Route Weather Resilience and Climate Change Adaptation Plans

Anglia

Contents

Purpose of this document

This document sets out a Weather Resilience and Climate Change Adaptation (WRCCA) plan for Anglia Route supported by an evaluation of the resilience of rail infrastructure to historical weather events and an awareness of potential impacts from regional climate change projections. The resilience of rolling stock operating within the Route is not specifically assessed.

The approach taken is consistent across all Network Rail's Routes, and describes our current planned mitigations, how we intend to develop the plans further, and how we are improving the embedment of WRCCA across the business to deliver *a railway fit for the future*.

Director Route Asset Management statement

Flash flooding and washout at Brundall June 2014

The railway network has been significantly affected by severe weather conditions including wind, snow, rainfall, lightning, heat and cold. Climate change projections suggest we will be entering a period with increasing average and maximum daily temperatures, drier summers, wetter winters, sea level rises and increased storminess. Increased storminess and winter rainfall will increase the risk of flooding, earthslip and coastal storm surges, heat causes soil desiccation and track buckling, high winds result in debris falling on to the track, and snow and cold weather result in frozen points and blocked routes.

Anglia Route is committed to respond to the future climatic changes by increasing the resilience of the assets during such adverse weather conditions with specific challenges presented by the region's geology, topography, coastal boundary and asset portfolio.

Anglia has already secured significant investment to improve the infrastructure assets in the next five-year control period and further funding will need to be sought to improve the resilience of the assets to future climate changes. This investment will ensure the safe operational use of the railway and minimise train delays at a time of growing demand for rail travel in Anglia.

More effective management will also be achieved by continuing to engage with a variety of stakeholders including flood groups, the Environment Agency and lineside neighbours.

Eliane Algaard
Director of Anglia Route Asset Management
September 2014

Executive summary

Weather events can cause significant disruption to the operation of train services and damage to rail infrastructure. A move to a warmer climate and a variance in the pattern of precipitation across the year, generally projected by the UK Climate Change Projections (UKCP09), could result in changes in the frequency and intensity of extreme weather events and seasonal patterns. A detailed understanding of the vulnerability of rail assets to weather events, and potential impacts from climate change, are therefore needed to maintain a resilient railway.

Anglia Route has developed a Weather Resilience and Climate Change Adaptation (WRCCA) plan based on assessments of weather-related vulnerabilities, identification of root causes of historical performance impacts and an understanding of potential future impacts from regional climate change projections.

Using this information, Anglia Route has determined whether previous investments have mitigated weather impact risks, if actions planned during Control Period 5 (2014 to 2019) are addressing these vulnerabilities, and where additional actions could further enhance weather and climate change resilience.

An analysis of Schedule 8 performance costs (the compensation payments to train and freight operators for network disruption) during the period 2006/07-2013/14, Figure 1, clearly shows wind, adhesion and snow-related events have had the most significant impact on the Route.

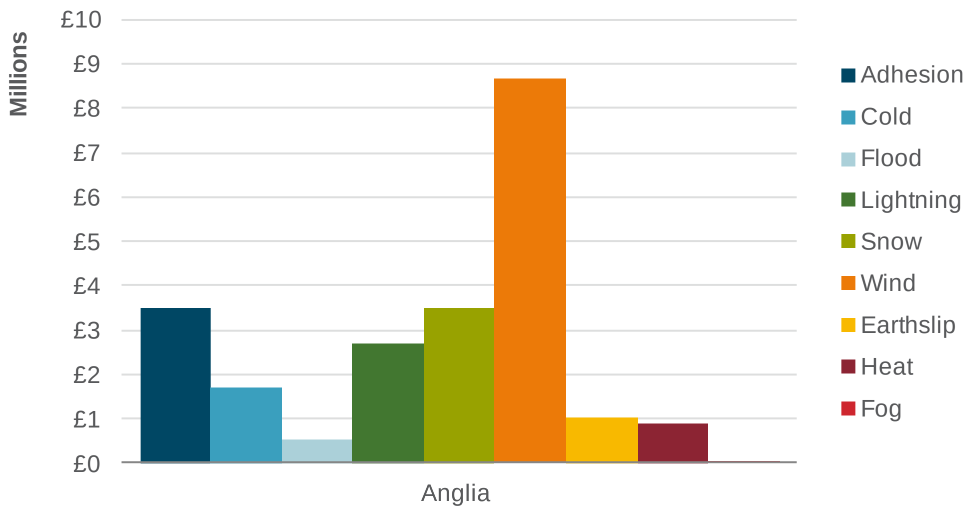

Figure 1 Anglia Route weather attributed Schedule 8 costs 2006/07-2013/14

Anglia Route is committed to supporting the delivery of improved weather and climate change resilience through Route-specific objectives, including:

- increase the understanding of weather and climate change impacts on the Anglia Route, having already completed a 2013 resilience study and the current WRCCA plan analysis
- improve the knowledge of weather impacts through identification of root causes and trends to support the identification of cost effective resilience measures
- predict the impacts of weather and use weather forecasting and asset monitoring to manage locations vulnerable to adverse weather
- review data from a recent Anglia aerial topographical survey in relation to earthslip, flood and coastal surge risks
- install Remote Condition Monitoring (RCM) on selected assets
- support initiatives and demonstration projects aiming to deliver network-wide resilience improvements
- establish a sustainable lineside environment which minimises performance and safety risk and maintenance intervention by removal of problem vegetation and dangerous trees utilising aerial and infrared photography captured by the RINM project
- develop and manage a Route WRCCA Plan to inform current and future Control Period investment plans and workbanks
- specify weather resilience and climate change adaptation in Route Requirements Documents for renewals and new works
- work with lineside neighbours to establish an environment beyond the boundary that does not negatively affect safety of the line or performance including the management of trees and surface water run-off
- engage with key regional stakeholders including flood risk groups and the Environment Agency.

Anglia Route has identified actions planned in CP5 that will increase weather and climate change resilience including:

- increase forecasting capability in order to predict flooding and earthwork failures at high-risk locations;
- renewals at critical earthworks, drainage and bridge scour sites
- engage with the Environment Agency and Local Authorities to reduce flood risk
- roll out strategic programmes of Remote Condition Monitoring
- engage with the wider industry, including train operating companies to minimise delay impacts;
- enhance lineside vegetation and third-party tree removal

Anglia Route will deliver the WRCCA plan in a timely, cost efficient and safe manner.

Introduction

Weather events can be a cause of significant disruption to the railway network. Recent prolonged periods of rainfall and extreme storm events demonstrated much of the network is resilient. However asset failures such as the Dawlish sea wall, Cambrian sea defences, Botley landslip, and the widespread tree falls following the St. Jude storm, reveal the vulnerability of the rail network and the severe impact these weaknesses in resilience have on train services and our resources. Recent examples of vulnerability in Anglia Route include the Lowestoft and Haddiscoe washouts in December 2013, the Brantham Hall Cutting failure in March 2014, the uprooted trees at Purfleet in November 2013 and accelerated slope movements at Wrabness in February 2014.

The impact of weather on the rail network is monitored using performance data. Schedule 8 costs; the compensation payments to train and freight operators for network disruption, are used as a proxy for weather impacts due to greater granularity of root cause reporting. Weather-related costs can also be captured within Schedule 4 payments; compensation to train and freight operators for Network Rail's possession of the network, and capital expenditure required to reinstate the asset.

Over the past eight years (2006/07 to 2013/14) the average annual Schedule 8 cost attributed to weather for the whole network was over £50m. The data clearly includes the impacts on train performance from the severe weather events during 2007, 2012 and 2013 from rainfall, and 2009 and 2010 from snowfall, Figure 2.

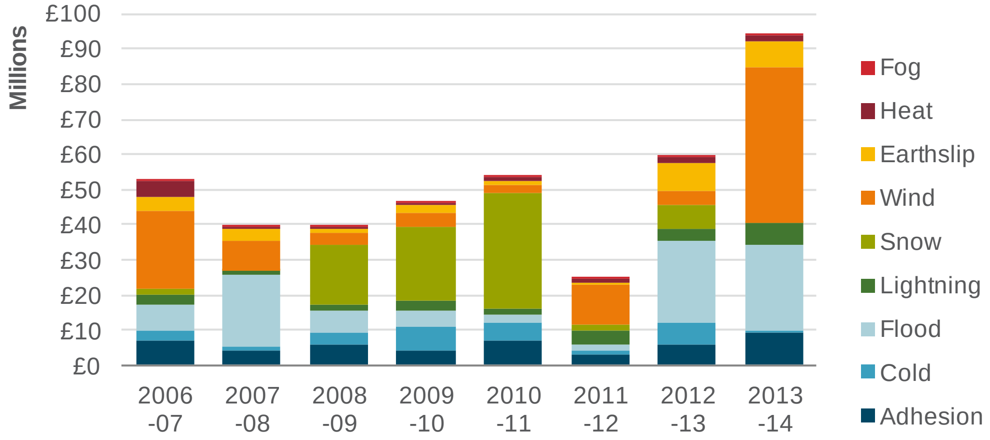

Figure 2 Whole network weather attributed Schedule 8 delay costs, 2006/07 to 2013/14

In terms of the proportion of delay minutes, weather and seasonal events on average caused 12% of all delays experienced during this eight-year period.

Following the recent increase in the rate of Schedule 8 compensation payments (by around 62%), the equivalent payments in future years would be over £80m per annum.

These levels of performance cost, consequential costs of repairing the rail infrastructure, and wider socio-economic impacts in the UK, justify Network Rail's enhanced investments to increase weather resilience. The interdependencies within transport and infrastructure systems similarly justifies Network Rails' efforts to improve collaborative understanding of the wider impacts of weather-related events and our role in supporting regional and national resilience.

Historical temperature records indicate that a significant relatively recent shift in climate has occurred. The Hadley Centre Central England Temperature (HadCET) dataset is the longest instrumented record of temperature in the world, Figure 3, and clearly shows a rising trend in temperature over the past century[1].

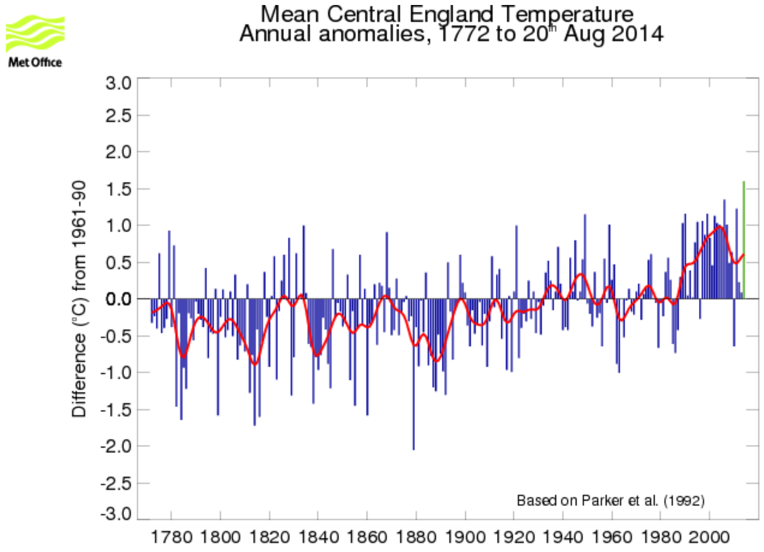

Figure 3 Mean Central England temperature record

[1] Parker, D.E., T.P. Legg, and C.K. Folland. 1992. A new daily Central England Temperature Series, *1772-1991. Int. J. Clim.*, ***Vol 12***, *pp 317-342*

Future climate change projections for the UK have been developed by the Met Office Hadley Centre, UK Climate Projections 2009 (UKCP09). UKCP09 provides probabilistic sets of projections based on low, medium or high greenhouse gas emission scenarios, for climate periods of 30 years to the end of this century. For Network Rail, as a safety critical focused organisation and major UK infrastructure manager, the high emissions scenario is an appropriate benchmark on which to base evaluations and decisions.

UKCP09 projects an overall shift towards warmer climates with drier summers and wetter winters, Figure 4 and Figure 5, with regional variations.

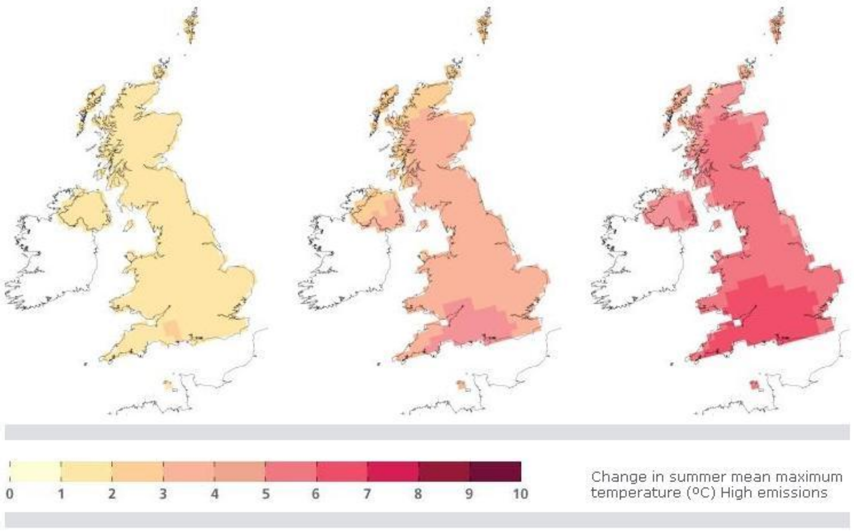

Figure 4 Change in summer mean maximum temperature (left 2020s, middle 2050s, right 2080s) (© UK Climate Projections, 2009)

Climate change projections include inherent uncertainties, associated with natural climate variability, climate modelling and future emissions, and these uncertainties increase with downscaling to local levels. However, the projections can be used by Network Rail to provide a direction of where the UK climate is heading, and this Route Weather Resilience and Climate Change plan uses the projections to support the prioritisation of weather resilience actions.

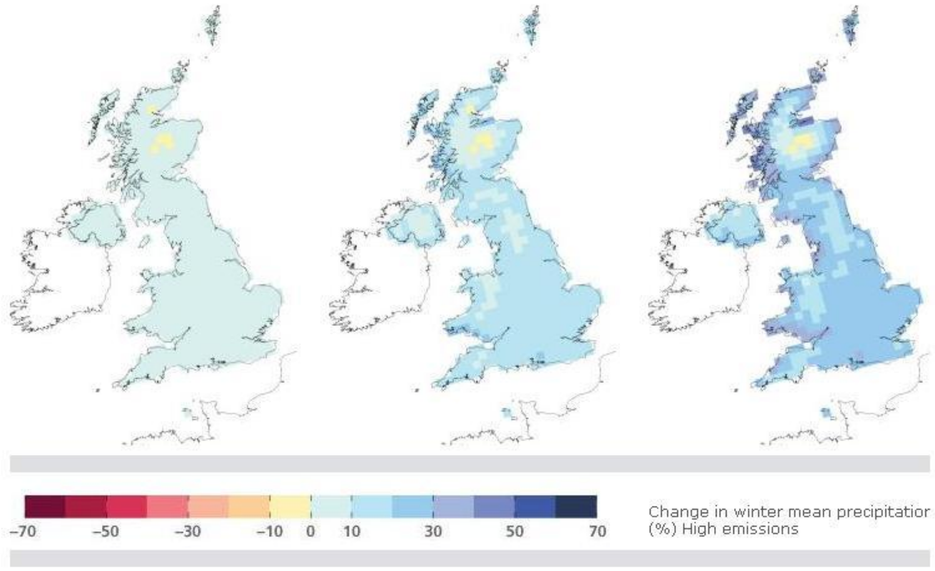

Figure 5 Change in winter mean precipitation (left 2020s, middle 2050s, right 2080s) (© UK Climate Projections, 2009)

To ensure weather resilience and climate change adaptation is approached consistently across Network Rail, an iterative framework provides key management stages: set strategy, assess vulnerability and impact, identify actions, and review, Figure 6. This framework has been applied to develop the Anglia Route WRCCA plan.

Figure 6 Weather resilience and climate change adaptation framework

Network Rail weather resilience and climate change adaptation actions will include a range of measures appropriate to the strength of evidence and level of risk:

- soft – changes to processes, standards and specifications, increasing knowledge and skill base
- hard – engineered solutions to increase resilience; e.g. raising of sea walls and increasing drainage capacity
- 'do nothing/minimum' – the option to 'do nothing' or 'do minimum' should be evaluated
- 'no regrets' – measures that increase the resilience of the assets to current and future impacts
- precautionary – investment into adaptation measures today in anticipation of risk in the future
- managed adaptive – a staged approach incorporating uncertainties in future risk and current investment funds, allowing assets to be retrofitted cost-effectively in the future.

The following sections provide findings from the Anglia Route vulnerability and impact assessments, and details of the actions, both completed and planned for Control Period 5 (CP5), that will increase weather and climate change resilience.

Track flooding at Surlingham

Anglia Route WRCCA strategy

The Network Rail Sustainable Development Strategy outlines corporate weather resilience and climate change adaptation objectives, and commits the business to:

- understand our current weather resilience, and seek to optimise resilience and enhance adaptation capability
- develop a thorough understanding of the potential impacts of climate change in terms of infrastructure performance, safety risks and costs
- embed climate change adaptation within our asset policies and investment decisions
- communicate the role that the rail network plays in supporting weather and climate resilience across Great Britain, and support efforts to increase national resilience.

These objectives will support the long-term management of a weather resilient railway and are fundamental steps towards achieving Network Rail's sustainable development vision of *a railway fit for the future*.

Anglia Route strategy

Anglia Route is committed to supporting the delivery of this strategy through Route-specific weather resilience and climate change adaptation objectives:

- increase the understanding of weather and climate change impacts on the Anglia Route, having already completed the 2013 Willis study and current WRCCA plan analysis into weather impacts
- improve the knowledge of weather impacts through identification of root causes and trends to support the identification of cost effective resilience measures
- predict the impacts of weather and use weather forecasting and asset monitoring to manage locations vulnerable to adverse weather
- review topographical data from recent Anglia aerial Light Detection and Ranging (LiDAR) survey from the Rail Infrastructure Network Model (RINM) project in relation to earthslip, flood and coastal surge risks
- develop and manage a Route WRCCA Plan to inform current and future Control Period investment plans and workbanks
- prepare additional site specific weather-related schemes identified following the St Jude's Storm high winds event of 27 and 28 October 2013, the storm surge event on 5 and 6 December 2013 and the prolonged rainfall experienced in January and February 2014
- specify weather resilience and climate change adaptation in Route Requirements Documents for renewals and new works
- support initiatives and demonstration projects aiming to deliver network-wide resilience improvements
- establish a sustainable lineside environment which minimises performance and safety risk and maintenance intervention by removal of problem vegetation and dangerous trees utilising aerial and infrared photography captured by the RINM project
- work with lineside neighbours to establish an environment beyond the boundary that does not negatively affect safety of the line or performance including the management of trees and surface water run-off
- engage with key regional stakeholders including flood risk groups, Environment Agency and Statutory Undertakers
- undertake quantitative studies to understand the tidal and fluvial flood risk to infrastructure at sites where flood risk is known
- undertake works on a risk basis to improve track and track support assets in areas where heat speeds have been imposed historically or where they are predicted to occur in the future.
- develop a longer-term WRCCA plan to include heat resilience of swing bridges, additional drainage capacity resulting from increased storm intensities and increased run-off from adjacent catchments, burst water mains and highway approaches to level crossings
- review Route weather preparedness plans and procedures in relation to climate change projections
- install Remote Condition Monitoring (RCM) on selected assets
- combine RCM data with Met Office, Hydrocast and Environment Agency 'broader' data and intelligence
- use triggers and action levels to apply operational restrictions based on asset condition and local weather observations.

Through these objectives, Network Rail's corporate commitments are applied in the context of Anglia Route, supported by the opportunities to deal locally with challenges of a changing regional climate. Meeting these objectives will contribute to the long-term resilience and sustainability of Anglia Route and the whole railway network.

Anglia Route vulnerability assessment

This section provides the details of the general vulnerability of the rail network in Great Britain and Anglia Route's specific vulnerabilities to weather impacts, and regional climate change projections.

Network-wide weather vulnerability

The challenge for Network Rail is to manage a complex and extensive portfolio of assets, with variations in geographic location, age, deterioration rates and vulnerability to weather impacts.

Continual analysis of the vulnerability of rail assets to weather, and identification of trends and characteristics of weather-triggered failures, improves our knowledge of the resilience of the rail network. An understanding of current weather impacts is an essential platform to implement cost-effective investments to adapt the network to future changes in climate.

The whole rail network is sensitive and exposed in some way to many primary climate drivers and secondary impacts, including:

- temperature
- rainfall
- wind gusts
- flooding
- landslips
- soil moisture
- sea level rise
- coastal erosion.

Network Rail has moved from subjective and expert review-based knowledge of weather and climate change risks to more detailed internal analysis of asset failure and weather data to understand thresholds at which failure rates significantly change. Figure 7provides an illustrative example of the analysis identifying assets with higher sensitivity to weather impacts. The horizontal lines are thresholds where there is 'no significant' (green), 'significant' (amber) or 'very significant' change in incident rates (red). This deeper dive analysis is critical to understanding the resilience of operational assets today and potentially in future climates.

From this analysis it has been established that high temperatures have wider impacts across assets, earthworks are the predominant asset sensitive to rainfall and overhead line equipment (OLE) to wind gusts.

Rail asset and weather impact relationships are complex, as demonstrated in the case of OLE where many wind-related failures are a result of vegetation incursion and not direct wind gusts as the primary impact. Therefore any analysis of rail assets and weather vulnerability requires deeper understanding of root causes to identify cost effective resilience actions.

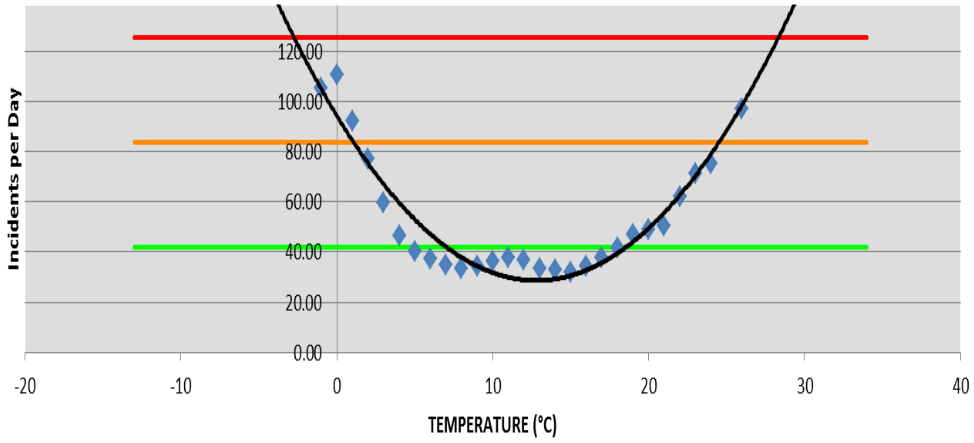

Figure 7 Example of asset failure and weather analysis

Managing operational response to weather vulnerability

Network Rail manages risks from weather-related impacts through a range of asset management tools, operational response standards and alert systems. Higher risk assets are prioritised for investment within asset policies and proactively managed through risk-based maintenance.

Defining 'normal', 'adverse' and 'extreme' weather conditions is fundamental to ensuring effective coordination across the rail industry. Network Rail and the National Task Force (a senior rail cross-industry representative group) are currently reviewing weather thresholds and definitions to improve the Extreme Weather Action Team (EWAT) process which manages train services during extreme weather alerts.

Control rooms monitor and respond to real-time weather alerts through a range of action plans. Operational response to the risks posed by weather events includes: temporary speed restrictions (TSRs), deployment of staff to monitor the asset at risk, proactive management of the asset; i.e. use of ice maiden trains to remove ice from OLE or protection of assets from flood water, and in some cases where the risk dictates, full closure of the line. Increasing the resilience of the infrastructure reduces the need for operational response however the range of weather events experienced today, potential changes in the future, and the prohibitive scale of investments required to mitigate all weather risks, means that operational response will always be a critical process for Routes to manage safety risks.

Network Rail seeks continuous improvement of weather-based decision support tools, including flood, temperature, wind speed and rainfall alerts. A trial aiming to significantly improve real-time weather forecasting has installed approximately 100 weather stations on the Scotland rail network. The pilot study is currently being evaluated to support a potential wider roll-out of this level of weather service and so existing radar feeds will continue to be used for real time weather monitoring in Anglia, Figure 8.

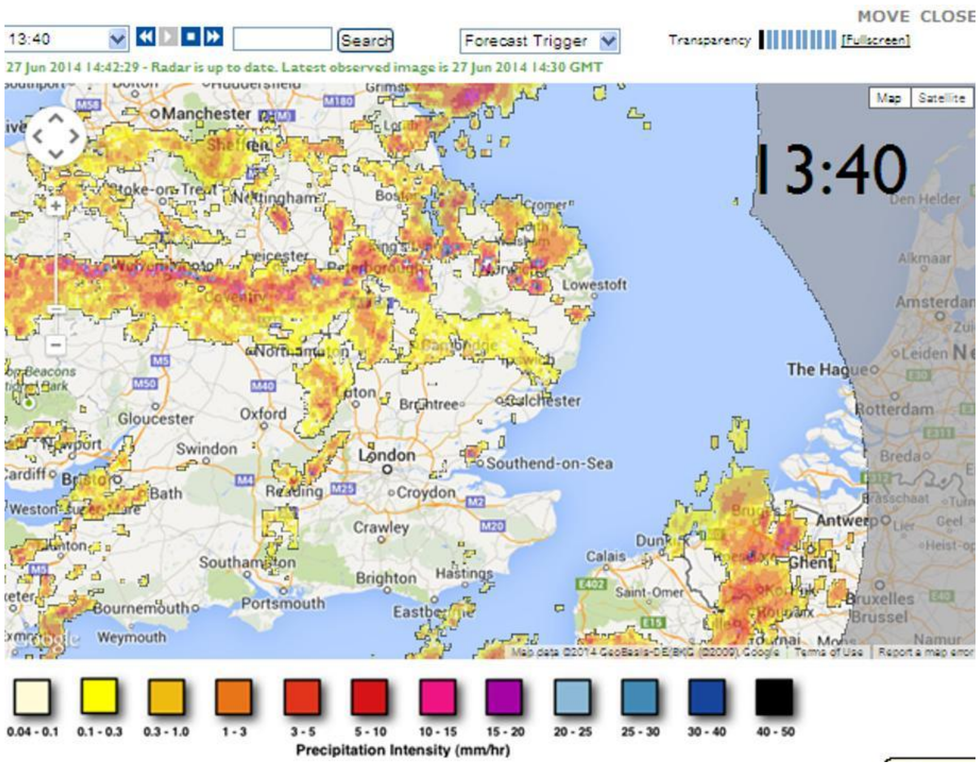

Figure 8 Anglia Route real-time weather monitor

For the management of operational flooding risk, Network Rail receives alerts through our Flood Warning Database based on warnings issued by the Environment Agency and the risk is translated to rail assets. In locations where no national flood warnings are available, Network Rail can arrange to receive alerts from bespoke river level monitoring equipment.

Longer-term flood risk management of rail assets is provided through geographic information system (GIS) decision support tools including flood datasets, such as Network Rail's Washout and Earthflow Risk Mapping tool (WERM). Transformative asset information programmes are currently aiming to improve weather-related hazard mapping in decision support tools.

Improving our network wide resilience

A Weather Resilience and Climate Change (WRCC) programme is at the centre of Network Rail's delivery plans. Its importance is underlined by the fact that it is one of the Company's top 15 business change projects. The programme was first identified in April 2013, but its priority and profile were heightened as a result of the extreme weather that was experienced between October 2013 and March 2014. The programme board and stakeholders include representatives from across the rail industry.

The WRCC programme is founded on a bow tie risk assessment, Figure 9, of weather-related disruption – this risk assessment methodology is used widely across Network Rail. The bow tie assessment provides a detailed understanding of the adequacy of the controls that are in place to reduce the causes of disruption and consequences and highlights those controls that may need to be enhanced.

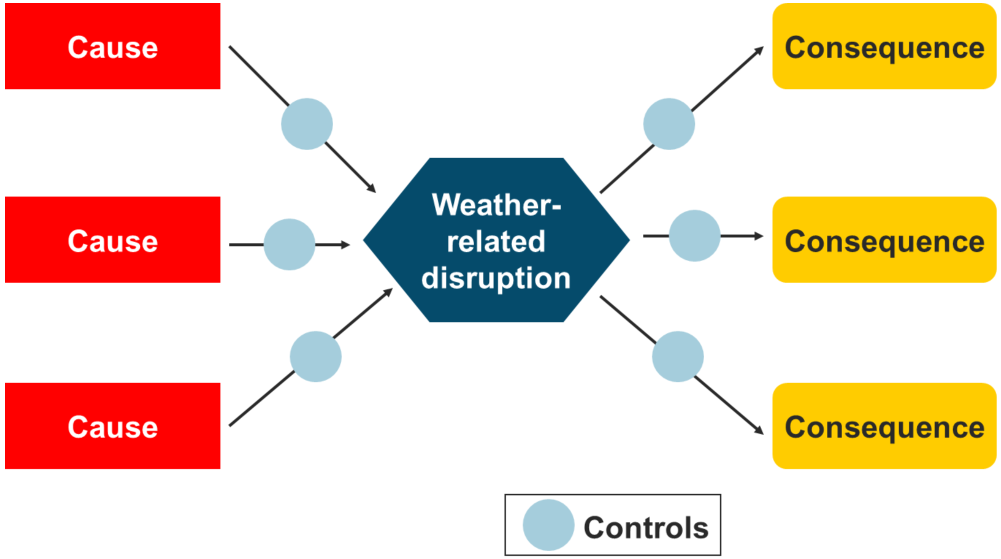

Figure 9 Bow tie risk assessment

The programme consists of six sub-programmes and their 23 constituent projects; these are described in Figure 10 below. Although the bulk of the outcomes that are currently defined expect to be delivered within the next 18 months, the programme is expected to extend throughout CP5.

It is important to emphasise the national-level programme supplements the work Routes are completing under their CP5 business plans.

WWRCC Sub-Programmes

1 Infrastructure Resilience

1. Year 1 Enhanced vegetation management strategy
2. Sustainable vegetation strategy
3. Identifying Highest Risk assets Enhanced resilience to effects of:
4. Flooding
5. Costal surge
6. Snow, Ice and extreme temperatures
7. High winds

2 Cross-industry Resilience

8. Property portfolio
9. Fleet
10. Timetabling-flexibility and contingency planning
11. Providing advice and communicating with customers

3 Earthworks Integrity

12. Improved Earthworks Knowledge
13. Improved Drainage Knowledge and Management
14. Improved Earthworks Monitoring
15. Improved Earthworks Management

4 National Weather Event Response

16. Weather Definitions and Thresholds
17. Weather Event Response
18. Weather Information and Decision Support systems
19. Strategic resource management

5 Climate Change Adaptation

20. Route Climate Change Adaptation Plans
21. Tomorrow's Railway & Climate Change Adaptation project

6 Information Exploitation

22. Delivering supplementary information
23. Delivering Weather Resilience Intelligence

Figure 10 The constituent components of Network Rail's WRCC programme

The WRCC programme is currently supporting the delivery of:

- an enhanced vegetation management project: £10m of accelerated funding to address high-risk trees and mitigate the impact of both extreme winds and adhesion issues
- points enhancements: installation of up to 7,000 points heat insulation and covers in support of Key Route Strategy
- forensic investigation of earthworks failures in 2012/13 and 2013/14: The 261 failures that occurred during this two-year period have been investigated with deep dive analysis being undertaken on 89 of them
- earthworks remote condition monitoring pilot: involving 250 high-risk sites across four Routes (Scotland, LNE, Wessex and Western) starting in December 2014
- improved drainage management: mobile works tools and drainage competency improvements by December 2014
- agreed weather thresholds and definitions
- an enhanced Extreme Weather Action Team process: This will be reviewed and the improved processes implemented into the first Route by end November 2014
- aerial surveys of infrastructure using the Light Detecting and Ranging (LIDAR) technique; this will be complete by December 2014
- enhanced weather forecast service which will be in use from April 2015

Route weather vulnerability

Anglia Route's vulnerability to weather impacts and climate change is generally related to the geology and topography of the region with region-specific features including the coastal fringes and swing bridges on the Norfolk Broads.

The southern parts of Anglia which are approximately south of a line from London to Ipswich are built on London Clay or using London Clay derived fill. These are moisture sensitive materials, prone both to conventional failure when saturated in winter but also to desiccation failure where track quality is very difficult to maintain in dry summer and autumn conditions. This affects several lines but is most pronounced on the FSS2 between West Horndon and Lower Dunton in Essex. The fenland peats in the Ely area and other local peat bogs are also notable shrinkage and swelling problem areas. Significant works are therefore required to improve resilience of such London Clay and peat-related assets.

Glacial sands and Glacial Till derived sand fills in the central and northern parts of the Anglia Route are vulnerable to washouts due to concentrations of water from surface run-off or intense storms. Cutting slopes where perched water tables exists in sands overlying clays will also be more vulnerable to earthslips with increased groundwater levels

Low-lying areas on poorly draining soils such as the Fens and the Norfolk Broads are vulnerable to flooding with embankment settlements and rising groundwater levels making drainage outfalling more difficult. Low-lying coastal and estuary areas such as Lowestoft, the Stour estuary and the Alluvial flats adjacent to the River Thames are also vulnerable to sea level rises, scour and storm surge events. The low-lying exposed areas and shallow earthworks also make the assets more vulnerable to wind damage, particularly OLE assets.

Figure 11 Storm surge washout at Oulton Broad

Figure 12 Earthslip at Acton Wells embankment

Figure 13 Tree-related issues

The Anglia Route commitment to better understanding of weather and climate change impacts on network operations and key assets is shown by the March 2013 Natural Hazards Resilience Study undertaken by risk and insurance advisors Willis Limited. This study used insurance market recognised quantitative models to assess the impact that natural hazard events could have on assets in terms of property damage and anticipated downtime impact. The key output from this study was a database ranking individual asset vulnerability to each of the perils modelled. The study concluded that windstorms produced the highest modelled damage in Anglia although the study was limited to considering only flood, wind and coastal surge perils. The Willis study also undertook a weather extremes and climate variations analysis that noted little variation in temperature or wind speed extremes across Anglia but a more marked future pattern of increased rainfall in the northern and western parts of Anglia.

Future climate change vulnerability

The relationship between weather events and climate is complex; therefore it is understandable that climate change projections do not forecast future weather events. However, Network Rail can use the climate projections to understand potential risks and make informed strategic decisions to increase future weather resilience.

The UK Climate Change Projections (UKCP09) provides regional climate change projections across 13 administrative regions in Great Britain, Figure 14. The East of England projections provide Anglia Route with indications of future climate change.

Figure 14 UKCP09 administrative regions

The following derived charts from UKCP09 data show the projected changes in temperature and precipitation for the high emissions scenario, 50th percentile (10th and 90th percentile data has been obtained). The projected changes are shown for future climate periods up to the 2080s (2070-2099) and are relative to the baseline climate of 1970s (1961-1990).

Mean daily maximum temperature change

The mean daily maximum temperature in the East of England, Figure 15, is projected to increase throughout the year, with greater increases expected in the summer months through the century. Average maximum daily temperature in July is expected to increase by 2.9°C, reaching 24°C by the 2050s, and by 4.7°C, reaching 25.8°C by the 2080s. Average maximum daily temperature in January is expected to increase by 2.2°C, reaching 8.4°C by the 2050s, and by 3.2°C, reaching 9.4°C by the 2080s.

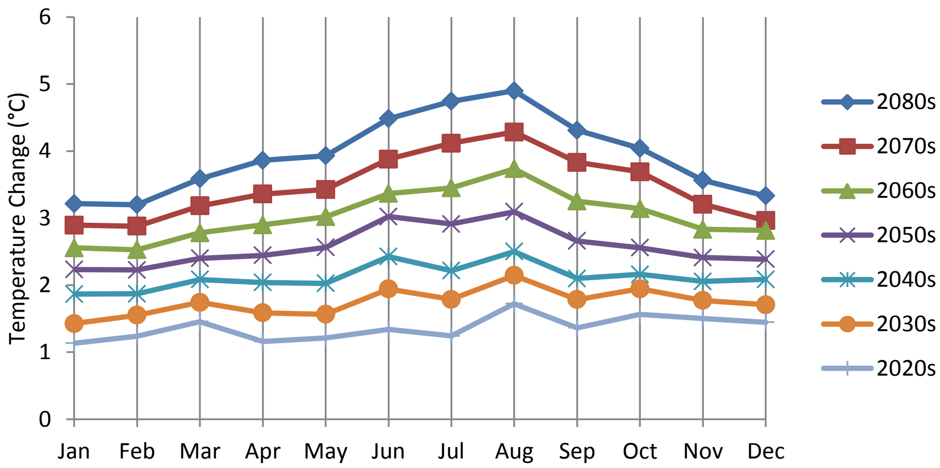

Figure 15 East of England, mean max temperature change (50th percentile)

Mean daily minimum temperature change

The mean daily minimum temperature in the East of England is also projected to increase throughout the year, Figure 16. Average minimum daily temperatures in July are projected to increase by 2.7°C, reaching 14.5°C by 2050s, and by 4.4°C reaching 16.2°C by the 2080s. Average minimum daily temperature in January is projected to increase by 2.9°C, reaching 3.9°C by 2050s, and by 4.2°C, reaching 5.2°C by 2080s.

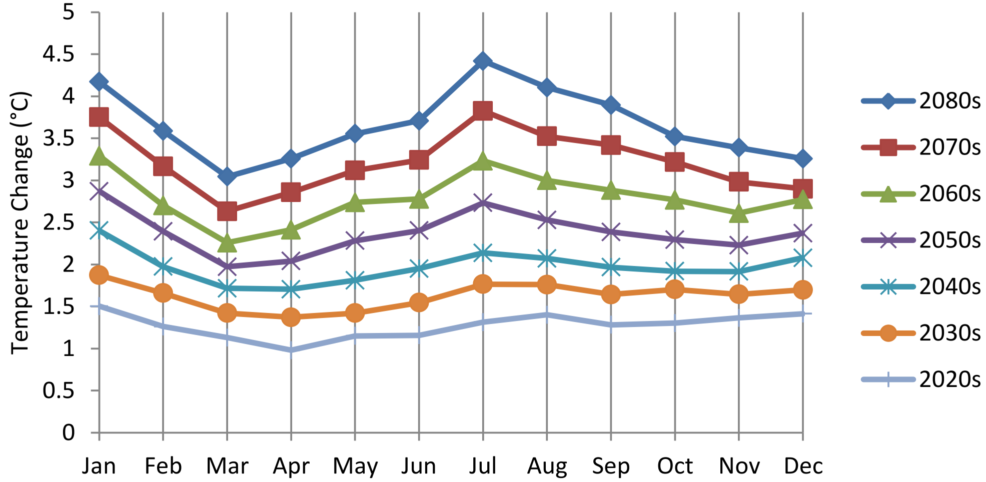

Figure 16 East of England, mean min temperature change (50th percentile)

Mean daily precipitation

The mean daily precipitation in the East of England is projected to significantly increase in winter months and decrease in summer months, Figure 17. The greatest increase is expected to occur in February, projected to be 22 per cent, reaching 1.6mm per day by the 2050s, and 37 per cent, reaching 1.8mm per day by the 2080s. The greatest decrease in precipitation is likely to occur in August. Mean daily precipitation is projected to decrease by 18 per cent by the 2050s, reducing to 1.3mm per day, and by 29 per cent, reducing to 1.1mm per day by the 2080s.

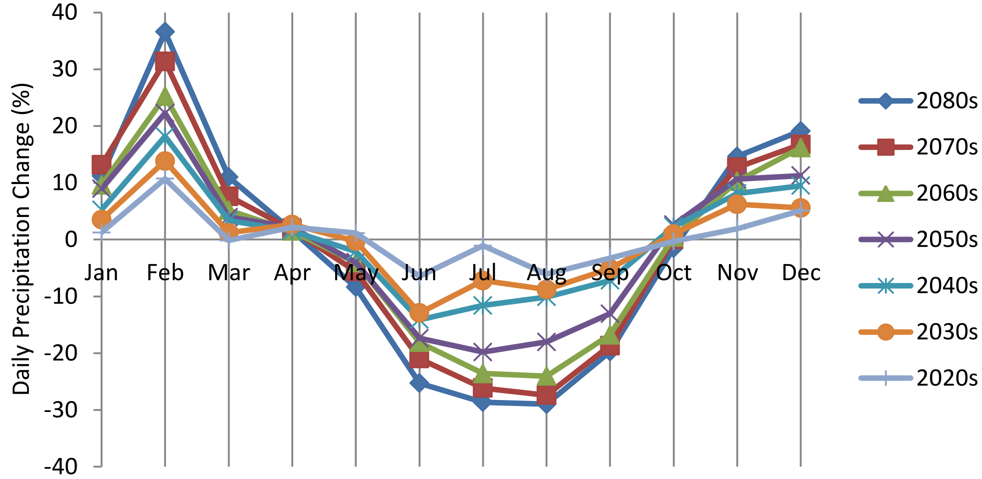

Figure 17 East of England, mean daily precipitation change (50th percentile)

Sea level rise

Sea level rise for the Anglia Route coastal and estuarine assets can be represented by the projections for Suffolk, near Lowestoft. For the high emissions scenario, the projections for the 50th percentile for 2050 is 0.268m and 0.581m by the end of century (the rise is unlikely to be higher than 0.411m and 0.904m respectively), Figure 18.

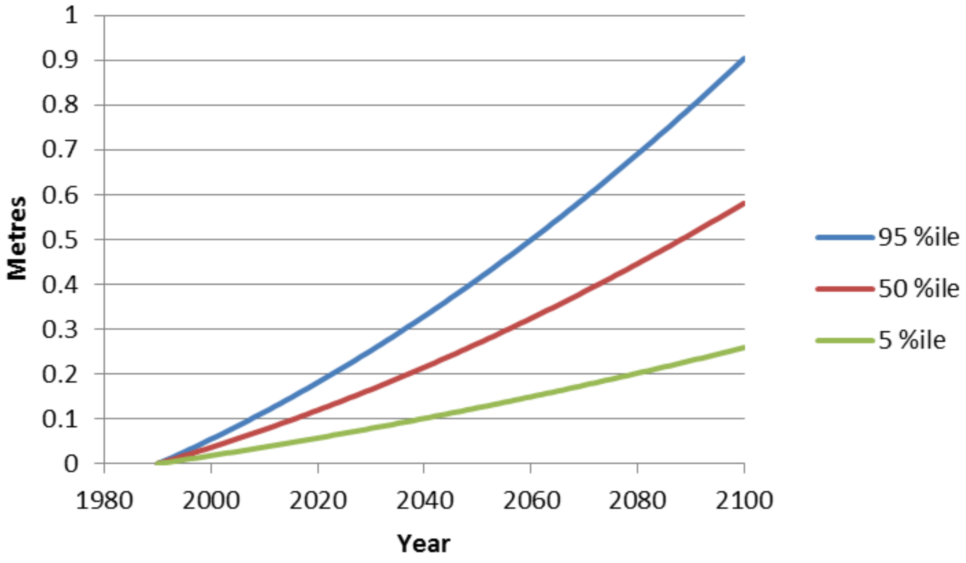

Figure 18 UKCP09 sea level rise projections for Lowestoft area

The understanding of the vulnerability of Anglia Route rail assets to current weather and potential risks from future climate change is an important stage in developing WRCCA actions.

Anglia Route impact assessment

This section provides the findings from the Anglia Route weather impact assessment, including annual performance impacts and identification of higher impact locations on the Route.

Performance impacts

The impact of weather on the rail network can be monitored within rail performance data. Schedule 8 costs, the compensation payments to train and freight operators for network disruption, are used as a proxy for weather impacts due to greater granularity of root cause reporting.

Schedule 8 costs for the past eight financial years for Anglia have been analysed, Figure 19, to provide an assessment of weather impacts.

- 'flooding' costs include delays due to a range of fluvial, pluvial, groundwater and tidal flooding of assets.
- 'earthslip' delays have been included due to internal analysis indicating primary triggers of earthworks failures are weather-related.
- 'heat' and 'wind' include direct impacts on assets and impacts on delay due to speed restrictions implemented as part of Network Rail's operational response during weather events.

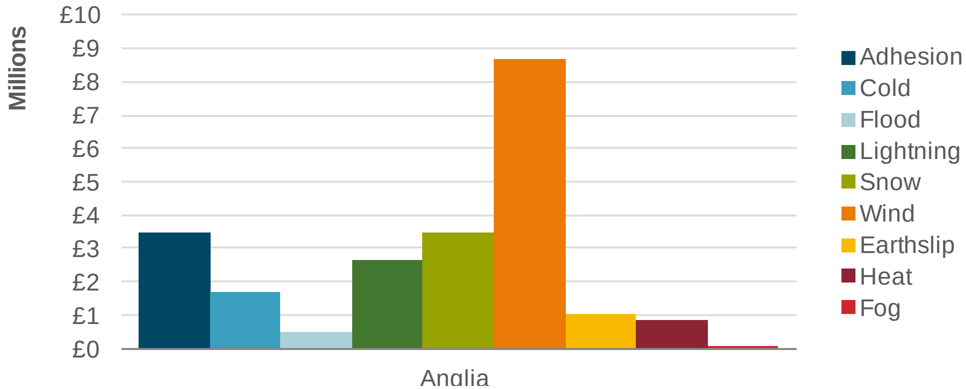

Figure 19 Anglia Route weather attributed Schedule 8 costs 2006/07-2013/14

The analysis shows that wind has been the most significant weather impact for the Route, with total Schedule 8 costs over £8m during the period 2006/07-2013/14.

Climate modelling cannot provide strong projections for future changes to wind speeds, though increased storminess is generally projected and may increase the risk of wind-related incidents on the Route. The risk of lightning strikes is also likely to be affected by increased storminess. With the low-lying topography of Anglia, increased winter rainfall, storminess and sea level rise, the risks of flooding and storm surges will increase.

A combination of the assessment of historical weather impacts on the Anglia Route and regional climate change vulnerability from UKCP09 can be used to prioritise resilience actions.

Table 1Prioritisation of weather-related impacts on Anglia Route

Weather-related impact	Schedule 8 costs[1]	Projected future impacts	Prioritisation
Wind	£1.08m	Wind changes difficult to project however generally projected to increase	High
Adhesion	£0.44m	Complex relationship between adhesion issues and future climate change.	Medium
Snow	£0.44m	2.9°C increase in January mean daily minimum temperature[2]	Medium
Lightning	£0.33m	Storm changes difficult to project however generally projected to increase	Medium
Cold	£0.21m	2.9°C increase in January mean daily minimum temperature[2]	Low
Earthslip	£0.13m	22 per cent increase in February mean daily precipitation[1]	High
Heat	£0.11m	2.9°C increase in July mean daily maximum temperature[2]	Medium
Flooding	£0.04m	22 per cent increase in February mean daily precipitation[2]	High
Sea level rise	£0.02m	0.27m increase in sea level rise[3]	Medium
Fog	£6k	Complex relationship, however research suggests fog events will decrease	Low

1 Annual average 2006/07 to 2013/14,
2 UKCP09 projection, 2050s High emissions scenario, 50th percentile, against 1970s baseline
3 UKCP09 projection, 2050s High emissions scenario, 50th percentile, against 1990 baseline

It is also worth noting the Schedule 8 cost per delay minute in CP5 will be on average 60 per cent higher, further reinforcing the importance of effective WRCCA actions.

Identification of higher risk locations

A geographic information system (GIS) based decision support tool, METEX, has been developed to analyse gridded observed weather data and rail data, including the past eight years of delays attributed to weather.

Over recent years our network has experienced some of the most extreme weather on record and weaknesses in existing assets will be captured in performance impacts. Climate change is projected to impact the UK with more intense and frequent extreme weather events, so taking actions on our current weaknesses, and proactively managing future risks are important steps to increasing our future resilience.

Higher-risk locations have been identified by assessing METEX outputs for high-frequency/high-cost sites across the whole Route, and detailed assessment of key sections of the rail network. These locations have been assessed to determine:

- validity of the delay attribution to a weather impact
- root cause of the delay
- resilience actions that have been undertaken
- resilience actions that are currently planned
- identification and prioritisation of additional resilience actions.

In addition, Routes have identified potential future risks and resilience actions based on climate change projections and Route knowledge.

Heat impact assessment

Based on 2006/07 to 2013/14 data, heat-related events account for total 3,960 delay minutes per year on average, costing £0.109m per year in Schedule 8 costs. This is 3.7 per cent of weather-related delay minutes.

Track asset

The impact of high temperature is often a problem in the management of the track asset although on some sites the overhead line (OLE) performance is affected before the track. Track maintenance teams put significant resource into managing the track asset in a way that limits the number and length of heat speeds required to manage safety which are largely successful resulting in the current impact being relatively small. Capital investment in the track asset is also partly targeted to remove assets that perform poorly in high temperatures including removing the remaining jointed track and works programmed to minimise heat-related formation disturbance to minimise the risk of a heat-related speed restriction. Jointed rail will remain in sidings, depots, passing loops and freight only lines with low usage or low speed limits until it is life expired.

As average temperatures increase the season available to undertake advance maintenance will reduce as the season where critical rail temperature (CRT) is possible will lengthen. The number of days where the CRTs are exceeded will increase which will require a corresponding increase in speed restrictions to manage the safety risk of a track buckle to be imposed on a greater number of days per year over a longer summer season, and potentially for longer periods on those days when the CRT is reached. This increase will have to be mitigated by concentrating advance track works that disturb the track formation into an ever smaller window during the winter. This will be a significant challenge for maintenance depots, who are unlikely to have access to any additional maintenance shifts in winter. This maintenance cannot be squeezed into an ever shorter season without radical efficiency improvements or changes in methodology or a larger workforce with more access to the track in the winter period. The Anglia CRT site register will continue to be the subject of an ongoing review including the processes when CRT is exceeded.

It is possible that track standards for rail stress management may be modified as the climate warms to increase track maintainability. One mitigation would be to reduce sleeper spacing but this would require a significant capital investment. Heavier sleepers also reduce the risk and areas with light sleepers (e.g. softwood) will need to be replaced with concrete sleepers. Other options to increase permissible rail stress include re-profiling areas with inadequate ballast shoulders and/or lateral resistance sleeper end support to prevent the rail slewing in towards the inside of curves in winter and to prevent slewing off the outside of curves in summer. More radical options may be to convert to a slab track system in high-risk areas or the development of engineering solutions to mitigate the increased lateral forces due to the thermal expansion and contraction of the running rails. Additionally ballast gluing can be explored in high-risk areas.

The common complication with most options to increase the track’s resilience to stresses induced by temperature variation is a need for a more robust track support system including more space on bridge decks and embankments for a more substantial formation. High-risk areas include areas where there are multiple track deficiencies (wet beds, inadequate ballast shoulder) or specific assets vulnerable to heat, including Switches and Crossings (S&C), notably switch diamonds. Anglia’s historical track maintenance practices have resulted in a higher track alignment than was originally designed to be accommodated leading to ballast loading to many underline bridge parapets and spandrels and to ballast retention problems on numerous embankments as track raising reduces the crest width. The problem could be managed by track lowering or significant engineering to increase the width of embankments and to retain ballast in an engineered way on underline bridges although track lowering would be prohibitively expensive. Over-ballasting in cuttings is less difficult to manage but has resulted in drainage becoming more difficult to maintain as cess ditches are filled and catchpits are buried.

There are two potential non-structural heat mitigations for track. The first is to use Remote Condition Monitoring (RCM) to detect either rail temperature or rail stress at regular intervals and this data allows automated speed restrictions to be applied only where rail temperature or stress is actually causing a risk to safety. This would remove the need to apply the current blanket controls which use a very conservative estimate of rail temperature based on a formula and a temperature forecast. This may also reduce or remove the need to place special restrictions in place following engineering works. The second mitigation is to paint the rails. Good results have been achieved by hand painting short lengths of rail in areas of high risk of significant rates of thermal expansion in direct sunlight, this work is currently carried out by hand and with little control of application methodology or paint specification. There is scope to mechanise this process and to closely control specification which could lead to much more effective rail temperature, reduced need to reapply the coating, and the potential to treat the entire network. The use of shading systems can also be explored.

Track is more likely to be affected by heat speeds if it is in direct sunlight. Works to significantly reduce the amount of tree cover to mitigate against the risk of increasing wind, to reduce adhesion problems and to reduce soil desiccation risks may significantly increase the proportion of the track asset that is unshaded. The benefits of de-vegetation are expected to outweigh those of reduced shading although such de-vegetation may need to be complemented by further track resilience such as rail painting or the use of sunscreens in high-risk areas such as areas of low ballast depth.

Vegetation

Shorter periods of temperature close to freezing will increase the active growing season for many plant species and when combined with wetter winters will lead to more vigorous growth in the spring. Vegetation management will become more expensive as a result. Plant species may generally migrate north, this will result in existing plants, such as some broad leaved trees becoming stressed by drier summers and becoming dangerous, these species will have to be removed from the network where they pose a risk, this is likely to be a significant problem with adjacent third-party trees over which network rail has less control. New species which are likely to be more vigorous than those they displace will require new management practices.

During drier summers the frequency and severity of lineside fires can be expected to increase, this can largely be mitigated by managing the lineside environment to be largely free of combustible materials, this will require a change in management practice as we currently leave most cut vegetation on the lineside either as cut material or as chipped material, both burn well when dry.

Buildings

As passenger densities and temperatures increase, passenger comfort must be monitored and alterations made to buildings to improve ventilation and cooling as required including reinvigoration of the solar powered air vent (SPAV) programme. Passengers may also become more agitated when overheated and in these conditions accidents are more likely.

Staff workplaces must also be modified or replaced to deal with increasing temperatures. Staff, particularly those undertaking safety critical roles such as signallers and electrical control room staff share their work space with large electrical and electronic installations so must be provided with sufficient ventilation and air conditioning to maintain a safe working environment.

Electrical equipment housed in both location cabinets and buildings will also overheat if ventilation or air conditioning is insufficient. This may be a greater problem if tree cover, which currently shades many such installations, is removed. Accelerated programmes for cabinet and building ventilation therefore need to be considered.

Soil desiccation

Hotter summers are also expected to be drier which poses a risk for embankments constructed of moisture sensitive clays or founded on clay soils which shrink as they dry and expand when they are wetted, Figure 20. These desiccation effects also impact on peat foundation soils, notably the problems experienced on the Fens and at Thrandeston bog. Embankments and foundation soils of these types dominate on several lines within Anglia Route most notably the EMP peats north of Ely and the FSS2 London Clay east of West Horndon. In future drier summers, these embankments will shrink more, resulting in significant track quality problems and increased need for re-ballasting and tamping. The interventions required to repair the damage to the track caused by embankment shrinkage require speed restrictions to be imposed until they have consolidated, particularly in hot conditions, thus increasing the time it impacts on the track quality performance.

Figure 20 Desiccation/shrinkage risk

Ongoing re-ballasting interventions to manage soil desiccation induced poor track geometry issues will generally raise the track and so reduce the crest width which will eventually require the introduction of cess support and may also require additional works to manage the associated reduced OLE clearances.

Structures

The thermal expansion of structures in hotter summers will also need to be managed, notably for the swing bridges which risk being unable to open if sufficient heat expansion occurs. This will require a review of how heat resilience can be improved

Replacement of the remaining fixed tension OLE wire systems will also be required to achieve the currently required temperature tolerance range of -15^{o}C to +35^{o}C. A programme is under way to achieve this by 2018, notably for the section of fixed tension OLE between London and Chelmsford. The majority of the known heat sites have already had interventions although the future heat-related workstreams include the following:

- more frequent de-vegetation
- more regular tamping
- increased use of cess support
- review of current adverse weather plans and Critical Rail Temperature database
- shoulder ballast/plate support/lightweight sleepers/rail painting for CRT stress
- accelerated cabinet ventilation programme
- development of a building ventilation programme
- review of heat resilience of swing bridges (e.g. sprinkler systems, replacement bridges)
- remote monitoring of rail temperature
- painting rails white in critical locations (review and extend database of sites)
- removal of fixed tension OLE to achieve temperature range -15^{o}C to +35^{o}C.

Cold and snow impact assessment

Based on 2006/7 to 2013/14 data, cold-related delays totalled 6,253 minutes per year on average, costing £0.211m per year in Schedule 8 costs. This is 5.9 per cent of weather-related delay minutes. Snow-related delays totalled 15,154 minutes per year on average, costing £0.437m per year in Schedule 8 costs. This is 14.3 per cent of weather-related delay minutes.

Cold weather without snow is largely managed as the management of snow.

The primary mitigation for snow and cold is good forecasting allowing robust emergency timetables to be implemented and the targeted use of MPVs to de-ice key routes. An increased robustness in these capabilities could improve preparation for well-forecasted cold weather and speed up recovery following ice or snow fall.

Icicles from bridges shorting the OLE wires and iced DC conductor rails in the London area cause the greatest disturbance to service. Further work is therefore warranted at reviewing the drainage provisions for bridges affected by icicles and in assessing the benefits of heating the DC conductor rails with the latter building on experience gained in Kent.

Frozen points are a key issue in cold weather and therefore an accelerated programme of points heater installations of those points without heaters would help to reduce the short-term risks. Similarly ensuring the thermal insulation of any points heaters not included in the CP4 programme should also be revisited. The Liverpool Street canopy area points are also still vulnerable to ice issues as a result of snow and ice falling off trains with procedures being reviewed to identify how resources can be effectively deployed in the Liverpool Street throat area to manage this risk.

The risk of significant delays due to cold and snow may reduce with increasing climate change temperatures and moderate investments in better procedures and relatively short-term investments such as more de-icing train capacity may provide more cost effective actions.

Snow is infrequent in much of Anglia Route and the very significant delay minutes are due to the wide spread nature of this problem when it does occur and the remote locations on the Anglia network. In particular snow will stop trains from running if it prevents contact with the DC conductor rails typically found in the London area. Although the number of cold and snow fall events is likely to fall in future years, and the season where there is a snow risk is likely to shorten, it is possible that snowfall may increase in intensity and in the short term is likely to remain a significant cause of weather-related delay.

The majority of the known sites have already had interventions although future cold and snow-related workstreams include the following:

- accelerated programme of points heater installations
- review of current weather procedures and forecasting
- review need for increased MPV capacity for snow clearance
- assess benefits of heating for 3rd rail (review Kent experience)
- review of drainage on structures affected by icicles
- check de-icing train has sufficient availability
- ensure CP4 thermal insulation of points heating completed
- staff deployment strategy for points at Liverpool Street throat area (for ice falling off trains).

Flooding and sea level rise impact assessment

Based on 2006/07 to 2013/14 data, inland and coastal flooding-related delays totalled 3,939 minutes per year on average, costing £0.064m per year in Schedule 8 costs, of which approximately one third is coastal storm surge-related and two thirds are surface water run-off issues. This represents 3.7 per cent of weather-related delay minutes in Anglia.

Flooding

The climate is forecast to become warmer and wetter in the winter with an increasing number of storms of increasing ferocity which will be a challenge to manage. Drainage assets throughout the Route require investment and geotechnical assets are sensitive to intense storms and the impacts of very heavy rainfall. Numerous landslips occurred nationally in the winter of 2012/2013 and also the very wet winter of 2013/2014 although the Anglian region was much less severely affected than further south and west. Speed restrictions were, however, imposed at some locations in Anglia at these times in order to mitigate against the risk of flooding damaging bridges or washing out the track at locations where the flood risk was high, notably during the Lowestoft to Haddiscoe storm surge washouts in 2007 and 2013. Many other areas are also prone to surface flooding including the previously noted recent flash flood at Surlingham and sites such as these would benefit from having remote monitoring cameras to provide instant assessments of flood risks.

Figure 21 Storm surge damage at Oulton Broad

Figure 22 Scour damage at Melton

Parts of the Anglia infrastructure are built along the margins of floodplains and other flat poorly drained areas such as the Norfolk Broads, the Fens and the northern bank of the Thames Estuary. Modern flood risk assessments were not carried out when the railways were built, and floodplains have generally accreted in the intervening 100 plus years. Increasing urbanisation and changing farming practices have also increased run-off rates. These problems all combine to increase the vulnerability of the network to flooding, and this will worsen as winter storms intensify. Third-party run-off is a particular problem at highway level crossing sites and there is a need to manage these in partnership with local authority highway departments with reviews of the capacity of the system, floodpaths and the benefits of locally raising signalling cabinets.

A programme of bridge scour protection has been undertaken in Anglia in CP4 with five of the most critical scour sites mitigated in CP4 and a further two already programmed for CP5 which will significantly reduce the risk of bridge failure due to scour or surcharging local to the bridge footings. A further 13 at-risk structures will be remediated in CP5.

Increasingly frequent and intense storms will overwhelm the existing track drainage networks which have suffered from under investment in previous decades. This will lead to increasingly frequent traffic disruption and accelerated degradation of assets that depend on good drainage, particularly geotechnical assets and the track formation. The current drainage asset currently requires interventions in parts of the route and a robust long-term maintenance regime to be implemented and funded. In the coming decades the drainage assets should be assessed and where capacity is insufficient for predicted climatic conditions improvements should be implemented. In future years it is likely that some locations, particularly in the coastal floodplain will no longer function as effective gravity drainage systems unless significantly greater system storage is constructed and if this is not practical pumped drainage will become increasingly necessary.

Sea level rise

Sea level increase will not have a day-to-day impact in the short to medium term but in the longer term the impact will increase. Minor coastal storms will have an ever-greater impact and over time the proportion of the tidal cycle that coastal gravity drainage systems are able to discharge over will reduce. In the short term this will result in more tide locking and flooding only if rain falls over the high tide period, however in the longer term there is a risk available drainage capacity will be utilised to discharge 'normal' flows leaving no capacity to deal with storm water. When combined with the increased storminess and more intense rainfall the number of occasions when the capacity of surface water drainage systems in the coastal zone is exceeded will increase with possible mitigations comprising managing the water through the high tide period by increasing the system storage, or pumping at high tide. Coastal Estuarine and River Defence management plans (CERD) will be developed during CP5 to aid the management of the sea level and storm surge risks

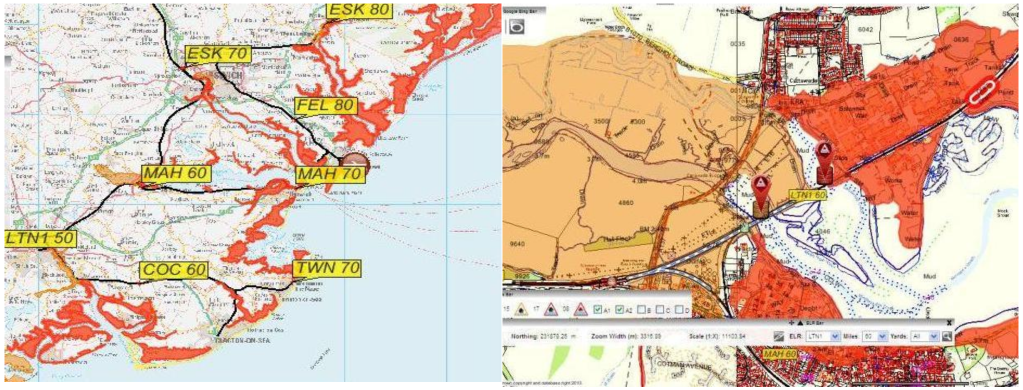

Figure 23 December 2013 storm surge flood risk maps used by Anglia Route

Sites where flooding and storm surge interventions have been undertaken in CP4 include:

- Highbury and Islington to Dalston sewer
- Fordley Hall drainage
- Woodgrange Drive Southend
- Lindsay Close BrentWood
- Gunnersbury Junction

In CP5, planned interventions include sites located at:

- Wrabness (Phase 1)
- Bishops Stortford flooding
- West Horndon to Dunton

Over time ground levels in areas discharging into tidal rivers, coastal marsh and the floodplain of lowland river systems have increased as successive floods or tides have deposited silt. The rail infrastructure is a fixed point in this rising landscape and the maintenance of culverts, and associated approach ditches, which discharge on to neighbouring land, needs to manage these changes. The impact of these changes is difficult to quantify but the height of the railway above the floodplain will reduce with time increasing the chance of track flooding and infrastructure damage which is exacerbated by particular difficulties in maintaining drainage features. A secondary important impact is that with reducing drainage effectiveness embankments will sit in water for increasing periods of time or are permanently wet at the toe which significantly reduces the stability of the earthworks.

Remote monitoring has a role to play in managing climate change drainage risks. The benefits of camera systems at known flood risk sites are clear but other remote systems to automate manually operated pumps and as alerts for trash screens prone to blockages should also be considered.

The majority of these flooding and sea level rise sites are known sites but several of them have yet to be progressed with future flood-related workstreams including the following:

- improved flood defences at Lowestoft in partnership with other interested parties
- increased River Stour scour resistance adjacent to the LTN1 at Cattawade Creek and the MAH at Harwich
- rock armour for increased washout resilience to future storm surges at Oulton Broad
- localised raised sheet piling to reduce at flood risk at New Cut canal near Haddiscoe
- remote monitoring of known high-risk flood sites (e.g. Oulton Broad)
- interventions on the remaining significant flood sites (e.g. Surlingham)
- undertake scour protection on remaining high-risk bridge structures
- review flood risks associated with pumping stations
- management of third-party run-off at Level crossings
- locally raised signalling cabinets at sensitive level crossing flood sites
- review of Gunnersbury remote pump system
- remote monitoring of trash screens.

Earthslip impact assessment

Based on 2006/07 to 2013/14 data, earthslip-related delays totalled 4,045 minutes per year on average, costing £0.128m per year in Schedule 8 costs. This is 3.8 per cent of weather-related delay minutes. It should be noted that the winters of 2012 and 2013 were far wetter than the long-term average with December 2013 and January 2014 being particularly wet months with the associated increased risks of earthslip.

Earthslip risk is likely to increase with prolonged saturation of clay soils notably on the London Clay and clay fills in the southern part of the Anglia Route with typical examples of failures at the MAH at Copperas Wood and the LTN1 at Chelmsford, Figure 24, and typical examples of increased movements on the MAH at Wrabness and on the LTN1 at Chitts Hill. Resilience to washouts will also need to be improved with risks from increases in short intense storms and such effects are more noticeable in the glacial sands and sand fills in the central and northern parts of the Anglia Route. Cutting slopes where perched water tables exists in sands overlying clays will also be more vulnerable to earthslips with increased groundwater levels with typical examples of the recently remediated LTN1 sites at Brantham Hall and Tumulus cuttings, Figure 25. Gradual near surface creep is also experienced by many over-steepened embankments such as the LTN1 at Hill Farm. These risks can often be mitigated by enhanced management of drainage although significant investment will be required to renew some of the more vulnerable earthworks assets to avoid significant problems in the longer term.

Figure 24 Earthslip at Chelmsford embankment

Figure 25 Earthslip at Tumulus cutting

Intense rain and flooding can cause the failure of geotechnical assets via a number of mechanisms each with a different suite of mitigation options:

- washout failure due to water flowing over the crest of cuttings, mitigated by increasing capacity of crest drainage and works to stabilise cutting slopes
- cutting failure due to saturation of face mitigated by face drainage and stabilisation.
- cutting failure due to wet cutting toe, often accompanied with track quality problems, mitigated by improved cutting and track drainage
- embankment failure due to saturation during rainfall events are very difficult to mitigate against. The slope must be re-engineered to retain a factor of safety of greater than unity when saturated which requires assessment and engineering intervention which is usually toe support such gabion walls or sheet piles. A re-grade is also frequently required
- embankment failure due to saturated toe conditions mitigated by drainage of toe. Many embankments are land locked and this is difficult to achieve this in some cases, particularly in areas impacted by sea level rise, low-lying areas or areas with high groundwater.
- embankment failure due to scour at the toe which occurs where the toe of the embankment is adjacent to a river stream or drainage ditch which conveys water at high velocity during storm events. These failures can occur very quickly and require increased toe scour protection such as sheet piles, gabion and rock armour.

As embankments weather and near surface layers of overstep slopes gradually creep downslope they also become narrower at the crest. All current track maintenance practices raise the track which has resulted in parts of the route suffering from no safe cess width and insufficient space to maintain a compliant ballast shoulder. The lack of cess in places not only makes maintaining the track difficult, it also increases the chance of failures impacting on the track support zone.

There is also an increased risk of washout from burst water mains that are also vulnerable to climate change effects on the near surface soils and increased surface water run-off from third-party land, Figure 26.

Figure 26 Toe ponding from third-party surface water run-off

Many of these known sites have been remediated in CP4 and planned in CP5 including:

CP4	CP5
Victoria Mews	Wash Road
Ramsey Road Embankment	Ramsden Park Farm
Blackbush Drove Embankment	Park Lane
Fornham Lane	Wickford
Symonds Farm	Meadow Farm
Littlebury Tunnel	Tostock
Bishop Stortford Drainage Investigation	Audley End Cutting
Crome Road Embankment	Lower Dunton
Walthamstow Central Cutting Emergency Phase 2 TPI	Ashdon Way
Broomheath	Thorpe Hall
Hubbards Embankment	River Wid
Mill Lane Washout	Chitts Hill Embankment
Broomheath	South Manningtree
Hubbards Embankment	Coppey Farm
Timberlog Lane Cutting	Wherstead
Stamford Hill to Seven Sisters Embankment	Pesthouse Lane
Mayfield Cutting	Gilsingham
Brantham Hall	Hill Farm
Belstead Cutting	Marsh Farm
Markshall Farm Road	Tumulus Cutting
South of Manningtree	Jacques Hall
Thrandeston Bog	
Colchester to Ardley Embankment	
Chelmsford Embankment - Emergency Works	
Marsh Farm Embankment	

Further investments that could enhance weather resilience have yet to be progressed with earthslip-related workstreams including the following:

- embankment renewal at Wrabness
- earthworks renewals on other sensitive sites that are outside current Network Rail policy for a renewal intervention such as Hill Farm and Chitts Hill
- renewals at other vulnerable monitored sites that start to show movements which are accelerating or of high magnitude
- remote monitoring cameras, ground movement markers and remote inclinometers at known high-risk embankment movement sites
- increased use of cess support systems for narrow embankment crest sites
- remote monitoring of steep cutting slopes and tunnel portals.

Wind impact assessment

Based on 2006/7 to 2013/14 data, wind-related delays totalled 39,932 minutes per year, costing £1.084m per year in Schedule 8 costs. This is 37.6 per cent of weather-related delay minutes.

Wind affects performance directly in that blanket speed restrictions are imposed when thresholds of wind speed are reached. Wind also affects performance indirectly primarily as a result of damaging lineside trees which then fall, or drop branches on or near the line. Wind also moves other debris on to the line from the lineside environment, frequently from neighbouring sites. High winds can also lead to significant wave formation even in waters protected from the open sea which have the potential to cause damage to the infrastructure.

The primary operational risk mitigation to strong wind is to impose speed restrictions on the parts of the route forecast to be impacted, or in extreme conditions to suspend operations completely. Remotely monitored cameras can also be used to provide instant advance warning of problems at any identified high-risk sites. A camera is already present at Brentwood and further cameras have already been programmed for installation at Prittlewell, Ingatestone, Wymondham, Elmswell and Stoke Newington principally for vegetation-related adhesion risks.

The primary longer-term mitigation is to remove trees which are able to fall on to the line, Figure 27. Other Routes have a 10 phase plan to clear a 6m strip of trees from adjacent to the track, and to remove dangerous trees beyond the 6m strip which is also being considered in Anglia route. There is also a significant risk associated with trees on third-party land, many of which are sufficiently tall enough to fall across the running lines. Undertaking works on high-risk third-party trees is also being considered including clearing trees in danger of falling and those that may generate root wedging instability in soft chalk cuttings in the western part of Anglia providing they are not legally protected or providing an important visual screen. Further development of vegetation management plans should therefore consider third-party trees together with acceleration of a programme to improve OLE wind blow off resilience.

Figure 27 Vegetation management at Purfleet

The known wind-related sites have all been remediated and therefore future wind-related workstreams include the following:

- more frequent de-vegetation of earthworks slopes
- remote monitoring cameras at any identified high-risk sites
- further development of Network Rail vegetation management system to include third-party trees
- accelerate programme of OLE wind blow off resilience.

Lightning impact assessment

Based on 2006/7 to 2013/14 data, lightning-related delays totalled 14,561 minutes per year on average, costing £0.333m per year in Schedule 8 costs. This is 13.7 per cent of weather-related delay minutes.

There is little that can be done to mitigate the effect of lightning on existing signalling systems, as vulnerabilities are a fundamental of system design. Ensuring OLE have adequate lightning surge protection is an ongoing programme of works that if accelerated would improve the lightning resilience. Similarly localised lightning protection on signalling and lightning array protection for sensitive structures such as substations could also be considered building upon the experiences with such systems in other Routes such as Kent.

As signalling systems are replaced over time, new systems should be specified with a greater degree of resilience. Until this is possible a good stock of spare parts in danger of failure during a lightning strike should be obtained to ensure service recovery is swift.

The known lightning sites have all been remediated and therefore future lightning-related workstreams are more generalised including the following:

- review of current weather procedure
- accelerated programme of surge protection for signalling
- lightning array protection at sensitive locations (e.g. for substations)
- localised bus-bar lightning protection on signalling.

Adhesion impact assessment

Based on the 2006/07 to 2013/14 Schedule 8 data, adhesion-related delays totalled 15,875 minutes per year on average, costing £0.436m per year in Schedule 8 costs. This is 14.9 per cent of weather-related delay minutes.

Adhesion is difficult to deal with but has the second greatest number of incidents over the eight-year period. Adhesion is extremely complex with many interlinked causes, both infrastructure and operational. Many cases of adhesion delays are attributed to a lack of appropriate rail head treatment.

The weather that causes the greatest adhesion problems is still cold mornings and evenings which promote heavy dew. If combined with leaf fall the railhead can become contaminated as the leaves are crushed to form a carbon coating to the rails. This weather may become less common in the future with climate change.

A programme of railhead treatment including rail cleaning to remove contamination and application of adhesion gel or sand is the current primary mitigation. Increased Rail Head Treatment Train (RHTT) capacity could therefore assist with rail head treatments and therefore a review of the efficiency of the current RHTT in Anglia should be undertaken to assess the benefits of increasing their number. More modern rolling stock with wheel slip detection also reduces the impact of railhead contamination, and good forecast and robust alternative timetables that build sufficient time in to allow trains to slow and accelerate gently when conditions are poor would also significantly reduce the impact.

Another major mitigation is tree removal in areas where the problem is persistent. Plans to reduce the vegetation cover on the route will therefore improve the problem requiring a review of the current vegetation plans.

Remote monitoring using cameras will also be used at the most vulnerable and most regular adhesion sites. A camera is already installed at Brentwood for this reason and further adhesion-related cameras have already been programmed for installation at Prittlewell, Ingatestone, Wymondham, Elmswell and Stoke Newington. A review of the current leaf fall register should be undertaken to assess which sites should be monitored. Intelligent infrastructure systems should also be rolled out to cover high-risk sites.

The known adhesion sites have all been remediated and therefore future adhesion-related workstreams include the following:

- review of current weather procedure
- review of vegetation management plan
- more frequent devegetation
- review leaf fall register
- remote cameras for leaf fall detection at high-risk sites to be considered
- review efficiency of RHTT in Anglia with a view to increasing numbers
- intelligent infrastructure systems to be rolled out to cover high-risk sites.

Fog impact assesment

Based on 2006/7 to 2013/14 data, fog-related delays totalled 2,569 minutes of delay per year, costing £0.086m per year in Schedule 8 costs. This is 2.4 per cent of weather-related delay minutes.

The fog risk sites have been and will continue to be intermittent and unpredictable and therefore no further works are proposed at this stage. Fog risk is expected to decrease as temperatures rise and current controls are considered adequate for future management of fog.

Anglia Route WRCCA actions

Network-wide weather and climate change resilience will be driven predominately by Network Rail's Central functions through revision to asset policies and design standards, technology adoption and root cause analysis. The location specific nature of weather impacts will require analysis and response at Route level.

This section is a concise summary of Anglia Route actions planned in CP5, Table 2, beyond Business as Usual (BAU), and potential additional actions for consideration in CP5 and future Control Periods, Table 3, to increase weather and climate change resilience.

Table 2 Planned actions in CP5

Vulnerability	Action to be taken	By when
All Impacts		
Climatic conditions and specific weather-related risks to asset renewal and enhancement processes	Include clear requirements for climatic conditions and resilience levels in Route Requirements Documents	Ongoing
Climatic conditions and specific weather-related risks to assets	Review adverse Weather Plans	Ongoing
Flooding		
Level of engagement with flood risk management authorities to support effective discussions	Strengthen relationship with EA through setting up of a Local Liaison Group on flood risk management to share information and resolve issues (e.g. Cattawade Creek).	March 2015
Bridge foundation scour and surcharging	Increase scour and surcharge resistance of most urgent bridge sites (e.g. River Gipping at Blakenham and Worlingham)	March 2015
Early identification of flood sites	Install remotely monitored cameras (e.g. Oulton Broad), trash screen monitors (e.g. Johnsons Crossing) and automated pumps (e.g. Gunnersbury).	March 2016
Surface water run-off flooding	Review of interventions at high-risk and known flooding sites including highway level crossings and pumping station (e.g. Bishops Stortford and Pitsea LC)	Ongoing as part of DMP
Ineffective drainage systems	Effectively manage drainage maintenance interventions	Ongoing as part of DMP
Earthworks		
Embankment instability during adverse weather	CP5 earthworks renewal intervention at critical earthworks sites (e.g. Marsh Farm and Gilsingham)	April 2017
Embankment instability during adverse weather	Accelerate delivery of other Schedule 8 problem sites and sites showing significantly elevated rates of movement (e.g. Playford Hall and Chitts Hill)	March 2017
Embankment instability during adverse weather	Programmed business plan earthworks refurbishment and maintenance interventions	April 2019
Early and continuous warning of unstable embankments	Remote monitoring of vulnerable sites using cameras, movement markers/wires and remote inclinometers (e.g. Tostock)	March 2015
Near surface slope instability and loss of track support	Review requirements for increased cess support systems (e.g. Hill Farm)	March 2018
High temperatures		
Track buckling in hot weather	Review current adverse weather plans and CRT database including reviews of remote rail temperature monitoring and further white painting of rails.	March 2015
Loss of OLE wire tension	Remove fixed tension OLE systems	March 2018
Signal cabinet overheating	Accelerate completion of cabinet ventilation installations	March 2016
Poor environmental conditions in buildings	Develop building ventilation programme	March 2017
Coastal and estuarine		
Level of engagement with flood risk management authorities to support effective discussions	Engage with existing Local flood resilience forums (e.g. Lowestoft flood alleviation group)	March 2015
Flood, scour and washout risks to assets	Development of Coastal Estuarine Management Plans (CERD)	December 2014
Wind		
Trees falling on to track, OLE and associated assets	Review vegetation management plans including management of third-party trees	October 2014
Trees falling on to track, OLE and associated assets	Commence programme of third-party tree removal	March 2015
Trees falling on to track, OLE and associated assets	Increase frequency of lineside vegetation management	March 2015
Loss of OLE wires	Accelerate programme of OLE wind blow-off resistance	March 2017
Cold and Snow		
Line blockages	Review weather preparedness plans	Ongoing

Vulnerability	Action to be taken	By when
Frozen Points	Accelerate delivery of points heating and thermal insulation of points	March 2016
Frozen Points	Assess capacity of de-icing trains and benefits of increased number of them	March 2016
Shorting of OLE wires	Review of drainage of structures affected by icicles	March 2016
Frozen Points	Staff deployment strategy for points at Liverpool Street throat area	March 2016
Loss of service due to blockages or frozen points	Review weather preparedness plans including assessing third rail heating benefits	Ongoing
Adhesion		
Loss of adhesion due to crushed leaf falls	Remote monitoring and intelligent infrastructure systems to cover high-risk historic leaf fall sites	March 2015
Loss of adhesion due to crushed leaf falls	Review weather preparedness plans, vegetation management plans and leaf fall register	Ongoing
Trees leaf falls on to track	Continue programme of third-party tree removal	March 2019
Tree leaf falls on to track	Maintain frequency of lineside vegetation management	March 2019
Lightning		
Loss of electrical systems for signals	Accelerate delivery of lightning surge protection	March 2016
Loss of electrical systems for OLE and signals	Review current weather procedure	March 2015
Loss of electrical systems for OLE and signals	Review benefits of lightning array protection of sensitive locations	March 2016
Fog		
Delays resulting from poor visibility	No action to be taken – business as usual as no fog increase expected and no clear mitigation.	No action required

In addition to the above actions in CP5, the following actions in Table 3 have been identified as potential enhanced WRCCA actions which will require business case evaluation and funding submission.

Table 3 Potential additional WRCCA actions requiring further evaluation

Vulnerability	Action to be evaluated
All Impacts	
Climatic conditions and specific weather-related risks to asset renewal and enhancement processes	Monitor climate change trends and intervention innovations
Flooding	
Bridge foundation scour and surcharging	Increase scour and surcharge resistance of remaining vulnerable bridge sites
Early identification of flooding sites	Install additional remotely monitored cameras
Surface water run-off flooding	Review of interventions at high-risk and known flooding sites including highway level crossings
Earthworks	
Embankment instability during adverse weather	Design development and earthworks renewal intervention at Wrabness
Embankment instability during adverse weather	Additional critical earthworks renewal interventions
Embankment instability during adverse weather	Additional earthworks refurbishment and maintenance interventions
Early and continuous warning of unstable embankments	Remote monitoring of vulnerable sites using cameras, movement markers/wires and remote inclinometers (e.g. Wrabness)
High temperatures	
Loss of track support due to rail tension	Identify sites where cess support, shoulder ballast restoration, replacement of lightweight sleepers or plate support systems would be beneficial for CRT management
CRT speed restrictions	Additional monitoring stations to record more accurate temperatures
Inability to open or close swing bridges	Review alternative measures to improve the heat resilience of swing bridges
Coastal and estuarine	
Loss of support due to scour at the toe of embankment	Increased embankment resilience/scour protection at Cattawade Creek and Harwich
Earthworks washouts during storm surges	Increase washout resilience at storm surge sites at Oulton Broad
Earthworks washouts during storm surges	Reduce washout channelling by raising Haddiscoe sheet piles adjacent to New Cut canal on the Norfolk Broads

Vulnerability	Action to be evaluated
Wind	
Trees falling on to track, OLE and associated assets	Increase frequency of lineside vegetation management
Trees falling on to track, OLE and associated assets	Continue programme of third-party tree removal
Cold and Snow	
Line blockages	Review need for increased MPV capacity
Adhesion	
Loss of adhesion due to crushed leaf falls	Review need for additional RHTT capacity
Loss of adhesion due to crushed leaf falls	Remote monitoring and intelligent infrastructure systems to cover additional leaf fall sites

Management and review

Corporate management and review

Weather resilience and climate change adaptation will require long-term commitment to regular review and management across the business. The challenge for the industry, and for all organisations managing assets vulnerable to weather events, is to develop cost-effective strategies to accommodate climate change and implement these strategies in a timely manner to avoid an unacceptable increase in safety risk, reduction in system reliability or undeliverable downstream risk mitigation strategies.

Key actions being taken within corporate functions include:

- Safety, Technical and Engineering – Review of weather and climate change within asset policies and standards, and monitoring of WRCCA actions through the S&SD Integrated Plan
- Network Operations – Review of the Extreme Weather Action Team process and definition of ‘normal’, ‘adverse’ and ‘extreme’ weather
- Group Strategy – Delivery of future weather resilience in the Long-Term Planning Process
- Infrastructure Projects – Review of weather and climate change within the Governance for Railway Investment Projects (GRIP).

The progress on WRCCA actions is reported through Network Rail’s governance process to the Executive Committee as part of regular Strategic Theme business management updates.

Anglia Route management and review

Anglia Route recognises the importance of external stakeholder engagement in climate change adaptation management to support the awareness of best practice and identification of cost-effective adaptation actions.

Anglia Route is aware of its role as an informed asset manager to increase awareness of projected risks and the resilience of rail assets to future impacts. The designation of clear accountabilities and a climate change ‘champion’ will deliver effective management of climate change adaptation within the Route.

Review of Route WRCCA plan actions

The actions within all eight Route WRCCA plans will be monitored through internal Network Rail governance processes.

Route WRCCA plan progress will be reported every six months through the S&SD Integrated Plan. The plan monitors the actions being taken across Network Rail delivering safety and sustainable development objectives. The whole plan is monitored monthly by the cross-functional S&SD Integration Group.

Enhancement of assets will be included in Network Rail workbanks and monitored through our asset management processes.

Network Rail will also look to engage with the wider rail industry, specifically Train Operating Companies and Freight Operating Companies, to discuss the Route WRCCA actions to identify opportunities for collaboration to facilitate effective increase of rail system resilience. We will also update the Office of Rail Regulation (ORR) on progress through regular bilateral meetings.

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