriers and walls (whether retaining earth or not) are affected by wind loading and the strength of the foundations.

The impact of climate change could be more important for noise barriers than walls. This is because the former type of structure is formed from less robust structural members and they have relatively shallow foundations: timber fences and high brick walls seem to be most vulnerable. There might not be much of a problem with earth retaining walls: older structures (which predominate in the UK) would have withstood the gales of the past, and there should be sufficient reserve of safety in structures built to current codes to cope with increases in wind speed.

However, the fabric of fences and walls can be deteriorated by the weather and by other agencies. Thus, a change in climate might increase the rate of deterioration of stone, brick and timber structures and elements, and this could have a knock-on effect on maintenance work and expenditure.

***Vegetation***

Although vegetation might not be considered to be a construction feature, its adoption for environmental and aesthetic reasons is increasing. Buffer zones are commonly used to shield residential areas from the noise and air pollution generated by rail corridors. The risk of fire developing in vegetation will increase with (a) an increase in temperature, (b) increases in the frequency and length of dry weather and (c) an increase in lightning strikes.  With a change in climate, the existing vegetation may become unsuited to the new conditions and die.  This may lead to instability of embankments and cuttings.

All of the above changes are predicted for the UK.  An increase in lightning strikes and in the strength of winds might in turn increase the occurrence of felled trees on the permanent way and also their impact on overhead telecommunication and power lines. Research on the frequency of felled trees and the risks they pose should be considered, to support the development of maintenance strategies.

Changes in the timing, duration and intensity of the leaf fall in autumn have important implications for road and rail operators. The most likely consequence of climate change in the UK is a later, longer season and an increase in the weight of the leaf mulch, which might exacerbate the problems of rail adhesion. This might be lead to a more frequent cutting back of existing vegetation, the planting of different species, the development of better technologies, or all of these.

### 4.3.3 Adaptation Strategies

A report published by the DLTR (2000) stresses that the UK needs to adapt to predicted impacts of climate change, including sea level rise, drought and more intense rain fall. The key aspects of adaptation are to increase resilience, resistance and adaptive capacity, for the transport infrastructure, which might include:

- Improvements in flood defences along some lengths of coastline and selected reaches of rivers.
- Restrictions on development in areas prone to flooding.
- The use of more durable materials, such as more corrosion resistant metals.
- Increases in the stability of telegraph poles, pylons and other structures prone to wind loading.
- Better wind-proofing of buildings, and the strengthening of roofs and claddings on existing buildings.
- Better drainage systems, particularly along highways and railways.

- The use of low maintenance vegetation to act as buffer zones, whilst not hindering the growth of other vegetation.

## 4.4 DATA ASSESSMENT AND SUMMARY

Overall, we identify a wide variety of data sources of relevance to the current study as follows:

- Industry knowledge and operating experience. There would appear to be a considerable body of knowledge within the industry that responds to weather related safety and operational impacts on the railway. Expertise has developed according to local needs and knowledge is apparently uncoordinated. The knowledge and expertise should provide a solid technical basis for addressing climate change impacts but accessing it may require significant effort.
- Industry data systems. Data systems such as those supporting the System Risk Model and the SMIS and TRUST data bases hold considerable amounts of information that might be employed to determine which weather related precursor events make a significant contribution to system risk and hence those that would be seen to be priorities for future research activities in respect of climate change;

Taken together with the identified information on climate change impacts, described in Section 3, we recognise a substantial body of relevant information that should support the development of a cost-effective response by the railway industry to the potential threats associated with climate change. The subsequent phases of the current work programme build on this information base to begin the development of that response through the identification of future research needs and associated actions that address significant risks in a prioritised manner.

# 5 Risk Scenario Analysis

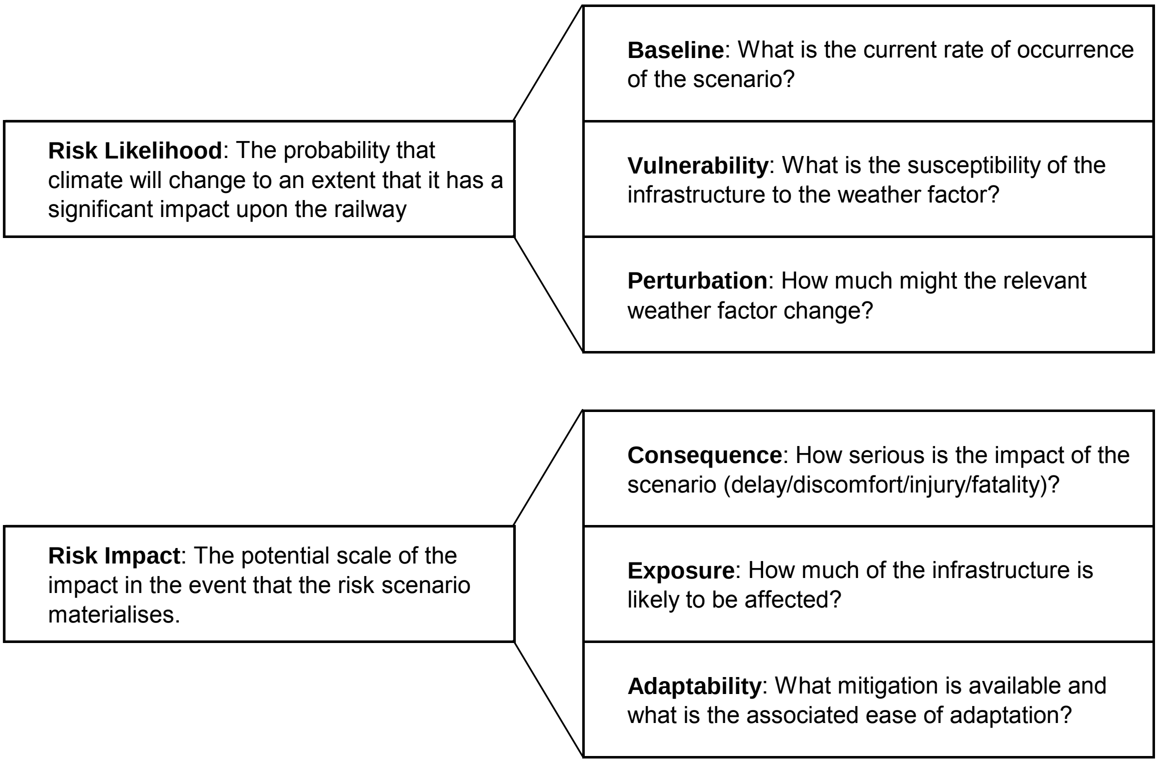
The ultimate objectives of the work programme are to identify research needs and actions that the Rail Safety and Standards Board needs to take to ensure safety in the context of current and future climate change, as defined in the specification for the Phase 3 and 4 elements of the programme. The Phase 1 and 2 elements described in the previous sections of this report have identified basic information and information sources to support that objective. We proceed now to analyse that initial information as the first step in defining appropriate research needs and actions to address climate change impacts on safety.

Drawing on the information provided by the Phase 1 and 2 elements of the work programme a series of risk scenarios can be identified, associated with various weather factors. For the purposes of the current assessment, the analysis has been developed around the following weather, climate and related factors:

1. Rain;
2. Hail;
3. Snow/Sleet/Ice;
4. Fog;
5. Wind;
6. Temperature (High / Low);
7. Lightning;
8. Insolation;
9. Sea;
10. Vegetation.

The various risk scenarios arising from each of these factors that have been postulated are summarised in Table A.5, comprising Appendix 5 to this report. The objective of the current analysis process is to determine, on the basis of currently available information, the recommended future actions to be taken by the Rail Safety and Standards Board to address the risks arising from the identified climate change scenarios. To support the identification of priority issues and associated responses, in particular in respect of research needs, the following basic structure for assessment has been proposed.

### Figure 3: Risk Scenario Prioritisation Factors




The basic assessment process undertaken on the basis of this structure involves the following steps:

- Develop an initial characterisation of each of the risk scenarios in terms of the identified factors;
- On the basis of that characterisation, identify priority risk scenarios in respect of which it is recommended that the Rail Safety and Standards Board take further action;
- For the identified priority risk scenarios, identify information needs and other actions appropriate to the risks and their significance.

That process has been undertaken iteratively, with an initial assessment being undertaken by the AEA Technology project team, followed by review with a wider group of participants from the Railway Industry. The output of that process is summarised in Table A5, presented in Appendix 5. That tabular summary is not intended to be a comprehensive account of all the information concerning the risk scenarios that is available but is designed to collate sufficient basic information to allow an analysis to be undertaken.

Before developing the analysis of the risk scenarios it is worth briefly reviewing the factors and how they relate to risk significance and prioritisation. As far as identification of priorities is concerned, a risk scenario would be identified as potentially a higher priority where the consequence and exposure are relatively high. However, the significance of a risk scenario would also be influenced by the mitigation measures available and the associated adaptability. If mitigation can be achieved by management measures that are already in place to address the current level of risk then the scenario might be identified as a lower priority on the basis that, if it does become more significant in future it may be comparatively straightforward to adapt to it. On the other hand, where mitigation is through system design features, responding now to the threat may be a much higher priority.

As far as the other three risk likelihood related factors are concerned, where the baseline risk for the scenario is already identified as a non-trivial contributor to the current level of risk and the perturbation will increase that risk, it should generally be possible to identify the scenario as a higher priority. Where the current baseline risk for a scenario is low then more attention to the level of the perturbation as compared with the vulnerability of the system will be required in determining the potential significance of a scenario. Where knowledge of the perturbation or vulnerability is limited but the risk potentially significant, further research is likely to be a priority.

On the basis of this assessment process, the various risk scenarios have been analysed and the outline findings are presented below. On the basis of these outline findings, more detailed proposals for response actions by the Rail Safety and Standards Board are developed in the subsequent sections of this report, focusing on identified priorities.

## 5.1 SCENARIOS ASSOCIATED WITH RAIN

The primary climate change impacts of concern associated with rain-related events are:

- the predicted increase in rainfall during the winter months and the potential for more intense and concentrated periods of rainfall at other times;
- the predicted decrease in rainfall during the summer months which, allied to higher average temperatures, is expected to give rise to significantly reduced soil moisture.

The two sets of scenario are addressed in turn below.

### 5.1.1 Scenarios Associated with Increased Rain

The key scenarios identified that relate to these increased rainfall events are as follows:

Scenario 1.1: Rain in excess of local system drainage capacity leading to local flooding of the permanent way and resulting in disruption of services;

Scenario 1.2: Excessive rainfall, leading to river inundation and flooding of the permanent way and resulting in disruption of services;

Scenario 1.3 Excessive rainfall giving rise to increased river flows, leading to mechanical scour of bridge supports, earthworks, etc and ultimately resulting in failure of structures and potentially severe consequences;

Scenario 1.4 Flooding leading to disruption of electricity supplies and resulting in disruption of services;

Scenario 1.5 Excessive rainfall (perhaps linked to earlier periods of extreme dryness) that weakens shallow mine-workings leading to displacement of track with potentially severe consequences;

Scenario 1.6 Excessive rainfall and volume of water flow beyond design levels leading to degradation of track formation and, if unmitigated, potentially severe consequences;

Scenario 1.7 Excessive rainfall leading to flooding of tunnels, resulting in disruption of services and potentially more severe consequences;

Scenario 1.8 Excessive rainfall, giving rise to embankment and cutting instability and slip, with the potential for severe consequences;

Scenario 1.9 Excessive rainfall, giving rise to instability of tunnel structure and resulting in tunnel collapse with the potential for severe consequences.

In general, the identified risk scenarios are non-trivial contributors to the baseline risk: i.e. those associated with potential fatalities contribute of the order of 0.25 to 1.5 equivalent fatalities per annum against a total network risk of 138 equivalent fatalities per annum and those associated with disruption to services are currently recognised as significant. A limited analysis has given an indication of the scale of their contribution.

There is confidence in the general predictions of an increased level of winter rainfall and UKCIP studies indicate a substantial increase (i.e. approximate doubling) in the frequency of severe flooding events in the UK. Short-term extremes are less well characterised quantitatively but there is still confidence in the prediction of a significant increase in such events that involve excessive rainfall. Given the significance of the baseline risk and the scale of the increase in the causal factor of excessive rain, the above risk scenarios are generally identified as priorities for further work.

For the majority of the scenarios, some of the key risk mitigation measures in place involve the implementation of particular management processes. There is significant expertise in respect of such particular management processes within the industry, for example in respect of scour susceptible bridges, areas susceptible to mine-working collapse, anticipation of the likelihood of embankment collapse on the basis of various identified risk factors (including geological factors as well as factors relating to excess level of rainfall). The role of improved design standards to address some of the issues is also identified (e.g. new design or assessment standards in respect of scour). One key area for potential further work therefore relates to the further development of such mitigation measures. This applies in respect of all of the above rain related risk scenarios, except Scenario 1.6 for which an effective routine management process is in place.

To support improved risk mitigation, in accordance with the types of measures identified above, better determination of the practical implications of the predicted future weather events for the railway system is identified as beneficial. This might, for example, involve the overlay of indicative flood plain mapping on the network, with more detailed assessment of areas at higher risk and better characterisation of short-term extremes against the capacity of the infrastructure to withstand them.

In summary, we identify a requirement for more systematic definition of research needs in respects of Scenarios 1.1 – 1.5 and 1.7 - 1.9, the main features of which will involve the following:

- Improved characterisation of the extreme weather events associated with the priority risk scenarios;
- Improved characterisation of the sensitivity of the network to the causal weather events;
- Development of potential mitigation strategies, in some cases at least linked to work programmes already in place to address the current risk.

### 5.1.2 Scenarios Associated with Reduced Rain

The risk scenarios associated with reduced summer rainfall, increased temperatures and reduced soil moisture are:

- subsidence of permanent way, leading to possible track mis-alignment;
- settlement of other structures.

The general conclusions drawn concerning these scenarios are that it should be possible to address the risk through general routine management procedures and that the future climate change may not represent a significant safety risk. In principle, settlement may give rise to the potential for severe consequences if undetected. Measures to prevent or repair such defects can sometimes be costly and disruptive to the running of the railway. Although the preliminary conclusion is that current management procedures should be able to address these risks, there may be benefit to be gained from review of procedures against the possible future demands made by climate change.

## 5.2 SCENARIOS ASSOCIATED WITH HAIL

Climate change predictions do not specifically consider hail but identify a decreased frequency of relevant storms (e.g. those involving lightening) and an increased intensity in those storms that do occur. Assuming that the incidence of hail correlates with that for storms, these factors may to some extent balance out such that the future risk associated with hail remains similar to the current risk. However, there is uncertainty in respect of the nature of extremes within the currently available predictions and concern has been expressed that the individual size of hailstones may increase in more energetic thunderstorms and lead to increased damage. All factors considered, risk scenarios associated with hail are not identified as priorities. Given the uncertainty associated with extreme storm events, better characterisation of possible extremes in respect of hail may be beneficial. This would allow better judgement on whether hail might represent a relevant future issue.

## 5.3 SCENARIOS ASSOCIATED WITH SNOW / SLEET / ICE.

A general reduction in the incidence of snow, sleet and ice is anticipated according to current climate change predictions. A reduction in incidence of the associated risk scenarios is similarly anticipated and additional risk management actions are therefore not identified as a requirement. At some point in the future, if risk scenarios arising from these factors reduce sufficiently, it may be appropriate to consider a reduction in resources allocated to their management. In the immediate future at least, it is anticipated that the measures currently in place will continue to be required. However, there may be a benefit to be gained from following developments with a view to possible future reallocation of resources if appropriate. Whereas the general conclusion is that these scenarios are not priorities for immediate action, it is noted that the competence to deal with a scenario may depend on the experience of those operating the system. This experience may decrease with decreasing incident frequency. A reduction in the frequency of snow, sleet and ice events in the future may therefore lead to increased problems when incidents do occur.

## 5.4 SCENARIOS ASSOCIATED WITH FOG.

Climate change predictions are for a 20% reduction in the incidence of fog. Evidently the risks associated with fog can be expected to decrease slightly but not to the point where they can be neglected. Accordingly, no response by the Rail Safety and Standards Board in respect of this weather factor may be required.

## 5.5 SCENARIOS ASSOCIATED WITH WIND

The identified climate change impact of potential concern is an increase in events involving excessive wind speed. A series of scenarios associated with excessive wind have been identified, for example involving wind-related damage to various elements of the network (e.g. overhead lines, line-side structures, stations) or instability of rail vehicles at speed and susceptibility to wind blown objects, including but not limited to trees.

In general, wind-related events are not identified as a particular priority on the basis of the current assessment of the baseline risk. However, against the climate change scenario of an increase in events involving excessive wind speed, the question would arise as to the potential for the events involving excessively high wing becoming more frequent and the peak wind speeds within them increasing to the point where it exceeds some critical threshold, such that wind-related events may become substantially more significant contributors to the network risk.

Our initial investigations have indicated some threshold values for wind speed at which the railway system may become sensitive to excessive wind. However, these studies have not, at present, adequately characterised the extremes in wind speed that are anticipated. Generic information presented by UKCIP, as based on the predictions made according to the Hadley Centre model, indicates an increase in average wind speed in winter months. However, the data requirement in this instance is for the likelihood of winds in excess of a given threshold speed. It is expected that information concerning extremes in wind speeds may be accessible through the Hadley Centre model. However, we note the comments of the climate modellers made during the course of our current investigations that the predictions in respect of wind speed are subject to a comparatively high degree of uncertainty.

Recommended actions in respect of wind-related risk scenarios therefore relate to better characterisation of the scenarios addressing the following:

- Confirmation of the threshold wind speeds of potential concern;
- Specific interrogation of the available climate models to determine the likely frequency with which the threshold wind speeds may be exceeded in future;
- Consideration of methods to permit safe running in periods of high winds.

Such additional studies should provide a more substantial basis on which to evaluate the potential future significance of the identified wind-related risk scenarios. Any such evaluation would need to take account of the uncertainty in predictions of future wind speeds. In this context we note relevant work undertaken previously within Network Rail, for example in respect of overhead line faults in Scotland and the incidence of fallen trees within Great Western Region.

## 5.6 SCENARIOS ASSOCIATED WITH TEMPERATURE

### 5.6.1 Scenarios associated with extreme temperatures

Climate change impact predictions are for an increase, not only in the average temperature but also the frequency with which any given extreme in might occur. The critical risk scenario currently identified in this respect is the potential for buckling of rails, potentially leading to derailment and severe consequences. (Other scenarios identified relate to less severe consequences and are not currently identified as priorities.)

Threshold temperatures beyond which the system becomes vulnerable can be identified. Generic information presented by UKCIP, as based on the predictions made according to the Hadley Centre model, gives generic indications of the increase in incidence of extreme temperatures, for example at selected temperatures and for selected regions. The available summary data, whilst indicating the possible significance of the extreme temperature risk scenario, does not provide information of specific relevance to the thresholds of primary concern.

Recommended actions in respect of extreme temperature-related risk scenarios are therefore analogous to those identified above for wind-related risk scenarios and comprise:

- Identification of the threshold temperatures of potential concern (for example rail temperatures or air temperatures at which a given rail temperature might be reached);
- Specific interrogation of the available climate models to determine the likely frequency with which the threshold temperatures may be exceeded in future.

### 5.6.2 Scenarios associated with low temperatures.

Both an increase in average winter temperature and decrease in winter time diurnal range are expected, according to current climate predictions and the associated risk is therefore expected to decrease. As for the scenarios associated with snow, sleet and ice, additional risk management actions are evidently not required in this case but it may be appropriate to monitor changes with a view to taking advantage of opportunities to reallocate resources in the future, should the possibility arise.

## 5.7 SCENARIOS ASSOCIATED WITH LIGHTNING.

As alluded to earlier in the discussion of hail, the frequency of lightning discharges during storms is expected to double but the overall storm frequency is expected to halve. This implies a similar risk level in the future as at present, although more prolonged and intense lighting activity could be expected to have a larger footprint on the network, add to the time to restore the system to normal operating condition and thus cause more significant delay to operations.

All factors considered, risk scenarios associated with lightning are not identified as priorities. However, given the uncertainty associated with extreme storm events, better characterisation of possible extremes in respect of lightning and of the system's sensitivity to it may be beneficial. It is suggested that the impact of electromagnetic pulses generated by lightning be assessed and enumerated for their effect on the railway, potential risk to users of the system and methods of mitigating these risks.

## 5.8 SCENARIOS ASSOCIATED WITH INSOLATION.

The predicted decrease in cloud cover in summer indicates an increase in sunshine and potential for impaired vision associated with sun glare. There have been several accidents where the enquiry has considered glare to be a contributory factor as in the case of being able to view the correct aspect of signal SN109 leading to the accident at Ladbroke Grove[7]. It is expected that actions arising out of this incident, for example ensuring appropriate positioning of signals, should address these risks and that the relatively modest increase in incidence of sunshine anticipated should not require any additional measures to be taken. On that basis, this risk scenario has been discarded from further consideration.

## 5.9 SCENARIOS ASSOCIATED WITH THE SEA

Increased flooding risk in coastal areas is anticipated, both as a result of the average sea level rise and, potentially, due to changed or more extreme storm conditions. The increase in average sea level alone is expected to reduce the return period of given coastal flood events. Climate change could also lead to greater wave heights and more frequent storm and tidal surges. Apart from the coastal defences directly

[7] Ladbroke Grove Public Inquiry Report, Part 1 paragraphs 5.109 and 5.111

at risk (for example from overtopping) there are many other areas of the railway that are vulnerable to this risk.

Current procedural measures for managing this hazard rely primarily on the consideration of short-range weather forecasts against past experience. This approach may not be reliable in the future. The anticipated changes may both increase the severity of risk to those areas currently identified on the basis of historical incidents as vulnerable and increase the areas at risk. Where physical flood defence measures are in place, these may cease to be adequate to deal with the increased threat.

On that basis, this risk scenario is identified as deserving further attention.

## 5.10 SCENARIOS ASSOCIATED WITH VEGETATION.

There are a number of risk scenarios associated with vegetation that relate to changes in various weather factors. A combination of weather factors is involved in some cases. Key risk scenarios include:

- High wind causes trees to be blown down and leading to collision risk, perhaps exacerbated by excessive autumn rainfall or the occurrence of high winds when trees are still in leaf or deadloads caused by snow or ice causing trees to be less stable;
- Increased growing season and increased autumn winds leading to excessive leaf fall and resulting in low adhesion and ineffective braking;
- Increased growing season and rate of growth leading to obscuring of signals;
- Failure of some vegetation to survive longer, hotter and drier summers with knock-on effects on the stability of the track-side environment.

- The potential consequences associated with these scenarios are generally high and there is widespread exposure of the railway system. The baseline risk (current risk identified on the basis of the RSSRM) is also comparatively high, making this a priority issue. However, the identified measures for risk mitigation are management measures (i.e. lineside vegetation management). Significant efforts are already being made by the railway industry (in particular Network Rail) to address these problems. Our initial conclusion is that the management of any addition risk associated with climate change related factors might best be integrated into these current programmes as that becomes necessary in the future. There may, however, be scope for supporting research outside of any specific Network Rail programmes, for example looking at the introduction of new species designed for a specific function within the infrastructure.

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# 6 Initial Research Needs

The previous section has outlined primary areas for further work and its general nature. On the basis of the earlier analysis of identified risk scenarios, initial suggestions for more specific research needs arising in respect of them have been identified, as summarised below.

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 1 | RAIN | |
| 1.1 | Rain in excess of system drainage capacity leading to local flooding of permanent way. | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of system drainage capacity.**<br>What is the current capacity of the drainage system? For example, what design standards are applied, how much of the infrastructure meets them and what is the status of the remainder?<br>How frequently are problems encountered at present?<br>Are there currently identifiable rainfall thresholds beyond which problems are encountered?<br>Are there regional differences that provide any insight?<br>**Characterisation of shorter-term extreme rainfall events.**<br>What increased frequency of short-term extreme rainfall events, in excess of an identifiable level of significance, is to be expected?<br>**Assessment of Significance / Mitigation Options.**<br>What is the increased risk and does it merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*CIRIA standards and CoP RT/CE/C006 give guidance on drainage design. Given the age of much of the railway infrastructure a significant proportion of the network will not have been designed to meet these more recent requirements. Drainage that has been assessed to be inadequate will be upgraded to modern standards. However, modern standards need to be applied with loading based on return periods that are representative of the weather and climate for the expected lifetime of the asset, set against a baseline defined by predicted future rainfall.*<br><br>*In addition to design standard revision to reduce event frequency incident response and management measures will also merit attention, for example as regards the procedures for measuring and accounting for rainfall within the rail industry and responding to extremes.*<br><br>*Some modelling of events may be appropriate to determine future significance and determine the need for and justifiable costs of mitigation measures.* |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 1.2 | Excessive rainfall, leading to river inundation and flooding of permanent way. | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>How severe is the current risk?<br>What proportion of the network is expected to be affected by significant flooding in the future?<br>**Assessment of Significance / Mitigation Options.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*The initial requirement will be for better definition of the areas at risk, for example based on flood mapping such as provided by the Environment Agency (EA), taking account of predicted future levels of precipitation and sea level. In principle, such information could be overlaid on the rail network to identify areas at risk and develop a detailed picture of future flood incident severity and frequency. However, since the areas at primary risk should be identifiable without detailed modelling it may be better, in practice, to undertake an initial screening assessment to be followed up by targeted and more detailed studies of priority areas only. This should allow characterisation of the future vulnerability of the network.*<br><br>*Mitigation will evidently be essentially by means of incident response and management measures, as already developed for locations already identified as sensitive. Flood defence measures might also be of merit. Such measures will merit further attention and might include, for example, the development of rainfall related alert criteria for identified vulnerable locations.* |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 1.3 | Excessive rainfall giving rise to increased river flows, leading to mechanical scour of bridge supports, earthworks etc. and failure of structures | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem, based on information for identified scour susceptible bridges / structures?<br>For anticipated future peak rainfall and river flow events, what increase in scour damage to identified susceptible structures would be anticipated?<br>For anticipated future peak rainfall and river flow events, to what extent will additional bridges / structures become subject to significant risk.<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*Management systems are already in place to assess the condition of assets and to categorise their vulnerability to these hazards. A study has been carried out to generate the Scour Action database. This is a decision making tool that contains algorithms to predict assets at risk due to a given predicted rainfall, flood warning etc. and enables the appropriate action e.g. speed restrictions, monitoring or closure to traffic. This process has currently been piloted in Network Rail Eastern Region and will be considered for roll out to the whole network.*<br><br>*Design standards are also defined in respect of this hazard.*<br><br>*These measures for addressing the hazard may need to be extended to account for anticipated future peak rainfall and river flow events and the potential increase in scour damage to identified susceptible structures and the increase in the numbers of structures at risk. To this end, there may be a need to determine the increase in risk to the network from the anticipated future peak rainfall and river flow events.*<br><br>*The cost of management, associated with an appropriately targeted approach may be far outweighed by the cost of repair, replacement and disruption. An inspection regime that confirms asset condition at intervals appropriate to changes in weather and locations affected might usefully be considered*. |
| 1.4 | Flooding leading to failure of distribution of electricity supply to trains and Signalling, resulting in stranded or suspended rail services | **Recommendation: Better characterisation of network vulnerability.**<br>Supported by needs under scenarios 1.1 & 1.2.<br>**Significance / Mitigation**<br>What programmes are in place to provide better protection against the current level of risk?<br><br>*These systems are designed to fail to safety. Investigation of the significance of the threat posed by this scenario may be appropriate with measures to protect vulnerable sites being developed and implemented where this is considered necessary*. |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 1.5 | Excessive rainfall (perhaps linked to periods of extreme dryness) weakens shallow mine-workings leading to displacement of track, derailment and collision. Water table changes increase likelihood of collapse | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is current status of the problem, based on current information derived from existing management practices?<br>For anticipated future extremes, what increase in the scale of the problem is anticipated.<br>**Assessment of Significance / Mitigation.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*The impact of mine working in general has required the recent re-routing of the East Coast Mainline.*<br>*The frequency of events in this specific category and related to climate is currently thought to be less than three events in a year and are often detected before catastrophic events occur.*<br>*Mine working instability is related to significant changes in the weather such as the sudden onset of rain.*<br>*The anticipated cycle of drier summers and wetter winters is expected to cause a higher incidence of failures caused by this mechanism. Against this background, focused efforts to provide an improved characterisation of this hazard is appropriate.*<br><br>*The cost of management, associated with an appropriately targeted approach may be far outweighed by cost of repair, replacement and disruption. An inspection regime that confirms asset condition at intervals appropriate to changes in weather and locations affected might usefully be considered.* |
| 1.6 | Excessive rainfall and volume of water beyond design levels leading to degradation of the track formation | **No action.**<br>No action judged necessary – this is a routine maintenance issue and the assumption is that modest evolution of current procedures should be able to accommodate the future situation. |
| 1.7 | Excessive rainfall beyond design levels leading to flooding of tunnels.<br><br>Also risk of tunnel collapse associated with this weather feature. | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem, based on information for areas already identified as being at significant risk?<br>For anticipated future peak rainfall, what increase in tunnel flooding events in areas at risk would be anticipated?<br>For anticipated future peak rainfall, to what extent will additional areas become subject to significant risk.<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*Tunnels susceptible to this failure have been identified during recent flooding events and include Chipping Sudbury.*<br>*The anticipated future peak rainfall is considered to increase the risk due to flooding due to variations in the level of the water table.*<br>*Current management procedures remove these assets from use when flooding is detected.*<br>*Disruption to train running by these failures is costly and should be evaluated. In that context, this specific failure mechanism should be investigated and the significance evaluated.* |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 1.8 | Excessive rainfall giving rise to embankment instability & slip, leading to derailment or collision | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem, based on information for areas already identified as being at significant risk?<br>For anticipated future peak rainfall, what increase in embankment slip in areas at risk would be anticipated?<br>For anticipated future peak rainfall, to what extent will additional areas become subject to significant risk?<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*Management systems are in place to assess the condition of assets and to categorise their vulnerability to these hazards and to modify or suspend train running where appropriate. Work is planned to adapt the approach taken in the Scour Action database to generate the Earthworks Action Database. This will be a decision making tool that contains algorithms to predict assets at risk due to a given predicted rainfall, flood warning etc. and enables the appropriate action e.g. speed restrictions, monitoring or closure to traffic. Once successfully piloted in Network Rail Eastern Region, the method will be considered for roll out to the whole network.*<br><br>*These efforts may need to take account of the implications of climate change and to be extended if necessary to meet the new demands that may arise.* |
| 1.9 | Small amounts of rain giving rise to wet railhead leading to exacerbation of rolling contact fatigue failure of rails and wheels with potential for derailment and collision | **No action.**<br>Addressed by other programmes and no significant increase in future risk anticipated. |
| 1.10 | Lack of rain, reducing soil moisture, subsidence of permanent way leading to track misalignment, settlement of structures | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem, based on information for areas already identified as being at risk?<br>For anticipated future soil moisture reduction what increase in problems in areas already affected would be anticipated?<br>For anticipated future soil moisture reduction, to what extent will additional areas become subject to significant risk.<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*The geology associated with this mode of failure is believed to be understood and the locations at risk known. Management procedures exist to modify operations where gauge infringement has been identified. Future climate change may increase the level and extent of risk. The significance of the risk and potential future increase in risk has not been characterised.* |
| | | |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 2 | HAIL | **Common recommendation for all hail-related events: better characterisation of extremes to determine their significance**<br>What will extremes be? (Better definition required compared with general picture identified to date from UKCIP information that is inconclusive concerning potential change.)<br>Given that better understanding of extremes, is the change in risk significant? |
| 2.1 | Heavy hail storms leading to lack of visibility of signs, inappropriate use of speed, derailment, collision | See common recommendation for hail above. |
| 2.2 | Heavy hail storm reducing visibility below signal sighting distance, signals passed at danger, collision | See common recommendation for hail above. |
| 2.3 | Excessively vigorous storms and large hailstones, giving rise to equipment damage | See common recommendation for hail above. |
| | | |
| 3 | SNOW/SLEET/ICE | **Common recommendation for all snow-related events: at what stage, if any, might resources applied to mitigating these events be redirected to other areas?**<br>What specific mitigation measures are currently in place to address the identified snow / sleet / ice-related events?<br>What is the threshold frequency / intensity of events at which those mitigation measures would cease to be required?<br>On a regional basis, is climate change beyond the identified thresholds expected and on what time-scale?<br>Does this imply that resources allocated to these mitigation measures might be reduced and, if so, on what time-scale? |
| 3.1 | Heavy snow/high winds giving rise to snow drifts, blocked lines, stranded trains | See common recommendation for snow / sleet / ice above. |
| 3.2 | Fine powdered snow, ingestion into vehicle and trackside equipment - loss of function, traction or signalling | See common recommendation for snow / sleet / ice above. |
| 3.3 | Snow/sleet: signs not visible, inappropriate use of speed, derailment, collision | See common recommendation for snow / sleet / ice above. |
| 3.4 | Snow/sleet: visibility reduced below signal sighting distance, signals passed at danger, collision | See common recommendation for snow / sleet / ice above. |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 3.5 | Snow/ice, poor adhesion, ineffective braking (skid, loss of traction, wheel slide), signals passed at danger, collision, derailment | See common recommendation for snow / sleet / ice above. |
| 3.6 | Snow/ice, dead load in excess of strength of structure - station roof damage | See common recommendation for snow / sleet / ice above. |
| 3.7 | Icicles obscure tunnels or detach leading to vehicle damage | See common recommendation for snow / sleet / ice above. |
| 3.8 | Build up of ice leading to poor electrical connection with OHLE | See common recommendation for snow / sleet / ice above. |
| 3.9 | Build up of ice leading to failure of OHLE | See common recommendation for snow / sleet / ice above. |
| 3.10 | Ice build-up overloading light lineside structures leading to possible derailment and vehicle damage | See common recommendation for snow / sleet / ice above. |
| | | |
| 4 | FOG | **General recommendation: no action**<br>Moderately decreased future incidence and associated risk anticipated. |
| 4.1 | Fog obscures visibility of signs, inappropriate use of speed, derailment, collision | No action, as above for Fog in general. |
| 4.2 | Patchy fog, visibility reduced below signal sighting distance, signals passed at danger, collision | No action, as above for Fog in general. |
| | | |
| 5 | WIND | **Common recommendation for majority of wind-related events: better characterisation of network vulnerability to future extremes.**<br>What are the critical thresholds beyond which wind-related events are identified as significant?<br>What is the likely future incidence of events exceeding these critical thresholds?<br><br>*Preliminary indicative threshold wind speed levels that have a safety impact on current railway assets have been identified. These thresholds should be confirmed to provide a sound basis for determining the sensitivity of the network to wind. The occurrence across the network of wind speeds in excess of these thresholds should be determined and vulnerable assets identified.* |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 5.1 | Higher wind speeds, flying debris causing impacts and damage to vehicle and line-side equipment | See common recommendation for wind above. |
| 5.2 | Increased wind speeds or gusts, passenger rail vehicles overturning, collision | See common recommendation for wind above. |
| 5.3 | Increased wind speeds or gusts, freight vehicles overturning, collision | See common recommendation for wind above. |
| 5.4 | Increased wind speeds or gusts, overhead line out of alignment, torn down by pantographs, direct contact with 25kV | See common recommendation for wind above. |
| 5.5 | Increased wind speeds or gusts, damage to station roofs and exacerbated by pressures generated by increased pressures due to higher train speeds | See common recommendation for wind above. |
| 5.6 | Increased wind speeds or gusts, trees or other objects blown across the line, derailment | **Recommendation: to be addressed in part by vegetation management practices.** See item 10 below. Note that wind-blown objects other than trees may represent a threat and also that trees outside land owned by Network Rail may present risks to the railway. Such risks may need to be addressed through the common recommendation for wind above. |
| 5.7 | Sustained high wind speeds, sea waves that overtop sea defences, speed, direction, fetch | See scenarios under item 9 “SEA” |
| 5.8 | Sustained high wind speeds and gusts, speed restrictions and delay to services to counter vehicle instability | See common recommendation for wind above. |
| 5.9 | Sustained high wind speeds, wind pressures lead to bridge instability and possible failure fatigue on suspension bridges | See common recommendation for wind above. |
| | | |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 6 | TEMPERATURE | |
| 6.1 | High air temperature, giving rise to track buckling, derailment and collision | **Recommendation: better characterisation of network vulnerability to likely future extremes**<br>What are the critical thresholds beyond which these types of extreme temperature-related events are identified as significant?<br>What is the likely future incidence of events exceeding these critical thresholds?<br><br>*Management arrangements are in effect for this hazard see GO/RT3411; 5021; 5022 and RT/CE/S/011.*<br>*Those interviewed by the project were not aware of any research being carried out on the impact of anticipated changes in the weather.*<br>*Current track stressing regime would be able to accommodate rail temperatures of 53ºC air temperature 36ºC for track and formation in good condition. We understand that current rail stressing practices provide a wide margin of safety. An increase in maximum temperature in the region of 3ºC would not lead to a significant increase in risk.*<br>*Research should be carried out into the impact of anticipated diurnal temperature ranges on track in as specified condition and also track in the minimum acceptable state for service.* |
| 6.2 | High air temperature, increased demand of air conditioning equipment on power supply, trains stranded by failure of inadequate power supplies | **Recommendation: review of system capacity versus likely future demand**<br>What are the implications (on a regional basis) for increased power demand due to extreme temperatures?<br>Is that increase significant compared with current system capacity?<br>Is there a need for improved design standards to meet a required level of reliability?<br>Also are specifications for train air conditioning systems adequate to meet anticipated future demand?<br><br>*Current network capacity is most stressed in the South East with work in hand to improve security of supply. More modern trains will impose increasing loads on the supply system.*<br>*Current work to increase security of supply should be re-visited to ensure that the demands made on supply due to increased temperature have been considered.* |
| 6.3 | High temperatures giving rise to degraded signalling systems | **Recommendation: review of system reliability versus likely future environmental conditions.**<br>What are the temperature effects on signals – threshold temperatures for system degradation?<br>How often will these thresholds be breached?<br><br>*The most vulnerable signalling assets are considered to be those located within signalling centres. These are provided with air conditioning systems to prevent thermal overload of control systems. Systems are designed to fail to safety. Threshold values for failure are in the region of 40°C. On that basis the risk would appear low but may merit further consideration.* |
| 6.4 | Excessively high temperature leading to diesel engine overheating (electric traction failure)? | **Recommendation: review of system reliability versus likely future environmental conditions.**<br>At what threshold temperature do problems occur?<br>How often will these thresholds be breached?<br><br>*For the expected increase in temperature, this is not thought to present a significant increase in risk for cooling systems that are designed and maintained to a good standard. This general conclusion may merit confirmation.* |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 6.5 | Low temperature, points frozen in one position leading to derailment and collision | **Common recommendation for low temperature-related events analogous with those for snow / sleet /ice: at what stage might resources applied to mitigating these events be redirected to other areas?** |
| 6.6 | Low temperature leading to ineffective diesel engine starting systems | See common recommendation for low temperature under Scenario 6.5 above. |
| 6.7 | Low temperature leading to brittle fracture of rail and steel structures leading to derailment and collision | See common recommendation for low temperature under Scenario 6.5 above. |
| 6.8 | Low temperature, leading to freezing of brake mechanisms | See common recommendation for low temperature under Scenario 6.5 above. |
| | | |
| 7 | LIGHTNING | |
| 7.1 | Lightning strikes, leading to disruption of electronic signalling systems e.g. axle counters electromagnetic compatibility of railways | **Recommendation: better characterisation of system sensitivity.**<br>What will the extremes be? (Better definition is required compared with general picture identified to date from UKCIP information that is inconclusive concerning potential change.)<br>How sensitive is the system? - review outcome of current programme on electromagnetic issues when results become available.<br>Given that better understanding of extremes, is the change in risk significant?<br><br>*Procedures exist to manage rail operations when information provided by devices including track circuits and axle counters is defective. These procedures lead to delays by reducing running speeds or suspending services.*<br><br>*A current programme is being considered to generate EMI maps of the infrastructure and models EMI from rail vehicles The prediction of coupling methods could usefully be extended to include weather generated electromagnetic issues.*<br><br>*It is considered that more intense electromagnetic but more infrequent storms could be more disruptive to the network than storms of the current intensity and frequency. Further work to confirm the nature of future lightning storms would be appropriate to determine whether that is indeed likely to be the case. In the light of improved information on EMI effects associated with lightning, the impact of electromagnetic pulses generated by lightning on the railway should be assessed and methods of mitigating these risks developed as appropriate.* |
| 7.2 | Lightning strike leading to collapse of structures or trees | **No specific action**<br>Can be covered more specifically under vegetation management. Lightning strike on its own is not expected to be a major contributor to increased risk above other factors (e.g. wind combined with heavy rain etc). |
| | | |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 8 | INSOLATION | |
| 8.1 | Less cloud cover leading to more periods of direct sunshine, glare leading to driver impaired vision and misreading signals, Signals passed at danger | **No action**<br>Not an identified priority risk, provided it is adequately addressed by current measures for provision of well-placed signals. (Note that, to some extent, insolation will influence the incidence of high temperatures and it is assumed that these impacts are covered under Item 6 above.) |
| | | |
| 9 | SEA | |
| 9.1 | Increased average sea level and effect of wind, leading to exposure of vulnerable structures and vehicle components and corrosion | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response, if any.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem – what is the scale of impact for areas that can be identified as currently exposed?<br>If that impact is identified as potentially significant, how large an increased area might be affected in the future?<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*The current UK network has significant sections of track in potentially vulnerable locations. The extent to which the impact may be significant in areas currently identified as exposed to these effects has not been well characterised at present.* |
| 9.2 | Increased sea level and effect of wind (storm), leading to exposure of vulnerable coastal defences, (changes in surge, wave height, deep depression, wind direction, fetch) | **Recommendation: Better characterisation of the scale of the problem with a view to determining appropriate mitigation response.**<br>**Characterisation of network vulnerability.**<br>What is the current status of the problem, based on information for areas already identified as being at significant risk?<br>For anticipated future rise in average sea level and future wind conditions, what increase in events in areas at risk would be anticipated?<br>For anticipated future conditions, to what extent will additional areas become subject to significant risk.<br>**Assessment of Significance.**<br>Does the increased risk merit additional mitigation measures?<br>What measures are available and how cost-effective are they?<br><br>*The current UK network has significant sections of track in vulnerable locations.*<br>*Current procedural mitigation measures are limited to short range (2-3 days in advance) weather forecasts being considered by Infrastructure Controllers and may be inadequate to accurately predict these events.*<br>*Flood defences currently in place may be unable to cope with the increased severity of future events.*<br>*An assessment to identify the adequacy of current measures against this risk is considered appropriate. The assessment should have regard to the increased threat to areas already identified as vulnerable and the additional areas that might be affected in the future for the anticipated sea levels, wind directions and windspeeds.* |
| | | |

| ID | Risk Scenario | Research Needs |
|---|---|---|
| 10 | VEGETATION | |
| 10.1 | Increased temperatures throughout the year, increased winds, increased vegetation mass due to longer growing season and levels of leaf fall, leading to low adhesion and ineffective braking - (skid, loss of traction, wheel slide/spin) and leading to signals passed at danger | **Recommendation: better characterisation of system vulnerability and ability of available measures to address the risk.**<br>To what extent might the associated risk increase?<br>Can improved vegetation management practices, such as those required to meet the current level of risk, meet future requirements?<br>If not, what other measures might need to be taken?<br><br>*Significant efforts are already underway to address risks associated with vegetation, given the current level of risk to the system. Provided that these measures can address the future risk, the measures already in hand may adequately deal with this risk in the future.*<br>*Review of the ability of such measures to meet likely future needs is therefore appropriate.*<br>*Note that a major part of this work might be accommodated within current vegetation management programmes within Network Rail, perhaps supplemented by additional research efforts elsewhere.* |
| 10.2 | Increased temperatures throughout the year, increased vegetation growth, obscuring of signals and leading to signals passed at danger. | **Recommendation: evolution of vegetation management practices with evolution of climate change and associated impacts on vegetation**<br>Develop improved general awareness of anticipated impacts and timescale.<br>Develop programme to monitor changes.<br>Implement revised vegetation management practices to meet new growth characteristics.<br><br>*The general comments under 10.1 apply. It is expected that management practices will be able to address future risks.* |
| 10.3 | High temperature and low moisture, plants do not survive and earthworks susceptible to collapse, derailment collision | **No action**<br>Not expected to be a problem – vegetation is expected to adapt to meet new climatic conditions |
| 10.4 | High temperature and low moisture leading to desiccated vegetation and line-side fires | As for Scenario 10.2. |
| 10.5 | Fauna, rabbits, badgers, teredo navalis beetle, marine bacteria - collapse of earthwork embankments, cutting structures, accelerated low water corrosion of steel 120 to 7 years | **Recommendation: better characterisation of vulnerability**<br>Are there any increases in impacts associated with these factors that would not be identified and addressed by existing management systems?<br>*Management systems are in place to assess the condition of assets and to categorise their vulnerability to hazards caused by animals.*<br><br>*Assessment, prediction and testing of effect of changing types and numbers of land, fresh water and sea creatures should be carried out, considering the potential impact on railway infrastructure for a range of predicted levels of precipitation, types of habitat, availability of food sources and ranges of air, land, river and sea temperatures.*<br>*The impact that changing fauna has on the railway network should be assessed and mitigation methods developed where there is a significant impact. New structures should be designed and existing structures reworked in line with standards that incorporate resistance to these hazards, if necessary.* |

# 7 Research Programme Recommendations

The previous section has sought to summarise the research recommendations in respect of the various identified risk scenarios. We now consider how this set of proposed initial research needs may be structured in to a coherent programme.

We identify distinct aspects to the recommendations as follows:

- Involvement of the rail industry in UK climate change impact research programmes;
- Extension of existing rail safety research and hazard management programmes to meet future requirements in respect of climate change;
- Development of specific new research efforts, where appropriate, to meet identified technical information needs and related hazard management activities.

These different aspects of the research recommendations are discussed in turn below. Consideration is then given to supporting efforts relating to the assessment of hazard significance and how resource allocation might be prioritised. Finally we consider organisational aspects of future research needs.

## 7.1 RAIL INDUSTRY INVOLVEMENT IN CLIMATE CHANGE IMPACTS RESEARCH

Currently UK climate change impacts research is focused around the UK Climate Impacts Programme (UKCIP). This organisation acts to some extent as a 'matchmaker' linking groups with common interests and possible work programmes in order to ensure that future climate impacts research is carried out in an orderly manner.

The recent publication of 'Building Knowledge for Changing Climate', a research needs statement from the EPSRC and UKCIP, contains a section on transport research needs. This represents an opportunity for the railway industry to enter discussions that could shape the nature of any future research programme. In this context we note Network Rail's involvement in the recently established "CRANIUM" project, concerning embankment stability.

In addition to this there are significant opportunities for the railway industry to engage with UKCIP to allow common linkages between organisations to be identified and expanded upon. This could allow further climate change impacts research of relevance to multiple parties to be carried out in a more cost effective manner.

In this context we note the previous involvement of Network Rail Managers in the relevant areas, for example with the CRISP working group, with UKCIP and DEFRA workshops and in the development and implementation of this programme.

In this respect there are a number of areas where the railway industry might usefully shape future research:

- ***Research in to impacts on the built environment.*** Possibly in conjunction with other partners with common interests, the railway industry is in a position to take part in works that actively influence the development of the impacts model, allowing more precision of impact assessment. This could deliver more useful data, although there are still questions as to the certainty that the current climate model can deliver, especially on the geographical resolutions that might be required for precise determination of impacts on the railway system. There is evidently scope for joint research with other infrastructure managers, for example the Highways Agency in respect of common civil engineering structures.
- ***Improved climate modelling.*** Uncertainty is inherent in climate and climate change modelling work. Although UKCIP provides predictions with current resolutions of 50 km squares, with the potential for the model to produce data at 10 km square resolutions, UKCIP suggest that reasonable confidence can be placed only if regional trends are used as a guide. An indication of the relative confidence level for various predictions has been provided by UKCIP (see Appendix 6). The Hadley Centre is currently undertaking further investigation in to methods of improving uncertainty and of presenting it in terms of probability distribution functions. There is potential benefit for the railway industry in guiding future generic climate modelling efforts, where there is currently uncertainty in aspects of climate change that relates to significant hazards. The railway industry could utilise the existing models to test threshold levels deemed important within the industry, in respect of identified hazardous extreme events. However communications with the Hadley Centre have suggested that this type of bespoke work would need to be ‘fitted in’ with ongoing work programmes. Further communications with the commercial department of the Hadley Centre are expected to deliver a more comprehensive understanding of how this might be achieved. This type of work may not generate new knowledge but rather it would use existing technology to estimate likely impacts on specific scenarios fed into the model. It is thought that this approach would be likely to deliver useful results cost effectively. However there could be limitations due to the inherent restrictions associated with use of a model not expressly designed for these needs. Improvements in modelling capability specifically in respect of extremes relevant to hazards on the railway may be beneficial.

The general recommendation is therefore for railway industry involvement with UKCIP and EPSRC research programmes, guiding future research efforts towards those areas of most practical value to the industry. In addition, there may be scope for collaboration with other organisations that may encounter similar hazards.

A significant component of this work is likely to be covered within government-funded programmes and the anticipated input from the railway industry would be in the form of steering those programmes towards issues of importance to the railway. This would be expected to be the case at least in respect of the more generic elements of both climate change modelling and built environment impacts assessment. The associated costs may therefore be relatively modest, although, any more rail industry specific aspects of research into impacts on the built environment may need to be directly funded by the industry.

The recommendation in this respect is therefore to establish a link between the rail industry and its generic needs for improved climate change information, other parties with similar interests and the current climate change impacts programmes, as coordinated by UKCIP.

## 7.2 LINKS TO EXISTING PROGRAMMES

As identified in Section 6, there are a number of areas where significant efforts within Network Rail are already being made to address climate related hazards (e.g. embankment collapse, scour, vegetation management). There will evidently be benefit in linking future efforts to address climate change related risks to these on-going programmes.

In some areas, for example, the rain related risk scenarios of embankment collapse and scour, on-going efforts towards characterisation of risk scenarios, in terms of the relationship between the weather event and its impact and towards development of risk management measures, will obviously be of direct relevance to addressing any increased risk from these hazards arising from climate change. In this respect, new research programmes may not be required to be undertaken and the existing programmes, with minor adjustment only, may be able to address climate change related needs.

In these areas, a key climate change related research need is an improved definition of the scale of impacts arising from future climate change. Knowledge within these existing hazard management programmes may assist in the specification of the requirements of more detailed climate change impacts research programmes.

Review of Rail Safety and Standards Board research and other research programmes has identified that other potentially relevant research is currently under way and due to report soon. Potentially relevant research includes the following:

- Theme 1 – Vehicle-track interaction: Overturning in high winds; Train aerodynamic stability in high winds; Wind loading on trains; Adhesion Management.
- Theme 4 – Infrastructure integrity: Flood risk to railway structures; Overhead line equipment mechanical failure modes; Prediction of bridge scour.
- Theme 8 – Abnormal and degraded working, contingency planning: Failure of train control systems; Gaining a greater understanding of abnormal working.
- Theme 16 – Safety management systems: A systematic approach to safety management on the railways; Standards setting process; Wider sources of safety intelligence; SMIS review.

The possible benefits of linking on-going research to these other programmes may merit consideration.

Provided that climate change aspects related to existing weather-related hazards can be integrated in to existing safety research and hazard management programmes under way within the industry, additional costs associated with this element of the research needs should be limited. For example, we anticipate that vegetation risk mitigation issues might be addressed largely by current vegetation management programmes within Network Rail, perhaps supported by specific research efforts outside Network Rail.

However, we identify a need for coordination with these other programmes. Although some elements of other work have been identified as part of the current initial climate change research programme, as yet there has been no systematic attempt to identify all potentially relevant work, determine its value to future climate change research and identify how it might be utilised within an integrated programme. Accordingly, the recommendation in this respect is a systematic assessment of other work programmed to address these needs. In this context we note, for example, the possible benefits to be gained through links with European research, both in respect of climate change and the railway system, through UIC or ERRAC.

## 7.3 SPECIFIC ADDITIONAL RESEARCH RECOMMENDATIONS

A number of specific and focused new research requirements can be identified, in some cases linked to existing programmes. A common theme is the need for better characterisation of the threat to the system, for example in terms of the thresholds at which a weather-related factor may have a significant impact upon the railway and the frequency with which that threshold may be breached.

In the preceding sections, risks to the rail industry that can be described in terms of critical thresholds have been identified (e.g. generically in the case of wind and temperature and perhaps on a more location specific basis for flood risk). The Hadley Centre's model[8] is able to predict the likely frequency of threshold breach if critical values are provided. One identified research need is therefore for relevant critical threshold values to be identified and provided to the Hadley centre for analysis, requiring specific technical inputs first in respect of railway safety and second in respect of climate change. For flood risk, specific analysis beyond initial climate predictions may be required in order to characterise the risk, taking account of location specific factors.

A further common theme is the need for evaluation of risk mitigation measures and the evaluation of risk significance. (Some aspects of this latter issue are considered in the following section.)

Specific projects would need to be established to address these needs and appropriate budgets identified. We suggest that projects might best be established on the basis of hazard themes. Primary themes identified from this study may be summarised as follows:

- Excess rain related impacts, covering different aspects of flooding, scour; embankment instability; tunnel collapse;
- Settlement arising from reduced moisture;
- Wind related impacts;
- Impacts arising from extreme temperatures;
- Sea related impacts.

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[8] UKCIP uses this model to establish likely future trends

As a somewhat lower priority, snow, ice and low temperature related impacts might be considered.

## 7.4 ESTABLISHING HAZARD SIGNIFICANCE

In the initial stages of this research programme, reference was made to the potential use of SMIS and TRUST data in assessing the significance of weather-related hazards. Initial work focused on SMIS data, as reflected in the Safety Risk Model, and identified that weather-related hazards represent a non-trivial contributor to the total system risk. Further work has been undertaken in this area, investigating first TRUST and second accident precursor indicators, the latter being compiled by the Rail Safety and Standards Board from SMIS information.

***TRUST***

The Rail Safety and Standards Board, Safety Intelligence Centre provided textual records abstracted from daily National Incident Report (NIR) logs and selected by association with weather key words.

The scope of the study is any area subject to the reporting regime that supports NIR.

Four months were chosen arbitrarily to represent the seasons. These were April 2002 – Spring; July 2003 – Summer; October 2002 – Autumn; January 2003 – Winter.

The relative delay caused by each weather-associated failure has been calculated and these are displayed in four charts, presented in Appendix 7. These reinforce the traditional view of the variation in weather effects between each of the seasons.

The results of the research are summarised in Table 4 below:

**Table 4: Indicative Seasonal Weather-related Delays and Costs**

| Season | “Spring” | “Summer” | “Autumn” | “Winter” |
|---|---|---|---|---|
| TRUST mins. | 2652 | 43,714 | 215,423 | 120,474 |
| Proportion of total delays | 0.005 | 0.063 | 0.214 | 0.106 |
| Indicative cost | £132,600 | £2,185,700 | £10,771,150 | £6,023,700 |

Indicative cost here is based on a notional average cost of £50 for one TRUST delay minute.

Some of the narrative explains the cause as a selection of similar descriptions that include exceptional, extreme and severe weather, but does not mention the specific weather type concerned e.g. wind, rain, snow etc. This type of input has been categorised by the project as “Weather!”, Other narrative records, coded by the project as "- not defined" describe a failure e.g. lack of adhesion at the time reported, but the weather related failure mechanism had yet to be investigated e.g. leaf fall suspected but not confirmed.

NIR records returned from this type of analysis could be improved by the use of a limited set of keywords to describe the weather type that has created the failure.

The TRUST records returned, do however, give a useful indication of weather related failures, the proportion of disruption each failure type presents compared to other weather related failures and the proportion of weather related delays compared with the total of all delays within a period. The accuracy of the delay minutes allocated to each entry can be considered to be good as it is a contractual vehicle for reclaiming costs for delay within the industry.

The year on year cost of weather related delays assists with the business case for making investment to improve asset condition and management arrangements to ensure that mitigation against failure is effective.

A more rigorous analysis of data provided by this route would indicate the impact of weather related failures in terms of disruption and cost on a month by month, season by season and year by year basis.

These trends could help direct new streams of research and give confirmation to those programmes already in process.

***Accident precursor indicators***

At our request, the Rail Safety and Standards Board have generated a Quarter 3 Safety Performance Report that allows review of the information that the current systems can provide. The section on Railway Group Safety Plan Objective 2a in respect of Catastrophic Risk, discusses the train accident precursor indicator model and improvements in the way that the environmental factors precursor is measured. The output is presented in Appendix 8. The moving average for the current indicator has increased, in part, due to an increase for Quarter 3 in the environmental factors group to 84% above a benchmark in 1997/98.

The Environmental Factors precursor represents a proportion of 6% of train accident risk and has been allocated 1.462 equivalent fatalities.

The chart entitled "Environmental factors annual moving average" displays data from period 1, 1997/98 to period 10, 2002/03, and demonstrates interesting national trends as follows:

The number of flooding incidents has two broad based peaks, one commencing around August 1998 and the second around August 2000. The first peak has a local maximum of around 54 incidents and the second around 68. These are obviously related to periods of intense rainfall. The increased number of incidents may be caused by heavier rainfall in autumn 2000 and a combination of more drainage assets reaching a threshold value for flow beyond which they become ineffective, or that the assets involved have not received adequate maintenance.

The correlation of trains running into obstructions (weather) has a good correlation with the flooding map and hence rainfall. This may reflect an increased instability of trees following the rapid onset of rain in autumn compounded by the effect of wind.

The rail adhesion (non SPADs) line exhibits a general inverse relationship to the flooding graph with local flat-topped peaks corresponding to the reduced rainfall pattern between August 1999 and June 2000. Rail adhesion incident numbers were locally depressed during the rainfall peaks of the season associated with August 1998 and August 2000. This could imply a mechanism where increased rainfall prevents leaves from reaching the railhead or contributes to them being cleared from it.

The report also displays a chart titled “Flooding and landslips- annual moving average”. The correlation of the peaks and troughs in the graphs is close. The landslip line demonstrating a delay following abrupt increases and decreases in the flooding trace. This helps demonstrate the complex nature of landslips and the build up of ground water at any given site until the embankment becomes unstable.

The presentation of data in such a way can lead to a simplistic yet direct inference of cause and effect. This could be used to better direct more detailed research programmes.

***Conclusions***

The main conclusions that we draw are that these management information systems might usefully be used as a mechanism for assessing hazard significance and in determining appropriate allocation of resources to risk mitigation. We recommend that further work be undertaken in this area. We identify two aspects that deserve attention. In the first instance, using existing data to establish priorities. Second, identifying improvements to data capture within the existing information systems to ensure that the weather-related events are recorded in an appropriate manner that facilitates this risk prioritisation process.

## 7.5 PROGRAMME ORGANISATION

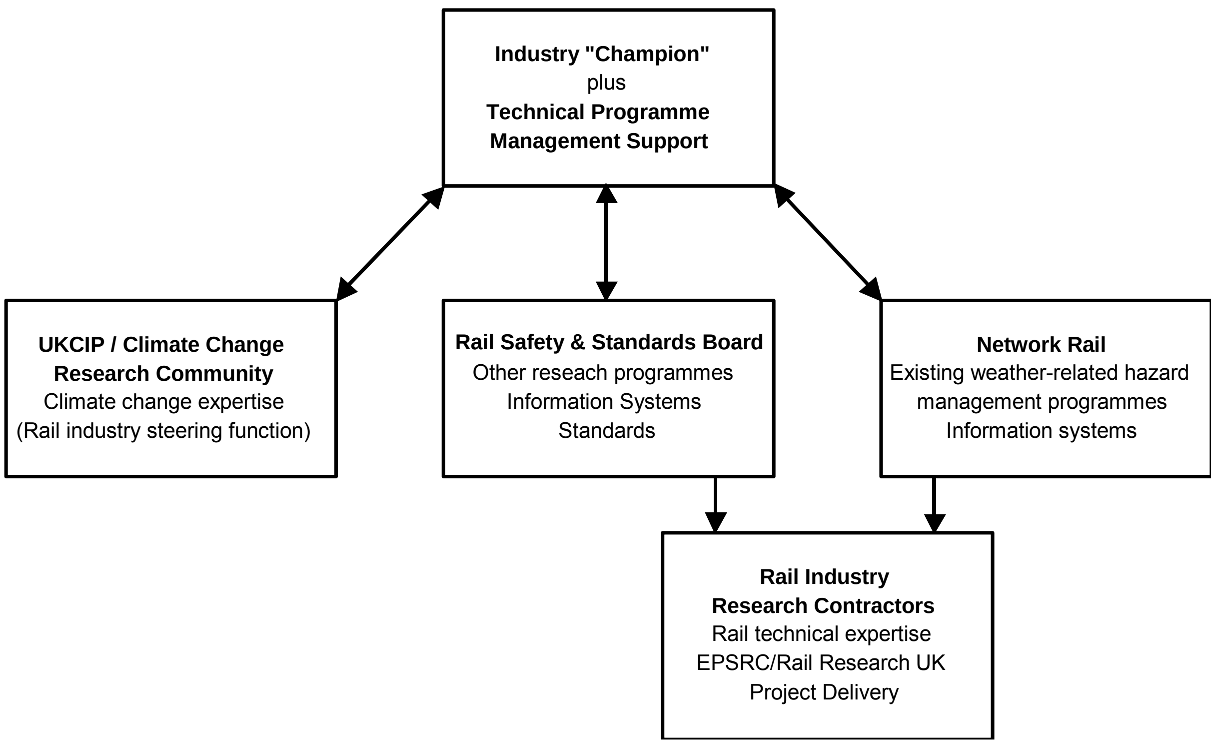
An effective programme to meet the identified research recommendations will require interdisciplinary inputs from a range of organisations both within and outside the railway industry and coordination of existing and new research projects. Organisations to be involved will include the following:

- UKCIP and the associated climate change research organisations, with railway industry representation steering the direction of effort towards areas of practical importance to the industry;
- Network Rail, providing support in particular in respect of on-going technical programmes that address current weather-related hazards, relevant information systems (TRUST) and further input professional engineering expertise where

appropriate and strengthening commitment of management and engineers to tackle relevant threats;
- The Rail Safety and Standards Board, with interests relating to potential links to existing climate-related safety research, the initiation of new research projects, safety related information systems (e.g. SMIS) and standards;
- Rail industry contractors providing appropriate technical expertise;
- The Strategic Rail Authority, taking a broad view concerning the significance of the impact of climate change on the operation and safety of the railway in the longer term.

We have noted previously the perceived need for a coordinated approach across the industry and some leadership and focus. We currently envisage that nomination of a “champion” from the rail industry, supported by some coordinating technical programme management unit could effectively meet this particular need and those arising from the diverse nature of the research requirements. This basic organisational structure is summarised in Figure 4, below. It is proposed that these issues be given further consideration by representatives of the rail industry with a view to developing a more detailed specification for the organisational requirements.

**Figure 4: Outline research programme organisational structure**




The recommended initial work packages identified earlier in this section may be summarised as follows:
- A programme to coordinate links between the rail industry and climate change impacts research;
- Work to provide for the systematic identification of complementary programmes already underway within the rail industry and their future support roles;

- Hazard theme related technical research programmes:
    - Excess rain related impacts, covering different aspects of flooding, scour; embankment instability; tunnel collapse;
    - Settlement arising from reduced moisture;
    - Wind related impacts;
    - Impacts arising from extreme temperatures;
    - Sea related impacts.
- Information systems related activities.

As regards phasing and costs, the first two activities will need to be undertaken initially, to establish relevant sources of information and supporting effort. There is a need to establish what information can be accessed immediately from current climate change research and what may be available only after a more extended period of generic research. Nominally we allocate costs of the order of £50k to the first activity in the first year and £30k to the second activity.

As regards the hazard theme related technical work, the initial phase of work would follow the first two activities and be focused primarily at better characterisation of the risk scenarios, probably with a subsequent phase directed towards hazard management / risk mitigation. The programme might be spread over a period of two to three years and there may be some benefit in initiating work in some areas first and leaving others until later, enabling experience to develop during the course of the programme and linking to other projects as appropriate. Phasing may be influenced by the availability of basic climate change information that should be clarified by the initial activities, identified under the first element of the programme. Nominally we allocate of the order of £50-100k to each phase of each theme. For each of the excess rain related issues, given that the climate element is common, this theme might be taken as a single project within the programme and cost slightly more than this nominal figure. On that basis the approximate cost would be of the order of £300k for each year of the 3 year programme. Additional technical programme support would be required throughout the programme.

The phasing of the final activity is not linked specifically to any of the other activities. The nominal cost we allocate to this component of the programme is £50k.

We have not addressed the allocation of funding responsibilities but recognise that different aspects of the required response to climate change impacts might be identified as directed more or less to safety or operational management and that this may influence decisions concerning the most appropriate source of funding.

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# Appendix 1
# List of Contacts

The following contacts have been consulted in the course of this work. Their views and recommended documents have been incorporated into the main text of this report.

| Name | Organisation | Contact Details |
|---|---|---|
| Peter Bates | Engineering and Physical Science Research Council | 01793 444338 |
| Dr. Abigail Bristow | Institute of Transport Studies | 0113 343 5342 |
| Dr. Sebastian Catovsky | Defra | |
| Dr. Richenda Connell | United Kingdom Climate Impacts Programme (UKCIP) | 01865 432 076 |
| Michelle Francis | Network Rail | 020 7557 8972 |
| Julie Gregory | Network Rail, Great Western Region | 01793 499163 |
| Prof. Robert Lowe | Leeds Metropolitan University, Centre for the Built Environment | 0113 283 2600 Ext. 4047 |
| Dr. Geoff Levermore | Centre for Built Environment, UMIST | |
| Ian Meadowcroft | Environment Agency | |
| Simon Price | Highways Agency | |
| Carlton Roberts Jones | Institute of Highways and Transportation | 020 7387 2525 |
| Prof. Austin Smyth | Napier University | 0131 455 5121 |
| John Turnpenny | The Tyndall Centre, University of East Anglia | |
| Dr. Paul Van der Linden | The Hadley Centre, Bracknell | |
| Karl Kitchen | Consultancy Account Manager, Met Office | 01344 856322 |
| John Dora | Network Rail HQ | 0207 577 8987 |
| Eifion Evans | Network Rail HQ | 0207 577 8370 |
| Quentin Phillips | Network Rail HQ | 0207 577 8714 |
| Steve Scott | Network Rail HQ | 0207 577 8066 |
| John Stothard | Network Rail HQ | 01332 262716 |
| Neil Strong | Network Rail HQ | 07876 578848 |
| Lynne Docherty | Network Rail Scotland | 0141 335 3500 |

# Appendix 2
# Reference List of Documents on Climate Change

The following key documents have been identified during the course of the review and are recommended as primary sources of information for ongoing studies.

| Author | Year | Title | Comment |
|---|---|---|---|
| Adger, Huq, Brown, Conway, Hulme – The Tyndall Centre | 2002 | Adaptation to Climate Change: Setting the Agenda for Development Policy and Research | A summary of a one day workshop that intended to facilitate the integration of the development and climate change communities. Useful conceptual material. |
| DETR | 2000 | Potential UK Adaptation Strategies for Climate Change | Identifies likely impact base on UKCIP 98 scenarios and indicates steps that would need to be taken for adaptation to occur. Also indicates likely costs. |
| Graves and Philipson BRE | 2000 | Potential implications of climate change in the built environment | Describes climate change impacts on the built environment, and possible adaptation routes. Does not link adaptation strategies to mitigation strategies. |
| IPCC | 2001 | Climate Change 2001: Impacts, Adaptation and Vulnerability, Technical report of working group II | Global analysis of likely scenarios of global climate and weather patterns expected to 2080. IPCC are the leading global climate change impacts research organisation. UKCIP (see above) provide data to the IPCC so UKCIP and IPCC scenarios should be seen as compatible. |
| Lowe, Leeds Metropolitan University | 2001 | A review of Recent and Current Initiatives on Climate Change and its impact on the Built Environment | Presents some impact assessment and indicates possible responses from the construction sector as a whole. Also prioritises adaptation actions in accordance with magnitude of impact and rates of response. |

| Author | Year | Title | Comments |
|---|---|---|---|
| United Kingdom Climate Impacts Programme (UKCIP) | 1998 and 2002 | Climate Change Scenarios for the United Kingdom, | Provides authoritative scenarios for the UK based on data from the Hadley Centre's Global Circulation Model. |
| United Kingdom Climate Impacts Programme (UKCIP) | 1998 - 2002 | Regional Assessments of Climate Change in the United Kingdom | Estimate likely impacts of climate change on the regions of the United Kingdom. Clearly identify sectoral impacts of significance for each region. Areas covered include: London, the South East, Wales, the East Midlands, the North West, Scotland, Yorkshire and Humber and Northern Ireland. |
| United Kingdom Climate Impacts Programme (UKCIP) | 2000 | Climate Change: Assessing the impacts – Identifying responses | Summary of first three years of UKCIP activity. Explains rationale and methodology of UKCIP's work, and expected outputs. |
| United Kingdom Climate Impacts Programme (UKCIP) | 2002 | REGIS: Regional Climate Change Impact and Response Studies in East Anglia and North West England | Combines regional and sectoral analyses of climate change impacts. Currently only complete for north west England and East Anglia. However it is believed that further work is intended. |
| Wilson and Burtwell, TRL Ltd | 2002 | Prioritising Future Construction Research and Adapting to Climate Change: Infrastructure (Transport and Utilities) | Funded by the Construction Research and Innovation Strategy Panel (CRISP), an industry led group. Clearly identifies areas of increased risk for rail operators. |

# Appendix 3
# Results of Preliminary Analysis of the SRM

## Table A3.1: Summary of System Risk and Weather Related Precursor Contributions

| Hazardous Event | Description | Contribution to Total Risk | Frequency of Precursor Event | Precursor Contribution to HE Risk | % | Precursor Contribution to Total Risk |
|---|---|---|---|---|---|---|
| HET-1 | Collision between two passenger trains (other than in stations) | 5.81 | 2.61 | 1.28 | 22.09 | 0.05 |
| HET-2 | Collision between a passenger train and non-passenger train | 1.19 | 5.13 | 0.14 | 11.92 | 0.01 |
| HET-3 | Collision between two non-passenger trains | 0.08 | 2.52 | 0.00 | 5.29 | 0.00 |
| HET-4 | Collision of train with object on line (Not resulting in derailment) | 0.31 | 6.24E-08 | 0.12 | 38.35 | 0.00 |
| HET-6 | Collision between two passenger trains in station (permissive working) | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 |
| HET-9 | Collision with buffer stops | 1.17 | 2.07E-08 | 0.26 | 22.11 | 0.01 |
| HET-10 | Passenger train collision with road vehicle on level crossings | 6.12 | 7.74E-09 | 0.56 | 9.12 | 0.06 |
| HET-11 | Non-passenger train collision with road vehicle on level crossings | 0.93 | 7.74E-09 | 0.08 | 9.12 | 0.01 |
| HET-12 | Derailment of passenger train | 4.32 | 1.79E-08 | 1.46 | 33.80 | 0.04 |
| HET-13 | Derailment of non-passenger train | 2.93 | 5.86E-07 | 1.18 | 40.17 | 0.03 |
| **Totals** | | **23.01** | **10.25** | **5.09** | | **0.21** |
| | Total Network Risk | 137.874 | | | | |

## Table A3.2: HET – 1 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| **PMJEC2+.PHJ** | **PT driver misjudges environmental conditions and passes signal at junction OL200+ - D** | 1.14925E-07 | 0.1892 | 3.3 |
| PMJEC2+.PPJ | Prob train passes OL given PT SPAD due to driver misjudging environmental conditions at junction OL200+ - D | 0.054435484 | 0.1892 | 3.3 |
| WVEGON<2PEJ | Vegetation on track causes PT SPAD at junction OL<200 - D | 2.22436E-08 | 0.1734 | 3.0 |
| WVEGON<2PPJ | Prob train passes OL given PT SPAD due to vegetation on track at junction OL<200 - D | 0.791666667 | 0.1734 | 3.0 |
| PMJEC<2.PHJ | PT driver misjudges environmental conditions and passes signal at junction OL<200 - D | 3.70726E-08 | 0.09809 | 1.7 |
| PMJEC<2.PPJ | Prob train passes OL given PT SPAD due to driver misjudging environmental conditions at junction OL<200 - D | 0.26875 | 0.09809 | 1.7 |
| WVEGON2+PEJ | Vegetation on track causes PT SPAD at junction OL200+ - D | 1.76095E-08 | 0.08408 | 1.4 |
| WVEGON2+PPJ | Prob train passes OL given PT SPAD due to vegetation on track at junction OL200+ - D | 0.157894737 | 0.08408 | 1.4 |
| PMJEC<2.PHPL | PT driver misjudges environmental conditions and passes signal on pln line OL<200 - D | 1.43656E-08 | 0.0417 | 0.7 |
| PMJEC<2.PPPL | Prob train passes OL given PT driver misjudging environmental conditions and on pln line OL<200 - D | 0.548387097 | 0.0417 | 0.7 |
| WVEGON<2PEPL | Vegetation on track causes PT SPADs on pln line OL<200 - D | 6.95112E-09 | 0.02208 | 0.4 |
| WVEGON<2PPPL | Prob train passes OL given PT SPAD due to vegetation on track on pln line OL<200 - D | 0.6 | 0.02208 | 0.4 |
| PMJEC2+.PHPL | PT driver misjudges environmental conditions and passes signal on pln line OL200+ - D | 5.88528E-08 | 0.01905 | 0.3 |
| PMJEC2+.PPPL | Prob train passes OL given PT driver misjudging environmental conditions and on pln line OL200+ - D | 0.086614173 | 0.01905 | 0.3 |
| WVEGON2+PEPL | Vegetation on track causes PT SPADs on pln line OL200+ - D | 3.79994E-08 | 0.01385 | 0.2 |
| WVEGON2+PPPL | Prob train passes OL given PT SPAD due to vegetation on track on pln line OL200+ - D | 0.097560976 | 0.01385 | 0.2 |
| WOENC<2.PEJ | Other environmental conditions eg oil, ice etc on track causes PT SPAD at junction OL200+ - N | 0 | 0 | 0.0 |
| WOENC<2.PPJ | Prob train passes OL given PT SPAD due to other environmental conditions on track at junction OL<200 - N | 0 | 0 | 0.0 |
| WOENC<2.PEPL | Other environmental conditions eg oil, ice etc on track causes PT SPADs on pln line OL<200 - N | 0 | 0 | 0.0 |
| WOENC<2.PPPL | Prob train passes OL given PT SPAD due to other environmental conditions on track on pln line OL<200 - N | 0 | 0 | 0.0 |
| WOENC2+.PEJ | Other environmental conditions e.g. oil, ice etc on track causes PT SPAD at junction OL200+ - N | 0 | 0 | 0.0 |
| WOENC2+.PPJ | Prob train passes OL given PT SPAD due to other environmental conditions on track at junction OL200+ - N | 0 | 0 | 0.0 |
| WOENC2+.PEPL | Other environmental conditions eg oil, ice etc on track causes PT SPADs on pln line OL200+ - N | 0 | 0 | 0.0 |
| WOENC2+.PPPL | Prob train passes OL given PT SPAD due to other environmental conditions on track on pln line OL200+ - N | 0 | 0 | 0.0 |
| Total | | 2.605309443 | 1.2829 | 22.1 |

## Table A3.3: HET – 2 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| PMJEC2+.PHJ | PT driver misjudges environmental conditions and passes signal at junction OL200+ - D | 1.14925E-07 | 0.0158921 | 1.3360178 |
| PMJEC2+.PPJ | Prob train passes OL given PT SPAD due to driver misjudging environmental conditions at junction OL200+ - D | 0.054435484 | 0.0158921 | 1.3360178 |
| WVEGON<2PEJ | Vegetation on track causes PT SPAD at junction OL<200 - D | 2.22436E-08 | 0.0145643 | 1.2243922 |
| WVEGON<2PPJ | Prob train passes OL given PT SPAD due to vegetation on track at junction OL<200 - D | 0.791666667 | 0.0145643 | 1.2243922 |
| PMJEC<2.PHJ | PT driver misjudges environmental conditions and passes signal at junction OL<200 - D | 3.70726E-08 | 0.00824033 | 0.6927484 |
| PMJEC<2.PPJ | Prob train passes OL given PT SPAD due to driver misjudging environmental conditions at junction OL<200 - D | 0.26875 | 0.00824033 | 0.6927484 |
| FMJEC<2.FHJ | FT driver misjudges environmental conditions and passes signal at junction OL<200 - D | 6.10668E-08 | 0.00804863 | 0.6766326 |
| FMJEC<2.FPJ | Prob train passes OL given FT driver misjudging environmental conditions at junction OL<200 - D | 0.44 | 0.00804863 | 0.6766326 |
| WVEGON2+PEJ | Vegetation on track causes PT SPAD at junction OL200+ - D | 1.76095E-08 | 0.00706314 | 0.5937844 |
| WVEGON2+PPJ | Prob train passes OL given PT SPAD due to vegetation on track at junction OL200+ - D | 0.157894737 | 0.00706314 | 0.5937844 |
| FMJEC2+.FHJ | FT driver misjudges environmental conditions and passes signal at junction OL200+ - D | 1.49003E-07 | 0.00665176 | 0.5592005 |
| FMJEC2+.FPJ | Prob train passes OL given FT driver misjudging environmental conditions at junction OL200+ - D | 0.081967213 | 0.00665176 | 0.5592005 |
| WVEGON<2FEJ | Vegetation on track causes FT SPAD at junction OL<200 - D | 9.77068E-09 | 0.00292677 | 0.2460478 |
| WVEGON<2FPJ | Prob train passes OL given FT SPAD due to vegetation on track at junction OL<200 - D | 1 | 0.00292677 | 0.2460478 |
| PMJEC<2.PHPL | PT driver misjudges environmental conditions and passes signal on pln line OL<200 - D | 1.43656E-08 | 0.00282411 | 0.2374174 |
| PMJEC<2.PPPL | Prob train passes OL given PT driver misjudging environmental conditions and on pln line OL<200 - D | 0.548387097 | 0.00282411 | 0.2374174 |
| WVEGON<2PEPL | Vegetation on track causes PT SPADs on pln line OL<200 - D | 6.95112E-09 | 0.00149512 | 0.1256918 |
| WVEGON<2PPPL | Prob train passes OL given PT SPAD due to vegetation on track on pln line OL<200 - D | 0.6 | 0.00149512 | 0.1256918 |
| PMJEC2+.PHPL | PT driver misjudges environmental conditions and passes signal on pln line OL200+ - D | 5.88528E-08 | 0.0012899 | 0.1084394 |
| PMJEC2+.PPPL | Prob train passes OL given PT driver misjudging environmental conditions and on pln line OL200+ - D | 0.086614173 | 0.0012899 | 0.1084394 |
| WVEGON2+FEPL | Vegetation on track causes FT SPAD on pln line OL200+ - D | 4.88534E-09 | 0.00098447 | 0.0827626 |
| WVEGON2+FPPL | Prob train passes OL given FT SPAD due to vegetation on track on pln line OL200+ - D | 1 | 0.00098447 | 0.0827626 |
| WVEGON2+PEPL | Vegetation on track causes PT SPADs on pln line OL200+ - D | 3.79994E-08 | 0.00093811 | 0.0788652 |
| WVEGON2+PPPL | Prob train passes OL given PT SPAD due to vegetation on track on pln line OL200+ - D | 0.097560976 | 0.00093811 | 0.0788652 |
| FMJEC<2.FHPL | FT driver misjudges environmental conditions and passes signal on pln line OL<200 - D | 1.70987E-08 | 0 | 0 |
| FMJEC2+.FHPL | FT driver misjudges environmental conditions and passes signal on pln line OL200+ - D | 7.08375E-08 | 0 | 0 |
| WVEGON2+FEJ | Vegetation on track causes FT SPAD at junction OL200+ - D | 1.4656E-08 | 0 | 0 |
| Total | | 5.127276983 | 0.14183749 | 11.924 |

## Table A3.4: HET – 3 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| FMJEC<2.FHJ | FT driver misjudges environmental conditions and passes signal at junction OL<200 - D | 6.10668E-08 | 0.000956846 | 1.154651394 |
| FMJEC<2.FPJ | Prob train passes OL given FT driver misjudging environmental conditions at junction OL<200 - D | 0.44 | 0.000956846 | 1.155 |
| FMJEC2+.FHJ | FT driver misjudges environmental conditions and passes signal at junction OL200+ - D | 1.49003E-07 | 0.000790782 | 0.954 |
| FMJEC2+.FPJ | Prob train passes OL given FT driver misjudging environmental conditions at junction OL200+ - D | 0.081967213 | 0.000790782 | 0.954 |
| WVEGON<2FEJ | Vegetation on track causes FT SPAD at junction OL<200 - D | 9.77068E-09 | 0.000347944 | 0.420 |
| WVEGON<2FPJ | Prob train passes OL given FT SPAD due to vegetation on track at junction OL<200 - D | 1 | 0.000347944 | 0.420 |
| WVEGON2+FEPL | Vegetation on track causes FT SPAD on pln line OL200+ - D | 4.88534E-09 | 9.51534E-05 | 0.115 |
| WVEGON2+FPPL | Prob train passes OL given FT SPAD due to vegetation on track on pln line OL200+ - D | 1 | 9.51534E-05 | 0.115 |
| FMJEC<2.FHPL | FT driver misjudges environmental conditions and passes signal on pln line OL<200 - D | 1.70987E-08 | 0 | 0.000 |
| FMJEC<2.FPPL | Prob train passes OL given FT driver misjudging environmental conditions on pln line OL<200 - D | 0 | 0 | 0.000 |
| FMJEC2+.FHPL | FT driver misjudges environmental conditions and passes signal on pln line OL200+ - D | 7.08375E-08 | 0 | 0.000 |
| FMJEC2+.FPPL | Prob train passes OL given FT driver misjudging environmental conditions on pln line OL200+ - N | 0 | 0 | 0.000 |
| WOENC<2.FEJ | Other environmental conditions eg oil, ice etc on track causes FT SPAD at junction OL<200 - N | 0 | 0 | 0.000 |
| WOENC<2.FPJ | Prob train passes OL given FT SPAD due to other environmental conditions on track at junction OL<200 - N | 0 | 0 | 0.000 |
| WOENC<2.FEPL | Other environmental conditions eg oil, ice etc on track causes FT SPAD on pln line OL<200 - N | 0 | 0 | 0.000 |
| WOENC<2.FPPL | Prob train passes OL given FT SPAD due to other environmental conditions on track on pln line OL<200 - N | 0 | 0 | 0.000 |
| WOENC2+.FEJ | Other environmental conditions eg oil, ice etc on track causes FT SPAD at junction OL200+ - N | 0 | 0 | 0.000 |
| WOENC2+.FPJ | Prob train passes OL given FT SPAD due to other environmental conditions on track at junction OL200+ - N | 0 | 0 | 0.000 |
| WOENC2+.FEPL | Other environmental conditions eg oil, ice etc on track causes FT SPAD on pln line OL200+ - N | 0 | 0 | 0.000 |
| WOENC2+.FPPL | Prob train passes OL given FT SPAD due to other environmental conditions on track on pln line OL200+ - N | 0 | 0 | 0.000 |
| WVEGON<2FEPL | Vegetation on track causes FT SPAD on pln line OL<200 - N | 0 | 0 | 0.000 |
| WVEGON<2FPPL | Prob train passes OL given FT SPAD due to vegetation on track on pln line OL<200 - D | 0 | 0 | 0.000 |
| WVEGON2+FEJ | Vegetation on track causes FT SPAD at junction OL200+ - D | 1.4656E-08 | 0 | 0.000 |
| WVEGON2+FPJ | Prob train passes OL given FT SPAD due to vegetation on track at junction OL200+ - N | 0 | 0 | 0.000 |
| Total | | 2.52196754 | 0.004381451 | 5.287 |

## Table A3.5: HET – 4 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| BTREOBJEUE | Train collision with trees - D | 3.54948E-08 | 0.06832 | 21.80567037 |
| MISCOBJEUE | Train collision with miscellaneous objects on the line - D | 1.46875E-08 | 0.02827 | 9.022925956 |
| PTRAOBJEPF | Train collision with objects/debris fallen from trains - D | 3.67188E-09 | 0.007067 | 2.255571904 |
| ROHLOBJEUF | Train collision with debris from OHLE structures - D | 3.67188E-09 | 0.007067 | 2.255571904 |
| BBLNOBJEUE | Train collision with objects blown onto the line - D | 2.44792E-09 | 0.004711 | 1.503608213 |
| RLNSOBJEUF | Train collision with debris from landslips - D | 2.44792E-09 | 0.004711 | 1.503608213 |
| Total | | 6.24219E-08 | 0.120146 | 38.34695656 |

## Table A3.6: HET – 9 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| TBSPAHRCPE | Low adhesion due to rail contamination leading to buffers stop collision - D | 1.08E-08 | 0.1349 | 11.53018061 |
| TBSPAHDRPH | Low adhesion and driver fails to adjust to conditions leading to buffer stop collision - D | 6.31E-09 | 7.88E-02 | 6.7361 |
| WBSPAHWTPE | Low adhesion due to weather conditions leading to buffers stop collisions - D | 2.70E-09 | 3.37E-02 | 2.882117792 |
| WBSPAHLFPE | Low adhesion due to leaves leading to buffer stops - D | 9.02E-10 | 1.13E-02 | 0.963270093 |
| Total | | 2.07E-08 | 2.59E-01 | 22.11162138 |

## Table A3.7: HET – 10 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| WAOCLENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on AOCL - D | 3.78E-09 | 0.272646 | 4.455602547 |
| WAHB-ENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on AHB - D | 2.52E-09 | 0.182 | 3.0 |
| WMG/BENVTR | RV incorrectly on LC due to environmental factors - RV struck by Train on MG/B - D | 1.26E-09 | 0.091 | 1.5 |
| WABCLENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on ABCL - E | 1.77E-10 | 0.0128 | 0.21 |
| Total | | 7.74E-09 | 0.5581 | 9.12 |

## Table A3.8: HET – 11 Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| WAOCLENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on AOCL - D | 3.78E-09 | 0.0414325 | 4.455602381 |
| WAHB-ENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on AHB - D | 2.52E-09 | 0.0276 | 3.0 |
| WMG/BENVTR | RV incorrectly on LC due to environmental factors - RV struck by Train on MG/B - D | 1.26E-09 | 0.0138 | 1.5 |
| WABCLENVTE | RV incorrectly on LC due to environmental factors - RV struck by Train on ABCL - E | 1.77E-10 | 0.00194 | 0.21 |
| Total | | 7.74E-09 | 0.08481 | 9.12 |

## Table A3.9: HET – 12 (including 14) Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| TSPG----PF | Gauge spread leading to PT derailment - D | 0.000000006 | 0.448865 | 10.38495565 |
| RLNS----UF | Running into landslip leading to train derailment - D | 4.10E-09 | 0.2808 | 6.5 |
| RSCR----UE | Rail bridge collapse - scour leading to train derailment - D | 9.30E-11 | 0.1835 | 4.2 |
| TTWS----PF | Track twist leading to PT derailment - D | 1.60E-09 | 0.1197 | 2.8 |
| TBKR----PF | Broken rail leading to PT derailment - D | 1.60E-09 | 0.1096 | 2.54 |
| BTRE----UE | Running into trees leading to train derailment - D | 1.40E-09 | 0.0959 | 2.22 |
| PTRA----PF | Running into objects fallen from trains leading to PT derailment - D | 1.10E-09 | 0.0823 | 1.90 |
| RBGD----UF | Running into to debris from overbridges leading to train derailment - E | 4.50E-10 | 0.0308 | 0.71 |
| RBLD----UF | Running into debris from lineside structures/buildings leading to train derailment - D | 4.50E-10 | 0.0308 | 0.71 |
| RSLP----PF | Subsidence/ landslip under track leading to PT derailment - E | 4.50E-10 | 0.0308 | 0.71 |
| WSNO----UE | Running into snow/ice leading to train derailment - D | 4.50E-10 | 0.0308 | 0.71 |
| RDRN----UF | Drainage culvert/pipework collapse leading to train derailment - E | 1.90E-10 | 0.01301 | 0.30 |
| RWAL----UF | Running into debris from retaining walls leading to train derailment - E | 3.70E-11 | 0.00253 | 0.06 |
| BBLD----UE | Running into objects from building site leading to train derailment - E | 7.50E-12 | 0.00051 | 0.01 |
| BBLN----UE | Running into items blown onto the line leading to train derailment - E | 7.50E-12 | 0.00051 | 0.01 |
| ROHL----UF | Running into debris from OHLE structures leading to train derailment - E | 1.90E-12 | 0.00013 | 0.00 |
| WWIN----UE | High winds leading to train derailment - E | 1.90E-12 | 0.00013 | 0.00 |
| RQAK----UE | Structural damage due to earthquake leading to train derailment - E | 3.70E-13 | 0.00003 | 0.00 |
| WFLD----UE | Running into flooding leading to train derailment - E | 1.90E-13 | 0.00001 | 0.00 |
| RSIG----UF | Running into debris from signalling gantries leading to train derailment - E | 1.90E-13 | 0.00001 | 0.00 |
| Total | | 1.79E-08 | 1.46085 | 33.80 |

## Table A3.10: HET – 13 (including 15) Weather Related Precursor Contribution to System Risk

| Precursor Code | Cause Precursor Description | Frequency | Risk Contribution Eq. Fats/yr | Risk cont. % of total HE risk |
|---|---|---|---|---|
| TSPG----FF | Gauge spread leading to FT, ECS or PCLS derailment - D | 0.0000003 | 0.611466 | 20.87782034 |
| TTWS----FF | Track twist leading to FT, ECS or PCLS derailment - D | 1.40E-07 | 0.2854 | 9.7 |
| TCYCLIC-FF | Cyclic top leading to FT, ECS or PCLS derailment - D | 7.10E-08 | 0.1447 | 4.94 |
| TBKR----FF | Broken rail leading to FT, ECS or PCLS derailment - D | 3.20E-08 | 0.0567 | 1.93 |
| RSLP----FF | Subsidence/ landslip under track leading to FT, ECS or PCLS derailment - D | 2.10E-08 | 0.0372 | 1.27 |
| RSCR----UE | Rail bridge collapse - scour leading to train derailment - D | 9.30E-11 | 0.0167 | 0.57 |
| TBCK----FF | Buckled rail leading to FT, ECS or PCLS derailment - D | 5.30E-09 | 0.0094 | 0.32 |
| RLNS----UF | Running into landslip leading to train derailment - D | 4.10E-09 | 0.0073 | 0.25 |
| RTUNWALLUF | Running into debris in the tunnel leading to train derailment - E | 9.30E-09 | 0.00249 | 0.08 |
| BTRE----UE | Running into trees leading to train derailment - D | 1.40E-09 | 0.00248 | 0.08 |
| RBGD----UF | Running into to debris from overbridges leading to train derailment - E | 4.50E-10 | 0.00080 | 0.03 |
| RBLD----UF | Running into debris from lineside structures/buildings leading to train derailment - D | 4.50E-10 | 0.00080 | 0.03 |
| WSNO----UE | Running into snow/ice leading to train derailment - D | 4.50E-10 | 0.00080 | 0.03 |
| RDRN----UF | Drainage culvert/pipework collapse leading to train derailment - E | 1.90E-10 | 0.00034 | 0.01 |
| RWAL----UF | Running into debris from retaining walls leading to train derailment - E | 3.70E-11 | 0.00007 | 0.00 |
| BBLD----UE | Running into objects from building site leading to train derailment - E | 7.50E-12 | 0.00001 | 0.00 |
| BBLN----UE | Running into items blown onto the line leading to train derailment - E | 7.50E-12 | 0.00001 | 0.00 |
| ROHL----UF | Running into debris from OHLE structures leading to train derailment - E | 1.90E-12 | 0.00000 | 0.00 |
| WWIN----UE | High winds leading to train derailment - E | 1.90E-12 | 0.00000 | 0.00 |
| RQAK----UE | Structural damage due to earthquake leading to train derailment - E | 3.70E-13 | 0.00000 | 0.00 |
| WFLD----UE | Running into flooding leading to train derailment - E | 1.90E-13 | 0.00000 | 0.00 |
| RSIG----UF | Running into debris from signalling gantries leading to train derailment - E | 1.90E-13 | 0.00000 | 0.00 |
| Total | | 5.86E-07 | 1.17654 | 40.17 |

# Appendix 4
# Web site and document information sources

A number of potential information sources were reviewed with a view to identification of expertise in weather and climate change impacts on the railway system as set out below.

UN FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCC)
http://www.unfcc.int/sessions/workshop/010611/present.html

BBC WEATHER CENTRE

BIRMINGHAM UNIVERSITY

BRITISH ATMOSPHERIC DATA CENTRE (BADC) RUTHERFORD APPLETON LAB

BUILDING RESEARCH ESTABLISHMENT (BRE)
http://www.bre.co.uk

CAMBRIDGE UNIVERSITY, DEPARTMENT OF GEOGRAPHY
http://www.geog.cam.ac.uk/RESEARCH/ENVISSPOL/envisspol.htm

CEH WALLINGFORD (formerly the Institute of Hydrology)
http://www.nwl.ac.uk/ih/

CENTRE FOR THE SOCIAL AND ECONOMIC RESEARCH (CSERGE)
http://www.uea.ac.uk/env/cserge/

CENTRE FOR THE STUDY OF ENVIRONMENTAL CHANGE (CSEC)
http://www.lancs.ac.uk/users/csec/

CENTRE FOR URBAN AND REGIONAL ECOLOGY, THE UNIVERSITY OF MANCHESTER
http://www.netaproject.org.uk

CHELTENHAM CLIMATE CHANGE FORUM
http://www.cclic.com/climate.html

CLIMATE NETWORK
http://www.climatenetwork.org

DERBY UNIVERSITY, DEPARTMENT OF GEOGRAPHY

DEPARTMENT OF THE ENVIRONMENT

DEPARTMENT OF THE ENVIRONMENT FOOD AND RURAL AFFAIRS (DEFRA)
http://www.defra.gov.uk

DEPARTMENT FOR TRADE AND INDUSTRY
http://www.dti.gov.uk

DEPARTMENT FOR TRANSPORT, LOCAL GOVERNMENT AND THE REGIONS
http://www.dltr.gov.uk
http://www.detr.gov.uk/shipping

DURHAM UNIVERSITY, DEPARTMENT OF GEOGRAPHY

DURHAM UNIVERSITY, SEA LEVEL RESEARCH UNIT
http://www.dur.ac.uk/~dgg0www9/

EDINBURGH UNIVERSITY

ENVIRONMENT AGENCY (includes flood maps)
http://www.epa.gov/globalwarming/impacts/index.html

FINISH METEOROLOGICAL INSTITUTE
http://www.fmi.fi/research_climate/climate.html

FOUNDATION FOR THE BUILT ENVIRONMENT (FBE)
http://www.fbe.co.uk

THE GREEN PARTY
http://www.greenparty.org.uk

HERRIOT-WATT UNIVERSITY

HIGHWAYS AGENCY

H M TREASURY
http://www.hm-treasury.gov.uk

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPC)
http://www.ipcc.ch

INSTITUTE OF CIVIL ENGINEERS (ICE)
http://www.ice.org.uk

IRISH GOVERNMENT
http://www.irlgov.ie/tec/transport/reports

KINGS COLLEGE DEPARTMENT OF GEOGRAPHY
http://www.kcl.ac.uk

LIVERPOOL UNIVERSITY, DEPARTMENT OF ECONOMICS
http://www.liv.ac.uk/economics

LONDON UNDERGROUND
http://www.thetube.com

LOWE, R (2001) A review of recent and current initiatives on climate change and its impact on the built environment: impact, effectiveness and recommendations.
Leeds Metropolitan University.

MET OFFICE
http://www.metoffice.com

MID-ATLANTIC WORKSHOP ON REGIONAL CLIMATE IMPACTS
http://www.essc.psu.edu/ccimar/papers/wht_ppr3.pdf

MIDDLESEX UNIVERSITY

NATIONAL AUDIT OFFICE
http://www.naogov.uk/publications

NEWCASTLE UNIVERSITY, DEPARTMENT OF CIVIL ENGINEERING

NOTTINGHAM UNIVERSITY

OXFORD BROOKES UNIVERSITY, DEPARTMENT OF ARCHITECTURE

PARRY (2000) Rope ACACIA Project – assessment of potential effects and adaptations for climate change in Europe. Jackson Environmental Institute, UEA
http://www.jei.uea.ac.uk/

PLYMOUTH UNIVERSITY, RESEARCH SUPPORT UNIT

NETWORK RAIL WEATHER GUIDANCE NOTES

RAIL SAFETY AND STANDARDS BOARD (Safety Performance Report)
http://www.railwaysafety.org

READING UNIVERSITY

ROYAL INSITUTE FOR CHARTERED SURVEYORS

ROYAL METEOROLGICAL SOCIETY

SEPA

STRATEGIC RAIL AUTHORITY
http://www.sra.goc.uk/sra/publications

SCOTTISH EXECUTIVE, CENTRAL RESEARCH UNIT
http://www.Scotland.gov.uk

SOUTHAMPTON UNIVERSITY

TRL LIMITED
http://www.trl.co.uk

TYNDALL CENTRE FOR CLIMATE CHANGE RESEARCH, UMIST
http://www.tyndall.ac.uk

UK CLIMATE IMPACTS PROGRAMME (UKCIP)
http://www.ukcip.org.uk/

UK COMMISSION FOR INTEGRATED TRANSPORT
http://www.cfit.gov.uk/research

UNIVERSITY OF EAST ANGLIA, CLIMATE RESEARCH UNIT
http://www.cru.uea.ac.uk

UNIVERSITY COLLEGE LONDON

UNIVERSITY OF IRELAND

US GLOBAL CHANGE RESEARCH PROGRAMME
http://www.usgcrp.gov/

VRIJE UNIVERSITY
http://www.vu.nl

WILSON, MI (1999) A rail weather sensitivity and leaf fall analysis for Birmingham
MSC Dissertation, Birmingham University

WOLVERHAMPTON UNIVERSITY

WORLD MET ORGANISATION

# Appendix 5
# Risk Scenarios and Associated Analysis

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| **1** | **RAIN** | | | | | | |
| 1.1 | Rain in excess of system drainage capacity leading to local flooding of permanent way. | Stranded or suspended rail services, exposure for passengers, delay to services due to speed restrictions, short-term revenue loss | Prevention: drainage design standards, Management: rainfall monitoring, weather forecasting, reduced running speed | Any part of the system would appear to be potentially at risk but certain areas may be more at risk according to various factors: e.g. mountainous regions; large catchment areas; rapid runoff, seasonal effects; soil type. Such factors will be relevant to vulnerability of given locations and also relevant in respect of scenario 1.2 below. | A proportion of 2.6 E-8 EF/yr (from RSSRM). Not a large safety risk but currently identified as a significant issue in respect of disruption. Could quantify further through TRUST delay information. | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation. Information on short term extremes has not been accessed at present. Analysis of extreme events required to determine how much worse it is likely be. | Not currently determined. Would need to know what drainage capacity current design standards identify and what is the capacity provided by historical practices, as compared with the foreseeable perturbation. Key issues include design standard, performance of asset, implementation of asset and management of condition. |
| 1.2 | Excessive rainfall, leading to river inundation and flooding of permanent way. | Stranded or suspended rail services (short term), exposure for passengers, delay to services due to speed restrictions, short-term revenue loss | Prevention: flood plain management schemes & flood defences Management: system to capture flood alerts, reduced running speed | Expectation that, by the nature of its layout and design, a significant proportion of the system is exposed | A proportion of 2.6 E-8 EF/yr | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation and associated flooding. UKCIP predict 1.5 extra UK major flooding events per winter in 2080 (compared to baseline of 1 - 1.5). | Given location of railways (see comment on exposure), the expectation is that the network would be inherently vulnerable. Further characteristion from indicative flood plain information and areas currently identified with poor drainage is appropriate. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 1.3 | Excessive rainfall giving rise to increased river flows, leading to mechanical scour of bridge supports, earthworks etc. and failure of structures | Multiple fatalities,longer term disruption of services, engineering repaircosts | Management arrangements to ensure condition monitoring and repair & maintenance. | There are 95,000 bridgespans and culverts in 10,000 route miles. The proportion associated with watercourses would need to be identified | 0.5 EF/yr | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation with potential for more periods of unusually high peak flows. UKCIP predict 1.5 extra UK major flooding events per winter in 2080 (compared to baseline of 1 - 1.5). | Given location of railways (see comment on exposure), the expectation is that the network would be inherently vulnerable |
| 1.4 | Flooding leading to failure of distribution of electricity supply to trains and Signalling, resulting in stranded or suspended rail services | Stranded or suspended rail services (short term), exposure for passengers, delay to services due to speed restrictions, short-term revenue loss | Prevention: improved protection of electrical distribution system. Management: system to capture flood alerts. | Evidently limited to electrified lines. Happens often. Electrical system review (N Aspinall) | Assumed moderate Could quantify with data from TRUST and comparison of electrified line layout with Environment Agency flood maps | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation with potential for more periods of unusually high peak flows. UKCIP predict 1.5 extra UK major flooding events per winter in 2080 (compared to baseline of 1 - 1.5). | Given location of railways (see comment on exposure), the expectation is that the network would be inherently vulnerable |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 1.5 | Excessive rainfall (perhaps linked to periods of extreme dryness) weakens shallow mineworkings leading to displacement of track, derailment and collision. Water table changes increase likelihood of collapse. | Multiple fatalities, longer term disruption of services engineering repair costs | Prevention: design standards, improve available drainage, infill and stabilise workings Management: condition monitoring | Unknown on network wide basis. Number of shallow mineworkings have been identified on Settle and Carlisle line | A proportion of 1.46 EF/yr | Prediction of wetter winters and dryer summers. UKCIP predicts winter precipitation increases between 5 and 30% by 2080 and decrease in summer of 20-40%. | Information required from Engineers specialising in track formation and its resistance. (NRIL Mining Engineer, John Stodard and liaison with "Coal Board".) |
| 1.6 | Excessive rainfall and volume of water beyond design levels leading to degradation of the track formation | Multiple fatalities,longer term disruption of servicesengineering repair costs | Enhanced condition monitoring following periods of excessive rainfall, inspection, speed restrictions. | Unknown on network wide basis.There is a small selection of options for track and its support but a multitude of different geological conditions throughout the UK | A proportion of 1.46 EF/yr | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation with potential for more periods of unusually high peak flows. UKCIP predicts winter precipitation increases between 5 and 30% by 2080. Short term extremes not determined at present. | Uncertain and merits characterisation, e.g. through information from NRIL Zonal Civil Engineers. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 1.7 | Excessive rainfall beyond design levels leading to flooding of tunnels | Multiple fatalities disruption of services | Prevention: design standards, pumping systems, flood gates Management: weather forecasting, monitoring and suspension of services | There are 232 tunnels in 10,000 route miles. The proportion with significant catchment areas would need to be identified. | Assumed low for network as a whole. No data has currently been identified for this scenario. | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation with potential for more periods of unusually high peak flows. UKCIP predict 1.5 extra UK flooding events per winter in 2080 (compared to baseline of 1 - 1.5 now). Shorter term extremes also of potential interest but not currently characterised. | Uncertain and merits characterisation, e.g. through information from NRIL Zonal Civil Engineers. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 1.8 | Excessive rainfall giving rise to embankment instability & slip, leading to derailment or collision | Multiple fatalitiesdisruption of services | Prevention: design standards,adequate drainage.Management: weather forecasting,rainfall monitoring,condition monitoring,slip monitoring,reduced running speed,one track only use of adjacent lines | A large proportion of the UK rail network runs on embankments or in cuttings. | 0.288 EF/yr | Predictions indicate less rainfall on average but increased incidence of high intensity precipitation with potential for more periods of unusually high peak flows.<br>UKCIP predicts winter precipitation increases between 5 and 30% by 2080. Shorter term extremes also of potential interest but not currently characterised. | Uncertain and merits characterisation, e.g. through information from NRIL Zonal Civil Engineers. |
| 1.9 | Small amounts of rain giving rise to wet railhead leading to exacerbation of rolling contact fatigue failure of rails and wheels with potential for derailment and collision | Multiple fatalities<br>disruption of services<br>costs | Prevention: railhead and wheel monitoring and conditioning | Any part of the system would appear to be potentially at risk | A proportion of 0.16 EF/yr | Predictions indicate less rain in general which should mean reduced incidence of this risk.<br>UKCIP predicts summer precipitation decreases by 20 - 40% and winter precipitation increases between 5 and 30% by 2080. | Not assessed given identified perturbation. Covered by other research, no further attention required for this project |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 1.10 | Lack of rain, reducing soil moisture, subsidence of permanent way leading to infringement of gauging and striking of infrastructure by vehicles. Leading to track misalignment, settlement of structures. | Multiple fatalities disruption of services costs | Driver reporting rough running, condition monitoring track alignment routine inspection procedures. | More prevalent in south-east and dependent upon local soil and geological conditions. Likely to be a long term issue. | Assumed moderate for network as a whole. No data has currently been identified for this scenario. | Predictions indicate less rain in summer and higher temperatures leading to potentially significant reductions in soil moistures. UKCIP predicts summer precipitation decreases by 20 - 40% by 2080. | Information required from NRIL Zonal Civil Engineers |
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| 2 | **HAIL** | | | | | | |
| 2.1 | Heavy hail storms leading to lack of visibility of signs, inappropriate use of speed, derailment, collision | Multiple fatalitiesdisruption of servicescosts | Temporary speed restrictions, driver briefing | Any part of the system would appear to be potentially at risk | Low for the network as a whole, due to TPWS and AWS functionality | Potential for increased intensity of hail storms in principle but detail of such short term extreme events not presented by UKCIP. | Not characterised at present. |
| 2.2 | Heavy hail storm reducing visibility below signal sighting distance, signals passed at danger, collision | Multiple fatalities disruption of services costs | Train Protection & Warning System monitor forecasts driver briefing | Any part of the system would appear to be potentially at risk | Low for the network as a whole, due to TPWS and AWS functionality | Potential for increased intensity of hail storms in principle but detail of such short term extreme events not presented by UKCIP. | Not characterised at present. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 2.3 | Excessively vigorous storms and large hailstones, giving rise to equipment damage | Disruption of services costs | Safety critical equipment is mainly failsafe in design and operation | Any part of the system would appear to be potentially at risk | No data identified for this scenario | Potential for increased intensity of hail storms in principle but detail of such short term extreme events not presented by UKCIP. | Assumed that lineside equipment and vehicles resist current impacts from hail. Effect of an Increase in expected individual hail particle size not known at present. Keep as watching brief with UKCIP predictions on hail size. |
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| **3** | **SNOW/SLEET/ICE** | | | | | | |
| 3.1 | Heavy snow/high winds giving rise to snow drifts, blocked lines, stranded trains | Disruption and delay, exposure injuries | Monitor forecasts, snowploughs, snowblowers, driver briefing, contingency planning | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole. No data currently identified for this scenario | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.2 | Fine powdered snow, ingestion into vehicle and trackside equipment - loss of function, traction or signalling | Disruption to services and delay | Design standards, selection and design of intakes and equipment | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole, could quantify with data from TRUST | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 3.3 | Snow/sleet: signs not visible, inappropriate use of speed, derailment, collision | Multiple fatalities disruption of services costs | Temporary speed restrictions, driver briefing | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Low for the network as a whole, due to TPWS and AWS functionality | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.4 | Snow/sleet: visibility reduced below signal sighting distance, signals passed at danger, collision | Multiple fatalities disruption of services costs | Train Protection & Warning System monitor forecasts driver briefing | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Low for the network as a whole, due to TPWS and AWS functionality | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.5 | Snow/ice, poor adhesion, ineffective braking (skid, loss of traction, wheel slide), signals passed at danger, collision, derailment | Multiple fatalities disruption of services costs | Monitor forecasts, snowploughs, driver briefing, contingency planning | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | No incidents recorded in RSSRM. Could quantify with data from SMIS. | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 3.6 | Snow/ice, dead load in excess of strength of structure - station roof damage | Multiple fatalitiesdisruption of servicescosts | Designcondition monitoring | Widespread but severity & frequency regionally dependent | No incidents recorded in RSSRM. Could quantify with data from SMIS. | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP indicates 50 - 100% decrease in snow events by 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.7 | Icicles obscure tunnels or detach leading to vehicle damage | disruption of services<br>costs | Design<br>condition monitoring | Widespread but severity & frequency distinctly dependent on location | No incidents recorded in RSSRM. Could quantify with data from SMIS. | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP predicts average winter temperatures around 2˚C higher in 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.8 | Build up of ice leading to poor electrical connection with OHLE | disruption of services<br>costs | Design<br>condition monitoring | Widespread, but limited to electrified area with severity & frequency distinctly dependent on location | Assumed low for the network as a whole, could quantify with data from TRUST | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP predicts average winter temperatures around 2˚C higher in 2080. | Not an issue given the perturbation and so not assessed further. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 3.9 | Build up of ice leading to failure of OHLE | disruption of services costs | design condition monitoring | Widespread but severity & frequency distinctly dependent on location | Assumed low for the network as a whole, could quantify with data from SMIS, and TRUST | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP predicts average winter temperatures around 2˚C higher in 2080. | Not an issue given the perturbation and so not assessed further. |
| 3.10 | Ice build-up overloading light lineside structures leading to possible derailment and vehicle damage | Injuriesdisruption of servicescost | design standards | Widespread but severity & frequency distinctly dependent on location | No incidents recorded in RSSRM | Reduced incidence anticipated but not likely to reduce to levels where the risk can be disregarded. UKCIP predicts average winter temperatures around 2˚C higher in 2080. | Not an issue given the perturbation and so not assessed further. |
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| **4** | **FOG** | | | | | | |
| 4.1 | Fog obscures visibility of signs, inappropriate use of speed, derailment, collision | Multiple fatalities disruption of services costs | Temporary speed restrictions, monitor forecasts, driver briefing | Widespread but severity & frequency distinctly dependent on location | Low for the network as a whole, due to TPWS and AWS functionality | Reduced incidence anticipated (UKCIP predicts - 20% incidence of fog by 2080) but not to levels where the risk can be disregarded. | Not an issue given the perturbation and so not assessed further. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 4.2 | Patchy fog, visibility reduced below signal sighting distance, signals passed at danger, collision | Multiple fatalities disruption of services costs | Train Protection & Warning System monitor forecasts driver briefing | Widespread but severity & frequency distinctly dependent on location | Low for the network as a whole, due to TPWS and AWS functionality | Reduced incidence anticipated (UKCIP predicts - 20% incidence of fog by 2080) but not to levels where the risk can be disregarded. | Not an issue given the perturbation and so not assessed further. |
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| **5** | **WIND** | | | | | | |
| 5.1 | Higher wind speeds, flying debris causing impacts and damage to vehicle and line-side equipment | Disruption of servicescosts | Exclude debris,clear line-side,designwind fences | Widespread but severity & frequency distinctly dependent on location | Assumed moderate for network as a whole, could quantify with data from TRUST | Average wind speeds expected to increase by 4 - 10% in winter by 2080. Little change is expected for summer months. The relationship between maximum gust speed and average wind speed (max. gust is 2 x average wind speed) is expected to remain unchanged. Interrogate UKCIP when threshold values identified. Statement on uncertainty of UKCIP prediction on wind speed. | Expect some susceptibility to potential level of increase and current baseline. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 5.2 | Increased wind speeds or gusts, passenger rail vehicles overturning, collision | Multiple fatalities disruption of services costs | Vehicle design standards, speed restrictions, design, wind speed monitoring, weather forecasting, reduced running speed, multi-agency contingency planning wind fences | Widespread but severity & frequency distinctly dependent on location | 1.3 E-4 EF/yr | See entry under 5.1 | Suggested threshold value of 40 m/s. Liaise with John Munday windspeed effect on passenger trains |
| 5.3 | Increased wind speeds or gusts, freight vehicles overturning, collision | Multiple fatalities disruption of services costs | Speed restrictions, wind fences, potentially vehicle design as being considered by other research outside this project but has to be confirmed as relevant. | Widespread but severity & frequency distinctly dependent on location | 3.4 E-6 EF/yr | See entry under 5.1 | Suggested threshold value of 30 m/s |
| 5.4 | Increased wind speeds or gusts, overhead line out of alignment, torn down by pantographs, direct contact with 25kV | disruption of servicescosts | design, circuit breaker protectionreduced spacing of overhead line supports,wind fences | Widespread but severity & frequency distinctly dependent on location. (One incident of driver killed by pantograph si identified.) | Assumed moderate for network as a whole, could quantify with data from TRUST | See entry under 5.1 | Suggested threshold value of 30 m/s. (c. 50mph) |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 5.5 | Increased wind speeds or gusts, damage to station roofs and exacerbated by pressures generated by increased pressures due to higher train speeds | possible multiple fatalities<br>disruption of services<br>costs | building design to resist, monitoring | Widespread but severity & frequency distinctly dependent on location | No incidents recorded in RSSRM | See entry under 5.1 | Suggested threshold value of 30 m/s. Should check validity of design codes. |
| 5.6 | Increased wind speeds or gusts, trees blown across the line, derailment. Note possibility of impact from other wind blown objects. | possible multiple fatalities<br>disruption of services<br>costs | clear line-side of vulnerable trees neighbour's trees, standard being developed (N Strong) | Widespread but severity & frequency distinctly dependent on location | 6.8 E-2 EF/Yr<br>0.1? | See entry under 5.1 | Suggested threshold value of 25 to 29 m/s, 22 to 27m/s individual trees uprooted (conifers) |
| 5.7 | Sustained high wind speeds, sea waves that overtop sea defences, according to wind speed, direction, fetch. | stranded trains | design,<br>sea defences and train systems | Widespread but severity & frequency distinctly dependent on location | Assumed moderate for network as a whole, could quantify with data from TRUST | See entry under 5.1 but note also sea level rise and see entry under 9.1. | Suggested threshold value of 25 m/s |
| 5.8 | Sustained high wind speeds and gusts, speed restrictions and delay to services to counter vehicle instability | delay to services, costs | safety management arrangements | Widespread but severity & frequency distinctly dependent on location | Assumed moderate for network as a whole, could quantify with data from TRUST | See entry under 5.1 | |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 5.9 | Sustained high wind speeds, wind pressures lead to bridge instability and possible failure fatigue on suspension bridges | multiple fatalities disruption of services costs | design standards | Widespread but severity & frequency distinctly dependent on location | No incidents recorded in RSSRM Refer to Tay Bridge (P Wigley) | See entry under 5.1 | |
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| 6 | **TEMPERATURE** | | | | | | |
| 6.1 | High air temperature, giving rise to track buckling, derailment and collision | Multiple fatalities disruption of services costs | Management procedure to impose differential speed limits. New maintenance procedures, e.g. adoption of US style winter and summer rail stressing | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | 7.1 E-2 EF/yr | Of all the factors considered, UKCIP have most faith in average temperature rise estimates (1-4˚ by 2080). As regards extremes, UKCIP show that for the 'Pembrokeshire' region there is currently a 3% chance of temperature above 25˚C on any summer day. By 2080 this is rate expected to increase to 20%. Analysis of threshold exceedance frequency for any given temperature and region is possible with UKCIP's models. | Threshold value 36˚ indicated by Railway Group Standard GO/RT3411 27 degrees for stress free temperature. (Contact Quentin Phillips NRIL, refer to RT/CE/S/011 for other temperatures research including diurnal effect.) |

| | | Risk Impact | | | Risk Likelihood | | |
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| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 6.2 | High air temperature, increased demand of air conditioning equipment on power supply, trains stranded by failure of inadequate power supplies | Passenger discomfort, heat exhaustion disruption of services costs | Design standard for power supply to meet anticipated demand within the life of the system | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed moderate for network as a whole, could quantify with data from TRUST | See entry under 6.1. | Uncertain |
| 6.3 | High temperatures giving rise to degraded signalling systems | disruption of services costs | system expected to fail to safety | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | No incidents recorded in RSSRM | See entry under 6.1. | Uncertain |
| 6.4 | Excessively high temperature leading to diesel engine overheating (electric traction failure)? | disruption of services costs | design standard for cooling systems to meet anticipated demand within the life of the system, maintenance | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | No incidents recorded in RSSRM | See entry under 6.1. | Not identified at present |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 6.5 | Low temperature, points frozen in one position leading to derailment and collision | multiple fatalitiesdisruption of servicescosts | design standardpoint heaters | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed moderate for network as a whole. RSSRM currently being interrogated | Diurnal range expected to decrease due to increased cloud cover in winter. Average winter temperatures expected to be 2˚C higher. UKCIP predicts that 'Invernesshire' experience of temperature below 5˚C for 15% of winter days, is expected to reduce to c. 4% of winter days in 2080. Reduced incidence therefore anticipated but not likely to reduce to levels where the risk can be disregarded. | Not an issue on the basis of the perturbation and so not assessed further. |

| | | Risk Impact | | | Risk Likelihood | | |
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| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| 6.6 | Low temperature leading to ineffective diesel engine starting systems | disruption of services<br>costs | operational arrangements to maintain running | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole, could quantify with data from SMIS, and TRUST | See entry under 6.5. | Not an issue on the basis of the perturbation and so not assessed further. |
| 6.7 | Low temperature leading to brittle fracture of rail and steel structures leading to derailment and collision | multiple fatalities<br>disruption of services<br>costs | design standard | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole around 0.17 EF/yr | See entry under 6.5. | Not an issue on the basis of the perturbation and so not assessed further. |
| 6.8 | Low temperature, leading to freezing of brake mechanisms | multiple fatalities<br>disruption of services<br>costs | anti-freezing agent placed in pneumatic system | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole, could quantify with data from SMIS, and TRUST | See entry under 6.5. | Not an issue on the basis of the perturbation and so not assessed further. |
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| | | Risk Impact | | | Risk Likelihood | | |
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| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| **7** | **LIGHTNING** | | | | | | |
| 7.1 | Lightning strikes, leading to disruption of electronic signalling systems e.g. axle counters electromagnetic compatibility of railways | disruption of services<br>costs | design standard, installation of system to withstand, suppress and restore to a safe condition equipment thought to fail to safe condition | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole, could quantify with data from SMIS, and TRUST | Frequency of flashes is expected to double by 2080, however storm frequency is expected to halve. Overall number of flashes stays the same. | Not known but not likely to be an issue given the identified perturbation. Research on Electromagnetic Interference with Track Circuit ongoing, no further input required by this project at present (N Aspinall) |
| 7.2 | Lightning strike leading to collapse of structures or trees | possible multiple fatalities<br>disruption of services<br>costs | design standard, effective lightning protection | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for the network as a whole, could quantify with data from SMIS, and TRUST | See entry under 7.1. | Not known but not likely to be an issue given the identified perturbation. |
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| **8** | **INSOLATION** | | | | | | |
| 8.1 | Less cloud cover leading to more periods of direct sunshine, glare leading to driver impaired vision and misreading signals, Signals passed at danger | multiple fatalities,<br>disruption of services<br>cost | TPWS | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Low for the network as a whole, due to TPWS and AWS functionality | UKCIP predicts 10 - 25% less cloud cover during summer in 2080 and an increase by 2 - 3% in winter. | Not known at present but identified baseline risk would indicate that the vulnerability is not high. |
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| | | Risk Impact | | | Risk Likelihood | | |
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| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| **9** | **SEA** | | | | | | |
| 9.1 | Increased average sea level and effect of wind, leading to exposure of vulnerable structures and vehicle components and corrosion | possible injuries, disruption of services, cost | design maintenance inspection | Widespread but severity & frequency distinctly dependent on location | Assumed low for the network as a whole, could quantify with data from TRUST | Quantitative estimates are available, with a range of around 20-60 cm, according to emissions scenario assumed and location within the UK. | Since extent of sea level rise is predicted, the impact in terms of increased exposure of the system could be estimated in principle. |
| 9.2 | Increased average sea level and effect of wind (storm), leading to exposure of vulnerable coastal defences, (contributory factors of surge, deep depression, wind direction, fetch.) | Injuries/fatalities, disruption of services, cost | Design standards(CIRIA website). Severe weather monitoring and suspension of services. | Widespread but severity & frequency distinctly dependent on location | Assumed low for the network as a whole, could quantify with data from TRUST | Some but not all factors (extreme events) are characterised to some extent. | Could, in principle, be estimated but some factors not well characterised. |
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| | | Risk Impact | | | Risk Likelihood | | |
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| **ID** | **Risk Scenario** | **Potential Consequence** | **Mitigation / Adaptability** | **Exposure** | **Baseline** | **Perturbation** | **Vulnerability** |
| **10** | **VEGETATION** | | | | | | |
| 10.1 | Increased temperatures throughout the year, increased winds, increased vegetation mass due to longer growing season and levels of leaf fall, leading to low adhesion and ineffective braking - (skid, loss of traction, wheel slide/spin) and leading to signals passed at danger | multiple fatalities<br>disruption of services<br>costs | Vegetation management | Widespread but severity & frequency regionally dependent, with potential local "hot spots"<br>This is a significant issue | Assumed high for network as a whole.<br>0.91 EF/yr<br>1.6 EF (N Strong) | Growing season expected to increase from a baseline of 150 - 200 days by 40 - 100 days in England and Wales and 20 - 60 days in Scotland. | Not quantified but current baseline risk identifies the system as inherently vulnerable. |
| 10.2 | Increased temperatures throughout the year, increased vegetation growth, obscuring of signals and leading to signals passed at danger. | multiple fatalities<br>disruption of services<br>costs | Vegetation management of succulent leaved plants<br>selective planting in certain locations, not in draft standard | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for network as a whole.<br>RSSRM currently being interrogated | See entry under 10.1. | See entry under 10.1. |

| | | Risk Impact | | | Risk Likelihood | | |
|---|---|---|---|---|---|---|---|
| ID | Risk Scenario | Potential Consequence | Mitigation / Adaptability | Exposure | Baseline | Perturbation | Vulnerability |
| 10.3 | High temperature and low moisture, plants do not survive and earthworks susceptible to collapse, derailment collision | multiple fatalitiesdisruption of servicescosts | Consider choice of resistant vegetationvulnerable species to be identified (Norwegian Spruce). System may adapt to change in climate naturally. | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed low for network as a whole. RSSRM currently being interrogated | Soil moisture could decrease by 20 - 40% in summer, and by 10% in England and Wales in winter. Scottish soil moisture may show a slight increase in winter. | Not assessed at present. Current baseline not an indicator of future vulnerability. |
| 10.4 | High temperature and low moisture leading to dessicated vegetation and lineside fires | disruption of services<br>costs | vegetation management | Widespread but severity & frequency regionally dependent, with potential local "hot spots" | Assumed moderate for network as a whole. RSSRM currently being interrogated | See entry under 10.3. | Not assessed at present. |
| 10.5 | Fauna, rabbits, badgers, teredo navalis beetle, marine bacteria - collapse of earthwork embankments, cutting structures, accelerated low water corrosion of steel 120 to 7 years | disruption of services | management systems to assess system condition. | | This gives rise to significant delays, asset management/ replacement | | |

# Appendix 6
# Climate Change Prediction Relative Confidence Levels

| VARIABLE | UKCIP02 SCENARIOS | RELATIVE CONFIDENCE LEVEL |
|---|---|---|
| Temperature | • annual warming by the 2080s of 1-5°C depending on region/ scenario | * * * |
| | • greater summer warming in the southeast than in the northwest | * * * |
| | • greater night-time than day-time warming in winter | * |
| | • greater warming in summer and autumn than in winter and spring | * |
| | • greater day-time than night-time warming in summer | * |
| Precipitation | • generally wetter winters for the whole UK | * * * |
| | • substantially drier summers for the whole UK | * * |
| Seasonality | • precipitation: greater contrast between summer (drier) and winter (wetter) | * * * |
| | • temperature: summers warm more than winters | * |
| Variability | • years as warm as 1999 become very common | * * * |
| | • summers as dry as 1995 become very common | * * |
| | • winter and spring precipitation becomes more variable | * |
| | • summer and autumn temperatures become more variable | * |
| Cloud cover | • reduction in summer and autumn cloud, especially in the south | * |
| | • increase in radiation | * |
| | • small increase in winter cloud cover | * |
| Humidity | • specific humidity increases throughout the year | * * * |
| | • relative humidity decreases in summer | * * |
| Wind | • average winter speeds increase more in the south than in the north? | - |
| Snowfall | • totals decrease significantly everywhere | * * * |
| | • large parts of the country experience long runs of snowless winters | * * |
| Soil moisture | • decreases in summer and autumn in the southeast | * * * |
| | • increases in winter and spring in the northwest | * * |
| Storm tracks | • winter depressions become more frequent, including the deepest ones | * |
| North Atlantic Oscillation | • the NAO tends to become more positive in the future - more wet, windy, mild winters | * |
| Lightning | • potential for substantial increases in lightning flashes in summer convective storms | - |
| Fog | • potential for fewer fog days in winter | - |

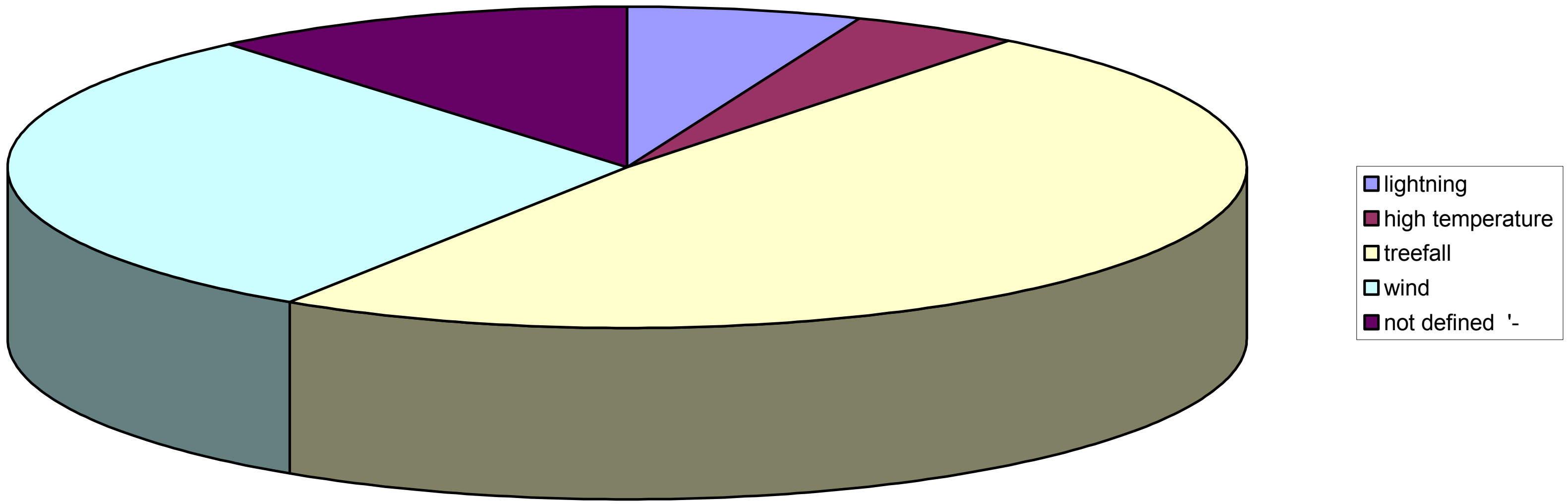
| VARIABLE | UKCIP02 SCENARIOS | RELATIVE CONFIDENCE LEVEL |
|---|---|---|
| Temperature extremes | • number of very hot days increases, especially in summer & autumn<br>• number of very cold days decreases, especially in winter | * * *<br>* * * |
| Precipitation intensity | • increases in winter | * * * |
| Thermal growing season length | • increases everywhere with largest increases in the southeast | * * * |
| Heating "degree-days" | • decrease everywhere | * * * |
| Cooling "degree days" | • increase everywhere | * * * |

| VARIABLE | UKCIP02 SCENARIOS | RELATIVE CONFIDENCE LEVEL |
|---|---|---|
| Global average sea level | • will continue to rise for several centuries and probably longer<br>• West Antarctic ice sheet will contribute relatively little to sea level rise in the present century<br>• will increase by the 2080s by between 9 and 69cm | * * *<br>* * *<br>* * |
| UK sea level change | • continuation of historic trends in vertical land movements will introduce significant regional differences in *relative* sea level rise around the UK<br>• will be similar to the global average | * * *<br>* |
| Extreme sea levels | • for some coastal locations and some scenarios, storm surge return periods by the 2080s will reduce by an order of magnitude<br>• changes in storminess, sea level and land movement mean that storm<br>surge heights will increase by the greatest amount off SE England | * *<br>* |
| Marine climate | • sea surface temperatures will increase around all UK coasts | * * * |

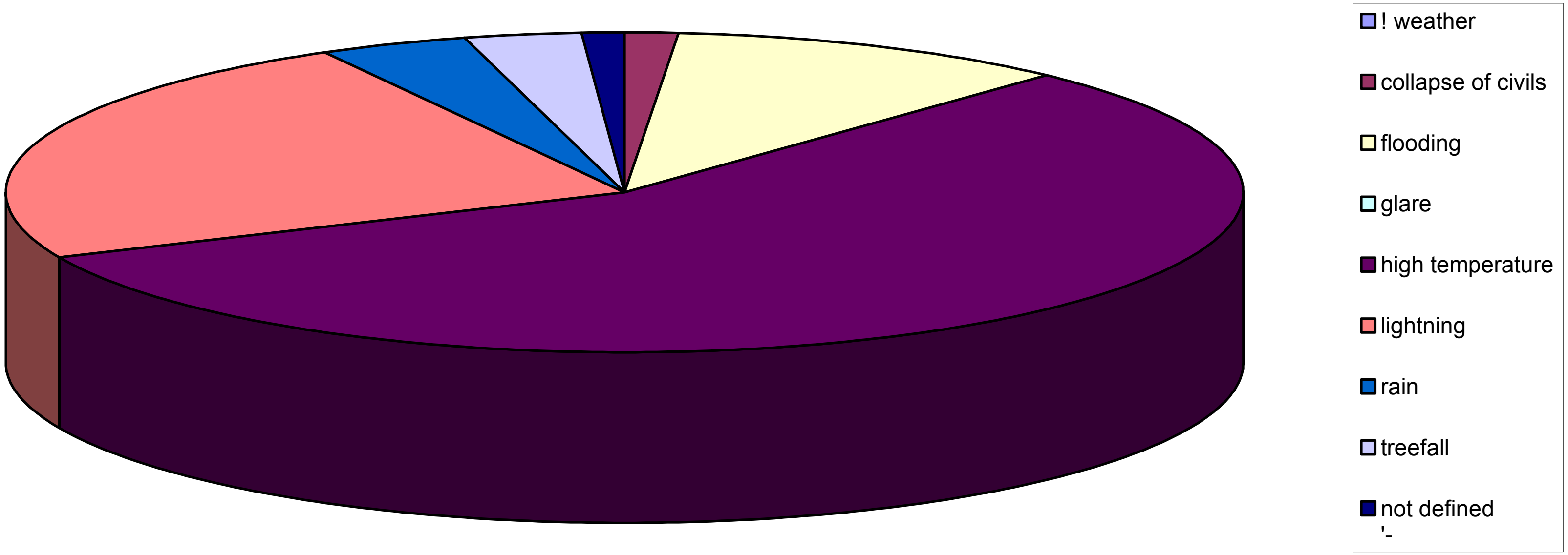
# Appendix 7
# TRUST Pilot Study
# Information Summary

| TRUST minutes for various weather related causes | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Drainage | Lightning | High temperature | Ice | Tree fall | Leaf fall | Wind | Landslip | Collapse of civils | Flooding | Glare | Rain | Sea Spray | Snow | Weather ! | Not defined |
| Season | | | | | | | | | | | | | | | | |
| Spring | - | 162 | 116 | - | 1291 | - | 784 | - | - | - | - | - | - | - | - | 298 |
| Summer | - | 9439 | 22656 | - | 1251 | - | - | - | 510 | 4249 | 18 | 1490 | - | - | - | 474 |
| Autumn | 407 | 2703 | - | - | 14803 | 125327 | - | - | 4144 | 2636 | - | - | 2193 | - | 16064 | 22976 |
| Winter | - | - | - | 8865 | 6342 | - | - | 667 | 8594 | 13392 | - | - | - | 44251 | 8861 | |

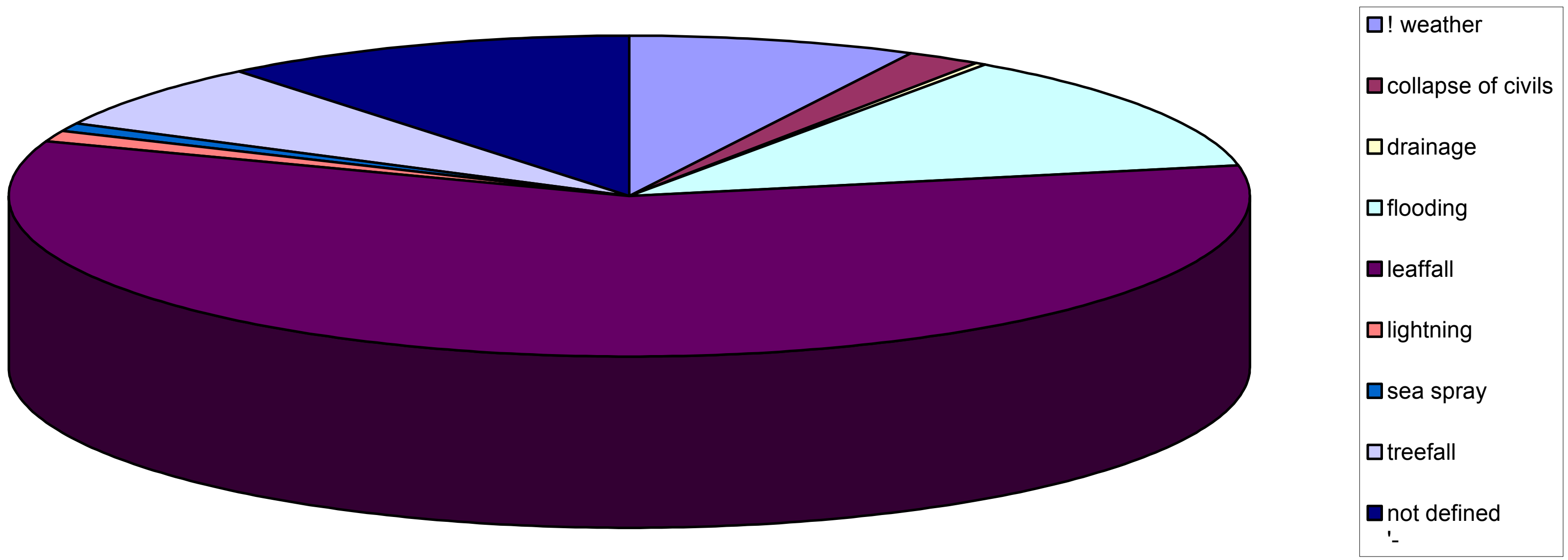
Proportion of TRUST Delay caused by Separate Weather Related Failure, Aprll 2002 ("Spring")



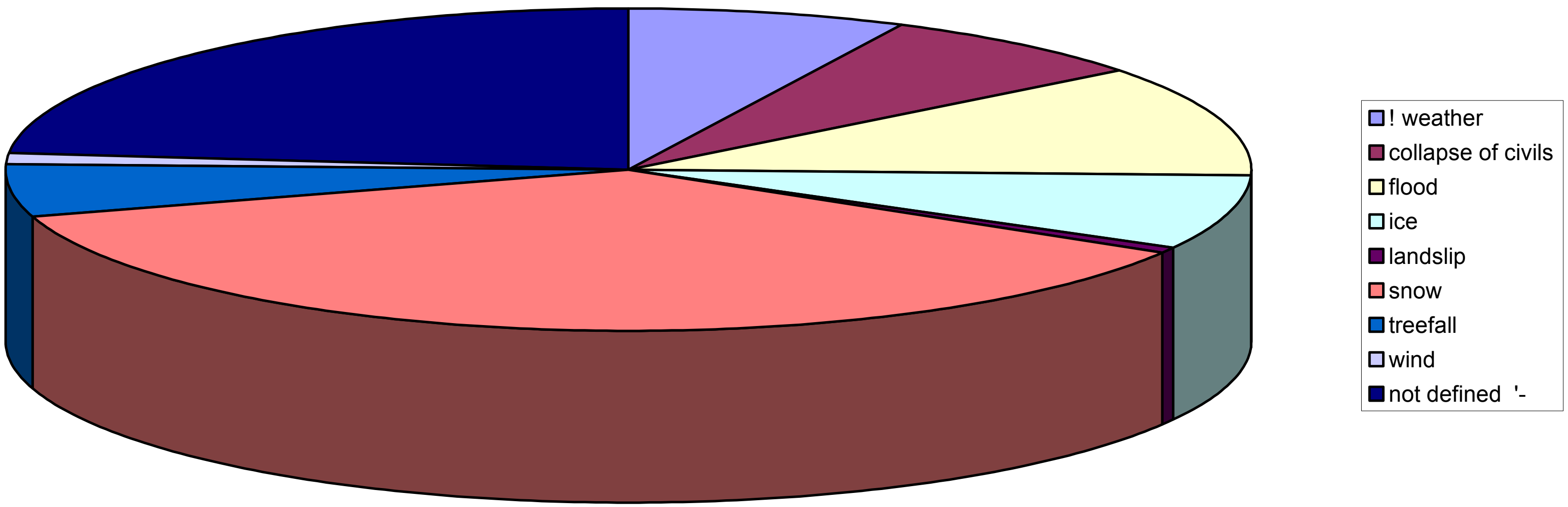
**Proportion of TRUST Delay caused by Separate Weather Related Failure, July 2002 ("Summer")**



**Proportion of TRUST Delay caused by Separate Weather Related Failure, October 2002 (Autumn)**



## Proportion of TRUST Delay caused by Separate Weather Related Failure, January 2003 ("Winter")



# Appendix 8
# Extract from Rail Safety and Standards Board Safety

# Catastrophic risk

| Objective 2a | During 2002/03 Railway Group members will implement measures to further reduce the number of events with the potential to cause catastrophic consequences. |
|---|---|

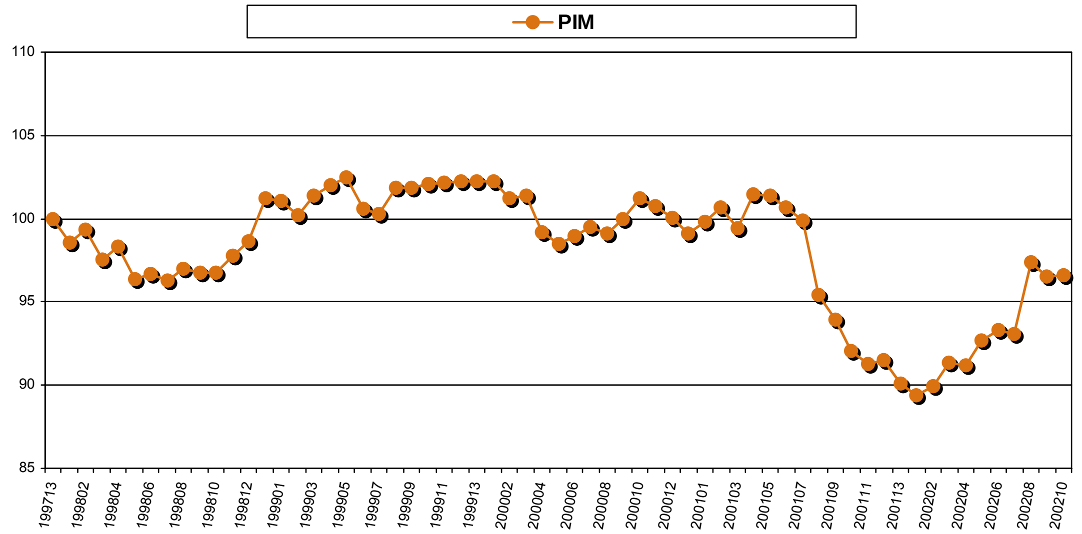
Since April 2002, performance against this objective is measured using the precursor indicator model (PIM).

The PIM measures the risk of a collision between two trains, a train derailment, a train fire, a buffer stop collision and a collision between a train and road vehicle at a level crossing.

Since the half-year safety performance report, an improvement has been made to the way one of the precursors, environmental factors, is measured. This new, more accurate, measure has resulted in a significant change to the shape of the model, most noticeably between 1998 and 2001. In addition, between now and the year-end report the model will be updated with the new version of the Safety Risk Model (SRM), which will also involve changes to the precursors and their associated weightings.

The objective in the 2002/03 RGSP requires a 10% year-on-year reduction in the PIM annual moving average. As illustrated in the following chart and tables, the current indicator has increased from the year-end position of 90.1 to 96.6 (ie by 7%). The difference is due mainly to increased incidents of *level crossing misuse*, *irregular working* and *environmental factors*.

**TRAIN ACCIDENT PRECURSOR INDICATOR MODEL**




| | | |
|---|---|---|
| 2002/03 target – 81.1 | 2002/03 current performance – 96.6 | 19% worse than target |

## Train accident precursor indicator model - values

| Risk Indicator (normalised per million train miles) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Indicator | % increase (decrease) in risk compared to 1997 | Period | Indicator | % increase (decrease) in risk compared to 1997 | Period | Indicator | % increase (decrease) in risk compared to 1997 | Period | Indicator | % increase (decrease) in risk compared to 1997 | Period | Indicator | % increase (decrease) in risk compared to 1997 |
| **9713** | 100.0 | | | | | | | | | | | | | |
| **9801** | 98.6 | *(1.4%)* | **9901** | 101.1 | *1.1%* | **0001** | 102.2 | *2.2%* | **0101** | 99.8 | *(0.2%)* | **0201** | 89.4 | *(10.6%)* |
| **9802** | 99.4 | *(0.7%)* | **9902** | 100.2 | *0.2%* | **0002** | 101.2 | *1.2%* | **0102** | 100.6 | *0.6%* | **0202** | 90.0 | *(10.0%)* |
| **9803** | 97.6 | *(2.5%)* | **9903** | 101.4 | *1.4%* | **0003** | 101.4 | *1.4%* | **0103** | 99.5 | *(0.5%)* | **0203** | 91.4 | *(8.6%)* |
| **9804** | 98.3 | *(1.7%)* | **9904** | 102.0 | *2.0%* | **0004** | 99.2 | *(0.8%)* | **0104** | 101.4 | *1.4%* | **0204** | 91.2 | *(8.8%)* |
| **9805** | 96.4 | *(3.6%)* | **9905** | 102.5 | *2.5%* | **0005** | 98.5 | *(1.5%)* | **0105** | 101.4 | *1.4%* | **0205** | 92.7 | *(7.3%)* |
| **9806** | 96.7 | *(3.3%)* | **9906** | 100.6 | *0.6%* | **0006** | 99.0 | *(1.0%)* | **0106** | 100.7 | *0.7%* | **0206** | 93.3 | *(6.7%)* |
| **9807** | 96.3 | *(3.7%)* | **9907** | 100.3 | *0.3%* | **0007** | 99.5 | *(0.5%)* | **0107** | 99.9 | *(0.1%)* | **0207** | 93.1 | *(6.9%)* |
| **9808** | 97.0 | *(3.0%)* | **9908** | 101.9 | *1.8%* | **0008** | 99.1 | *(0.9%)* | **0108** | 95.4 | *(4.6%)* | **0208** | 97.4 | *(2.6%)* |
| **9809** | 96.8 | *(3.2%)* | **9909** | 101.8 | *1.8%* | **0009** | 99.9 | *(0.1%)* | **0109** | 94.0 | *(6.1%)* | **0209** | 96.6 | *(3.5%)* |
| **9810** | 96.8 | *(3.3%)* | **9910** | 102.1 | *2.1%* | **0010** | 101.2 | *1.2%* | **0110** | 92.1 | *(7.9%)* | **0210** | 96.6 | *(3.4%)* |
| **9811** | 97.7 | *(2.3%)* | **9911** | 102.1 | *2.1%* | **0011** | 100.7 | *0.7%* | **0111** | 91.3 | *(8.7%)* | | | |
| **9812** | 98.7 | *(1.3%)* | **9912** | 102.3 | *2.3%* | **0012** | 100.1 | *0.1%* | **0112** | 91.5 | *(8.5%)* | | | |
| **9813** | 101.3 | *1.3%* | **9913** | 102.2 | *2.2%* | **0013** | 99.1 | *(0.9%)* | **0113** | 90.1 | *(9.9%)* | | | |

The table below gives an insight into how the precursors are changing. They are sorted according to their weighting within the model. Those precursors at the top of the list (*ie category A SPADS* and *level crossing mis*use) have the biggest effect on the risk (accounting for 55% of the risk). Shifts in the overall model tend to reflect shifts in the dominant precursors. The red figures denote increases in the annual moving average number of periodic incidents compared with the average for 1997/98 (when the model started). The blue bracketed figures denote decreases.

## Precursor groups – percentage change over time

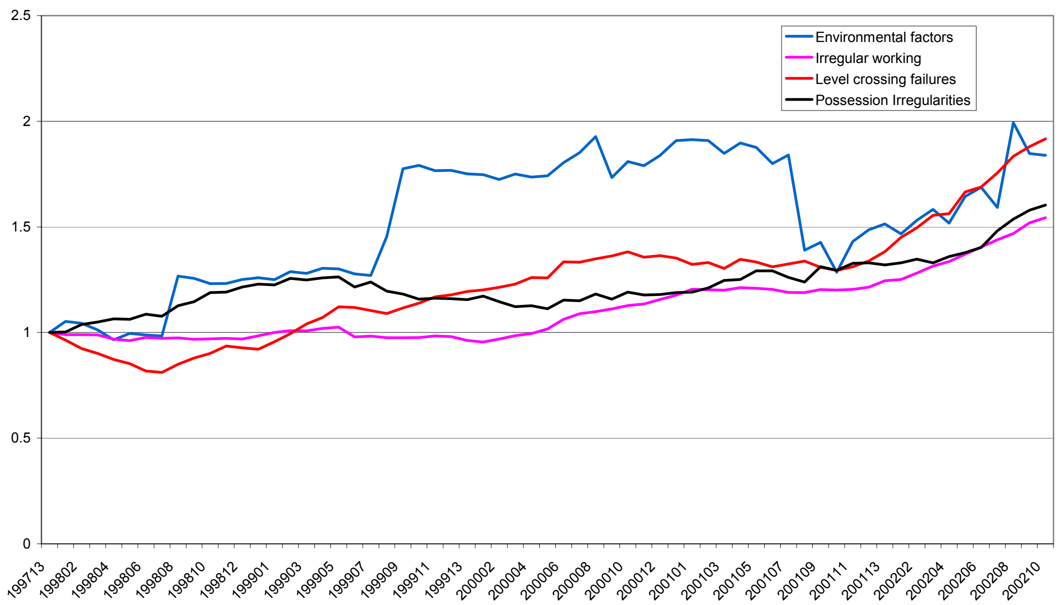
| | % increase (decrease) of the annual moving average of periodic incidents compared to 1997/98 | | | | | | | Average number of incidents / period |
|---|---|---|---|---|---|---|---|---|
| | 2002/03 at Q3 | 2002/03 at half year | 2002/03 at Q1 | 2001/02 end of year | 2000/01 end of year | 1999/00 end of year | 1998/99 end of year | 1997/98 |
| Category A SPADs | (39%) | (39%) | (36%) | (31%) | (25%) | (7%) | 7% | 49 |
| Level crossing misuse | 14% | 10% | 5% | (4%) | 0% | 5% | 4% | 127 |
| Discrete track faults (gauge, twist, top, line) per mile | (33%) | (35%) | (36%) | (34%) | (10%) | (5%) | (6%) | 2 |
| Irregular working | 54% | 40% | 31% | 24% | 18% | (4%) | (2%) | 245 |
| Rolling stock failures | 86% | 98% | 97% | 113% | 103% | 90% | 39% | 25 |
| Environmental factors | 84% | 69% | 58% | 51% | 91% | 75% | 26% | 6 |
| Vandalism | (39%) | (37%) | (34%) | (29%) | (26%) | (24%) | (26%) | 1587 |
| Structural failures | 4% | (3%) | (14%) | (6%) | 40% | (6%) | (8%) | 12 |
| Broken rails | (45%) | (38%) | (38%) | (32%) | (8%) | 23% | 22% | 61 |
| Train speeding | (44%) | (41%) | (37%) | (40%) | (56%) | (58%) | (14%) | 25 |
| Level crossing failures | 92% | 69% | 55% | 38% | 35% | 19% | (8%) | 94 |
| Irregular loading of freight trains | 22% | 47% | 52% | 65% | 59% | 42% | (37%) | 12 |
| Wrongside signalling failures | 5% | (30%) | (28%) | (24%) | (14%) | (15%) | (22%) | 66 |
| Buckled rails | (38%) | (38%) | 15% | 47% | (21%) | 76% | (47%) | 3 |
| Non rail vehicles on line | (43%) | (41%) | (33%) | (35%) | (24%) | (21%) | (14%) | 44 |
| Possession irregularities | 60% | 40% | 33% | 32% | 19% | 16% | 23% | 32 |
| Hot axle box | (16%) | (12%) | (17%) | (15%) | (24%) | (12%) | 14% | 144 |
| Animals on the line | (11%) | (8%) | (6%) | (4%) | 9% | 4% | 8% | 241 |

## Precursor group weightings

| | Proportion of train accident risk | Equivalent fatalities | | Proportion of train accident risk | Equivalent fatalities |
|---|---|---|---|---|---|
| Category A SPADs | 32.70% | 7.969 | Level crossing failures | 0.89% | 0.218 |
| Level crossing misuse | 22.74% | 5.543 | Irregular loading of freight trains | 0.82% | 0.201 |
| Discrete track faults (gauge, twist, top, line) | 10.88% | 2.653 | Cyclic top * | 0.60% | 0.145 |
| Irregular working | 8.28% | 2.019 | Animals on the line | 0.44% | 0.108 |
| Rolling stock failures | 7.98% | 1.944 | Non rail vehicles on line | 0.40% | 0.097 |
| Environmental factors | 6.00% | 1.462 | Wrongside signalling failures | 0.36% | 0.087 |
| Vandalism | 2.94% | 0.717 | Buckled rails | 0.29% | 0.071 |
| Structural failures | 1.37% | 0.334 | Possession irregularities | 0.15% | 0.036 |
| Broken rails | 1.08% | 0.263 | Hot axle box | 0.13% | 0.031 |
| Train speeding | 0.98% | 0.239 | **Total** | | **24.373** |
| Unknown fire causes * | 0.97% | 0.237 | ** no available data* | | |

A review of the table at the bottom of the previous page shows that over the period shown, four of the precursors have shown a steadily increasing trend. These are *irregular working*, *level crossing failures, environmental factors* and *possession irregularities*. The trends in these precursors are plotted on the next chart.

## Precursors with a long term increase pattern




As mentioned in the half-year report, investigations are being made into the causes of the rise in the precursors that are having a noticeable effect on train accident risk. Two such precursors, *environmental factors* and *level crossing misuse*, are now discussed.

### Environmental Factors

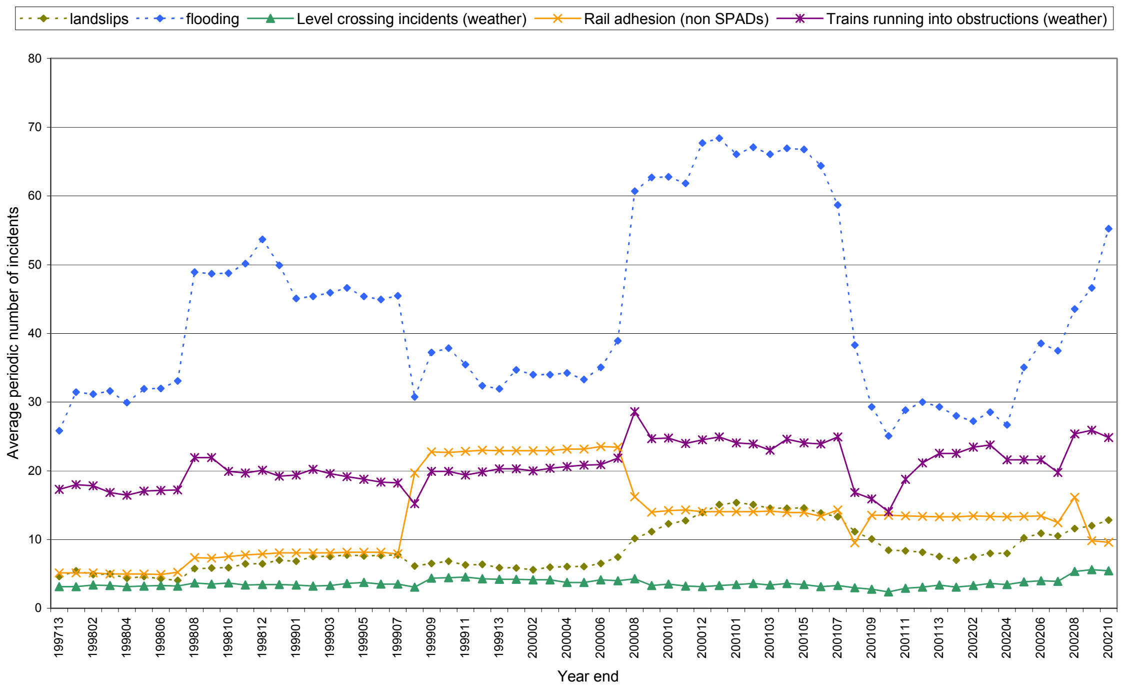
The environmental factors precursor group has five separate components, each of which is weighted according to its consequences as identified in the SRM. The following table shows how the five parts of the environmental precursor group are weighted.

## Environmental factors precursor- component weightings

| | Proportion | Equivalent fatalities |
|---|---|---|
| Level crossing incidents (weather) | 44.056% | 0.644311 |
| Landslips | 24.653% | 0.360539 |
| Rail adhesion (non SPADs) | 17.689% | 0.258700 |
| Trains running into obstructions (weather) | 13.601% | 0.198903 |
| Flooding | 0.001% | 0.000015 |
| **Total** | **100%** | **1.462468** |

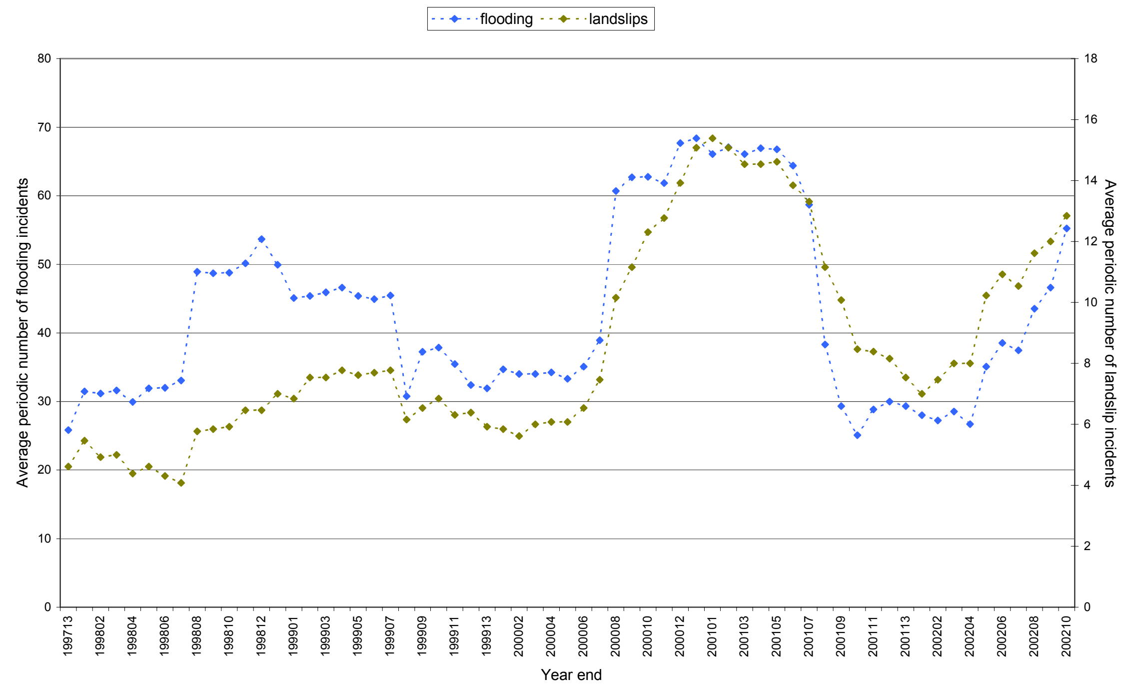
The following chart shows the trend in each separate component over time.

## Environmental factors annual moving average




The next chart examines the possible relationship between two of the compenents – landslips and flooding. Floods are plotted against the left-hand axis and landslips against the right. During the third quarter there was a derailment due to a train striking a landslip. Although the cause of the slip is under investigation, it highlights the role of environmental factors as a train accident precursor group.

**Flooding and landslips - annual moving average**




Although landslips can occur for reasons other than flooding, it is interesting to note that the shapes of the two curves are similar. As has been highlighted in last year's annual safety performance report, flooding is expected to occur with increased frequency and severity due to global warming (source: Department for Environment, Food and Rural Affairs).

Over the time represented in the above chart (period 1 of 1997/98 to period 10 of 2002/03) there have been ten occasions when a landslip has directly caused a derailment, resulting in a total of 19 minor injuries. Version 3 of the Rail Safety and Standards Board Safety Risk Model (SRM) estimates a risk contribution of 0.340 accidental equivalent fatalities (aef) per year from the precursor *running into landslip leading to train derailment*, which is an increase on the previous Version 2 estimate of 0.288 aef. The Version 3 estimate does not take into account any potential increase in landslips that may occur due to future environmental weather changes. Neither estimate takes into account cases where a landslip may indirectly cause a derailment, for example, by resulting in track movement.

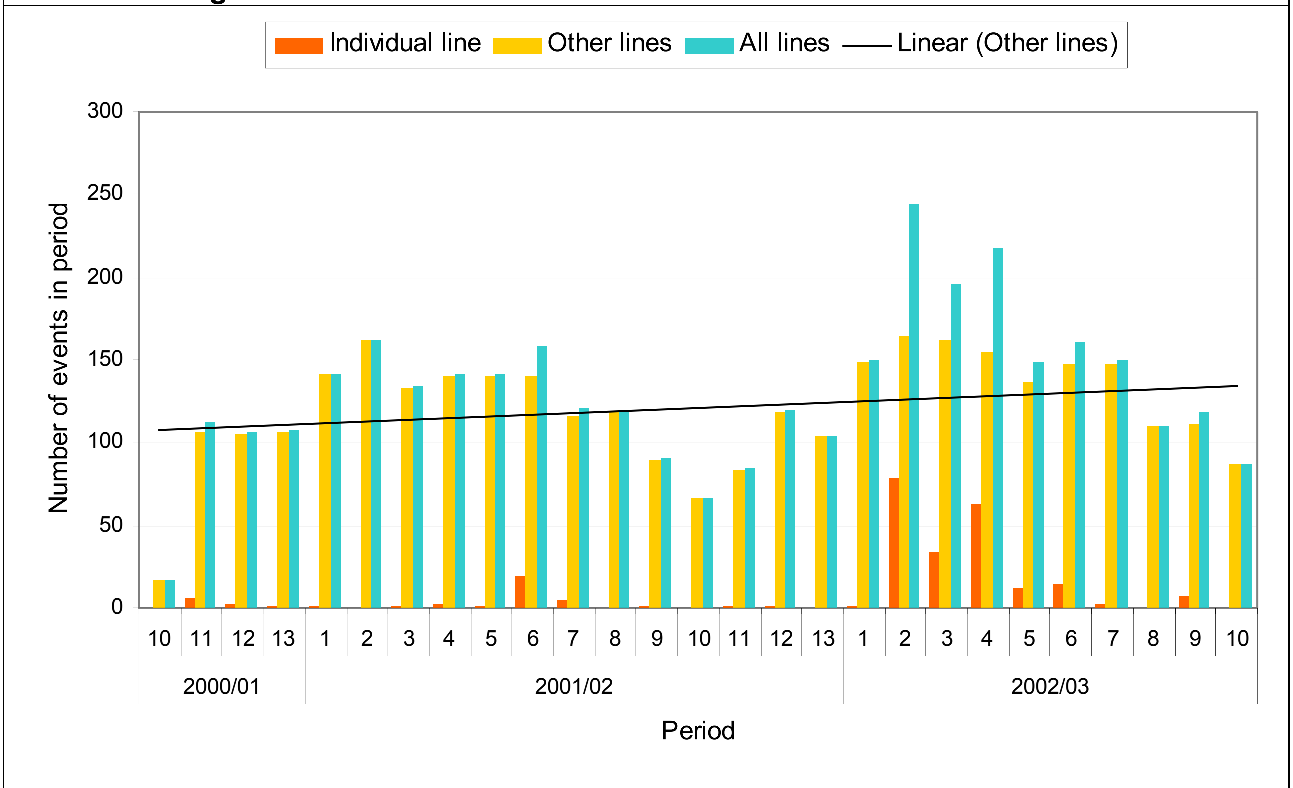
There are two relevant Rail Safety and Standards Board research projects underway. The first is to determine what effects weather and climate change have on safety hazards related to the railway, and to identify the likely effects of climate change. The second is to evaluate current tools for estimating the risk to railway structures from flooding, and suggest improvements. The outcome of these projects is likely to be important in addressing this potentially increasing source of risk on the railway.

**Level crossing misuse**

One of the main causes of the risk in the PIM compared with the end of 2001/02 is a rise in the recorded instances of level crossing misuse. As noted in the half-year report, a substantial part of the increase has been due to an increased number of reports on one individual line (from Preston to Ormskirk) following a period during which a fatality occurred at a level crossing on that line. The type of crossing involved was a user worked crossing (UWC) that had been risk-assessed prior to the incident.

The contribution of incidents on this individual line to the total number of incidents can be seen in the following chart. The orange bars relate to the number of incidents on the individual line, the yellow bars indicate the number on the other remaining lines, and the blue bars represent the total for all lines. The chart indicates that the increased rate for the individual line, which was noted in the half-year report, now appears to have fallen back to its previous level. This is discussed later in this section.

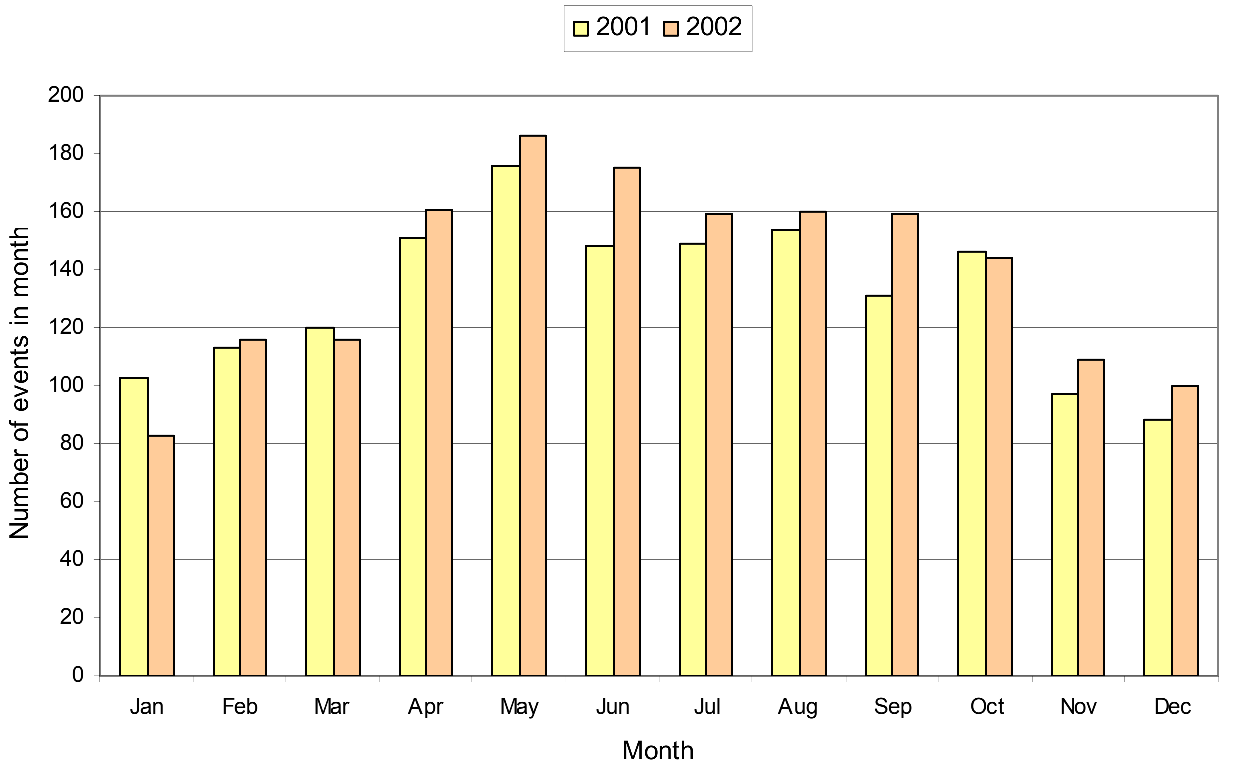
**Level crossing misuse**




The chart shows that even if the data for this particular line is removed from consideration there still appears to be an upward trend (shown by the solid black line) in the occurrence of level crossing misuse. The annual moving average for the modified data set at the end of the third quarter is around 8% higher than at the end of 2001/02.

The next figure analyses the seasonal variation in level crossing misuse, for the calendar years 2001 and 2002, again for the modified data set.

**Level crossing misuse by year, not including data for individual line**




The level crossing misuse data over the past two years appears to show a defined seasonal variation, peaking in the month of May. This could be related to the effects of domestic tourism, which are likely to increase both the number of cars on the road, and the number of cars making unfamiliar routes for the purposes of holidays or days out. Furthermore, it is interesting to note that the Association of British Travel Agents (ABTA) noted a decrease in the number of package holidays taken during 2002, as a result of September 11 and the general economic climate. This implies that more people holidayed in the UK, which may at least partly account for the increased number of incidents seen for 2002. The apparent seasonal variation also indicates that over the coming months, the number of level crossing misuse incidents can be expected to increase.

One further important point should be noted. The fact that following a fatal incident on one particular line, there was a marked increase in reports of level crossing misuse implies that general under-reporting of misuse may be a problem. The most commonly reported type of misuse on this line relates to the gates of UWCs being left open after use, which could be particularly dangerous for unfamiliar users.

Precursors are seen as a vital part of safety intelligence and we encourage their use throughout the industry. If you would like more information on precursors and how they can be used in safety performance monitoring, or would like to share how they are used in your company, then please call Paul Sizer, senior safety intelligence advisor, on 020 7904 7496 (or email: sizerp.railwaysafety@ems.rail.co.uk).

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