Executive Summary

It is considered likely that all the predicted incremental changes in the climate as well as increased frequency of extreme weather events will impact on the components of the rail system. Consequently, most of Network Rail’s roles, responsibilities and functions will be affected.

Network Rail is committed to deliver infrastructure that is capable of being operated effectively to changing climate in its sustainability policy.

Network Rail has previously produced, or been involved in, various climate change risk assessments using a range of climate projections. A range of well-established current extreme weather standards and risk management policies are already in place. These procedures range from routine to enhanced inspections triggered by forecast or actual weather events, and significant risks can be managed via bespoke asset plans for extreme events.

Currently, the Railway Safety and Standards Board (RSSB) study Tomorrow’s Railway and Climate Change Adaptation (TRaCCA), involving the Met Office, provides the basis for current rail industry climate change risk assessments.

TRaCCA has assessed the risk of heat and solar energy, precipitation, wind and sea level rise on railway assets and operations using a methodology that combines assessment of climate hazards and the vulnerability of railway infrastructure to them.

As a result the following major impacts have been identified;

- An increase in the number of days required to monitor track buckling and an increase in the frequency of speed restrictions as a result;
- A reduction in productivity for maintenance workers, due to heat stress;
- A small projected increase in sag of overhead line equipment;
- An increase of passenger heat stress;
- Increased river and localised flooding leading to scour and flooding of bridges, embankment scour, culvert washout, depot flooding and track and lineside equipment failure;
- Sea level rises and storm surge increases requiring improved railway flood defences.

The TRaCCA findings and outputs will be used by Network Rail’s asset, operational and regulation experts to develop risk mitigation actions. This work will be undertaken in preparation for Period Review negotiations (known as PR13) on outputs and funding for the next rail regulatory period running from 2014-19 (known as Control Period 5 or CP5), as well as the longer term.

There is considerable uncertainty about whether climate change will lead to an increase in landslips, lineside equipment failures, groundwater flooding and trees and leaves on the line. Further climate analysis and more detailed Network Rail performance and delay data in certain areas or even new metrics may be required to address these uncertainties.

The uncertainty surrounding climate projections and impacts, outputs and funding for CP5 and longer term and the precise network size, shape and traffic volume in the very long term represent the biggest barriers and challenges to the preparation of Network Rail’s adaptation plans.
However, once agreement is reached on adaptation measures with the government and our regulator, through CP5 negotiations, Network Rail’s adaptation requirements will be implemented and monitored at the highest levels of the organisation.

As well as addressing key threats, Network Rail, in partnership with universities such as Birmingham, is also exploring the opportunities that a changing climate could create for the railway. In particular, climate change may reduce the incidence of current weather conditions that affect network performance, such as freezing temperatures and snow in winter, as well as increasing travel demand in certain areas, for example, to coastal resorts during hotter, longer summers.

The railway is faced with the same interdependencies and ‘cascade failure’ threats to service continuity that all other critical infrastructure providers face namely; staff absence, denial of site or geographical areas, loss of power, transport networks, water and sewerage and oil/fuel and communications networks. As a result, we are engaged in a range of initiatives with other infrastructure, government and engineering institution representatives to identify vulnerabilities across all sectors, some of which are summarised in this report.

Introduction

This full report fulfills the requirement, under the 2008 Climate Change Act, for Network Rail to prepare and send an adaptation report to Defra containing an assessment of the current and predicted impacts of climate change on the railway and policies to address them.

This report reiterates, but also builds on, our interim report sent to Defra on 30 September last year. In particular, it provides an update on the development of our adaptation action and cost plans, ahead of the Periodic Review process which will determine rail outputs and funding for the next regulatory period from 2014-19 and also set long term strategies.

This updated adaptation report also provides more information in the areas that Defra and Cranfield University identified for further work from the interim report, namely:

- Risk assessment methodologies and details of the evidence base for risk assessments and prioritisation;
- More detail on risk management actions, policies and standards and how organisational practice might change and develop as a result of risk assessments;
- More information on the costs and benefits of adaptation; and
- Adaptation barriers, interdependencies and reliance on other infrastructure providers.

Functions impacted by climate change

Network Rail is a not for dividend company that owns and operates Britain’s rail infrastructure. Its mission is to provide a safe, reliable and efficient railway fit for the twenty first century.

Network Rail operates under a Network Licence which sets out the conditions under which it must operate.

In particular, Licence Condition 1 sets out Network Rail’s core obligations to secure the operation, maintenance, renewal and enhancement of the network in order to satisfy the reasonable requirements of persons providing services to railways and funders. This is in respect of the quality and capability of the network and the facilitation of railway service performance.

This condition also includes some specific obligations for Network Rail to:

- produce a delivery plan;
- establish and maintain route utilisation strategies (RUSs);
• develop policies and criteria demonstrating how it will meet the core obligations;
• maintain appropriate, accurate and readily accessible information about the relevant assets;
• co-operate with potential operators or funders on allocation of capacity;
• run an efficient and effective timetabling process; and
• asset management policies and criteria to maintain, renew, replace, enhance and develop the assets.

It is considered likely that all the predicted incremental changes in the climate as well as increased frequency of extreme weather events will impact on the components of the rail system. Consequently, most aspects of Network Rail’s role, responsibilities and functions will be affected.

We are already working closely with our customers, industry partners and key other stakeholders to understand the likely impact of climate change on our infrastructure, mitigate and adapt to climate change and respond effectively to the threats, and also opportunities, it brings.

In particular, Network Rail and the rail industry are focused on how the current and future climate will affect the ability to achieve and deliver:

• a safe railway;
• a highly reliable railway;
• increased capacity;
• value for money.

Network Rail already has well-established standards and policies in place to both respond to extreme weather events and deliver appropriate levels of infrastructure resilience and service continuity under currently experienced weather patterns.

Network Rail is also embarking on further protection of railway assets (some of which are one hundred and seventy years old) from the impact of extreme weather conditions, by investing a substantial amount of capital expenditure for renewal work at priority locations.

As a result Network Rail is committed to deliver infrastructure that is capable of being operated effectively to changing climate in its sustainability policy¹.

Overview of Britain’s broader rail industry

The figure above sets out Network Rail’s key stakeholders. On adaptation, Network Rail’s key stakeholders are:

- Passenger and freight operators (TOCs and FOCs) - our customers;
- The DfT and Transport Scotland – who specify and fund rail services;
- The broader supply chain – which will also need to adapt its products for the rail industry;
- The Office of Rail Regulation – that regulates Network Rail;
- Other government departments and agencies involved in climate change and a low carbon economy - such as Defra, the Environment Agency, the Cabinet Office and Business, Innovation and Skills;
- Local, regional and sub regional government - Network Rail works closely with sub national government on climate change adaptation and particular issues such as flooding and other extreme weather events.

Going forward, both Network Rail and our customers must build on current weather standards to formulate and adopt joint adaptation and extreme weather emergency plans. Network Rail also needs to get a clear idea on customer expectations and our recently announced new devolved structure will aid this process. Under this structure, more responsibility for asset management outputs and spend, operations, planning and delivering maintenance and delivery of some renewals and enhancements will be given to newly created business units.

One of Network Rail’s weather specialists has already looking at climate change vulnerabilities and infrastructure interdependencies at specially selected Sites of Special Scientific Interest on the Anglia route Walthamstow Marshes, Benfleet and Southend Marshes, Breckland Forest), in partnership with the train operator.

Network Rail already hosts an industry wide seasons management conference every year for the wider industry and its supply chain to raise awareness of the continued challenges faced through seasonal and severe weather conditions. This provides an insight to the various methods used to address the effects of severe weather and also demonstrates strategic direction in all weather management.

Furthermore, we are developing a series of seminars and workshops on current weather management across our routes with train operators, including visualisation exercises, in order to educate the industry of its long term implications and long term costs.

---

Network Rail is also working closely with our European and global industry partners, for example through the International Union of Railways Adapting Railway Infrastructure to Climate Change (UIC ARISCC) project, to both share our adaptation experiences and standards and learn from efforts of railways in adapting to current climate conditions which might become ours in future. Network Rail has also established an Adhesion Working Group which is part of a wider European group with colleagues in Holland, Ireland, Denmark and Germany.

With regards to the government and rail regulator, negotiations will shortly begin for CP5 during which the government and ORR will put forward their requirement with regards to climate change and the development of the railway.

Climate change risk assessments and evidence

Network Rail has a set of mature asset and extreme weather risk management procedures that have evolved over many years. These procedures range from routine to enhanced inspections triggered by forecast or actual weather events. Significant risks can be managed via bespoke asset plans for extreme events.

Network Rail has carried out various risk assessments related to climate change and its assets and has been involved in broader assessment projects and routine reporting, including:

- The Railway Safety and Standards Board (RSSB) TRaCCA³ project, as well as work to support it by the Met Office’s Hadley Centre⁴, currently provides the basis for our climate change risk assessments. Its outputs are being used Network Rail and the broader industry to develop adaptation strategies and costs. More specific RSSB projects have also been important previously, e.g. on T643 Impact of Climate Change on Coastal Rail Infrastructure⁵;
- Asset failures, which we report to our regulator;
- Delays due to asset problems which provide evidence for the development of risk assessments and thresholds;
- Asset risks caused by various climatic conditions produced for the Cabinet Office’s natural hazards team for their work on critical infrastructure resilience;
- Network Rail asset assessments following extreme weather events such as flooding in 2007 and 2009 and the heavy, prolonged snow fall last winter;
- Analysis of passenger comfort in extreme weather event, leading to the development guidance and contingency plans, developed in partnership with train operators;
- Network Rail route specific extreme weather plans based on climate predictions (climate change impacts and thresholds may vary greatly according to geography and climatic conditions in different areas);
- The International Union of Railways work stream on ARISCC⁶;
- Network Rail Report – “Climate Change - An Assessment of the Potential Impact of Flooding on Railways in the South West”⁷;
- The FUTURENET research project on UK transport networks in the 2050s⁸.

---
³ RSSB Study T925 Tomorrow’s Railway and Climate Change Adaptation, www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/Research/T925_rb_final.pdf
⁴ A Preliminary Report by the Hadley Centre on “The impact of Climate Change on the rail network” will be finalised on 30 September;
⁶ International Union of Railways Research Project ARISCC (in progress); www.uic.org/baseinfo/projet/projet.php?id=207
⁷ Internal Network Rail report Climate Change - An Assessment of the Potential Impact of Flooding on Railways in the South West; Prepared for the South West Regional Assembly Transport Officers’ Subgroup, 2006
⁸ EPSRC-funded research project FUTURENET, www.arcc-futurenet.org.uk/
• The Infrastructure Transitions Research Consortium research project on infrastructure transitions which includes cross-sectoral dependencies. 

These projects utilise a range of external and internal evidence sources to assess the likely future changes in the climate and the impact they will have on the operation of railway, including:

• Principally, we are using the Met Office Hadley Centre via a contract, to develop weather/climate modelling through the TRaCCA project;
• 2009 UK Climate Projections (UKCIP09) data which will be integrated with Network Rail’s Geographical Information System (GIS) to map key risks on a route by route basis – www.ukcip.org.uk (see response above);
• UKCIP Wizard adaptation tool;
• Internal Network Rail datasets such as earthwork, structures, track, drainage asset registers;
• Network Rail’s weather risk management standards and procedures (details of which are provided later in this submission) and supporting registers such as those used for track buckle risk management, bridge scour risk management;
• Network Rail’s safety hazard reporting systems;
• ATOC vehicle fleet reliability data;
• Design criteria for lineside equipment, including rail traction overhead power lines;
• Network Rail’s GIS data on flood plain extent;
• Network Rail’s Water and Earthworks Risk Model;
• The Rail industry Safety Management Information System;
• The Meteo group provide weather forecasts for Network Rail through their RailCast service (www.meteogroup.co.uk/uk/home/services_for_business/transport/rail.html);
• Environment Agency flood risk mapping.

Phase 1 of the TRaCCA project established priority risk areas of weather impacts on railway infrastructure and operations (set out below) for further research and analyses in Phases 2 and 3.

Phase 2 developed mathematical models on meteorological thresholds using the underlying science behind the 2009 UK Climate Projections (UKCP09), to facilitate risk assessments, for half the priority areas up to the 2040s, as identified in Phase 1, using the London – Glasgow West Coast Main Line (WCML) as case study. Only half the priority areas were examined because of limitations in the science and data as explained later.

The key findings, based on modelling of the WCML, were as follows:

• The number of heat watchman days and the frequency of speed restrictions being imposed (associated with buckle risk and high temperatures) is projected to increase out to the 2040s for all track conditions examined, for the whole of the WCML;
• The number of non-track-work days lost due to unsuitable temperature conditions is projected to increase by the 2040s along the WCML;
• Sag of overhead line equipment (OLE) has been investigated via a temperature threshold exceedance analysis. There is a small projected increase in the modelled average occurrence of OLE sag by the 2040s with respect to the baseline period;
• The projected number of days where human heat stress occurs by the 2040s is projected to become more frequent;
• River flooding can lead to many rail industry problems including scour and flooding of bridges, embankment scour and culvert washout, depot flooding and track and lineside equipment failure;
• The future risk of landslips caused by large monthly rainfall totals has been investigated and there is mixed evidence for whether critical events could become more or less frequent;
• Rail speed restrictions and track disruption can result from obstructions such as trees being blown onto the lineside when there are high winds;
• At key locations across the UK where rail infrastructure is at risk from inundation, sea level rise and storm surge projections for 2045 have been made.

In Phase 3, these innovative mathematical models have been combined with climate projections with metrics commonly used across the rail industry (mainly train delay minutes but also more specific measures, such as heat watchmen in the case of monitoring track buckling, during periods of high temperature) to assist the sector in developing business action strategies and costings (see actions and costs sections below).

Phase 3 builds on these phase 2 outputs beyond the WCML to cover the whole of the British rail network (see assessment of climate thresholds section below) and by undertaking further analysis of vulnerability to improve our risk assessments and produce recommendations.

Assessment of key climate risks

The TRaCCA project has identified asset and operational risks to the company which are set out in Annex 1. This sets out an overview of asset risks and their impact, while Annex 2 sets out our priority areas for action on assets and operations.

The TRaCCA project has prioritised assets and systems according to climate risks and their impact on safety and performance. This was achieved through a series of expert workshops during Phase 1 of TRaCCA. TRaCCA has also identified areas that require detailed weather modeling to inform risk assessments.

Climate change methodologies, thresholds and results

During Phase 1 of TRaCCA, seven expert workshops were held to examine:

• Maintenance activities
• Renewal activities
• Signalling, power and communications assets
• Track assets
• Civil engineering assets
• Operations including train risks
• System risks

At the workshops, known hazards were listed and consideration given to whether climate changes would result in worsening safety or performance. The resulting list (Annex 1) was then ‘filtered’ and any item with high safety and/or performance impact was included for further evaluation in Phase 2. A ‘moderation’ exercise then took place, where the filtered list was reviewed by senior engineers. Minor changes to the list were then made and taken forward to Phase 2.

Phase 2 of the TRaCCA project, reported on climate related vulnerability thresholds to frequency and severity of heat, precipitation, vegetation and sea level rise risks to the railway up to the 2040s, using the underlying data behind the UKCP09 projections and the WCML as a case study route.

Through this process TRaCCA has developed innovative techniques to combine climate model output with incident data to translate the findings into metrics commonly used across the industry. This will assist sector experts in developing risk management strategies to address changing climate.
TRaCCA aimed to use a risk-based framework whereby risk is quantified through two or more parameters which are multiplied together to give an overall rating. Risk was defined as hazard \times vulnerability, as used by the Met Office in the TRaCCA project.

Hazard refers to the extent of climate impact and vulnerability is measured through rail incident metrics, particularly delay minutes, where suitable data has been available in terms of time-series and geographical coverage.

Summary of specific methodologies, thresholds and results

Track buckling

Railway tracks are stressed at installation to withstand a range of temperatures. Some research\(^9\) suggests there is no need to increase these stress free temperatures (SFT). However, an increase in SFTs in areas with higher summer temperatures could be considered to combat the 3-5°C loss of SFT in the first few months of installation of track.

A number of actions are taken at Critical Rail Temperatures (CRT) to maintain safety and maintain network integrity and Network Rail has produced guidance on when to act. For three particular categories, the Network Rail procedure states;

- Provide a Watchman to monitor a piece of track at CAT(W) is reached
- Impose a 30/60mph speed restriction at CAT (30/60)
- Impose a 20mph speed restriction at CAT (20)

The temperature thresholds at which these measures are taken depends on track type and its composition. The air temperature (Degrees Celsius - °C) thresholds at which specific actions are carried out for different track conditions has been calculated\(^10\) and examples are set out below;

<table>
<thead>
<tr>
<th>Track condition</th>
<th>CAT (W)</th>
<th>CAT (30/60)</th>
<th>CAT (20)</th>
<th>Period for which CRT shall apply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undistributed, fully ballasted and</td>
<td>35</td>
<td>39</td>
<td>42</td>
<td>Permanently</td>
</tr>
</tbody>
</table>

\(^9\) Dobney, K., 2010, “Quantifying the effects of an increasingly warmer climate with a view to improving the resilience of the UK railway network: Is a new stressing regime the answer?” A PhD thesis submitted to The University of Birmingham.

\(^10\) Using the equation \(T_{air} = (2/3) T_{rail}\)
Using the critical air temperatures, the frequency of days falling into each temperature band associated with a different action, have been calculated for the baseline (1971-2000) and the 2020s, 2030s and 2040s, for each of the three track conditions.

Overall, the results project an increase in the number of heat watchman days and the frequency of speed restrictions being imposed out to the 2040s for all track conditions. For example, for the track condition ‘three or more consecutive slurried beds where ballast is not compacted against the sleeper ends’, the modelled number of heat watchman days in one part of South West England is around twice as many as occurred in the baseline period. In general, the number of heat watchman days and the frequency of speed restrictions are projected to remain most frequent across the South and East of Great Britain, but the largest percentage changes are projected to be in the North and West of Great Britain.

The two tables below show results for temperature threshold exceedances for three randomly chosen modeled locations, as examples of this general trend:

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t. baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Scotland</td>
<td>459</td>
<td>730</td>
<td>1140</td>
<td>1554</td>
<td>148</td>
</tr>
<tr>
<td>South West England</td>
<td>718</td>
<td>1066</td>
<td>1522</td>
<td>1864</td>
<td>112</td>
</tr>
<tr>
<td>North East England</td>
<td>750</td>
<td>1068</td>
<td>1525</td>
<td>1808</td>
<td>103</td>
</tr>
</tbody>
</table>

Example results for modeled number of exceedances of 21 Degrees Celsius in selected locations around GB, for the baseline and 2040s (2030-2059)

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t. baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Scotland</td>
<td>0.6</td>
<td>0</td>
<td>6.4</td>
<td>14</td>
<td>941</td>
</tr>
<tr>
<td>South West England</td>
<td>6.5</td>
<td>17</td>
<td>39</td>
<td>72</td>
<td>494</td>
</tr>
<tr>
<td>North East England</td>
<td>5.7</td>
<td>5.5</td>
<td>26</td>
<td>37</td>
<td>352</td>
</tr>
</tbody>
</table>

Example results for modeled number of exceedances of 31 Degrees Celsius in selected locations around GB, for the baseline (1970-2000 average)

Windows of opportunity for track maintenance
As the previous section shows, stone ballast has an essential role to play in limiting track buckle risks. Tamping and stone blowing are maintenance processes whereby ballast is laid down, added and consolidated. Network Rail guidance stipulates that track maintenance should not be conducted when rail temperatures are above 32 °C or predicted to exceed 38 °C – equating to air temperatures of 25 °C and 21 °C within three days of work being carried out. This is in order to mitigate the risks of a track buckle occurring and to reduce the potential imposition of speed restrictions and the consequent degradation of performance.

Research found that the most relevant performance indicators in the TRUST database to assess delays caused by temperature limiting track maintenance are possession over-run from planned work; speed restrictions due to a cancelled possession/work not completed and possession cancellation. However, the filtering criterion used for identifying these data is not as detailed as the criteria used for other priorities and it is not possible to separate possession delays caused by heat from other causes.

Risk is again defined as hazard x vulnerability

The change in the number of heat-related “non work” days between the baseline (1971-2000) and the 2040s has been found to be statistically significant across Great Britain at the 5% level. The table below gives results for three modelled locations around the country:

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t. baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Scotland</td>
<td>262</td>
<td>442</td>
<td>711</td>
<td>1045</td>
<td>171</td>
</tr>
<tr>
<td>South East England</td>
<td>1370</td>
<td>1877</td>
<td>2378</td>
<td>2725</td>
<td>74</td>
</tr>
<tr>
<td>North East England</td>
<td>927</td>
<td>1278</td>
<td>1819</td>
<td>2119</td>
<td>96</td>
</tr>
</tbody>
</table>

Currently, the most vulnerable route region in the context of heat-related track maintenance issues in London North West (LNW), while the least vulnerable regions are Sussex and Midland & Continental.

Sag in overhead traction power lines

Overhead cables that supply electrical power to trains (OLE) have a design temperature tolerance range of -18 °C to 38 °C. Air temperatures exceeding 38 °C could lead to line sag, impacting the running of trains and also damage of the pantograph on trains that connects with the OLE.
While the occurrence of 38 °C temperatures is extremely rare (only two exceedances observed in the UK), line sag occurrences are far more common. It is believed that the maximum difference between air temperature and overhead line temperature is 5°C. As a result, more temperature thresholds have been examined – specifically 33, 35 and 38°C. However, further work is needed to understand the relationship between air temperature and sag. Also, exposure of OLE to direct solar radiation is also an important factor.

TRaCCA results show that the modelled exceedance of the three temperature thresholds is relatively rare during the baseline period (1971-2000), with the greatest exceedance being in South East England.

Results show only two routes have experienced delays from summertime overhead line sag – Anglia and London North West, although whereas such systems also exist on Midland and Continental, Great Western and London North East routes. Around twice as many delay minutes were incurred in the Anglia region as in the LNW region, probably because of the different configuration of the two routes’ OLE systems; Anglian uses predominantly tethered OLE wires while LNW uses a tensioned system.

Exceedance of all three thresholds is projected to increase into the future for the 35°C and 38°C thresholds, and for all three time periods studied (2020s, 30s and 40s). However, there are some parts of the country where even the maximum projected exceedance remains zero (i.e. in some parts of country these thresholds are projected not to be exceeded).

For example, the table below gives examples of some results for the baseline and 2040s for exceedance of the 33°C threshold in three modelled locations around Great Britain. Although these locations have been arbitrarily selected, they illustrate that very small numbers of exceedances in the baseline can lead to very large percentage changes in the future compared with the baseline;

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Scotland</td>
<td>0.17</td>
<td>0</td>
<td>0.7</td>
<td>3</td>
<td>324</td>
</tr>
<tr>
<td>Central England</td>
<td>12</td>
<td>17</td>
<td>52</td>
<td>83</td>
<td>325</td>
</tr>
<tr>
<td>South Wales</td>
<td>3.6</td>
<td>7.6</td>
<td>24</td>
<td>45</td>
<td>577</td>
</tr>
</tbody>
</table>
**Staff exposure to heat stress**

The rail industry employs a significant number of people that work outside. Indeed, as discussed in a previous section, the number of heat watchman days will need to increase in future. It is therefore important to understand how climate change could affect staff exposure to heat stress; i.e. when control of human internal body temperature becomes less effective and starts to fail.

The Met Office’s Heat-Health Watch system has been used in TRaCCA as proxy for heat stress. This system triggers different alert levels depending on the probability that threshold temperatures are reached in a particular region on at least two consecutive days and intervening night (meaning less respite from hot daytime conditions). Various temperature thresholds are used for various regions – as set out below - as people are acclimatised to different temperatures in different areas. The Met Office system does not operate in Scotland, and temperature thresholds for the North East are used.

<table>
<thead>
<tr>
<th>Region</th>
<th>Day max (°C)</th>
<th>Night min (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East England</td>
<td>28</td>
<td>15</td>
</tr>
<tr>
<td>North West England</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Yorkshire and Humber</td>
<td>29</td>
<td>15</td>
</tr>
<tr>
<td>East Midlands</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>West Midlands</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>East of England</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>South East England</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>London</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>South West England</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Wales</td>
<td>30</td>
<td>15</td>
</tr>
</tbody>
</table>

The results below show heat stress going up across the country but, whilst the south and east of the country generally have the largest number of heat stress episodes, the greatest percentage changes between the baseline and future averages are generally in the north and west of Great Britain. The table below gives results for three randomly chosen modelled locations;

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t. baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Scotland</td>
<td>3.9</td>
<td>3.6</td>
<td>20</td>
<td>37</td>
<td>400</td>
</tr>
<tr>
<td>South East England</td>
<td>23</td>
<td>55</td>
<td>90</td>
<td>133</td>
<td>294</td>
</tr>
<tr>
<td>North Wales</td>
<td>2.1</td>
<td>1.3</td>
<td>13</td>
<td>30</td>
<td>531</td>
</tr>
</tbody>
</table>

**Freight risk and train performance**

Extreme cold and snow can affect the braking performance of trains.

Temperatures of 0 °C and - 5°C were selected for the TRaCCA project as representative of cold conditions.

The results show exceedance of the -5 °C threshold is rarer than exceedance of the 0 °C in all time periods. The largest number of exceedances of both thresholds in the baseline period are in Scotland,
Northern England and parts of central Wales. Exceedance of these temperatures – and therefore vulnerability of the railway - is projected to decrease in future. This is the opposite of what has been predicted for other risk priorities. Below, the results for three randomly chosen locations, demonstrates this;

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseline average</th>
<th>2040s minimum</th>
<th>2040s average</th>
<th>2040s maximum</th>
<th>% change 2040s average w.r.t. baseline average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scottish Highlands</td>
<td>3170</td>
<td>2463</td>
<td>2251</td>
<td>2035</td>
<td>- 29</td>
</tr>
<tr>
<td>North West England</td>
<td>1717</td>
<td>1105</td>
<td>980</td>
<td>891</td>
<td>- 43</td>
</tr>
<tr>
<td>Southern England</td>
<td>1275</td>
<td>770</td>
<td>616</td>
<td>540</td>
<td>- 52</td>
</tr>
</tbody>
</table>

Given these results we may also expect to see a decline in incidence of third rail and OLE power failure due to freezing temperatures and snow, going forward.

**Passenger risk**

The Met Office has produced risk thresholds for passengers stranded in hot conditions based on guidance from Network Rail and research carried out by the RSSB;

<table>
<thead>
<tr>
<th>Air Temperature (°C)</th>
<th>How long comfortable (mins)</th>
<th>Likelihood of requiring evacuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>180</td>
<td>Low</td>
</tr>
<tr>
<td>20</td>
<td>120</td>
<td>Low-medium</td>
</tr>
<tr>
<td>25</td>
<td>90</td>
<td>Medium</td>
</tr>
<tr>
<td>30</td>
<td>75</td>
<td>Medium-High</td>
</tr>
<tr>
<td>35</td>
<td>60</td>
<td>High</td>
</tr>
</tbody>
</table>

The risks to passengers from hot conditions requires further research, particularly the influence of factors such as degree of ventilation that can be provided, humidity levels, the nature of the train failure and the impact of traction failure which would know out air-conditioning as well as stopping a train. The train operators will need to be involved in this research, particularly on temperature accumulation vulnerabilities on current fleet types and how new carriage designs and retro fits can overcome them.

**Lineside equipment failure**

The British Rail standard for the conditions in which railway signalling apparatus should be stored, transported or operated (BR967, 1973) indicates that the ambient temperature inside locations should be kept between -20°C and 60°C at 100% humidity.

However, this standard needs to be reviewed and Network Rail is currently looking at casing temperatures across the country and their operational impact. However, data is currently not extensive enough to develop a new methodology for lineside equipment failure and the precise relationship between temperature, humidity, wind force, solar radiation and rain rate.

**River flooding**
River flooding occurs when a watercourse cannot cope with the amount of water draining into it from surrounding land, for example, when heavy rain falls on an already waterlogged catchment. In particular, the river flooding can cause the following damaging impacts for the railway:

- Scour and flooding at bridges;
- Embankment scour and culvert washout;
- Depot flooding;
- Track flooding and lineside equipment failure.

A selection of bridges, embankments and culverts that have suffered such damage over the last 6 years have been assessed. Results show that the majority of disruption followed multi-day rainfall, often associated with low-pressure systems and related frontal rainfall (a notable exception is Caldew Viaduct, near Carlisle, where a flood event took place after just one day of very heavy rainfall).

In the eight catchments that have been studied, the rainfall totals which resulted in flooding and disruption to the rail network were very extreme events, generally in the 98th or 99th percentiles. As well as rainfall, the impact of particular catchment characteristics and antecedent soil wetness also need to be taken into consideration, when assessing risk.

By the 2040s, across the different catchments, the frequency of threshold risk exceedance increases in over two-thirds of areas. However, up to a third of the models used suggest a decrease, creating significant uncertainty about the impact of climate change on rainfall and flooding. It is only with time that it will be possible to indentify underlying trends.

However, analysis shows a significant fluvial flooding impact between 2004-2010. The approximate number of delay minutes attributable to fluvial flooding was 156,000 amounting to a cost of £11,461,000.

**Localised rainfall flooding**

Flooding from localised rainfall causes several diverse problems to the rail assets and operations. Data suggests that flooding caused 520,000 delay minutes in total between 2004 and 2010, 65% (337,000) of which were a result of localised rainfall flooding. This amounts to a cost of £24,760,000.

Going forward, projections have been carried out for four percentiles – 90th, 93rd, 95th and 97th. They show both an increase and decrease in very wet day frequency by the 2040s across the country.
ranging from a 10% decrease to a 50% increase in very wet day frequency. The average change shows an increase everywhere of between 0% and 30%. The more extreme the rainfall event, the greater the future frequency increase, pointing an increase in localised flooding events. However, further research is required to quantify the impacts and future vulnerability of heavy rainfall events on Network Rail.

Rainfall impact on landslip

Landslips are a serious problem for the railway as they could cause derailments. The problem is particularly serious in areas where the underlying geology is clay, such as the south of England.

In previous studies, it has been found that if 30 day rainfall in an area is greater than 175% of the long term average for that month then there is an increased risk of a landslip.

Analysis of future vulnerability to landslips up to the 2040s suggest that there could be no significant change in the number of landslip events. The number of events might increase in future, but the relationship with climate change is unclear. Overall, the average results suggest that there is no clear evidence either way about how the number of landslips caused by large accumulations of rainfall could change by the 2020s, 30s and 40s.

Impact of groundwater flooding

Groundwater flooding occurs when water levels in the ground rise above surface levels. It is a particular problem in areas made up of permeable rock. It can lead to track flooding and lineside equipment failure.

UK Climate Impact Projections for the middle of this century suggest that annual totals of rainfall remain roughly the same as today. There may be some shift in the seasonality of rainfall, with winter increases and summer falls.

This could have a significant impact on groundwater flooding in vulnerable areas. However, more research is needed on how climate change will impact on it. More modelling of seasonal and annual variations in climate and also movement of water through the groundwater system and spatial variations is also needed, as noted by the Intergovernmental Panel on Climate Change.

Trees falling from the lineside

Network Rail has set out a series of wind thresholds and consequent actions if wind gusts reach or exceed certain thresholds; 60 to 69mph over a sustained period of 4 hours or more or 70 to 89mph over a non sustained period. When wind reaches such speeds there is a risk that trees or branches can be blown on to tracks and a 50mph speed restriction imposed. If wind speeds reach 90mph services are suspended.

Analysis of these thresholds being exceeded up to the 2040s, at a limited number of locations, do not give a clear indication of how wind gusts could change in the future. There is large variability between locations.

Overall, the mean of 11 model runs across 9 areas suggest 70% of locations modelled could see an increase in the exceedance frequency of the highest thresholds of 60 and 70 mph. Taking into account, model uncertainty and variability, analysis suggests the 70 mph threshold is likely to remain an extreme wind speed in future.

Leaves on the line
Vegetation – such as leaves on the line – particularly in the autumn months - can lead to significant delays on the rail network by causing adhesion and track circuit problems. Drizzly conditions can exacerbate the problem. In 2009 alone there were 400 incidents of foliage falling on to lines resulting in 240,000 lost minutes and a cost of £6 million.

However, there is currently little understanding of how climate change will affect leaf fall in future. It involves a complex range of factors many of which have not yet been modelled. The rail industry’s adhesion working group will look to investigate the relationship with climate change and the associated risk regarding leaf fall.

Sea flooding

Sea levels are projected to rise due to climate change and this poses a significant threat to coastal railway and defences. This has therefore been identified as a risk priority by Network Rail.

Set out below are projected ranges of time-mean relative sea-level rise at 2045 at priority locations identified by Network Rail.

<table>
<thead>
<tr>
<th></th>
<th>5th Percentile</th>
<th>Central estimate</th>
<th>95th Percentile</th>
<th>5th to 95th percentiles for present-day 50-year return period storm surge level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lancaster</td>
<td>0.060</td>
<td>0.161</td>
<td>0.262</td>
<td>1.8-2.1</td>
</tr>
<tr>
<td>Dover Estuary</td>
<td>0.080</td>
<td>0.181</td>
<td>0.282</td>
<td>0.9-1.2</td>
</tr>
<tr>
<td>Penzance</td>
<td>0.120</td>
<td>0.221</td>
<td>0.322</td>
<td>0.6-0.9</td>
</tr>
<tr>
<td>Penzance</td>
<td>0.094</td>
<td>0.196</td>
<td>0.297</td>
<td>0.9-1.2</td>
</tr>
<tr>
<td>Hastings STN</td>
<td>0.094</td>
<td>0.195</td>
<td>0.297</td>
<td>0.9-1.2</td>
</tr>
<tr>
<td>Folkestone to Dover</td>
<td>0.095</td>
<td>0.196</td>
<td>0.297</td>
<td>1.2-1.5</td>
</tr>
<tr>
<td>West of Whitstable</td>
<td>0.096</td>
<td>0.197</td>
<td>0.298</td>
<td>1.2-1.8</td>
</tr>
<tr>
<td>West of Southend and Thameshaven</td>
<td>0.096</td>
<td>0.197</td>
<td>0.298</td>
<td>1.2-1.8</td>
</tr>
<tr>
<td>Harwich</td>
<td>0.099</td>
<td>0.200</td>
<td>0.301</td>
<td>1.2-1.8</td>
</tr>
<tr>
<td>South of Arbroath</td>
<td>0.027</td>
<td>0.128</td>
<td>0.229</td>
<td>0.6-0.9</td>
</tr>
</tbody>
</table>

These results are only an initial indication of changes that might affect flooding. However, further specialised modelling is needed to assist decision making.

Case Study

July 2006 – the impact on the railway from heat

July 2006 was an exceptionally hot month. According to the Central England Temperature Series (which started in 1659), it was the warmest month on record, and one of the sunniest. The highest recorded temperature – 36.5°C – was recorded at Wisley, Surrey.

The impact of this extremely hot period of weather on the railway is clear from the vulnerability data for track buckling, heat-related speed restrictions and hot weather track patrols, where considerable proportions of particular heat-related incident types were recorded in a single month;
- All the recorded track buckling/critical rail temperature delay minutes in the Kent and Sussex route regions were recorded in July 2006;
- Around a third of the heat-related 20 mph speed restriction delay minutes in LNE and LNW were recorded in July 2006;
- Over four-fifths of the heat-related 30/60 mph speed restriction delay minutes in Western were recorded in July 2006;
- Each region saw a considerable number of work orders raised for hot weather track patrols during July 2006. In Anglia, the highest impacted region, over half of all recorded work orders raised were raised in July 2006;
- The Anglia region was particularly badly affected by OLE sag with 88% of the delay minutes attributed to it occurring in July 2006. LNW was the only other route to experience overhead line sag incidents in July 2006, though to a lesser extent than Anglia. The LNE, Midland and Continental, Scotland and Western regions did not experience delays due to overhead line sag in July 2006 (overhead line systems are not used in the Kent, Sussex and Wessex regions);
- The Western and LNE regions were worst affected by heat related track maintenance issues, with 7% and 8% of all recorded delay minutes being recorded in July 2006;
- However, the percentages of delay minutes recorded in July 2006 are considerably lower than those recorded for other incidents. This is probably due to the fact that the incident codes are too general to capture only heat-related track maintenance issues.

Network Rail is planning Met Office data with its Geographical Information System to identify particular climate threats and thresholds and their implications on a route-be-route basis. A visual summary tool has also been developed to TRaCCA, to accompany written reports, on to show the likely severity of risk priorities across the network in the decades up to the 2040s;

A screenshot of “TRaCCA4Rail” for the track maintenance priority (for the 2030s), in this example
During the evolution of the TRaCCA project, we have recognised that gaps and uncertainties in climate modelling and in the utility of rail-based data exist. These factors have meant that it has been difficult in some cases to build mathematical models that produce meaningful results. Much further work is thought necessary both in developing the science and in refining existing or developing new metrics so as to enable more accurate modelling of impacts and analyses of potential policy options for the longer term. Network Rail is discussing how best to achieve improved results and proposes to liaise closely with other infrastructure owners on this topic.

Risk mitigation actions

The understanding of current extreme weather impacts and asset/ system behaviour has already led to the evolution of a comprehensive range of asset policies and standards. Going forward, they can provide the basis for the development of future climate standards. The standards currently cover:

- All asset types (track, civils, buildings, signalling, power and communications) and particular asset class and geographic vulnerabilities;
- Particular weather and seasonal conditions affecting a range of assets (e.g. flooding, high winds, summer heat and solar energy, autumn leaf fall, winter snow);
- Operational and licence requirements (e.g. involvement of freight and train operators, use of weather forecasting, maintenance schedules, delay attribution).

These define inspection, maintenance and renewal regimes for each asset, and for new build, are generally developed on a minimum whole life whole system cost basis. For some assets, notably bridges and drainage, design and assessment also involves consideration of the likely change in operating environment resulting from climate change and how this may impact upon the performance of the asset.

Climate change adaptation, and the TRaCCA project specifically, is also already referenced in Network Rail’s Corporate Risk Register which the company uses in identifying and managing risks.

Following the publication of the Phase 2 TRaCCA report/Met Office research, the following preliminary recommendations were put forward (in no particular order) for discussion within rail industry and development into risk management policies and planning for Control Periods 5-8:

- Think system wide, and outside the rail sector;
- Review other organisations’ research and procedures (e.g. studies on landslips and Scotland’s trunk road network);
- Build up supplies and stocks of emergency repair materials and equipment with appropriate processes for deployment;
- Include climate change in current CP5 development work;
- Think about emerging/ alternative technologies to reduce heat and flood risks such as green landscaping, a technique particularly effective in urban environments;
- Consider design and build for long term resilience in the Rail Technical Strategy;
- Review likelihood of recurrent extreme events (such as the recent extreme winters) to determine if a case exists for enhanced preparations such as investment in snowblowers;
- Consider developing partnerships with flood, local and highway authorities to share resources eg: to preserve access to critical infrastructure during extreme weather events;
- Build cross-industry expertise that can develop robust adaptation strategies using targeted research and development and keep abreast of improving science and developments;
- Develop route-by-route adaptation strategies during CP5 for investment CP6 onwards;
- Keep things in proportion – prioritise against impact and benefits;
- Consider timing of decisions – organisations do not need to make decisions now for all operations;
• Broaden scope of any work emanating TRaCCA to include other influences such as supply chain vulnerability;
• Enhance industry weather/operational measures tailored to science, and vice-versa;
• Make stronger links between adaptation studies and current operations;
• Look abroad for current examples of what will be the British climate to learn how others manage their railways and other networks of assets.

Furthermore, Phase 2 has also identified the following ‘quick wins’ which will need to be turned into initial management actions;

• Agree a single focus in the rail industry for system resilience, with the ability to make decisions, geared to a customer focus (i.e. passengers and freight companies);
• Improve Emergency Response competences to improve reactions to perturbation from infrequent weather events; for example, by extending training and carrying out exercises;
• Look at use of DTS (dynamic track stabilisers) on maintenance sites to mitigate the effects of having low Critical Rail Temperatures. The intention would be to use DTS to make track systems more resilient to buckling and so permit more maintenance to be carried out where otherwise such work might be banned;
• Initiate cross-sectoral business continuity discussions – cross-sectoral plans are required because of inter-sectoral dependencies (i.e; Transport and Power need Information Communication Technology and vice-versa).

The initial specification for a tool to allow the rail industry to evaluate policy options (Adaptation Policy Evaluation Tool or APET) will also be developed. There is also potential to further develop APET into a comprehensive and expandable tool as a longer term ‘phase 4’ programme.

**Developing Initial Industry Plan proposed actions and costs**

The rail industry’s Interim Industry Plan (IIP), is due to be published in September this year, to start PR13 negotiations for the next rail regulatory period from 2014 (CP5). Subsequently, in 2013, Network Rail will publish a Strategic Business Plan (SBP), following the publication of a High Level Output Specification and Statement of Funds Available by the Government.

The IIP and/or SBP will include a programme of work the industry intends to carry out in CP5 to adapt our infrastructure to climate change, where necessary. The funding requirements needed in CP5 for this programme of work to be delivered will also be set out.
In preparation for this, Network Rail’s engineering, operations and regulatory heads will be asked to assess what impact key mean and maximum climate projections on heat, precipitation, wind, sea level rise, to the 2040s and beyond, will have in their assets/areas of responsibility.

On this basis, they will set out their assessments of adaptation measures, timeframes and capital and operational costs of addressing these impacts in order to maintain railway outputs (train service levels, reliability, punctuality, safety, condition/capability etc) and meet Network Rail’s licence requirements. A key feature is the consideration of what adaptation can be carried out during the routine renewals process. For many assets this might permit adaptation at marginal cost.

Once complete this work will allow Network Rail to begin discussions the wider industry, other key relevant sectors, its regulator and government on measures and funding necessary to adapt the railway to climate change.

**Interdependencies**

The Cabinet Office’s National Risk Assessment usefully summarises the business continuity interdependencies, all of which affect the operation of the railway. They are set out in Cabinet Office’s draft natural hazards and infrastructure guidance as follows;

- Large-scale temporary absence of staff
- Permanent or long-term loss of staff
- Denial of site or geographical area
- Loss of mains electricity
- Disruption of transport
- Loss of mains water and sewerage
- Loss of availability of oil and fuel
- Loss of fixed line/mobile communications

Network Rail closely co-operates with other, interdependent transport and broader infrastructure providers to address cross-sectoral current weather and future climate interdependencies. For example, we regularly meet Transport for London, the Highways Agency, the Environment Agency, SEPA, British Airports Authority, the Water sector and National Grid, to address interdependencies, share best practice and develop joint plans, where appropriate.

For example, in consultation with providers of rail and other transport modes we have developed integrated adverse seasonal weather mitigation, adaptation and response strategies. Network Rail has an agreement with the Highways Agency on share access to our weather stations and is also involved in a Greater London Assembly initiatives on the sharing of weather stations in the capital.

Network Rail and other key infrastructure providers have also recently collaborated with Engineering the Future partnership’s report for Defra on “Infrastructure, Engineering and Climate Change Adaptation”.

This report examines vulnerabilities that affect the infrastructure system as a whole specifically arising out of interdependencies between different sectors. It also puts forward measures that can be taken to adapt across various sectors and avoid “cascade failures” where failure of one type of infrastructure has a knock on effect on others.

This study was an activity of the ‘Engineering the Future’ partnership, carried out on behalf of Defra by The Royal Academy of Engineering, the Institution of Engineering and Technology, the Institution of Civil Engineers, the Institution of Mechanical Engineers and the Institution of Chemical Engineers. The conclusions of the study will feed into the Defra led cross-Government Infrastructure and Adaptation project. The study was carried out from the perspective of the engineering profession and the engineering response to the demands of climate change adaptation.
Network Rail currently is exploring whether these and similar bodies would be prepared to form an Infrastructure Owners’ Adaptation Working Group, as there would appear to be much in common between them.

Network Rail has also been involved in the work of the Cabinet Office’s Civil Contingencies Secretariat to systematically map out the key natural hazard interdependencies, encompassing climate change impacts, across the various infrastructure sectors.

Specifically on flooding, through the implementation of the 2010 Flood and Water Management Act and its equivalent in Scotland, the Environment Agency, Local and Regional Resilience Forums, and the Cabinet Office have also highlighted cross-sectoral issues, which will become more significant as the climate changes. In recent consultation responses on the Government’s developing national flooding strategy and funding regime and co-operation at a sub national level, Network Rail has highlighted the importance of infrastructure defence interdependencies and the need for close co-operation between communities, businesses, critical infrastructure providers and national and local authorities and agencies as a result.

**Opportunities due to the affects of climate change**

Network Rail is also aware that climate change could offer the industry with both short and longer term benefits. We are supporting research on this issue by the FUTURENET consortium and Infrastructure Transitions Research Consortium and have participated in workshops with Nottingham University on future travel patterns.

Network Rail is looking to identify geographical areas that might benefit in some ways from climate change. For example, coastal areas may experience longer, warmer summers and this may lead to tourism and leisure opportunities and increased demand for rail, and perhaps reusing decommissioned routes or developing new lines, in the longer term. This is something that could be developed in the future with local authorities within their future travel and tourism plans.

A short term example, is awareness raising and training within Network Rail on sustainability issues, including mitigating and adapting to climate change, which has already led to a greater appreciation of the way we consume resources, such as water, and is already leading to cost savings through out the industry.

The PR 13 processes described above will further increase understanding on climate change and the measures needed to adapt to it across the business.

Another opportunity is that climate change modelling will allow us to categorise and prioritise our efforts in a cost effective manner; short life assets (such as information technology) and rapid-wear components might not require long-term adaptation plans, whereas long life assets (bridges, earthworks and track systems) will.

The continued forecast reduction of cold days in winter may also lead to more reliable infrastructure and operations and fewer accidents on the railway for staff and passengers in future, such as a reduction in slips and falls from icy platforms, station entrances and exits, depot access walkways and roads.

Network Rail and the rail industry envisages improvements in its sustainable management of assets, of both infrastructure and TOC fleet, in terms of reliability and costs. Adaptation activities are likely to provide the impetus to:

a. improve the reliability of rail assets sooner rather than later;
b. develop longer-term strategies that will recognise a need for a systematic approach on the timing of key decisions on policy, for the maintenance and renewal of assets;

c. promote the development of geographically-based standards and measures for weather resistance and resilience that promote consistency of approach and expectations;

d. work more closely with other organizations such as the government departments, devolved administrations and the Environment Agency SEPA, and where common interests are apparent.

The TRaCCA project has been designed to look systematically at the opportunities presented by climate change, in areas such as the day-to-day operational management of the network.

One example of climate change research being used to improve operations has been in the Dawlish area on the Great Western route in Devon. Here the railway is exposed to the sea over a four-mile stretch. The RSSB-funded T643 study into climate change impacts on the coast required bathymetric modeling of the sea bed and the development of models to determine current and future impacts on the Dawlish Warren to Teignmouth sea wall and on railway operations. The results were utilised to develop a daily 36-hour ahead forecast of sea state and potential hazards to the safe operation of trains. This forecast is shared with train operators and gives more certainty of a reliable service than the previous system that required actions on a more reactive basis. Climate change modelling is likely to result in similar beneficial developments.

Uncertainties and assumptions

As the climate change methodologies, thresholds and results section of this report shows, climate change projection uncertainties arise from certain climate predictions. Risk and impact uncertainties also arise from an insufficient level of detail or utility in certain railway performance and delay datasets.

This has led to considerable uncertainty about whether climate change will lead to an increase in landslips, lineside equipment failures, groundwater flooding and trees and leaves on the line. Further climate analysis and more attention to identifying or developing improved or new metrics to address these uncertainties.

Evidence on the nature and impact of climate change becomes less certain the further the projections go out into the future. Projections beyond 2050 are currently extremely uncertain and are based on a range of assumptions. We have collaborated with UKCIP to understand their methodology and data and the assumptions they have made in their long term future projections.

Owing to the divergence of results in the UK Climate Projections, after the 2040s, and to the 30-year planning horizon covered by the Rail Technical Strategy (RTS)\textsuperscript{11}, we believe it is currently inappropriate to examine climate impacts beyond 2050s. However, we will endeavour to develop appropriate metrics, and examine the sensitivities of assets, operations and systems to the wide variations in climate and weather predictions, as part of future research.

The TRaCCA project will inform both the next Regulatory Review and policy for CP5 and beyond. The next RTS, being prepared under the auspices of the rail industry Technical Strategy Advisory Group (TSAG). The next RTS is due for publication in 2012.

Levels of confidence in the results will be determined from the nature of the input data, limitations of the modelling packages and uncertainties in the climate projections; it is likely that upper and lower bounds to the impacts will be shown along with the mean values. The sensitivity of the system or asset to changes in weather will be very relevant.

Other uncertainties include the size and shape of the rail network and traffic volumes up to 2050 and traffic patterns expected. However, modelling tools are being developed in the FUTURENET and ITRC research projects that should help.

**Barriers to adaptation and key challenges**

The major barriers and challenges facing Network Rail’s adaptation plans are three fold;

- Uncertainties surrounding particular climate changes and their impact on the railway, discussed earlier in this report; and
- Uncertainty about how the rail industry’s IIP/SBP adaptation plans will be received by Government and our regulator, how it will influence PR13 negotiations and the amount of funds available to deliver the plan;
- The precise size, shape and traffic on the network in the very long term (although Network Rail is engaged in a range of long term planning initiatives with the rest of the industry).

Discussions will shortly begin for PR13. During this process the industry will set out its plans for how it plans to adapt to climate change in the next regulatory period and longer term.

Once PR13 negotiations are complete Network Rail will be in a position to deliver its adaptation activities, including the development of plans, standards and specifications and budgets, with certainty. Our Defra reporting requirements will be fully integrated within this process.

**Monitoring and evaluation**

On going monitoring and evaluation processes will be put in place for the risk management plans that arise out of the PR13 process. These are likely to include a set of specific measures agreed between the ORR and Network Rail, covering a programme of work for CP5.

Once agreement is reached on adaptation measures with the government and our regulator for CP5 and beyond, Network Rail’s resulting reporting and regulatory requirements will mean that the risks associated with climate change are monitored and managed at the highest levels of the organisation. Existing policies and standards will be updated and new ones written and implemented to provide an appropriate response to risks.

Network Rail also expects to hold regular reporting review meetings with DEFRA and Cranfield University and other stakeholders.

Following the conclusion of the TRaCCA project more detailed studies are anticipated during CP5 and beyond. They are likely to focus on route reliability, building on the geographically specific visual summery tool developed by TRaCCA, and fitting in with Network Rail’s new devolved business unit structure.

Flexibility is also built into Network Rail’s adaptation plans and processes given the uncertainties around the precise impact of climate change. As demonstrated in the methodologies, thresholds and results section of this report, projections are formulated on the basis of a range of possible scenarios.

Furthermore, our plans will be regularly reviewed and developed, not least because of our Defra reporting requirement, to enable us to response flexibly to new evidence and experience of implementing our plans.

Network Rail already has various people and resources devoted to climate change activities, including a Principal Engineer for Climate Change, an Environmental Policy and Operations Seasons
Management Team. However, as has already been stated, Network Rail's reporting requirements to Defra, as well as forthcoming negotiations on PR13, have been very important in focusing attention on this issue in the company and also the broader industry and supply chain. It is intended that the outputs from TRaCCA will inform both the PR13 process and Rail Technical Strategy.

Feedback from this Report and the TRaCCA project will be used to develop further research needs, including the need for Route-based studies during CP5 and beyond.

As has already been stated, Network Rail is working closely with the industry and other project partners on the benefits and opportunities of climate change, for example, in saving money and resources and generating new travel patterns.

The findings from this work will be incorporated into Network Rail's future plans and the strategies of the particular functions they impact on, as appropriate. For example, Network Rail's Route Planning function, will look at the results of Network Rail's work with academics on how climate change will affect future travel patterns (e.g. increasing demand for leisure and tourism travel to British seaside towns as summers get longer and hotter) and plan the future development of the network accordingly.
## Annex 1 – overview of asset risks from TRaCCA Phase 1

<table>
<thead>
<tr>
<th>Climate Impact Group</th>
<th>Risks</th>
<th>Likelihood Impact</th>
<th>Performance Impact</th>
<th>Likely Negative Impact from Climate Change?</th>
<th>Long or Short Term?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat</strong></td>
<td>Air conditioning failure in carriages</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Short</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Track buckling</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Speed restrictions due to buckle risk</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Use of heat watchmen for buckle risk</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Floating electrical earth caused by a low water level</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Reduced window of opportunity for work – renewal and maintenance - due to heat restrictions on track</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Reduction in track quality due to less maintenance</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Staff working conditions in hot weather</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Earthworks desiccation</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Effect of heat on swing bridges</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Contact wire sagging at terminal stations</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Reduced transformer life</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Heat</strong></td>
<td>Solar gain affecting lineside equipment Signalling, Power, Telecoms</td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>Short</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Increased flooding generally</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding at stations</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding at depots</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding affecting plant and equipment rooms</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Short</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding caused by poor drainage and high water levels</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding at bridges – scour/ pressure/ obstruction damage</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding in tunnels</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Flooding - Track Circuitry/ Automatic Warning Systems/ Lineside cabinets and equipment flooding</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Short</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Pluvial (surface water) flooding</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Increased rainfall causing high surface run off</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Rising ground water level</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Scour due to high river levels</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Cabinets</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Increased rainfall</td>
<td>Safety of workforce in extreme flood conditions – watchmen at flood sites</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Cold</td>
<td>Heave caused by freeze thaw</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Cold</td>
<td>Rockfall caused by freeze thaw</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Cold</td>
<td>Freeze thaw action on bridges</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Cold</td>
<td>Ice in tunnels</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Cold</td>
<td>Broken Rails</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Cold</td>
<td>3rd rail ice and snow</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Cold</td>
<td>Snow and ice on the track</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Cold</td>
<td>Slips, trips and falls, ice &amp; snow</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Short</td>
</tr>
<tr>
<td>Wind</td>
<td>Effect of wind on bridges and traffic on bridges</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Effect on equipment (OLE, signal, telecomms) structures, station canopies etc</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Effect of wind on freight trains</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Lifting with crane in wind</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Change in direction and speed affecting trees</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Contact wire/ pantograph</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Sea level rise and increased storminess</td>
<td>Sea defences</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Increase and change in vegetation type</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Floral Adhesion</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Vegetation – Showing Clear When Occupied track circuitry from leaves</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Vegetation - Signal sighting</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Long</td>
</tr>
<tr>
<td>Wind</td>
<td>Trees growing on the lineside – obstruction risk</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Loss of a safe Cess from vegetation encroaching</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Long</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Vermin – signalling</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Long</td>
</tr>
</tbody>
</table>
### Annex 2 – Summary of asset and operational priority topics from TRaCCA

<table>
<thead>
<tr>
<th>Climate Impact Group</th>
<th>Cluster</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Track</td>
<td>Management of track buckle risk</td>
</tr>
<tr>
<td>Heat</td>
<td>Track</td>
<td>Reduced window of opportunity to carry out maintenance/ renewals work due to heat</td>
</tr>
<tr>
<td>Heat</td>
<td>People</td>
<td>Passenger health from train failure in extreme temperatures, including heat and cold</td>
</tr>
<tr>
<td>Heat</td>
<td>People</td>
<td>Impact on freight from train failure in extreme temperatures, including heat and cold</td>
</tr>
<tr>
<td>Heat</td>
<td>People</td>
<td>Staff working conditions, eg: use of heat watchmen</td>
</tr>
<tr>
<td>Heat</td>
<td>Power/ Signalling/ Telecomms</td>
<td>Sag in tethered overhead line systems at terminal stations</td>
</tr>
<tr>
<td>Heat</td>
<td>Power/ Signalling/ Telecomms</td>
<td>Heat affecting lineside equipment; specifically signalling and telecoms equipment</td>
</tr>
<tr>
<td>Heat</td>
<td>Power/ Signalling/ Telecomms</td>
<td>Floating electrical earth leading to stray earth currents caused by dry ground/ low groundwater*</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Track and lineside equipment Failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Groundwater flood</td>
<td>Track and lineside equipment Failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Pluvial flood</td>
<td>Track and lineside equipment Failure</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Scour and water effects at bridges</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Scour at embankments due to high river levels and culvert washout</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Safety of workforce carrying out inspections during an extreme flood event</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Pluvial flood</td>
<td>Landslips</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Fluvial flood</td>
<td>Accessibility of fleet and of maintenance depots</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Vegetation</td>
<td>Change in type, poor adhesion, and track-circuit non-activation</td>
</tr>
<tr>
<td>Insolation/ heat/ rainfall/ wind</td>
<td>Vegetation</td>
<td>Falling trees causing obstructions</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Sea level rise and storms</td>
<td>Coastal and estuarine defences</td>
<td>Wave overtopping and flooding at defended coastal and estuarine railways</td>
</tr>
</tbody>
</table>

*Floating earth has been re-prioritised to a low priority, but will remain on the list for possible consideration*

**Priorities will be subject to continuous review as detail emerges regarding the potential robustness of analysis based upon current climate projections and data availability**