2019 – 2024

ANGLIA

Route Weather Resilience and Climate Change Adaptation Plan

Contents

Purpose of this document

This document; defines the Anglia Route Weather Resilience and Climate Change Adaptation (WRCCA) Plan for CP6 and reviews progress against the WRCCA Plan published for CP5. This is 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 the rolling stock operating within the Route is not specifically assessed.

Anglia Route Weather Resilience and Climate Change Adaptation Plan – Version 1 – September 2020.

Director of Route Asset Management Statement

The railway network has been significantly affected by severe weather conditions including wind, snow, rainfall, lightening, 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, subsidence and coastal storm surges, heat causes soil desiccation and track buckling, high winds result in debris falling on to the track and overhead wires, and snow and cold weather result in frozen points and blocked routes.

Anglia Route is committed to responding 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.

Figure 1 Flooding at Gunnersbury, May 2018

Anglia has already secured significant investment to improve the infrastructure assets in the next five-year Control Period (CP) 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 (EA) and lineside neighbours.

Simon Thick
Interim Director of Anglia Route Asset Management

Executive summary

Current weather events can cause significant disruption to the operation of train services and damage to rail infrastructure.

The UK Climate Change Projections 2018 (UKCP18) indicate that there will be a shift to a warmer climate with significant changes in sea level and the pattern and intensity of precipitation across the year.

Changes in the frequency and intensity of extreme weather events and seasonal patterns as a result of this could alter the likelihood and severity of weather event impacts.

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 is committed to supporting the improvement of weather and climate change resilience through the delivery of the Route-specific objectives. We have developed an understanding of our risks by; assessing our weather-related vulnerabilities (for example Figure 2), identifying root causes of historical performance impacts and using UKCP18 regional climate change projections.

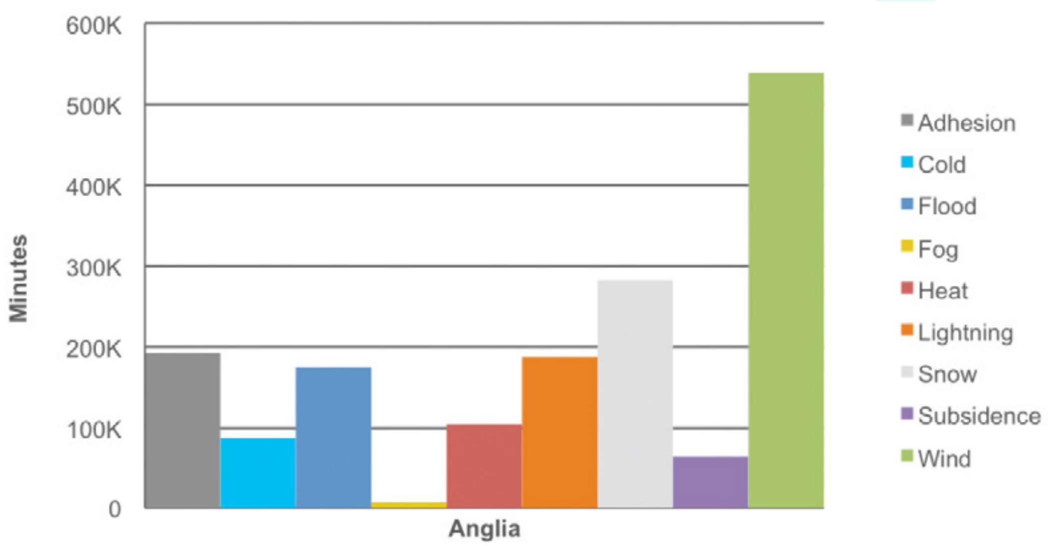
Our 2014 Route WRCCA Plan set out our Route WRCCA Strategy, summarised the findings of our Route vulnerability and impact assessments, detailed the CP5 investments and actions that we would take to mitigate these and highlighted future considerations.

This updated plan reports our CP5 progress, sets out our plan for CP6 and beyond and updates our vulnerability and impact assessments to account for changes in the Network Rail WRCCA Strategy and guidance. Key highlights include:

- In 2017 the Network Rail guidance on the climate change projections to be used for impact assessment and planning was reviewed. This recommended using the UKCP09 Medium scenario, 90th percentile probability[1]. With the release of the UKCP18 data this has been updated to the UKCP18 Representative Concentration Pathway (RCP) 6.0 90th percentile, and
- Subsidence risk sites remediated in CP5, and a look ahead at those planned for remediation in CP6.

Although the actions taken in CP5 improved aspects of our resilience, weather events continue to impact our operations. Anglia Route is committed to addressing the risks through the timely, cost efficient and safe delivery of this Route WRCCA Plan.

Figure 2
Anglia Route weather attributed delay minutes 2006/07 to 2018/19



[1]Previous recommendation used in the 2014 WRCCA Plan was UKCP09 High scenario 50th percentile probability

Introduction

The railway routinely operates in a wide range of weather conditions, however adverse and extreme weather can still cause significant disruption to our network.

Current weather events such as extreme rainfall, snow and high temperatures can cause delays, raise operating costs and increase safety risks. Recent examples of vulnerability in Anglia Route include:

- Widespread and significant flooding across the Route in June 2016,
- A culvert collapse at Thorrington in March 2018,
- Severe disruption due to snow in February 2018, and
- Several cases of wind-damaged trees fouling the track and Overhead Line Equipment (OLE).

We monitor the impact of weather events on the performance of our network by using delay minutes and Schedule 8 delay compensation costs[2]. Incidents are recorded under 9 categories as follows:

- Adhesion – line contamination leading to traction loss, e.g. leaf fall, moisture, oils,
- Cold – e.g. ice accumulations on conductor rails, points and in tunnels,
- Flooding – standing or flowing water leading to asset damage or preventing trains from accessing the track,
- Fog – reduced visibility obscuring signals,
- Heat – high temperature impacts e.g. rail buckles, Temporary Speed Restrictions (TSRs), overheated electrical components,
- Lightning strike – e.g. track circuit and signalling damage or power system failure,
- Snow – e.g. blocked lines and points failures,
- Subsidence – the impacts of landslips, rockfalls and sinkholes, and
- Wind – e.g. trees and other items blown onto the track and into the OLE or TSRs.

As these data include the duration and location of each disruption, and attribute cause, they give a high degree of granularity for use in analysing weather impacts and trends.

In the past 13 years (2006/07 to 2018/19) the average annual number of Schedule 8 delay minutes attributed to weather for the Anglia network was 125.7k. This represents 10.2 % of the total number of Schedule 8 delay minutes for all causes over that period equating to an average annual cost of £5.41m.

The impacts of severe weather events on the Anglia Route can be clearly seen in Figure 3, for example:

- Rainfall during 2008/9, 2013/14, 2014/15 and 2016/17,
- Snowfalls of 2009 through to 2011 and 2017/18,
- Storms, particularly lightning in 2009/10 and wind in 2013/14, and
- Heat impact in 2018/19.

[2] The compensation payments to passenger and freight train operators for network disruption

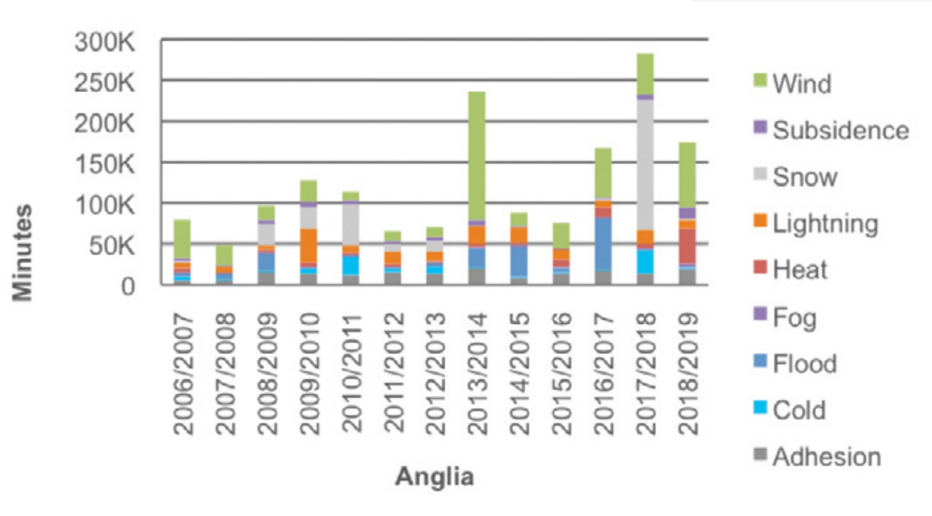
Introduction continued

Weather related costs can also be captured in Schedule 4[3] payments and the capital expenditure required for reinstating damaged assets.

The costs of weather attributed Schedule 8 and 4 payments and the wider socio-economic impacts of rail disruption on the UK justify continued investments to increase current weather resilience. Network Rail's collaborative approach to understanding weather impacts in the increasingly interdependent infrastructure, societal and environmental systems is key to identifying appropriate resilience responses that support our role in developing regional and national resilience.

Trends in the UK climate, and the UKCP18 data, indicate that there has, and will continue to be, a shift to a warmer climate. Figure 4 illustrates the changes in frequency and severity of Atlantic Winter storms and Figure 5 shows observed increases in the Central England Temperature record.

Figure 3
Anglia Route weather attributed delay minutes by year 2006/07 to 2018/19



[3]Compensation payments to passenger and freight train operators for Network Rail's possession of the network

Figure 4
Intensity and frequency of high latitude Atlantic Winter storms[4]

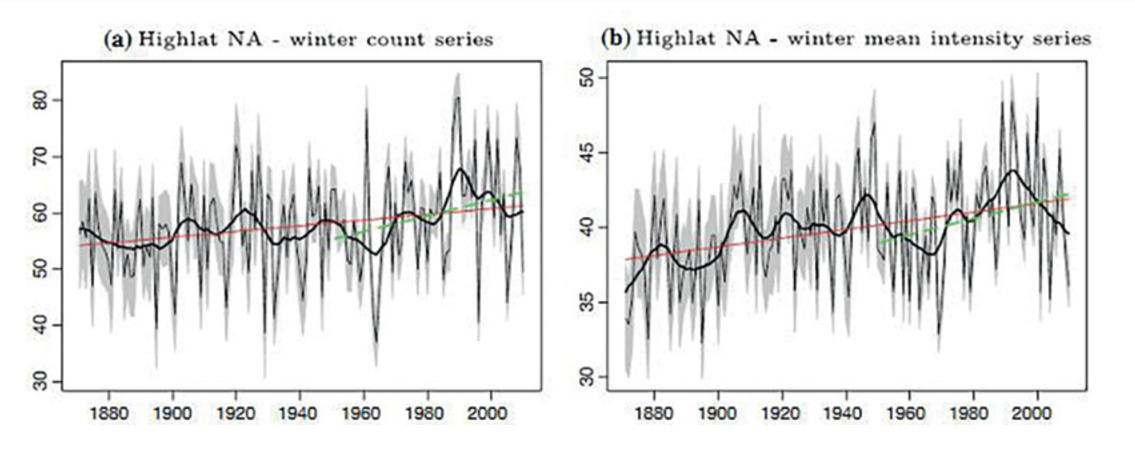
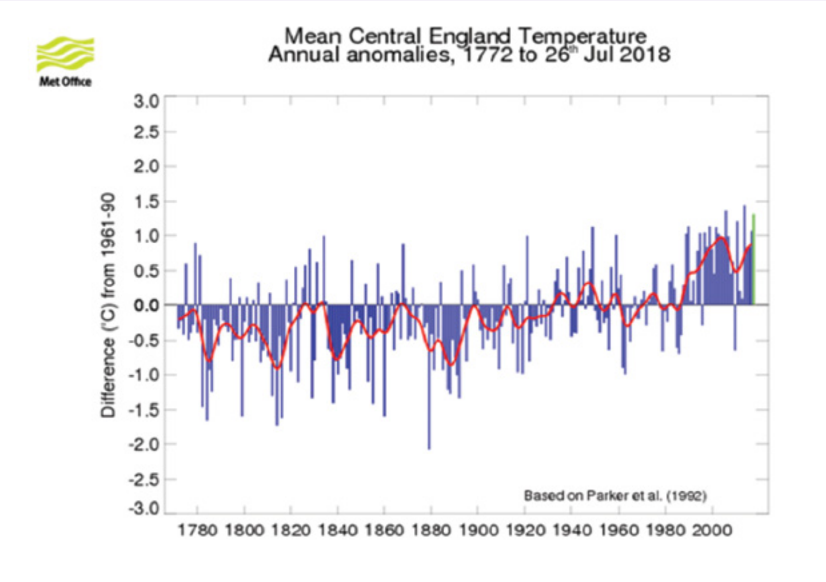


Figure 5
Mean Central England Temperature record[5]



[4]Xiaolan L. Wang, Y. Feng, G.P. Compo, V.R. Swail, F.W. Zwiers, R.J. Allan, P.D. Sardeshmukh. 2012. Trends and low frequency variability of extra-tropical cyclone activity in the ensemble of twentieth century reanalysis
[5]Parker, D.E., T.P. Legg and C.K. Folland. 1992. A new daily Central England Temperature Series, 1772-1992. Int. J. Clim., Vol12, pp 317-342

Introduction continued

UKCP18 projects an overall shift towards warmer climates with drier Summers and wetter Winters for the whole of the UK, although the level of change will vary across the regions.

Examples of the changes are shown in Figure 6 for the mean daily maximum Summer temperature and Figure 7 for Winter precipitation.

Figure 6
Change in mean daily maximum Summer temperature (°C) (left to right; 2030s, 2050s and 2070s) based on a 1981 -2000 baseline[6]

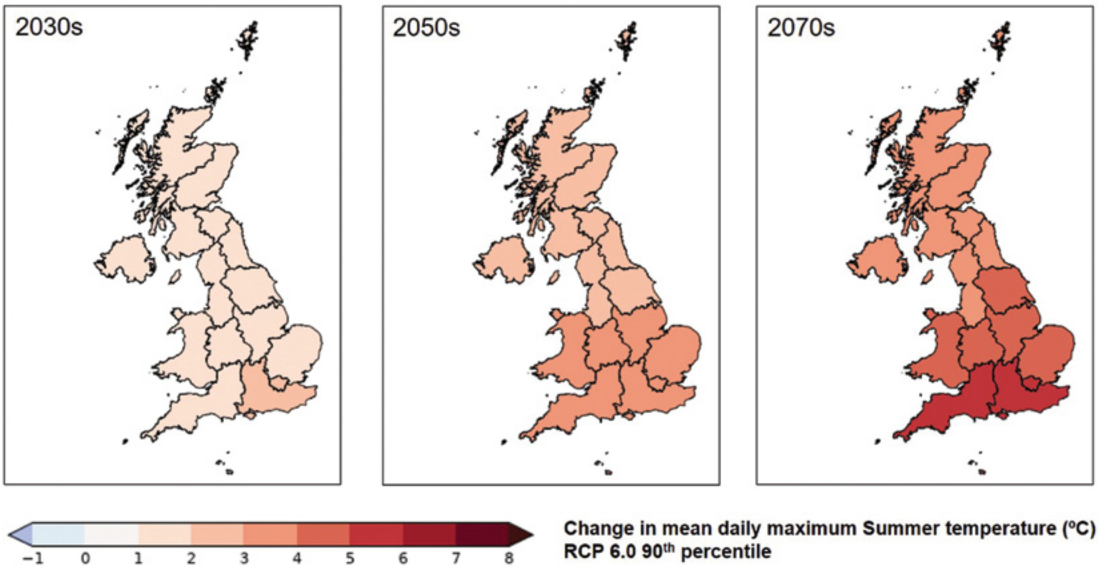
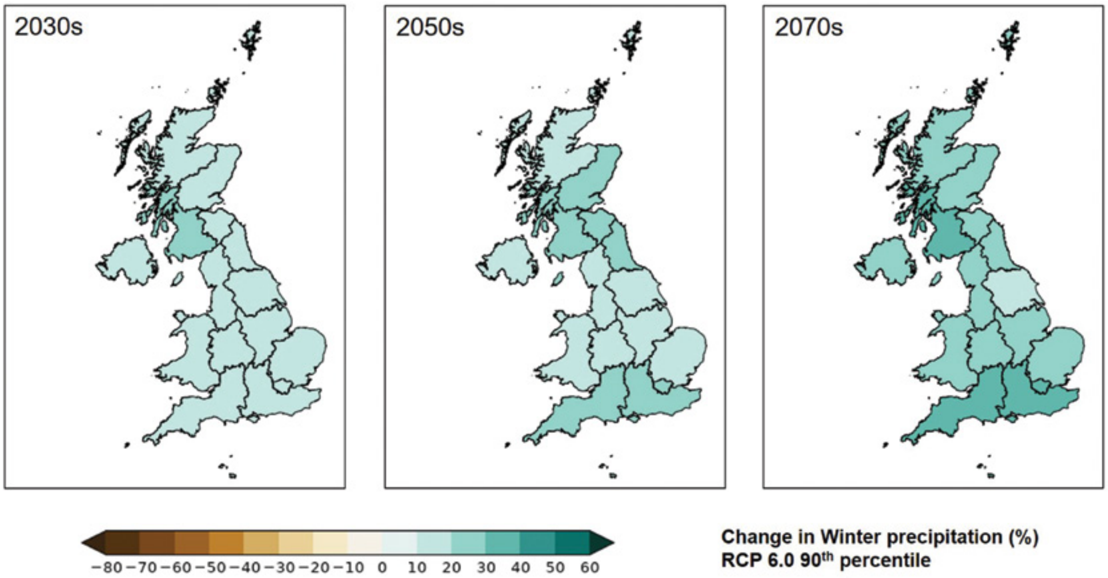


Figure 7
Change in Winter precipitation (%) (left to right; 2030s, 2050s and 2070s) based on a 1881 – 2000 baseline[7]



[6]© UK Climate Projections, 2018
[7]© UK Climate Projections, 2018

The potential increases in weather impacts due to climate change support the business case for enhancing weather resilience action and identifying actions that will deliver a railway that is safe and more resilient to the effects of weather, now and in the future.

The 2015 Paris Agreement unites nearly every nation in a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. The central aim is for a strong global response to the threat that keeps the global temperature rise this century to well below 2°C above pre-industrial levels and to pursue efforts to limit it to 1.5°C.

The Department for the Environment, Food and Rural Affairs (Defra) provides national climate change guidance in a number of ways to enable the assessment of future climate risks and the planning of adaptation actions to maintain and improve resilience. Most important to Network Rail and the Anglia Route are:

- The UK Climate Projection data sets which are produced by the Met Office Hadley Centre, and
- The National Adaptation Programme (NAP).

The UK Climate Projection data sets are produced for use in assessing the future risk and impacts of the possible climate projections for the UK. They are used by government to conduct the 5 yearly UK Climate Change Risk Assessment (UKCCRA) and by individual organisations to understand and plan for their specific risks.

For the 2014 Route WRCCA Plans Network Rail's national guidance was to use the UKCP09 high scenario, 50th percentile probability projections as an appropriate benchmark on which to base evaluations and decisions. In 2017 Network Rail commissioned a review of its guidance taking into account the Paris Agreement, advances in climate science and additional years of climate observations and the then pending release of the UKCP18 dataset.

The conclusions of the review[8] were that as a safety critical focused organisation and major UK infrastructure manager the most appropriate UKCP projections to use are:

- UKCP18 – RCP6.9, 90th percentile probability as the baseline scenario for evaluations and decisions, and
- RCP8.5 90th percentile as the sensitivity test on assets with a lifespan beyond 2050.

Analysis in this report has been updated using the UKCP18 projections where available. It should be noted that some UKCP09 parameters have not been updated in UKCP18. Where this is the case, the UKCP09 data has been used and this is clearly indicated in the report.

The NAP is based upon the UKCCRA and is published by Defra every 5 years. It contains a summary of the impacts expected for each sector of the UK economy and tables detailing adaptation actions that the UK Government requires those sectors to undertake to ensure the continuing resilience of the UK economy.

The sectorial actions are apportioned to key stakeholders such as regulators and national infrastructure operators. Details of the Transport Sector actions in the NAP 2018 that are apportioned to Network Rail and hence the Anglia Route are included in Table 7 in the Anglia Route WRCCA Actions section of this Plan.

Although climate change projections include uncertainties, associated with natural climate variability, climate modelling and future emissions, they and the actions from the NAP can be used to provide guidance on the direction that the UK climate may take. Anglia Route has therefore used the projections in the creation of this WRCCA Plan.

To ensure a consistent approach to WRCCA consideration and action across Network Rail an iterative framework of key management stages is used (see Figure 8). The same framework has been applied to develop this Route WRCCA plan.

[8]Identifying a climate change planning scenario, JBA Consulting 22/02/18

Introduction continued

Network Rail will take a range of soft (changes to processes, standards, specifications and knowledge and skill base) and hard (engineered solutions to increase resilience) WRCCA actions tailored to the level of risk and the strength of evidence for it. Examples include:

- Do nothing/minimum – the option to do nothing/minimum and the risks should be evaluated,
- No regrets – increasing current and future resilience without compromising future flexibility,
- Precautionary – investment in adaptation now in anticipation of future risk, and
- Adaptation pathways – staged adaptation balancing future risk and current investment funds through phased investment enabling assets to be retrofitted cost-effectively in the future.

The following sections provide findings from the updated Anglia Route vulnerability and impact assessments, and detail; progress on the CP5 resilience actions, actions planned for CP6 and additional actions for future consideration.

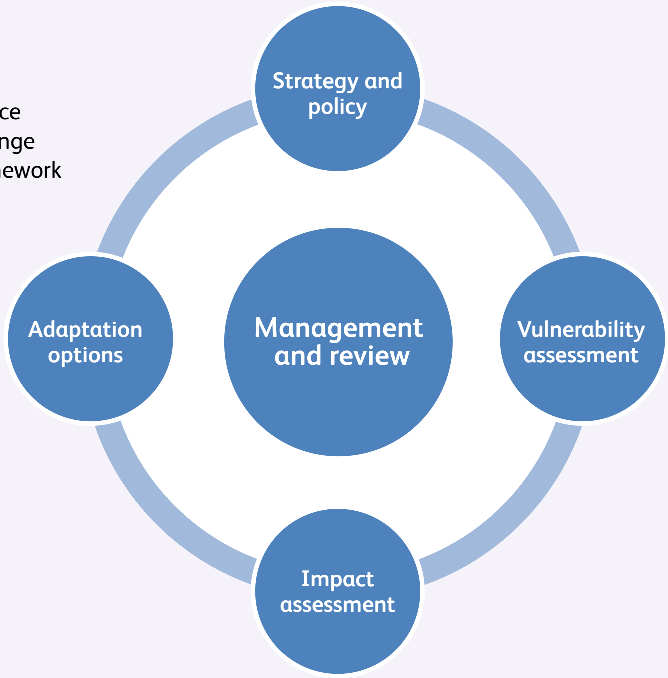


Figure 8
Weather resilience and climate change adaptation framework

Figure 9
Fallen tree (wind damage) causing a dewirement near miss, January 2018

Anglia Route WRCCA Plan

Network Rail's WRCCA Policy sets out the approach to achieving our company's vision of 'A better railway for a better Britain' by creating a railway that is safer and more resilient to weather impacts now and in the future.

It commits the business to seeking to apply the following key principles:

- Including current and future weather impacts in our risk analysis and investment decision making and embedding climate change specifications into policies, procedures and standards,
- Adapting at construction and at asset renewal, designing schemes to be resilient in the most cost-effective manner to and/or with passive provision for future weather conditions,
- In the event of catastrophic asset failure replacing on a like for better basis rather than like for like, considering the whole life cost and the best strategy for managing the railway,
- Identifying high priority locations for proactive resilience interventions and working to identify funding sources for projects not included within agreed Control Period funding, and
- Working with stakeholders to identify opportunities to enhance our preparation for, response to and recovery from adverse/extreme weather events.

Anglia Route Plan

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

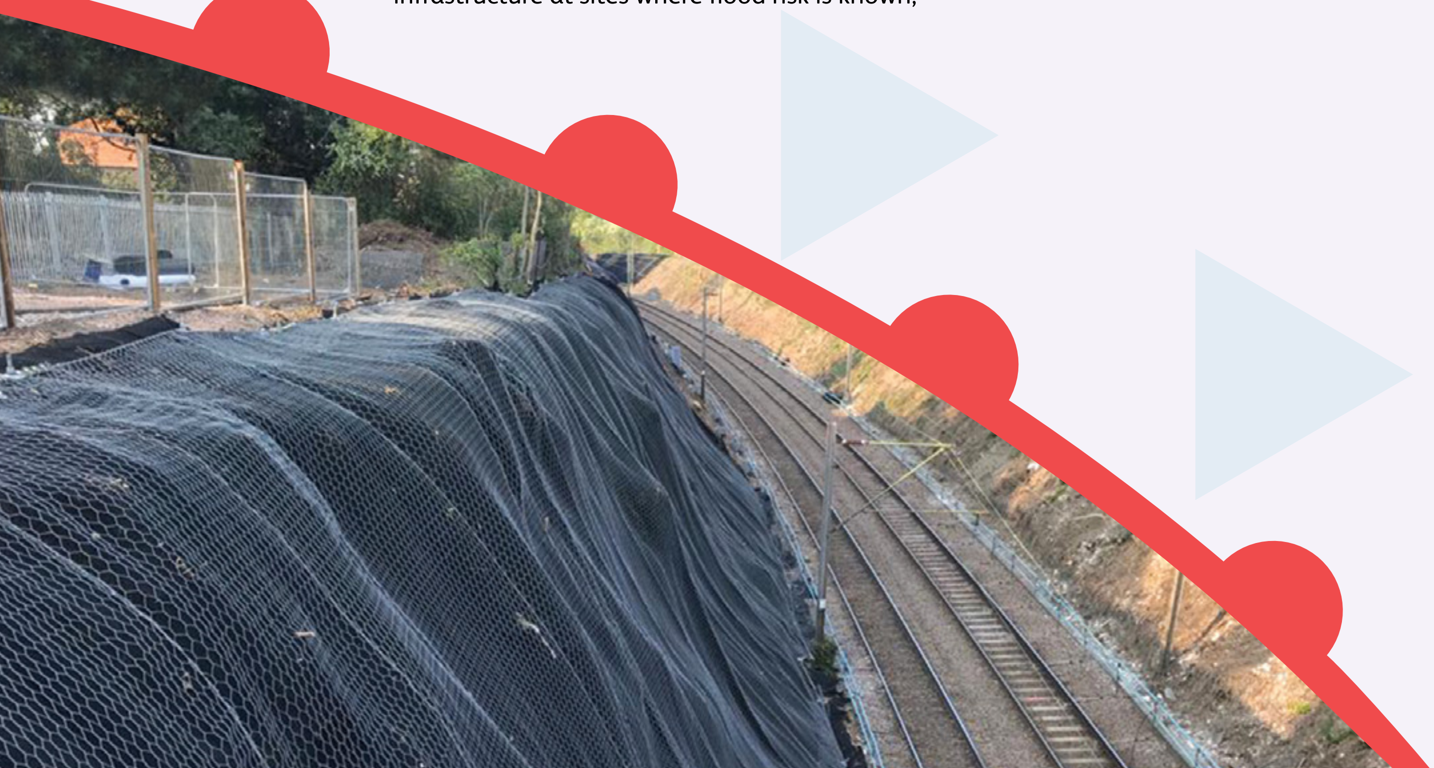
- Increase the understanding of weather and climate change impacts on the Anglia Route by using the Network Rail WRCCA planning scenario guidance that will be published in 2019 to build on the 2013 Willis study and the current WRCCA plan analysis into weather impacts,
- Improve the knowledge of weather 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 the latest 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,

Figure 10
Bank slip at Thorrington, March 2018

Anglia Route WRCCA Plan continued

- 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 floods of the 23rd of June 2016,
- 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, EA and Statutory Undertakers,
- Undertake quantitative studies to understand the groundwater, 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, Network Rail Weather Service and EA 'broader' data and intelligence, and
- 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.



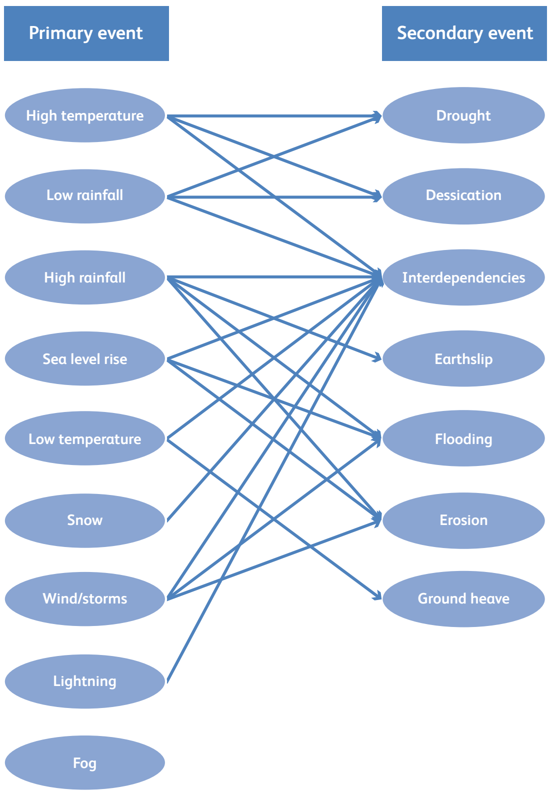
Anglia Route Vulnerability Assessment

In the 2014 Route WRCCA Plan this section provided details of the general vulnerability of the national rail network and Anglia Route's specific vulnerabilities to current weather impacts, and regional climate change projections.

This Plan updates the vulnerability assessment taking account of:

- Advances in climate science,
- Improvements in our understanding of the impacts of weather and future climate, and
- Changes in Network Rail's climate change policy and guidance since the last plan was published.

Figure 11
Examples of primary and secondary events



Network-wide weather vulnerability

The rail network and its component assets are sensitive to the effects of a number of weather types. These manifest as either primary events (one weather type) or secondary events which are the result of these and/or a combination of weather types. It should be noted that these are the mechanisms by which impacts are felt, not the actual impacts themselves. Figure 11 illustrates the primary event types and their related secondary event types.

Managing a complex array of assets with varying ages, condition and weather vulnerabilities across a wide range of bio-geographic regions in a variety of climates is a complex challenge. Interdependencies with other sectors of the economy, for example power, telecoms and water infrastructure add to this.

Understanding current weather impacts is essential for assessing the probable effects of climate change and for the planning and implementation of appropriate cost-effective resilience investments to adapt the network to the future impacts.

The 2014 Plan outlined how we monitor the impact of weather on the performance of our network by using Schedule 8 delay compensation costs and the process we used to carry out a detailed analysis of this data to understand:

- The characteristics of weather-events that trigger failures,
- The thresholds at which failure rates change, and
- Trends in the failures of assets and the performance of the network.

Anglia Route Vulnerability Assessment continued

The key findings of this work were that earthworks were the asset most affected by rainfall, OLE was most sensitive to wind and that temperature impacted the widest range of assets. These and the detailed outputs behind them have been disseminated to Network Rail's national asset function teams and the Routes for use in asset maintenance and investment planning.

As the above work was based upon current data the changes to Network Rail's national guidance for the climate change planning projections have not changed the conclusions.

We continue to monitor and analyse this data and we now have a 13-year series increasing our capacity to discern trends in failures and performance. We have now made the raw data available and we are continuing to look at how we can improve its use including through trend and performance reporting on a period, quarter an annual basis.

Route weather vulnerability

Anglia Route is located in Greater London, Cambridgeshire, Essex, Norfolk and Suffolk, and its weather and climate change vulnerabilities are closely related to its geology and topography. Other key regional features that increase the risk are the low, soft coast line and the presence of swing bridges in the Norfolk Broads.

Several lines in the south of the Route, approximately south of a line between London and Ipswich, are built on or of London Clay. These materials are moisture sensitive so Winter rainfall that causes them to become saturated can cause conventional failure and dry Summer and Autumn periods can cause desiccation failure. The worst affected lines are the FSS2 between West Horndon and Lower Dunton in Essex. Other lines at risk of failure due to the swelling and shrinking of their underlying geology are those running through areas of peat such as the Cambridgeshire fens and the Norfolk Broads.

In both of these areas it can be difficult to maintain track quality and significant works will be required to improve their resilience.

In the central and northern parts of the Route, Glacial Sands and Glacial Till derived sand fills are vulnerable to washouts as a result of intense rainfall events and other sources of surface water flooding. Sands can also be an issue where they overly clay and create perched water tables in cutting slopes. This causes them to become more vulnerable to landslips as groundwater levels increase.

Low-lying areas on poorly draining soils such as the Fens and the Norfolk Broads are vulnerable to flooding. In addition, embankment settlements and rising groundwater levels make the disposal of water form drainage systems harder. 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 flooding from sea level rises, scour and storm surge events.

Urban areas, particularly in the Greater London area, often rely on track drainage systems that are interconnected with outside party surface water drainage systems. These are vulnerable to surface water flooding during intense storms. Historical local track lowering beneath over-line bridges (for example, to accommodate the introduction of overhead line electrification and train gauge clearances) has resulted in some very localised railway low points, which are particularly vulnerable to flooding during heavy rain (e.g. at Manor Park, Ilford, Maryland and Seven Kings).

Wind damage is also a significant vulnerability due to the low-lying exposed areas and shallow earthworks. This particularly affects OLE assets.

Future climate change vulnerability

The complexity of the relationship between weather events and climate means that the UKCP18 data set cannot forecast future weather events. It projects modelled probabilistic trends that can be used to understand the potential future risks associated with certain climates and the likely changes in weather events/parameters. Network Rail therefore uses projections from the UKCP18 data set as a future baseline to understand potential risks and for making informed strategic decisions to increase future weather resilience.

UKCP18 provides regional projections across 13 administrative regions in Great Britain (Figure 13). Projections that cover the Anglia Route are provided by the East of England region.

In the 2014 Plan charts were generated using the UKCP09 High emission 50th percentile probability scenario for the East of England to show the projected changes in temperature and precipitation from the 2020s to the 2080s relative to the baseline climate of the 1970s (1961-1990).

Figure 12
Top: Flooding at Gunnersbury, May 2018 and bottom: Wind-blown tree on the OLE at Haughly Junction, January 2018

For this report the charts and text have been updated in line with the current Network Rail climate change guidance which uses the current UKCP18 climate projections where available. Replacing the UKCP09 emissions scenario used in the 2014 report with the UKCP18 emissions scenarios noted in the introduction has involved a number of changes to the data used. These include:

- Using a new baseline period of 1981-2000,
- Moving from projection time periods of 30 years (2020, 2050, 2080) to shorter 20-year periods (2030, 2050, 2070), and
- The use of UKCP18 RCP 4.5 95th percentile data for sea level rise as a proxy for RCP 6.0 data (UKCP18 did not model RCP 6.0 for sea level rise).

Figure 13
Map of UK administrative regions used in UKCP18[9]

[9] Met Office © Crown Copyright 2019 [available from UKCP18 Guidance: Data availability, access and formats: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance-data-availability-access-and-formats.pdf]

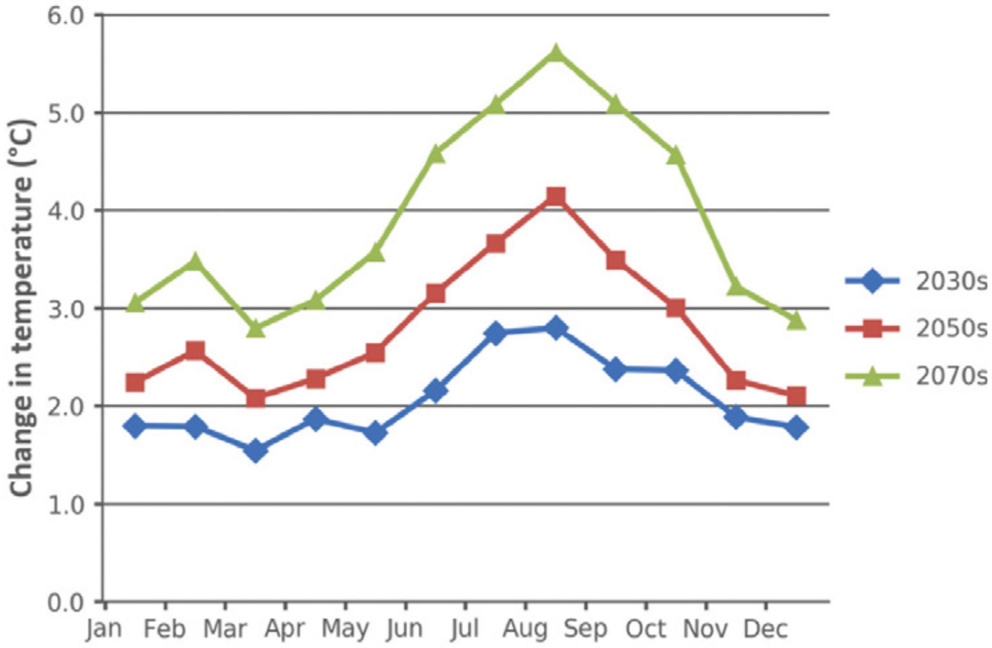
Anglia Route Vulnerability Assessment continued

Mean Daily Maximum Temperature change

The mean daily maximum temperature in the East of England is projected to increase in every month of the year, with the greatest increases expected in the Summer months. The increase becomes larger across the century.

The highest mean Summer temperatures are expected to be in August in the 2050s and 2070s with increases of 4.1°C to 26.3°C and 5.6°C to 27.7°C respectively. In Winter the highest mean temperatures will be seen in February with increases of 2.6°C to 9.7°C and 3.5°C to 10.6°C respectively.

Figure 14
East of England, mean daily maximum temperature change (°C) (RCP6.0 90th percentile)

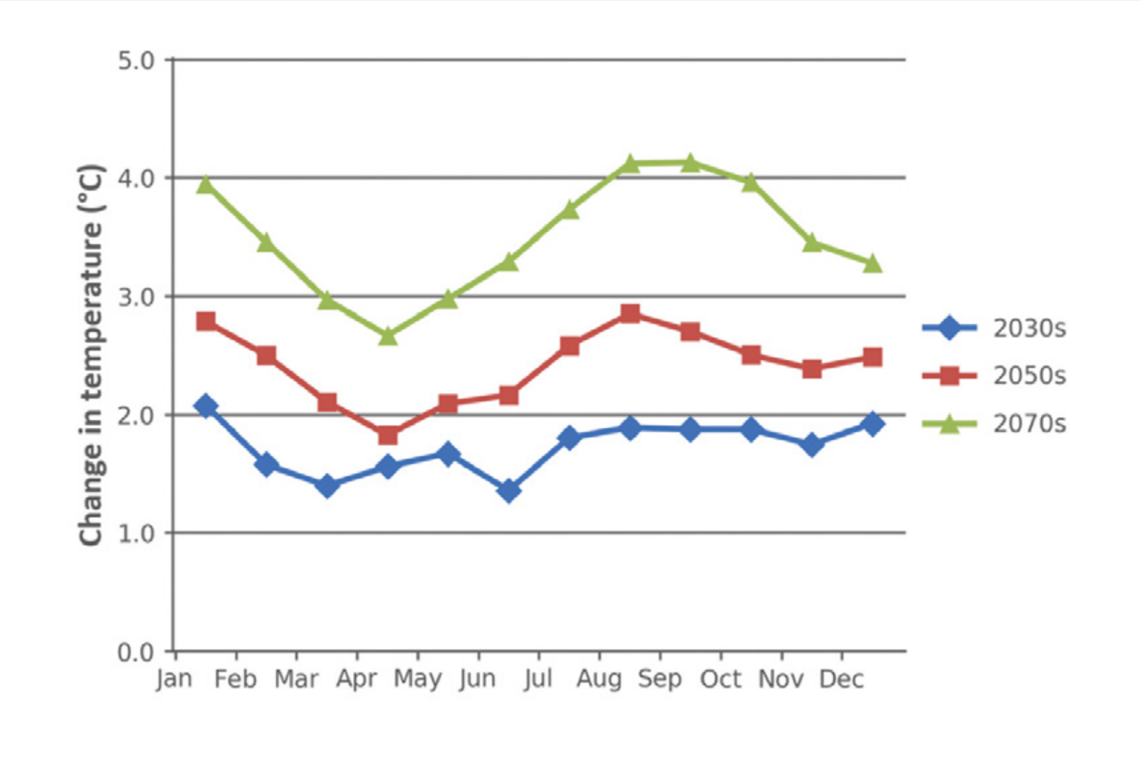


Mean Daily Minimum Temperature change

The mean daily minimum temperature in the East of England is projected to show increases throughout the year with the highest in Winter and Summer. The level of increase is expected to become higher across the century.

The highest mean minimum temperatures for Summer are expected to be in August, with increases of 2.9˚C to 14.7˚C by the 2050s and 4.1˚C to 16˚C by the 2070s. The lowest mean minimum temperatures for Winter will occur in February with expected increases being 2.5˚C by the 2050s to 3.3˚C, and by 3.5˚C by the 2070s to 4.3˚C.

Figure 15
East of England, mean daily minimum temperature change (˚C) (RCP6.0 90th percentile)



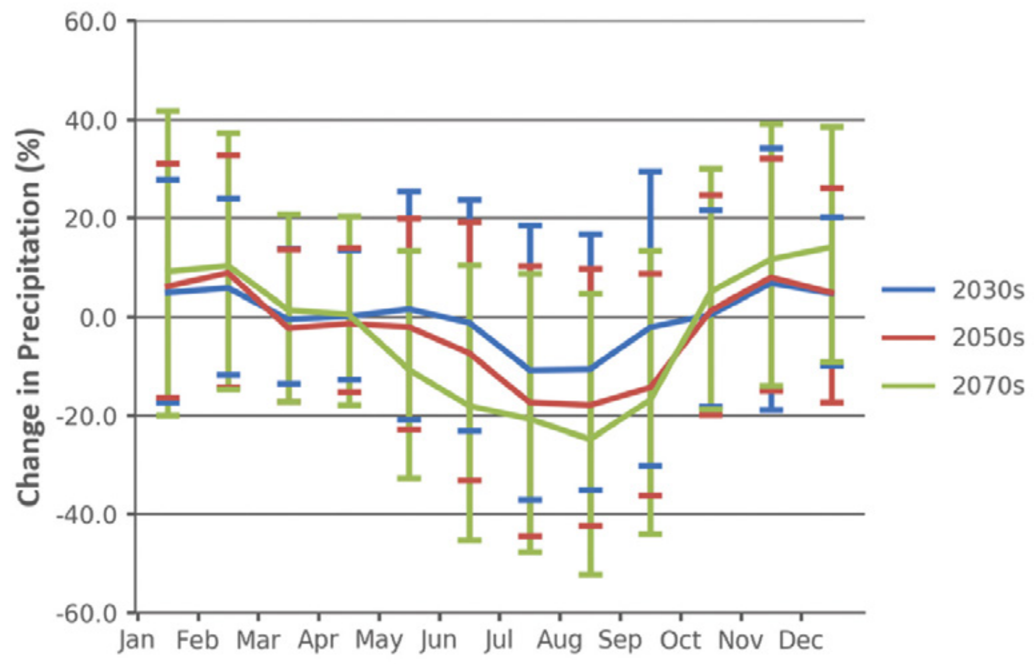
Anglia Route Vulnerability Assessment continued

Mean daily precipitation

The UKCP18 narrative for mean daily precipitation in the East of England is for significantly wetter Winters and drier Summers. Network Rail's chosen climate change planning scenario (RCP6.0 90th percentile) shows the upper range of Winter rainfall increases, but it does not illustrate the highest potential Summer rainfall reductions. These are best represented by the RCP6.0 10th percentile projections. Figure 16 therefore plots the RCP6.0 50th percentile projections with error bars that indicate the wider range of change associated with the 10th and 90th percentiles.

In the 2050s and 2070s November will be the wettest month with mean daily rainfall increases of 32.1 % to 2.5mm/day and 39.1 % to 2.7mm/day respectively. The driest month will be July showing decreases of 44.4 % to 0.9mm/day by the 2050s and 47.7 % to 0.8mm/day by the 2070s.

Figure 16
East of England, change in mean daily precipitation (%) (RCP6.0 50th percentile with the wider range showing the 10th and 90th percentiles)



Storm intensity and river flows

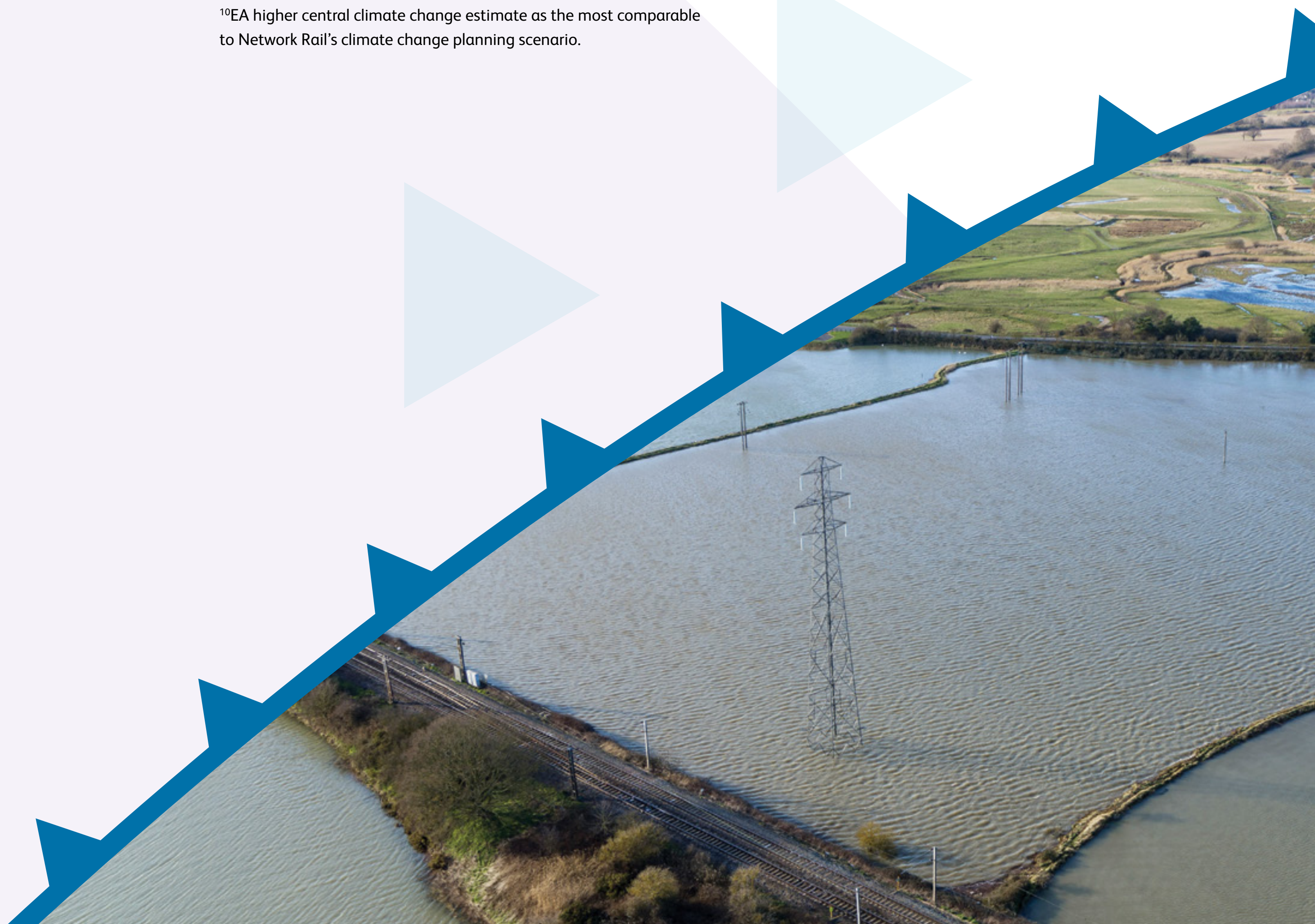
In addition to changes in total rainfall, climate change is also expected to increase the frequency and severity of river flooding events and individual rainstorm events, Summer rainstorms show the largest increases.

The EA produces guidance on the rainstorm intensity and river flow uplifts that should be used to account for climate change. This guidance is being reviewed due to the release of UKCP18 climate change data, however, at the time of publishing this plan the guidance is still based on the UKCP09 Medium Emissions scenario. This recommends that rainstorm intensities for the Anglia Route area should be increased by 10 % for the 2050s and 20 % for the 2080s. Climate uplifts[10] for river flows are provided by river basin and those relevant to the Anglia Route are shown in Table 1.

[10]EA higher central climate change estimate as the most comparable to Network Rail's climate change planning scenario.

River basin	2050s uplift	2080s uplift
Anglian	20 %	35 %
Thames	25 %	35 %

Table 1
River flow uplifts



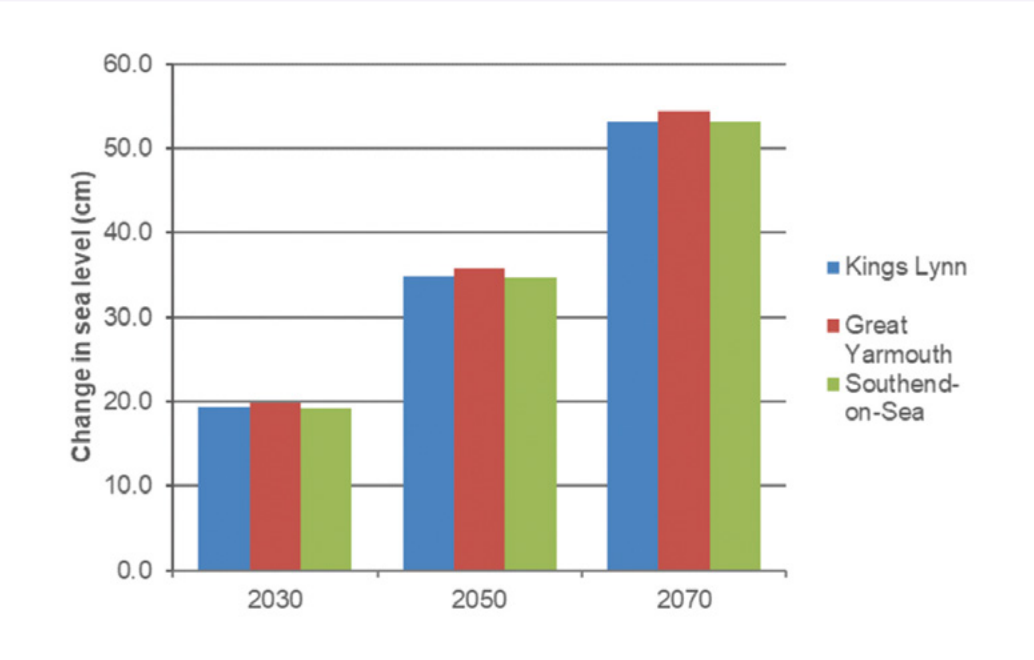
Anglia Route Vulnerability Assessment continued

Sea level rise

Sea level varies around the coast due differences in coastal morphology and isostatic rebound since the last ice age. As this also affects the degree of sea level rise, UKCP18 projections have been obtained for 3 locations in the administrative region covered by the Anglia Route[11].

Great Yarmouth will see the highest rises by 2050 and 2080 of 35.7cm and 54.4cm respectively and Southend-on-Sea will see the lowest at 34.7cm and 53.1cm.

Figure 17
Sea level rise projections for the East of England (cm), RCP4.5 95th percentile



[11]Sea level rise data in UKCP18 is not available for RCP 6.0, instead RCP 4.5 is used as a proxy on the recommendation of the Met Office. This is the most compatible with the Network Rail Primary planning scenario.

Anglia Route Impact Assessment

This section provides an update of the Anglia Route weather impact assessment findings published in the 2014 Anglia Route WRCCA Plan, including annual performance impacts and identification of higher impact locations on the Route.

Performance impacts

The impact of weather events on our network's performance is monitored using delay minutes and Schedule 8 delay compensation costs as proxies. As these data include the duration and location of each disruption, and attribute cause, they give a high degree of granularity for use in analysing weather impacts and trends.

In the 2014 plan eight financial years of Schedule 8 data were analysed to give an assessment of the weather impacts for the Anglia Route. This Plan updates that assessment using additional data from the past 5 years, see Figure 18.

The updated analysis shows that wind continues to be the most significant weather impact incurring 536.9k of delay minutes costing a total of £24m in the last 13 years, almost double the impact of snow related incidents with 281.9k minutes and £13.01m over the same period.

Climate modelling cannot provide future weather forecasts, but it does give us projections for the trends in future weather patterns. Combining these trends with our analysis of current weather impacts allows us to understand the future vulnerability and possible impacts upon the Anglia Route.

There is a high degree of confidence in the UKCP18 projections for temperature, rainfall and sea level rise, but lower levels for wind, lightning and snow fall. Planning for the latter parameters should still be undertaken, but outputs should be more flexible to acknowledge the higher possibility of alternative climate outcomes.

The findings from the combined analysis of current weather impacts and UKCP data (UKCP09 for wind, lightning and snow and UKCP18 for temperature, precipitation and sea level rise) will be used in the prioritisation of resilience actions as summarised in Table 2 below.

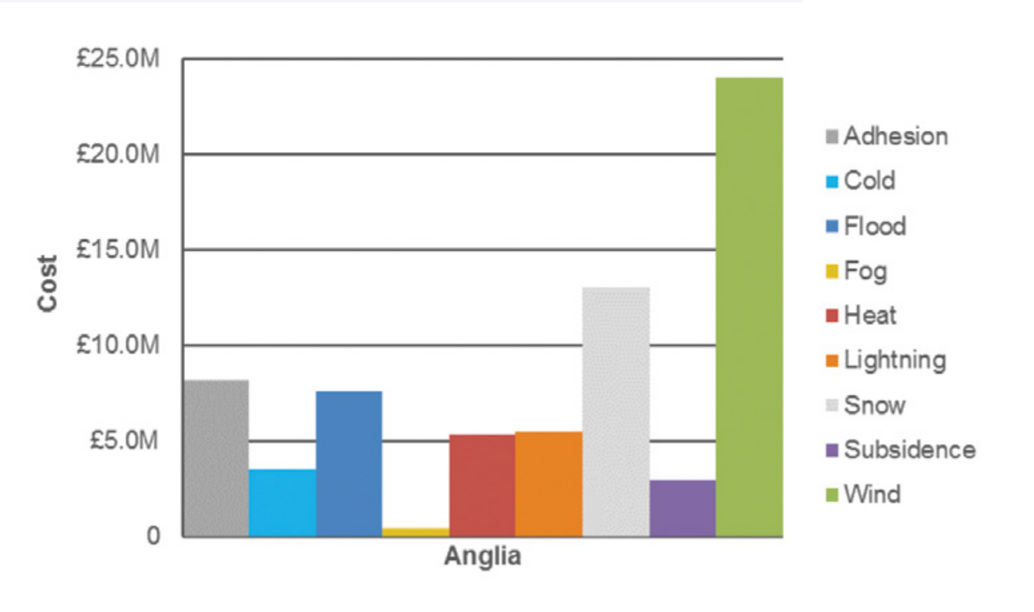


Figure 18
Anglia Route weather attributed Schedule 8 costs 2006/07 to 2018/19

Anglia Route Impact Assessment continued

Table 2
Prioritisation of weather-related impacts on Anglia Route

Impact	Schedule 8 Cost per year[12]	Climate projections[13]	Prioritisation
Wind	Average £1.85m Highest £4.10m	Changes difficult to project, however generally expected to increase	High
Adhesion	Average £0.63m Highest £1.38m	Complex relationship between multiple causes and their climate projections	Medium
Snow	Average £1m Highest £49.36m	Changes difficult to project, but increases in Autumn, Winter and Spring minimum temperatures suggest reduced snow days	Medium
Lightning	Average £0.42m Highest £0.99m	Changes in storms difficult to project, however generally expected to increase	Medium
Cold	Average £0.27m Highest £1.52m	Increases in mean daily minimum temperatures in Autumn, Winter and Spring range from 1.8˚C in April to 2.8˚C in January for the 2050s and 2.7˚C in April to 4.1˚C in January for the 2070s	Low
Subsidence (Landslip)	Average £0.22m Highest £0.53m	Increases in mean daily rainfall for late Autumn through to early Spring, for example; 14 % in April and 32.7 % in February by the 2050s becoming 20.3 % and 37.3 % respectively by the 2070s Decreases in mean daily rainfall for late Spring through to early Autumn, for example; -22.8 % in May and -42.3 % in August by the 2050s becoming -32.8 % and -52.3 % respectively by the 2070s Increased frequency and intensity of Winter and Summer storms	High
Heat	Average £0.41m Highest £2.6m	Increases in mean daily maximum daily temperatures range from 2.1˚C to 2.6˚C (Winter) and 3.2˚C to 4.1˚C (Summer) by the 2050s. In the 2070s this becomes 2.9˚C to 3.9˚C and 4.6˚C to 5.6˚C respectively	Medium
Flooding	Average £0.58m Highest £4.21m	Increases in mean daily rainfall for late Autumn through to early Spring and increased intensity and frequency of Winter and Summer storms (see subsidence)	High
Fog	Average £0.03m Highest £0.28m	This is a complex picture with low confidence[14] , however possible seasonal changes for the 2080s have been indicated as: Winter +7 % , Spring -33 % , Summer -61 % , Autumn -25 %	Low

It should be noted that the rate charged for Schedule 8 delays increased in 2015 and that this will have been responsible for some of the increase in delay costs. However, this affected all weather-related delays equally and it does not affect their relative impact rankings.

[12]Based on the range of Schedule 8 costs over the 12 years from 2006/07 to 2017/18
[13]UKCP09 projections still used for wind, snow lightning and fog as UKCP18 does not contain updates
[14]Probabilistic data is not available from the UKCP09 data sets, this has been sourced from a supplementary UKCP09 report and represents the average of 11 models run using the Medium Emissions Scenario

Identification of higher risk locations

Since the publication of the last Plan the Anglia Route network has continued to experience extreme weather events that have challenged weaknesses in our assets and operations. Climate change projects more frequent and intense extreme weather events, so understanding the impacts of current and future events is critical to investment decision making.

The impacts of weather on our Route are captured via the delay minute and Schedule 8 cost data and input into our METEX GIS system along with gridded observed weather data. The outputs of this allow high impact frequency/cost sites to be identified and targeted for detailed assessment to;

- Verify the attribution of the delay(s) to a weather impact(s),
- Determine the root cause of the delay,
- Identify if resilience action has been taken in the past or is already planned, and
- Generate and prioritise appropriate resilience actions.

In addition to the above assessments Anglia Route has also identified potential future risks and resilience actions based on climate change projections and Route knowledge.

Combining these findings allows us to proactively identify potential investments that would address current weaknesses and mitigate and/or enable the mitigation of future risks. This approach is critical to creating a railway that is safer and more resilient to weather impacts now and in the future.

Heat impact assessment

Between 2006/07 and 2018/19 heat related incidents accounted for an average of 7,982 delay minutes and £0.41m in Schedule 8 costs per year. This is 6.3 % of Anglia's annual average weather-related delay minutes and 7.5 % of the annual average cost.

Track asset

The impact of high temperature is often a problem in the management of the track asset although on some sites the 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. These 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. This includes 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 and the season where Critical Rail Temperatures (CRTs) are possible will lengthen. The number of days where the CRTs are exceeded due to reactive maintenance will increase which will result in a corresponding increase in speed restrictions to manage the safety risk of a track buckle. These will need 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.

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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. This prevents the rail slewing in towards the inside of curves in Winter and 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 that increase the track's resilience to temperature induced stresses is the need for a more robust track system. This includes 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. This has lead 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, however 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 uses Remote Condition Monitoring (RCM) to detect either rail temperature or stress at regular intervals allowing automated speed restrictions to be applied only where rail temperature or stress are actually causing a safety risk.

This would remove the need for the current blanket controls which use very conservative estimates of rail temperature based on the forecast and a set formula. It may also reduce or remove the need for special restrictions after 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.

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. 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. This increases the time it impacts on the track quality performance, particularly in hot conditions.

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

Vegetation

Shorter periods of temperature close to freezing will increase the active growing season for many plant species. This 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. While 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. Currently we leave most cut vegetation on the lineside either as safely stacked logs or wood-chips, both of which 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. This will include 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. These areas 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.

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.

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This will require a review of how heat resilience can be improved.

Replacement of the remaining fixed termination OLE wire systems will also be necessary to achieve the currently required temperature tolerance range of -15°C to +35°C. A programme is underway to achieve this by 2020, notably for the section of fixed tension OLE between London, Chelmsford and Southend. 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 CRT 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), and
- Removal of fixed termination OLE to achieve temperature range -15°C to +35°C.

Signalling

Signalling equipment can be impacted by extreme weather conditions depending on the type of equipment and type of weather condition. Standards are put in place to ensure correct operation of such equipment for example the Signalling Design Handbook and the Signalling Maintenance Testing Handbook. It is imperative to work closely with suppliers to ensure equipment can cope in different operating environments whilst not affecting the lifespan of the product. In order to gain product approval the suppliers must ensure rigorous testing takes place, with strict Quality Assurance and Quality Control to support it.

Periodic Route Asset Manager and Maintenance interface meetings take place which include agenda items such as performance, product approvals and amendments, and other items. In the Atkins Technical Investigation Centre Report Pack 3 30/07/2019, discussed in the August periodic meeting, a signal failure was investigated and the cause identified as water ingress inside a tunnel. Maintenance Delivery Units were instructed to identify and assess their own assets which could also suffer from the same failure. Any identified assets will be subjected to investigations to prevent the failure from reoccurring.

Maintenance and tech teams are responsible for installing other types of protection and condition monitoring equipment. Mitigations against lightning strikes to protect 110v busbars are in place using Power Supply Surge Protectors. In addition to the protection of the busbar, the units also provide a warning via LEDs as to the health of the busbar and inform the user if it has been struck by lightning.

During signalling renewals activities, project teams must follow the Anglia Signalling Equipment Policy which covers requirements such as reducing failures and improving longevity of the assets. Justifications for these requirements are to prevent failures caused by adverse weather conditions, examples are below:

- Location cases are painted galvanised unless within 3 miles of the sea or at any area at risk of corrosion such as tunnels, where they are instead stainless steel,
- Location cases prone to overheating are installed with ventilation systems to reduce the temperature inside the location case. Double-skinned location cases are also provided to assist in cooling,

- REBs are installed with air conditioning units with remote monitoring, however to avoid unnecessary power consumption only REBs which will benefit from air conditioning have them installed. Air conditioning protects the equipment from overheating whilst increasing the life span of the wiring to prevent degradation,
- Where 4 or more location cases are to be located together, a REB will be built instead. This provides a suitable environment for maintaining significant volumes of equipment which is more resistant to environmental impacts,
- Flood risk shall be assessed before installation of new cases with elevation to an appropriate height to mitigate against this, and
- Plug couplers shall only be fitted within equipment housings or to equipment itself. In line cable plug couplers situated on ballast or in troughing route shall only be temporary to facilitate staging and commissioning. This is to prevent risk of damage or water ingress in the cable route.

Signal Sighting can be affected during adverse weather conditions. Fog is a major contribution and particularly affects filament colour and semaphore signals. During CP6 a renewals scheme to install light engines is in progress to replace filament lamps. This will improve sighting during fog, with the added benefit of improved performance of the asset due to fewer failures. The use of signal hoods and long visors protect the signal from sun glare to prevent "ghosting" and to prevent build-up of snow which could obscure the signal.

Figure 19 shows the failure costs of impacted signalling equipment caused by weather-related issues from the start of the financial year in 2015. In comparison, Figure 20 shows the failure count for the same interval and shows that the higher costing failures are not the most frequent ones. Leaves on the line contribute to the largest cost and therefore axle counters are favoured during resignalling projects, however this increases the issue of axle counters suffering from lightning strikes. Further research and investigations to protect axle counters must be conducted.

Figure 19
Failure cost associated with Signalling Equipment

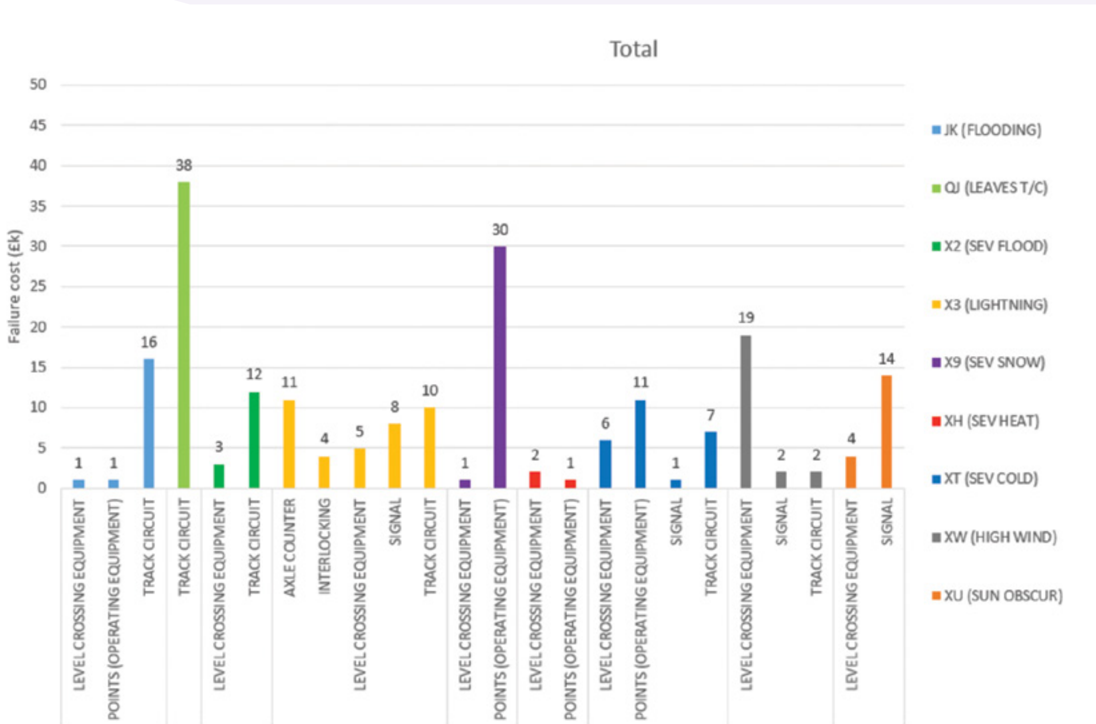

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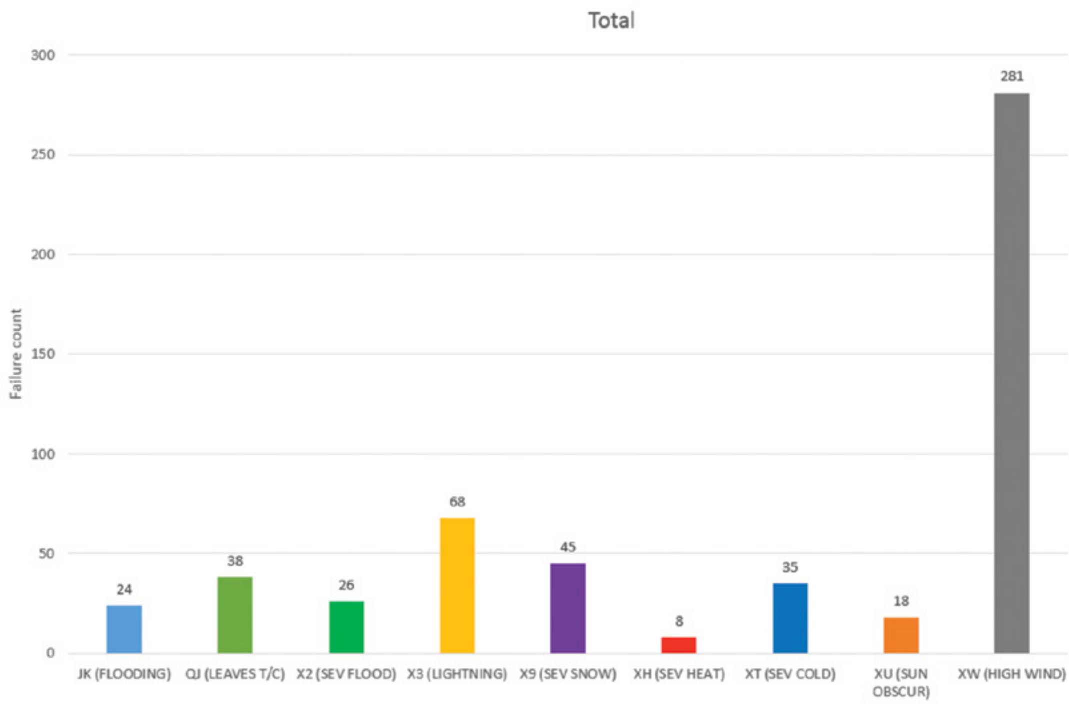
Figure 20
Failure count associated with Signalling Equipment



Cold and snow impact assessment

Between 2006/07 and 2018/19 cold related incidents accounted for an average of 6,664 delay minutes and £0.27m in Schedule 8 costs per year. This is 5.3 % of Anglia's annual average weather-related delay minutes and 5 % of the cost. Over the same period snow related delays averaged 21,681 delay minutes and £1m in Schedule 8 costs per year. This is 17.2 % of the annual average weather-related delay minutes and 18.5 % of the annual average cost.

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 and iced DC conductor rails in the London area cause the greatest disturbance to service. Further work reviewing the drainage provisions for bridges affected by icicles and assessing the benefits of heating the DC conductor rails is warranted. The latter builds on experience gained in Kent.

Frozen points are a key issue in cold weather and therefore an accelerated programme of points heater installations for those points without heaters would help to reduce the short-term risks. Similarly ensuring the thermal insulation of any points heaters not completed during the CP5 programme should also be revisited.

The risk of significant delays due to cold and snow may reduce as climate change increases temperatures. 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. 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. Also, in the short term it 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 which include the following:

- Ongoing review of current weather procedures and forecasting,
- Review of the need for increased MPV capacity for snow clearance,
- Assess the benefits of heating for 3rd rail (review Kent experience),
- Review of drainage on structures affected by icicles,
- Checking that the de-icing train has sufficient availability, and
- Ensure any deferred thermal insulation of points heating equipment from CP5 is addressed in CP6.

Flooding and sea level rise impact assessment

Between 2006/07 and 2018/19 inland and coastal flood related incidents accounted for an average of 13,378 delay minutes and £0.58m in Schedule 8 costs per year. In combination these represent 10.6 % of Anglia's annual average weather-related delay minutes and 10.8 % of the annual average cost.

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 wet Winter of 2015/2016 and then associated with a series of storms in 2018/2019. Although the Anglia region was much less severely affected than areas further south and west, speed restrictions were imposed at some locations at these times. This mitigated 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. Other areas are also prone to surface flooding including a number of locations, particularly in the Greater London area, which flooded in a single Summer storm event on 23rd June 2016. Some sites with ongoing flash flooding risk, such as at Surlingham, would benefit from having remote monitoring cameras to provide instant assessments of flood risks.

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. 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 during CP5 will have significantly reduced the risk of bridge failure due to scour or surcharging local to the bridge footings.

In a 'do nothing' scenario, increasingly frequent and intense storms will overwhelm the existing track drainage networks which have suffered from under investment in previous decades.

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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. Existing drainage systems currently require intervention in parts of the Route and a robust drainage inspection and maintenance regime is gaining maturity. In the coming decades the capacity of existing drainage assets and systems should be assessed and, where capacity is insufficient for predicted climatic conditions, improvements should be considered. 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. If this is not practical, pumped drainage will become increasingly necessary.

Railway drainage systems are typically not isolated and commonly receive water from, and/or discharge into outside party surface water drainage systems (e.g. surface water sewers, highways drainage, rural land drainage ditch and pipe systems). The resilience of the railway drainage to flooding will therefore continue to be heavily dependent on the use, condition and capacity of these outside party systems. Also the interconnectivity of our drainage systems means that changes to them to improve resilience/adapt to climate change may affect flood risk for those connected outside party systems. This could lead to increased flood risk for downstream land, properties or infrastructure. Therefore, as the climate changes, the railway's vulnerability to flooding will be somewhat dependent on the adaption actions taken by (or together with) outside parties. Coordination with these outside parties is important, both to maintain current levels of railway drainage system performance, and when considering improvements/upgrades for resilience.

In some areas, particularly where railway surface water discharge is into flat low-lying areas or lowland river systems, ground levels have increased over time due to silt deposited by past flooding.

In such areas the rail infrastructure is a fixed point in a gradually rising landscape. The effective maintenance of culverts, and their associated approach and outfall ditches, which discharge on to neighbouring land, needs to account for these changes. Similar effects are felt where railway embankments have progressively consolidated, or 'sunk', with time on weak underlying soils (e.g. on the Cambridgeshire Fens and Norfolk Broads). The impact of these changes is difficult to quantify but in both cases the height of the railway above the floodplain (or surrounding land) is reducing and will continue to reduce with time.

This increases the chance of track flooding and infrastructure damage. Maintaining the capability of existing railway drainage features is made more difficult when the capacity of downstream receiving features (e.g. streams, rivers and ditches) is ever decreasing. An important secondary impact is that reducing drainage effectiveness means embankments will sit in water for increasing periods of time or are permanently wet at the toe. This significantly reduces the stability of the earthworks.

Remote monitoring has a role to play in managing climate change drainage risks. Remote systems to automate manually operated pumps, act as alerts for trash screens or other critical assets prone to blockages, or the use of remote cameras, etc. should be considered on a site-specific basis.

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. 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. Possible mitigations comprise; managing the water through the high tide period by increasing the system storage or pumping at high tide. A Coastal Estuarine and Asset Management Plan (CEAMP) was developed during CP5 to aid management of Coastal and Estuarine River Defences (CERDS) against the risk of rising sea levels and storm surges. The CEAMP produced coastal risk ratings[15] for all of Anglia's CERDS for four epochs to identify their resilience to climate change. The findings of the CEAMP will be used to determine renewal works for CP7 and onwards.

Sites where flooding and storm surge interventions have been undertaken in CP5 include:

- Manor Park,
- Seven Kings,
- Ilford,
- Liverpool St, and
- Haddiscoe.

In CP6, planned interventions include sites located at:

- Brentwood,
- Gidea Park, and
- West Ham.

Future flood-related workstreams include 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,
- Interventions on significant flood risk sites (e.g. Surlingham cutting),
- Continual scour risk assessments on underbridges to ensure bridges are resilient to scour in the event of a 1in 200 year flood event,
- Review flood risks associated with pumping stations,
- Management of third-party run-off at Level crossings, and
- Locally raised signalling cabinets at sensitive level crossing flood sites.

[15]Coastal Risk Rating is a priority rating for CERDs accounting for risk of erosion, wave overtopping and flooding.

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Subsidence

Between 2006/07 and 2018/19 subsidence related incidents accounted for an average of 4,888 delay minutes and £0.22m in Schedule 8 costs per year. This is 3.9 % of Anglia's annual average weather-related delay minutes and 4.1 % of the annual average cost.

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. Typical examples of failures have been at the MAH at Copperas Wood and the LTN1 at Chelmsford and examples of increased movements have been seen 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. This will be 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 exist in sands overlying clays will also be more vulnerable to earthslips with increased groundwater levels. Typical examples of remediation are, LTN1 sites at Brantham Hall and Tumulus cuttings. 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 however, significant investment will be required to renew some of the more vulnerable earthworks assets to avoid significant problems in the longer term.

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 the 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 failures 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. This is usually toe support such as gabion walls or sheet piles. A re-grade is also frequently required,
- Embankment failure due to saturated toe conditions mitigated by drainage of the toe. Many embankments are land locked and it is difficult to achieve this in some cases, particularly in areas impacted by sea level rise, low-lying areas or areas with high groundwater, and
- Embankment failure due to scour at the toe where it 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, gabions or rock armour.

As embankments weather and near surface layers of over-steep slopes gradually creep down slope they also become narrower at the crest. Combined with current track maintenance practices which raise the track, this 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.

Many of these known sites have been remediated in CP5 with further identified sites planned in CP6 including those in Table 3.

Table 3
CP5 and CP6 remediation sites

CP5	CP6
Tostock	Wrabness Embankment
Audley End Cutting	Nags Head Lane
Lower Dunton Road	Stourview
Ashdon Way Basildon	Maldon Road
Thorpe Hall	Magnolia Road
River Wid	Ipswich Tunnel Portals
Park Lane	Blountswood Road
Lushington Avenue Frinton	Haughley Junction
Flordon Embankment	River Tas
Jubilee Drive Wickford	Mitre Curve
Pesthouse Lane	West Horndon to Dunton
Gislingham	Chitts Hill Embankment
Tumulus Cutting	Jimmys Lane
Brantham Hall Cutting Emergency Works	Coppey Farm
West Horndon to Dunton Embankment toe drainage	Wash Road
Wrabness Embankment toe drainage	Burston Road
–	Jacques Hall
–	Muntons Stowmarket
–	Hill Farm

Anglia Route Impact Assessment continued

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

- Earthworks renewals on other sensitive sites that are outside current Network Rail policy for a renewal intervention,
- 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, and
- Remote monitoring of steep cutting slopes and tunnel portals.

Wind impact assessment

Between 2006/07 and 2018/19 wind related incidents accounted for an average of 41,452 delay minutes and £1.85m in Schedule 8 costs per year. This is 33 % of Anglia's annual average weather-related delay minutes and 34.2 % of the annual average cost.

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. These are principally for vegetation-related adhesion risks.

The primary longer-term mitigation is to remove trees which are able to fall on to the line. 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. This is also being actioned in Anglia route through the vegetation management plans. 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. This will include clearing trees in danger of falling and those that may generate root wedging instability in soft chalk cuttings in the western part of Anglia, provided they are not legally protected or providing an important visual screen. Further development of vegetation management plans will include third-party trees together with acceleration of a programme to improve OLE wind blow off resilience.

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 the Network Rail vegetation management system which will include third-party trees, and
- Accelerating the programme of OLE wind blow off resilience.

Lightning impact assessment

Between 2006/07 and 2018/19 lightning related incidents accounted for an average of 14,381 delay minutes and £0.42m in Schedule 8 costs per year. This is 11.4 % of Anglia's annual average weather-related delay minutes. And 7.8 % of the annual average cost.

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 has 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. This builds 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 for those 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), and
- Localised busbar lightning protection on signalling.

Anglia Route Impact Assessment continued

Adhesion impact assessment

Between 2006/07 and 2018/19 adhesion related incidents accounted for an average of 14,758 delay minutes and £0.63m in Schedule 8 costs per year. This is 11.7 % of Anglia's annual average weather-related delay minutes and 11.6 % of the annual average cost.

Adhesion is difficult to deal with but has the second greatest number of incidents over the thirteen-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. When combined with high winds causing high volumes of leaf fall over a short period of time the railhead can become contaminated as the leaves are crushed to form a carbon coating to the rails.

A programme of railhead treatment including rail cleaning to remove contamination and application of adhesion gel or sand is the current primary mitigation. Increasing Rail Head Treatment Train (RHTT) capacity could assist with rail head treatments. A review of the efficiency of Anglia's current RHTTs should therefore be undertaken to assess the benefits of increasing their number. Anglia currently has six RHTTs in operation, a review of pathing is being undertaken to try and introduce another RHTT. In conjunction with this an annual review of the RHTT circuit is undertaken to ensure mitigation is provided at the sites required. More modern rolling stock with wheel slip detection also reduces the impact of railhead contamination. Good forecasts 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 and plans to reduce the vegetation cover on the route will therefore improve the problem. This will require a review of the current vegetation plans.

Intelligent infrastructure systems in use in Anglia cover our high-risk sites and are proving very effective. 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 de-vegetation,
- Review leaf fall register,
- Review efficiency of RHTT in Anglia with a view to increasing numbers,
- Review of existing RHTT circuits, increasing treatment at High-Risk sites where possible, as well as treating at 20mph as opposed to 60mph,
- Intelligent infrastructure systems to be rolled out to cover all high-risk sites, and
- Review of Traction Gel Applicators (TGAs) across the route.

Fog impact assessment

Between 2006/07 and 2018/19 fog related incidents accounted for an average of 555 delay minutes and £0.03m in Schedule 8 costs per year. This is 0.4 % of Anglia's annual average weather-related delay minutes and 0.5 % of the annual average cost.

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

As the impacts of weather events are location specific Anglia Route will be responsible for identifying and carrying out the WRCCA investments necessary to deliver the continued and improved resilience of their assets and operations.

Network Rail's central functions will assist and enable the Anglia Route in this by:

- Providing asset policies and design standards that have weather resilience and climate change considerations embedded within them,
- Carrying out root cause analysis of national weather and asset data, and
- Reviewing and adopting approraite new technologies.

This section summarises the WRCCA actions undertaken by the Anglia Route in CP5 and those that we have planned for CP6. The first two tables in this section show the:

- Progress against the; CP5 WRCCA actions identified in the 2014 Plan (Table 4), and
- WRCCA actions planned for CP6 (Table 5).

The third table, Table 6, contains potential additional actions that the Anglia Route has identified as desirable to deliver WRCCA resilience, but which are not funded in the current CP6 business plan. The delivery of these actions may be planned for one or more Control Periods in the future and they will require further development and business case evaluation before making a funding submission in the appropriate Control Period.

The final table details actions that have been apportioned to Network Rail, and hence the Anglia Route, in the Defra NAP. Some of these will align with CP6 planned and funded actions (Table 5), some will align with the actions in Table 6 and others will require further consideration in CP6 and beyond.

Table 5 and Table 6 cross reference with Table 7 to indicate the relationship between the Anglia Route actions and the delivery of the NAP actions.

Table 4 – 2014 WRCCA Plan CP5 actions review

Action name	Target completion date	Actual completion date	Comments
Include clear requirements for climatic conditions and resilience levels in Route Requirement Documents	Ongoing	Ongoing	As part of meeting the Environment and Social Requirements standard climate change adaptation will be considered for all projects
Review adverse weather plans	Ongoing	Ongoing	Ongoing reviews are carried out to better increase the robustness of our adverse weather plans, with new sites being identified and added as required
Strengthen relationship with the EA through setting up Local Liaison Group on the flood risk management to share information and resolve issues (e.g. Cattawade Creek)	End of CP6	Ongoing	Route asset specialists have been interacting with the EA as well as other Lead Local Flood Authorities, Internal Drainage Boards and Flood Risk Management Authorities/Committees as required on an ongoing basis
Increase scour and surcharge resistance of most urgent bridge sites (e.g. river Gipping at Blakenham and Worlingham)	Ongoing	Ongoing	Several high-risk scour sites were remediated against in CP5. Scour risk is assessed cyclically, typically every three years, and high-risk scour sites are remediated against following a stage 2 scour assessment. There are currently three high risk scour sites that are to be remediated in CP6 year 2, with two further high-risk sites undergoing a stage 2 scour assessment
Install remotely monitored cameras (e.g. Oulton Broad), trash screen monitors (e.g. Johnsons crossing	March 2015	Ongoing	Johnsons crossing risk is being managed through visual inspection rather than remote monitoring (there is currently no plan to install remote monitoring there). Camera installation at high risk CERDs to be installed during CP6
Review of interventions at high-risk and known flooding sites, including highway level crossings and pumping stations (e.g. Bishops Stortford and Pitsea LC)	Ongoing as part of Drainage Management Plan (DMP)	Ongoing as part of DMP	Ongoing action as new flood sites identified. Pitsea LC partially renewed in CP5, further renewal planned in CP6. Bishops Stortford planned for renewal in CP6
Effectively manage drainage maintenance interventions	Ongoing as part of DMP	Complete	Drainage supervisor posts created and staffed in each Maintenance Delivery Unit. Maintenance drainage intervention now part of 'business as usual'
CP5 earthworks renewal intervention at critical earthworks sites (e.g. Marsh Farm and Gilsingham)	Completed	CP5 Year 2	Renewal works completed on these assets in Year 2 of CP5
Accelerate delivery of other Schedule 8 problem sites and sites showing significantly elevated rates of movement (e.g. Playford Hall and Chitts Hill)	End of CP6	Ongoing	Sites are part of the CP6 Earthworks Renewal Portfolio
Programmed business plan earthworks refurbishment and maintenance interventions	End of CP6	Ongoing	Sites to be delivered in line with Earthworks Business Plan
Remote monitoring of vulnerable sites using cameras, movement markers/wires and remote inclinometers (e.g. Tolstock)	End of CP6	Ongoing	Rolling program of remote condition monitoring to be installed throughout CP6 at high-risk embankment sites
Review requirements for increased cess support systems (e.g. Hill Farm)	March 2018	Ongoing	Site by site assessments made from earthworks examination commentary and also local maintenance depot identification
Review current adverse weather plans and CRT database including reviews of remote rail temperature monitoring and further white painting of rails	March 2015	March 2015	Remote temperature monitoring equipment is located at strategic locations throughout Anglia to allow engineers to better manage CRT sites during periods of hot weather
Remove fixed tension OLE systems	March 2018	CP6	Sites not delivered through deferral in CP5 are programmed into CP6
Accelerate completion of cabinet ventilation installations	March 2016	March 2016	Sites completed
Develop building ventilation programme	March 2017	March 2017	Programme completed
Engage with local flood resilience forums (e.g. Lowestoft flood alleviation group)	March 2015	Ongoing	Route asset specialists have been interacting with the EA as well as other Lead Local Flood Authorities, Internal Drainage Boards and flood risk management authorities/committees as required on an ongoing basis
Development of Coastal Estuarine Management Plans (CERD)	December 2014	October 2017	CEAMP issued October 2017
Review vegetation management plans including management of third-party trees	October 2014	Completed	Vegetation Management plan for Anglia now in place and third-party tree programme was commenced in March 2019
Commence programme of third-party tree removal	March 2015	March 2019	Third Party tree removal programme commenced in March 2019 and is due to continue throughout CP6
Increase frequency of lineside vegetation management	March 2015	Completed	Frequency of vegetation management is in accordance with NR/L2/OTK/5100 and Vegetation Management Plan
Accelerate programme of OLE wind blow-off resilience	March 2017	March 2017	Programme completed
Review weather preparedness plans (cold & snow)	Ongoing	Ongoing	Ongoing reviews of weather preparedness plans take place to increase the robustness of the plans
Accelerate delivery of points heating and thermal insulation of points	March 2016	CP6	Any deferrals from the CP5 programme are to be completed in CP6
Assess capacity of de-icing trains	March 2016	Ongoing	Works are continuing into CP6 to assess benefits
Review of drainage structures affected by icicles	Completed	March 2017	In CP5 29 sites were remediated against the risk of icicles encroaching OLE. New emerging sites will be remediated as they are identified, either through examination or patrols

Table 4 continued – 2014 WRCCA Plan CP5 actions review

Action name	Target completion date	Actual completion date	Comments
Staff deployment strategy for points at Liverpool Street	March 2016	2019	Liverpool Street Track Section Manager and staff are now located at Liverpool Street Station
Review weather preparedness plans, vegetation management plans and leaf-fall register	Ongoing	Ongoing	Now included in the Vegetation Management Plan for Anglia
Continue programme of third-party tree removal	March 2019	Ongoing	Ongoing programme throughout CP6 to remove the risk posed by third party trees that affect the operational railway
Maintain frequency of lineside vegetation management	March 2019	Ongoing	As per NR/L2/OTK/5100
Accelerate delivery of lightning surge protection	March 2016	Complete	Lighting surge protection installed at critical locations
Review current weather procedure	March 2015	Ongoing	Ongoing reviews of weather procedure
Review benefits of lighting array protection of sensitive locations	March 2016	March 2016	Review completed and outcomes included in plan
Earthworks washouts during storm surges Raising sheet pile flood defences at Haddiscoe	April 2019	March 2017	Localised track washout risk removed to avoid Line Blockages and associated safety risks
Embankment instability during adverse weather Embankment Renewals at Ashdon Way, River Wid, Tostock, Gislingham, Jubilee Drive, Ullemans Farm and Flordon	April 2017	October 2015	Embankments stabilised to remove instability safety risk and associated risk of Line Blockages and Temporary Speed Restrictions
Near surface slope instability and loss of track support Ash shoulder degradation at wastage cess retention at Rose Hill, Lower Dunton Road and Pesthouse Lane	March 2017	November 2018 and Ongoing	Embankments shoulder stabilised to remove instability safety risk
Surface water run-off flooding and Embankment instability during adverse weather Deep toe drainage cut-off at Wrabness embankment	April 2017	October 2015	Improved embankment stability to reduce instability safety risk and associated frequency of Temporary Speed Restrictions
Surface water run-off flooding and embankment instability during adverse weather Embankment toe drainage renewals at Harringay Green Lanes, Thorpe Hall, Lower Dunton and West Horndon to Dunton	April 2019	April 2016	Improved embankment stability to reduce instability safety risk and associated frequency of Temporary Speed Restrictions
Near surface slope instability Chalk Cutting rock netting at Audley End	March 2018	November 2014	Rock cutting stabilisation to reduce instability and block fall safety risks and associated risk of Line Blockages and Temporary Speed Restrictions
Near surface slope instability Cutting Slope failure regrades at Brantham Hall, Tumulus Cutting and Wymondham	March 2018	August 2016	Soil cutting stabilisation to reduce instability safety risk and associated risks of Line Blockages and Temporary Speed Restrictions
Embankment instability during adverse weather Reactive localised embankment toe weighting at West Horndon to Dunton, Wrabness and M25 Nags Lane	April 2017	March 2019	Embankments stabilised to remove instability safety risk and associated risk of Line Blockages and Temporary Speed Restrictions
Embankment instability during adverse weather Programmed business plan earthworks refurbishment and maintenance interventions	April 2019	Ongoing	Improved earthworks stability to reduce instability safety risk and associated frequency of Temporary Speed Restrictions
Early and continuous warning of unstable embankments Remote condition monitoring inclinometers at Wrabness, Tostock, Ashdon Way and M25 Nags Lane	March 2015	July 2016 and Ongoing	More effective management of earthworks instability allowing timely interventions and workbank reprioritisation to reduce risks of earthworks instability with associated safety, Line Blockage and Temporary Speed Restriction risks

Table 5 – 2019 WRCCA Plan CP6 actions

Vulnerability	Location	Action to be taken	Cost of action	Expected benefit	Target completion date	Resilience change	NAP action reference
Flooding	Various	Drainage inspection and maintenance	Various	Flood risk/severity reduction	End of CP6	Local resilience improvement at selected flood risk sites, through improvement of existing asset condition by maintenance (does not extend to physical enhancements to adapt to climate change)	NRNAP3
Flooding	Various (e.g. Brentwood, Gidea Park, West Ham)	Drainage renewals	Various	Flood risk/severity reduction	End of CP6	Local resilience improvement at selected flood risk sites, generally through improvement of existing asset condition. Climate change allowance included as per NR/L2/CIV/005 where full system renewal is being designed	NRNAP3
Flooding	Various (typically not site specific)	Flood risk and impact reduction through drainage asset management continuous improvement initiatives	Variable	Flood risk/severity reduction through initiatives such as improved first responder flood guidance/training, better and more accessible drainage system information, more site-specific flood management plans, strategy for use of remote monitoring, best practice sharing with other asset/risk managers and other improvements identified through flood incident and desktop flood risk reviews	End of CP6	Increased resilience and/or impact mitigation, or improved risk awareness/ assessment	NRNAP3
Deep seated embankment slope stability	Notable sites are: Wrabness, Chitts Hill, West Horndon to Dunton, Maldon Road, Jimmys lane, Wilkinsons Brook, Wash Road	Typically soil nailing, slope regrade and toe weighting or, sheet piling	Variable	Safety and performance improvements by renewal of assets, savings from reduction in On Track Machine (OTM) interventions and Temporary Speeds	End CP6	Resilience Increased	NRNAP5
Cuttings instability during adverse weather Programmed business plan earthworks renewal	Ipswich Tunnel Portals	Drainage improvements and local soil nailing	Variable	Reduction in risk of soil cutting failure during adverse weather, safety and performance improvement	End of CP6	Resilience Increased	NRNAP5
Cuttings instability during adverse weather Programmed business plan earthworks refurbishment and maintenance interventions	Numerous sites including local sites on LTN1 between 60 miles and 111 miles	Counterfort drains in slopes and crest drain refurbishment	Variable	Reduction in risk of soil cutting failure during adverse weather, safety and performance improvement	End of CP6	Resilience Increased	NRNAP5
Peat Wastage	Prickwillow, West River, Queen Adelaide, Ely North Junction, Lakenheath, Manea West	Cess support and/or ballast lowering	Variable	Safety and performance improvement, savings from less OTM interventions and Temporary Speeds	End of CP6	Resilience Increased	NRNAP5
Clay desiccation	Numerous – FSS2, LTN1 and TLL desiccation sites	Increased levels of large tree removal	Variable	Safety and performance improvement, savings from less OTM interventions and Temporary Speeds	End of CP6	Resilience Increased	NRNAP5
Ash degradation	Hill Farm, River Tas, Muntons Stowmarket	Cess support	Variable	Safety and performance improvement, savings from less OTM interventions and temporary speeds	End of CP6	Resilience Increased	NRNAP5
Scour	BGK 1438, TLL 166, BDM 1	Rock armour, toe gabion baskets or Reno Mattress	Variable	Will remediate the risk of scour to high risk scour sites. Safety risk improvement	End of Year 2	Resilience Increased	NRNAP5
Chalk slope toppling and spalling	Purfleet	Rock netting	Variable	Significant safety risk improvement	End of CP6	Resilience Increased	NRNAP5
Early and continuous warning of unstable embankments	Various sites including Stourview and West Horndon to Dunton	Remote condition monitoring inclinometers	Variable	Risk reduction	Ongoing	No Change (Monitoring Only)	NRNAP4
Remote condition monitoring cuttings	Various sites including Ipswich Tunnel Portal and Brantham High Cutting	Remote condition monitoring tiltmeters	Variable	Risk reduction	Ongoing	No Change (Monitoring Only)	NRNAP4

Table 6
High priority actions not funded in CP6

Vulnerability	Location	Potential action	Target completion date	Predicted benefit	NAP action reference
Peat wastage	Numerous Fens peat embankment sites	Increased levels of longer-term research and site trials	Ongoing	Safety improvement, risk reduction, delay reduction and savings	NRNAP7
Clay desiccation	Numerous clay desiccation sites	Increased levels of longer term research	Ongoing	Safety improvement, risk reduction, delay reduction and savings	NRNAP7
Ash fill embankment shoulder degradation	Numerous clay desiccation sites	Increased levels of longer-term research into stabilisation and alternative cess retention options	Ongoing	Risk reduction, delay reduction, safety improvement	
Deep seated embankment slope stability	Numerous clay embankment sites	Increased and/or reprioritised levels of earthworks interventions	Ongoing	Risk reduction, delay reduction, safety improvement	NRNAP5
Cutting slope washout risks	Numerous Glacial Till cutting sites	Increased and/or reprioritised levels of cutting slope/crest drainage interventions	Ongoing	Risk reduction, delay reduction, safety improvement	NRNAP5

Table 7
NAP actions

Objective	Action	Timing	Network Rail NAP Reference	Monitoring and metrics
Network Rail will continue to address flood risk across its network by:	Ongoing monitoring of adverse weather through visual and thermal imaging	CP6	NRNAP1	NR report on performance on a quarterly basis. This includes a running performance of each operator and the punctuality of its services. These are summarised in annual reports each year, allowing for yearly comparisons
	Building pumping stations in flood-prone locations	CP6	NRNAP2	
	Building in measures to address flood risk in new lines installing equipment at higher levels to avoid flooding	CP6	NRNAP3	
Network Rail will continue to comprehensively manage its assets against geotechnical faults as part of its Asset Management Excellence Model (AMEM), this will include:	Ongoing identification of sites vulnerable to landslips with use of Light Detection and Ranging surveys, in-place motion sensors, CCTV and ground investigations;	CP6	NRNAP4	
	Slope stabilisation management via drainage, or steel rods, soil nails or slope re-profiling	CP6	NRNAP5	
	Service continuity management by rerouting services which are likely to be affected by embankment failure (via CCTV monitoring)	CP6	NRNAP6	
	Ongoing engagement with academia to research possible slope stabilisation techniques, in addition to modelling the response of slopes under different meteorological conditions	CP6	NRNAP7	
Transport interdependencies	Network Rail's Safety, Technical and Engineering (STE) Horizon Scanning Group will continue to identify, assess and manage external risks to Network Rail throughout their regional Strategic Business Plans for Control Period 6	CP6	NRNAP8	

Management and review

Governance and review

Successfully implementing WRCCA across the whole of Network Rail requires a long-term commitment to the regular review and management of the process at all levels of the business. This will ensure the timely delivery of the technical and cultural changes necessary to develop cost-effective WRCCA strategies and actions which will avoid unacceptable increases in safety risk, system unreliability or the compromising of downstream risk mitigation strategies.

Network Rail is committed to ensuring that we will appropriately govern and assure implementation of these plans. Although we are going through a reorganisation and the future governance structure is unclear, the Route WRCCA Plans are owned by the respective Director of Route Asset Management and the Office of Rail and Road (ORR - Network Rail's regulator) will monitor each Route's progress in implementation during CP6.

Effective governance of the wider WRCCA programme including Route WRCCA Plans will be embedded within the new governance structure. Based on existing structures, the following high-level management, review and reporting will be undertaken:

- Routes will provide updates on implementation of their WRCCA Plans to ORR and the central WRCCA Team twice a year (at the end of Periods 6 and 13),
- A report combining progress from all Routes will be presented to the National Asset Management Review Group and Quality, Health, Safety and Environment Integration Group (or future equivalents) twice a year,
- Progress in implementing milestones will be included in regular WRCCA reviews by the Network Rail Executive Leadership Team and the National Safety, Health and Environment Periodic Report (or future equivalent),
- Route WRCCA Plans form a key control in managing Network Rail's Enterprise Risk relating to weather related impacts on the railway which is managed through Route and National level Business Assurance Committees (or future equivalent),
- The WRCCA Working Group will review progress and identify any improvements which would be approved by the National Asset Management Review Group and Quality, Health, Safety and Environment Integration Group (or future equivalents) or Executive Leadership Team as appropriate, and
- The central WRCCA Team will use the information in the Route Reports to inform the next National Climate Change Risk Assessment being compiled by the Committee on Climate Change and as part of its Adaptation Report under the Climate Change Act which is due to be submitted to Defra by 2021.

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.

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. As part of their appointment the 'Champion' will develop a reporting process that will provide updates on progression of the WRCCA actions.

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