2019 – 2024

SOUTH EAST

Route CP6 Weather Resilience and Climate Change Adaptation Plan

Contents

Purpose of this document

This document; defines the South East 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.

South East Route Weather Resilience and Climate Change Adaptation Plan – Version 3 – May 2020.

Director of Route Asset Management Statement

The railway network has always been susceptible to severe weather, from trees blown onto the line in high wind, to landslips following heavy rain, flooding that damages electrical equipment including vital signalling, freezing rain that builds up on the conductor rail and prevents trains taking power, dry Summers that destabilise the track bed and cause rough rides, or high temperatures that expand the rails so they threaten to buckle.

Figure 1
Heathaze at Redhill

Over the years we have developed ways to prevent or reduce these problems but we still get caught out from time to time, and when that happens we can't provide the rail service that passengers and freight operators expect. With 500 million passenger journeys being taken on the South East Route annually, the potential for major disruption is significant.

Climate change is set to bring more extreme weather to the UK, more often. Unless we find ways to make the railway more resilient to weather effects, severe disruption to services will become more common. This report sets out what we are doing to improve our understanding of how the railway will be affected by climate change, and our plans for the next 5 years and beyond to make the railway better prepared for the challenges ahead.

Mark Morris
Director of 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 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.

South East 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.

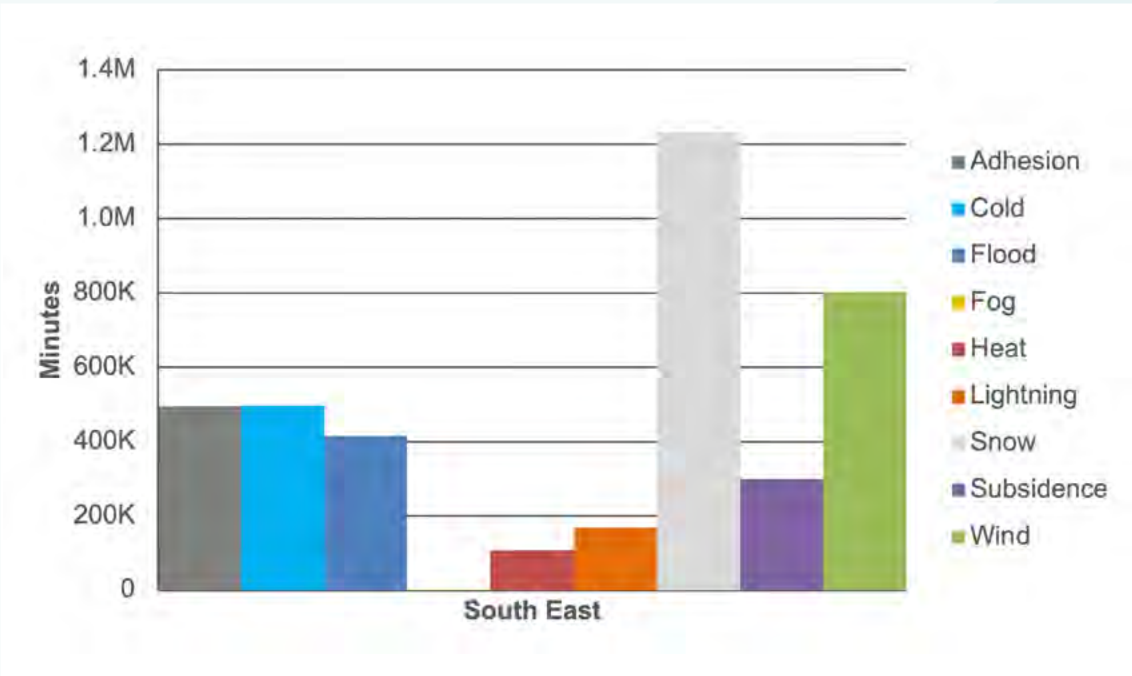


Figure 2
South East Route weather attributed delay minutes – 2006/07 to 2018/19

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 scenario, 90th percentile,
- Recovering from one of the wettest periods on record in 2014 which impacted performance. This included carrying out a lessons learnt exercise considering some of the human impacts of the event as well as the physical impacts (issued Oct 2015),
- Learning lessons from an incident at Lewisham in March 2018 caused by snow and freezing rain,
- Receipt of funding for CP6 (2019 – 2024) of £4.3bn which is over £1bn more than we received in CP5 (2014 to 2019). This will build more resilience to weather prone assets in particular earthworks (£121m) and drainage (£40m),
- Built a better relationship with the Environment Agency (EA) including sharing of project details and joint working to optimise projects which have dependences,
- Seasonal reviews to understand impacts of and improvements of Autumn, Winter and Summer preparations,
- Works to susceptible flooding locations such as Pangdean in 2017 and Shalmsford Street in 2019,
- Updating the Route's Weather Forecasting Website to include site specific information and adopting the use of Soil Moisture Index to improve the prediction of landslips and soil moisture deficit to improve the management of dry weather impacts, and
- Reduced effect of trees falling on the railway by examination to identify dead, diseased or dying trees and associated removal and minimizing adhesion related issues.

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

[1]Previous recommendation used in the 2014 Route WRCCA Plans 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 South East Route include:

- Effects from snow (The Beast from the East) in February and March 2018,
- Landslips at Barnehurst in February 2010, February 2014, January 2016 and February 2019,
- The collapse of a section of retaining wall at Dover due to a storm event closing the line from December 2015 until September 2016, and
- The effects of severe drought on track quality in Summer 2016 and Summer 2018,
- A significant period of wet weather between October 2019 and March 2020 (the wettest Winter on record) causing over 60 landslips in South East Route

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 overhead line equipment (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 delay minutes attributed to weather for the South East network was 309k. This represents 14.7 % of the total number of delay minutes for all causes over that period and equates to an average annual cost of £12.3m.

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

- Snowfalls of 2009 through to 2011, 2013 and 2017/18,
- Wind in a number of years, but particularly 2006/07 and 2013/14,
- Heat impact in 2018/19, and
- Flooding in 2007/08, 2013/14 2016/17 and 2019/20.

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.

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

Figure 3
South East Route weather attributed delay minutes by year – 2006/07 to 2018/19

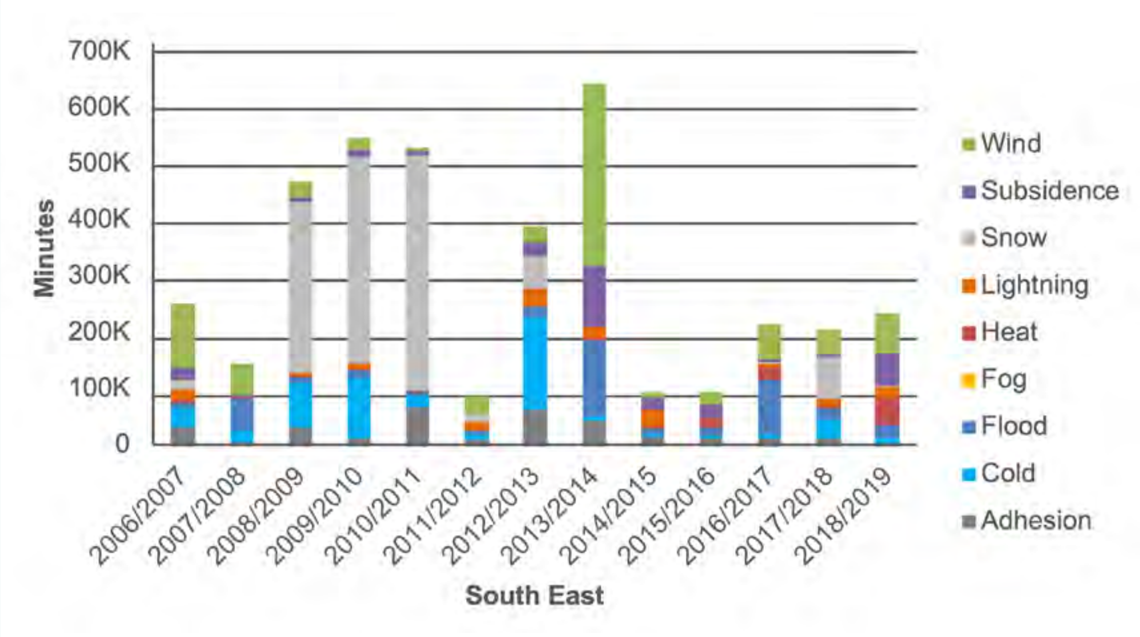


Figure 4
Intensity and frequency of high latitude Atlantic Winter storms[4]

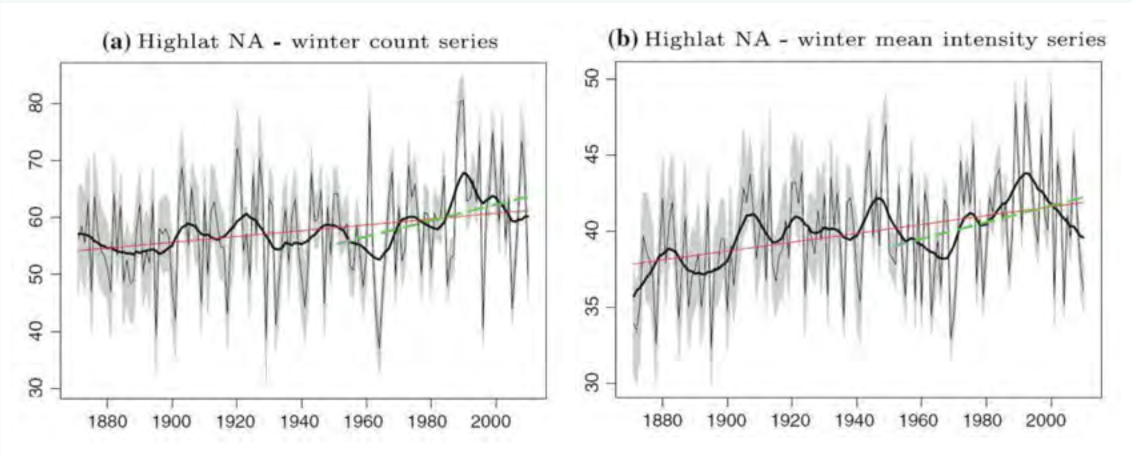
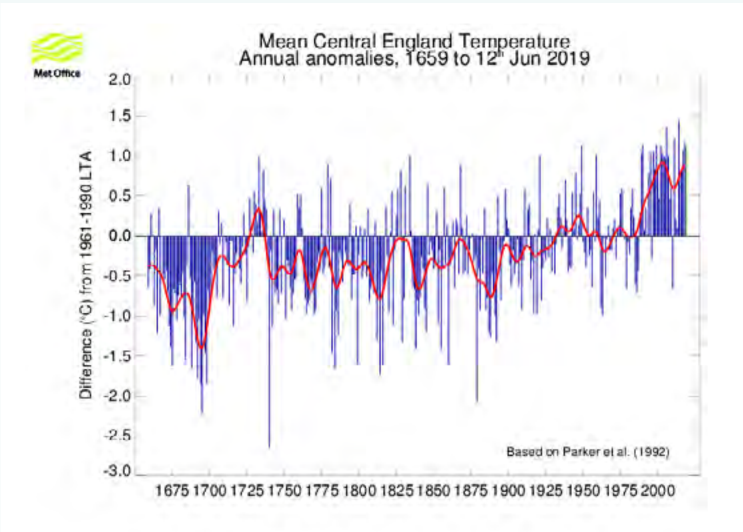


Figure 5
Mean Central England Temperature Record[5]



[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.

[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 reanalysis.

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 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]

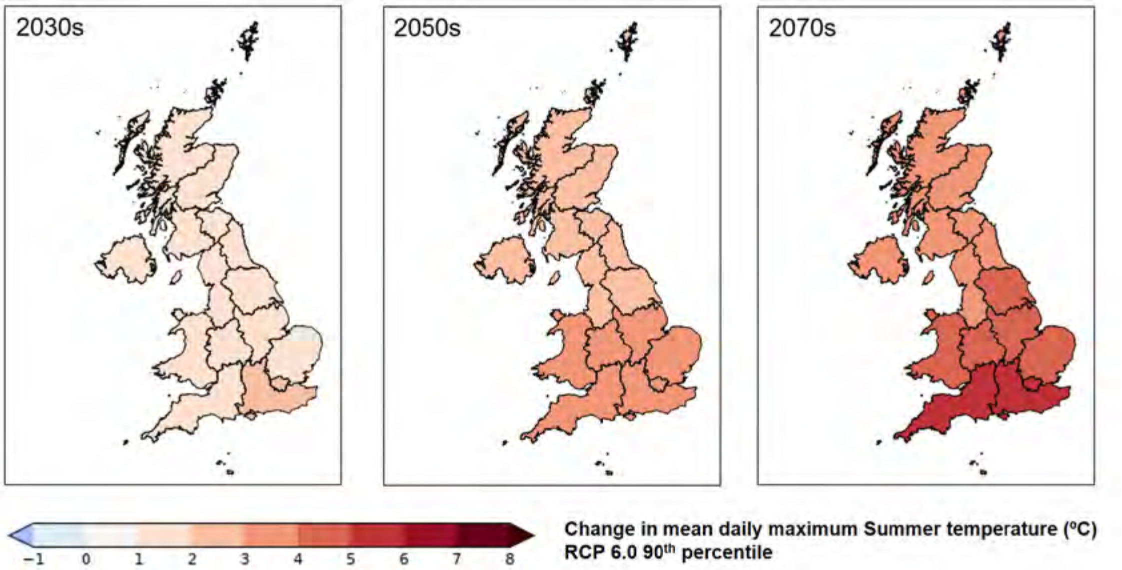
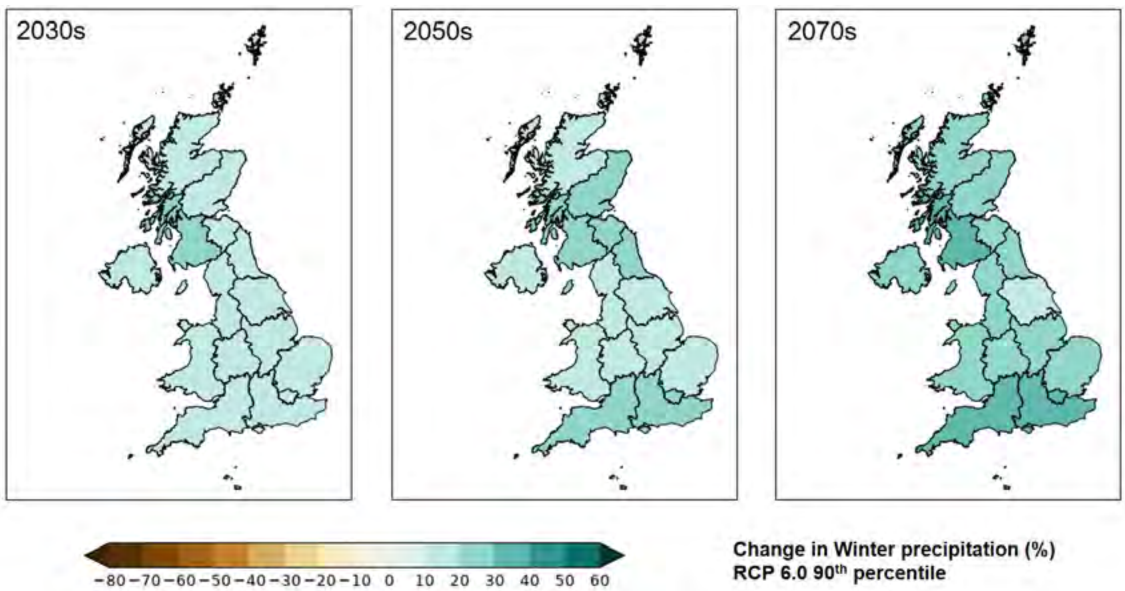


Figure 7
Change in Winter precipitation (%) (left to right; 2030s, 2050s and 2070s) based on a 1981-2000 baseline[7]



[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 South East 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.

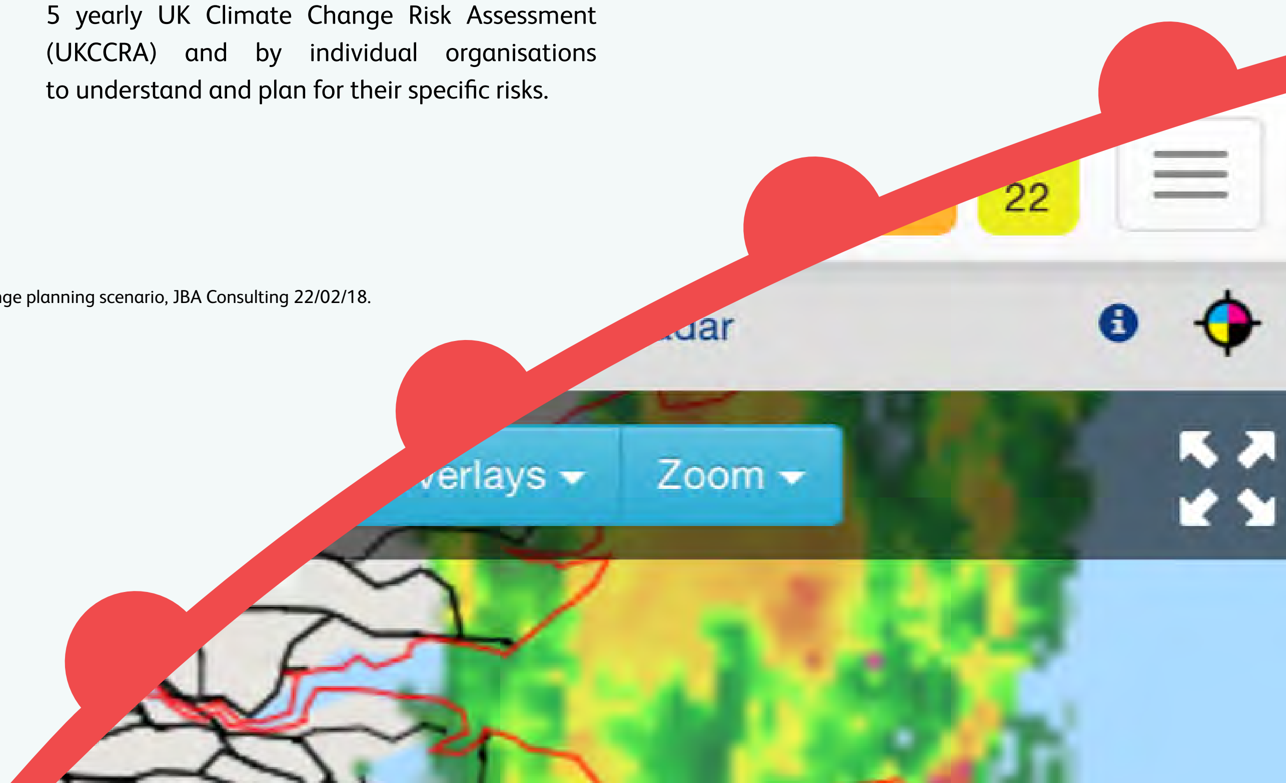
For the 2014 Route WRCCA Plans Network Rail's national guidance was to use the then current UKCP09 High scenario, 50th percentile probability projections as an appropriate benchmark on which to base evaluations and decisions. In 2017 Network rail commissioned a review of its guidance taking into account the Paris Agreement, advances in climate science, additional years of climate observations and the then pending release of the UKCP18 projections 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 – RCP 6.0 90th percentile probability as the baseline scenario for evaluations and decisions, and
- RCP 8.5 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.

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



Introduction continued

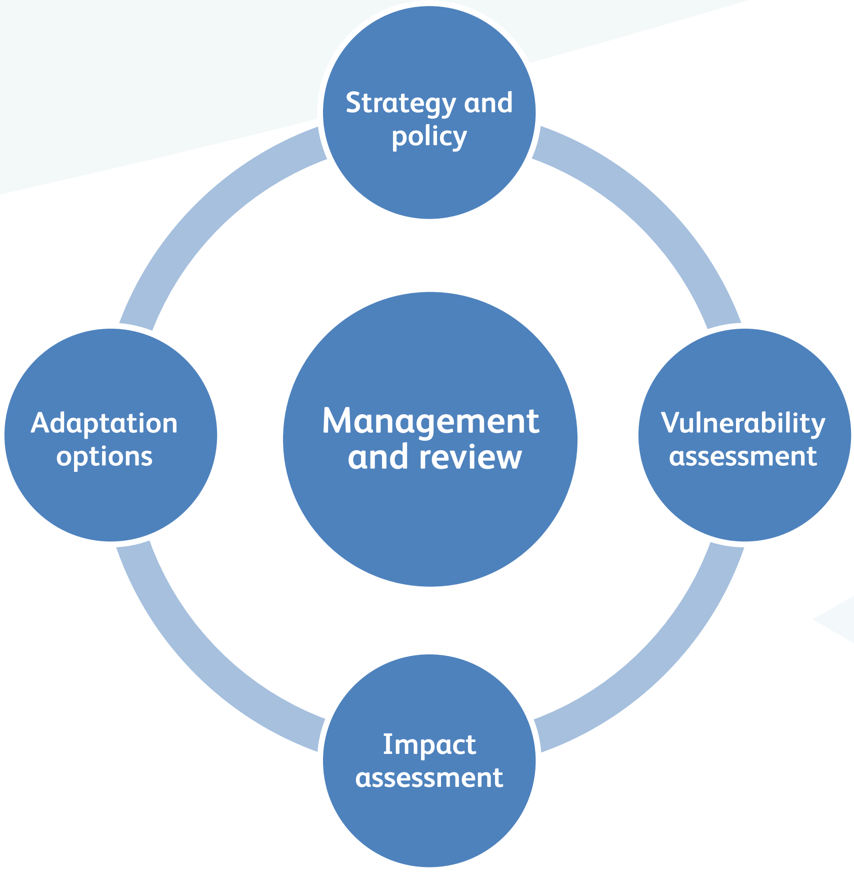
The NAP is based upon the UK Climate Change Risk Assessment which is published by Defra every 5 years. It contains a summary of the impacts expected for each sector of the UK economy and tables detailing adaptation actions that the UK Government requires those sectors to undertake to ensure the continuing 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 South East Route are included in Figure 34 in the South East 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. South East 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.

Figure 8
Weather resilience and climate change adaptation framework



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 South East Route vulnerability and impact assessments, and detail; progress on the CP5 resilience actions, actions planned for CP6 and additional actions for future consideration.

Figure 9
Track patrolling near Uckfield in hot weather

South East 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.

South East Route Plan

South East Route is committed to supporting the delivery of this strategy through Route specific weather resilience and climate change adaptation objectives linked into the Route Control Period 6 Delivery Plan for CP6 published in March 2019.

This states that "For South East Route to be dependable, punctual, sustainable and safe it is crucial that its infrastructure is resilient". The ability to minimise the impact of weather on performance, and to recover quickly from weather-related incidents, will be critical to the Route's success. A number of interventions from the Route's Weather Resilience and Climate Change Adaptation Plan (WRCCAP) have been included in the constrained base plan. These interventions, which improve our ability to adapt to varying weather conditions, are outlined on the next page. Our standard renewals will also select asset components suitable for the expected conditions and they will be located to avoid potential flooding sites.

Figure 10
Embankment failure on TTH at Stonegate in Kent – February 2014

The strategy includes:

- Increasing the understanding of potential climate change impacts on South East Route,
- Embarking on a 5-year programme to identify, assess the condition and rejuvenate existing drainage systems. Following this a sustainable inspection and maintenance regime will be set up with a legacy of good asset data,
- Ensuring that high-risk earthwork assets have suitable mitigations in place for severe weather and investment plans in place to remove the need for special mitigations in the long-term. Although the condition of earthworks is expected to stay the same across CP6, targeted works will allow a gradual reduction in risk and reduction in sites prone to adverse and extreme weather condition impacts,
- New approaches to the management of the lineside vegetation following the Vegetation Management Review by John Varley in 2018 will see identified trees and other vegetation managed to improve safety and performance whilst protecting and enhancing biodiversity. A total of £15.3m will be spent managing lineside vegetation during CP6,
- Work with lineside neighbours to ensure the environment beyond the boundary does not negatively affect safety of the line or performance by adopting the principles of the Varley Report issued in November 2018,
- Continuing key planning actions to mitigate against deteriorating track geometry in response to clay bank desiccation during hot dry Summers. These include ensuring that sufficient access to the track and track maintenance plant is available to carry out increased levels of track maintenance in advance of and during these severe weather events, and
- Work with key stakeholders and lineside neighbours in the implementation of our strategy through sharing knowledge on climate change trends and their impacts on infrastructure and operations. This has already started with Kent County Council and the EA.

Through these objectives, Network Rail's corporate commitments are applied in the context of South East 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 South East Route and the whole railway network.

Figure 11
Flooding on the River Ouse on BTL at Offham in Sussex – January 2014

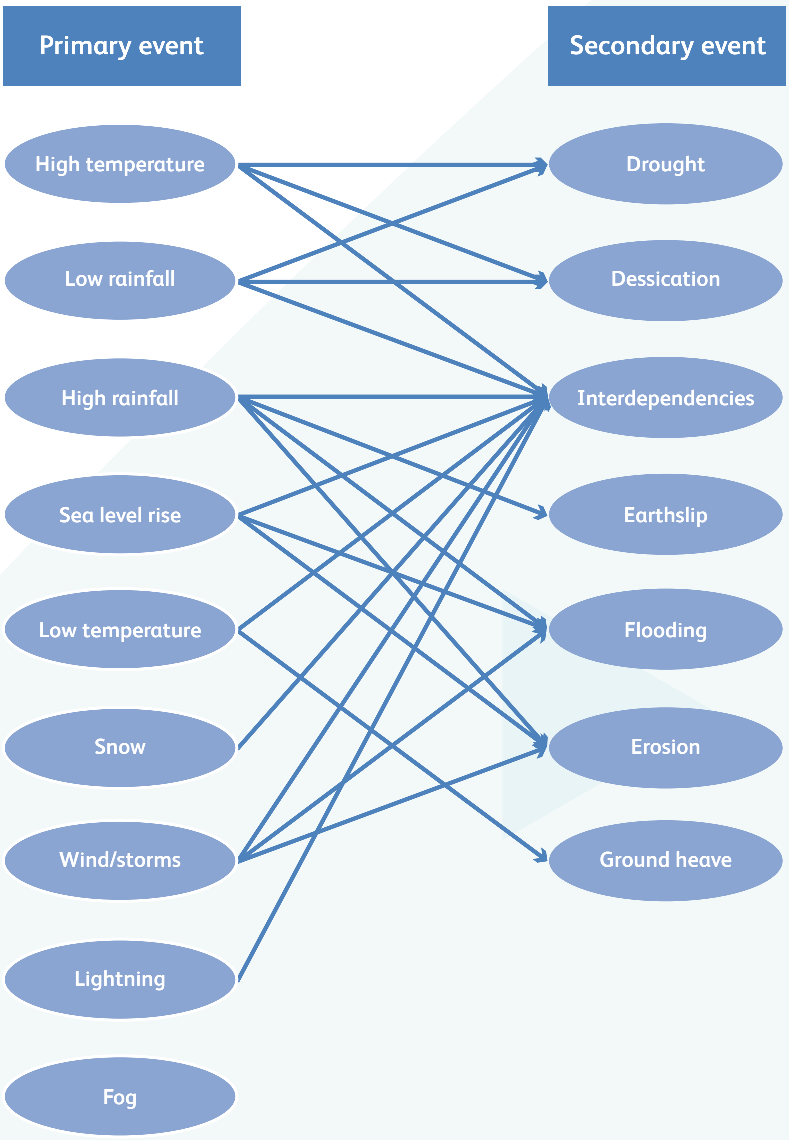
South East Route vulnerability assessment

In the 2014 Route WRCCA Plan this section provided details of the general vulnerability of the national rail network and South East 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 12
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 12 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.

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 Route's 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 and annual basis.

Route weather vulnerability

The characteristics of the Kent and Sussex areas are largely influenced by the physiography or surface expression and underlying geology.

The harder chalk formations give rise to the higher ground of the North and South Downs, while the intervening softer clays have eroded away to leave tracts of lower ground and valleys. The older more mixed strata (sandstones and mudstones) of the High Weald give rise to more undulating country, through which the railways must meander, such as the Tonbridge to Hastings line and the Uckfield line.

These factors influence both the orientation of the primary lines and the track situation, in terms of being within a cutting, 'at grade' or on embankment. Approximately 60 % of the lines are situated on or within earthworks, the remainder being on level ground, on structures within urban areas or within tunnels. There are 450 miles of embankments, 322 miles of soil cuttings and 89 miles of rock cuttings across the Route.

South East Route vulnerability assessment continued

The principal Kent Route's are East-West, parallel to the structural trend of the Wealden Anticline and run largely along the chalk of the North Downs (VIR) or along the lower ground of the gault (SBJ) or Weald clay (XTD).

In contrast, the principal Sussex Route's are North-South, at right angles to the axis of the Wealden Anticline. They pass quickly through the formations with shorter sections within deep chalk cuttings and less exposure to the troublesome clay formations.

These geographical features also influence the localised weather behavior. The escarpments of the North and South Downs form physical barriers to the moist winds of the Atlantic airstreams with increased rainfall occurring through the process of orographic rainfall intensification.

The history of railway construction is another factor affecting Route vulnerability to adverse weather. Much of the network was developed from the 1840s as lines radiating out from London were built by competing companies using the best of their engineering ability available at that time. While the understanding of the behaviour of man-made materials was commendable, that of natural materials was limited, as the science of soil mechanics was not established for another 60 years. This factor, combined with the shareholders pressure for returns on their investments, led to minimal land take and maximum slope angles. This has left a legacy of timed-out earthworks which are far more vulnerable to weather than those designed and built to modern day standards.

Earthworks

One of the most significant aspects of weather impact particular to the South East Route, is susceptibility of earthworks, i.e. embankments and cuttings, to adverse or extreme weather. The five key variables which determine the performance of our earthwork assets are:

- Type: ranging from steep-sided deep cuttings through 'at grade' to high embankments over areas of low ground or river valleys,
- Geology: the geology of the South East Route is dominated by weak, moisture-sensitive, over-consolidated clays. These contrast with areas of stronger limestones (chalk) and sandstones which give rise to the undulating terrain of the High Weald and the upland regions of the North and South Downs,
- Condition: earthwork 'condition' is regularly determined by our programme of earthwork examinations. Condition trend is always deteriorating until such time as there is intervention, which brings the condition back to a satisfactory level,
- Moisture: this is the most significant factor as excess moisture causes mobilisation of materials, in particular where embankments are composed of the weak over-consolidated clays. At the reverse end of the moisture cycle is the drying out, or desiccation of the same clays, which shrink and cause a loss of track quality on clay-cored embankments during hot dry Summers, and
- Trees: the management of vegetation is crucial to minimise the re-growth of high-water demand trees, which can exacerbate track geometry defects during periods of hot weather. Research has determined that deformation of soil slopes is 10 times greater where trees are present compared with grassed slopes.

Earthwork type and geology are highly constrained factors however, variations in condition, moisture and vegetation can be managed to a degree. Extreme variance, especially in moisture, may cause failures due to excessive moisture, or track defects due to desiccation, which represent safety and serviceability risks, respectively. It is this aspect which is set to be a feature of climate change.

Vegetation

Vegetation on embankment and cutting slopes can be detrimental to performance. Given that the expectation of climate change is for warmer Summers and heavier rainfall, the management of woody growth will present an increasing challenge.

The already occurring threat from 'ash die back', which can be seen on the east coast of Kent, and the currently unknown impact of the introduction of alien species in response to changing climate, such as insects or plants are becoming an increasing risk.

South East Route vulnerability assessment continued

Flooding

The geological fabric also controls the propensity for flooding. The softer clay bedrocks give rise to tracts of low-lying, poorly drained landscape where fluvial flooding occurs through the limited ability of the natural watercourses to cope with heavy rainfall. Gatwick is situated within such an area.

River and estuarine flooding occur in main river valleys where outfall is impeded by natural or man-made constrictions, such as in the Arun Valley south of Pulborough.

Groundwater flooding occurs less frequently when the water level in the chalk aquifers of the North and South Downs rise into the floor of the railway's cuttings and tunnels.

This occurs on the Sussex Route where the Redhill line passes through a deep cutting in chalk south of Coulsdon and again on the Brighton line at Pangdean, just north of Brighton. Further groundwater flooding occurs at Shalmsford Street on the Kent Route where the Ashford line passes through the chalk escarpment of the North Downs by way of the River Stour valley. Flooding has at worse caused 3,500 to 5,000 minutes delay in 2009 and 2017.

Figure 13
River Ouse flooding near Lewes – January 2014

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 14). Projections that cover the South East Route are provided by the South East England region.

In the 2014 Plan charts were generated using the UKCP09 High emissions 50th percentile probability scenario for the three regions 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).

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 14
Map of UK administration 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]

South East Route vulnerability assessment continued

Mean Daily Maximum Temperature change

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

The highest mean Summer temperatures are expected to be in August for both the 2050s and 2070s with increases of 4.6˚C to 26.4˚C and 6.3˚C to 28.1˚C respectively. In Winter the highest mean temperatures will be seen in December, with increases of 2.1˚C to 10.1˚C and 2.9˚C to 10.9˚C respectively.

Mean Daily Minimum Temperature change

The mean daily minimum temperature for South East England is also projected to show increases throughout the year with the highest in 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 3.1˚C to 15.0˚C by the 2050s and 4.6˚C to 16.5˚C by the 2070s. The lowest mean minimum temperature will still occur in February with expected increases being 2.5˚C by the 2050s to 3.6˚C, and 3.5˚C by the 2070s to 4.5˚C.

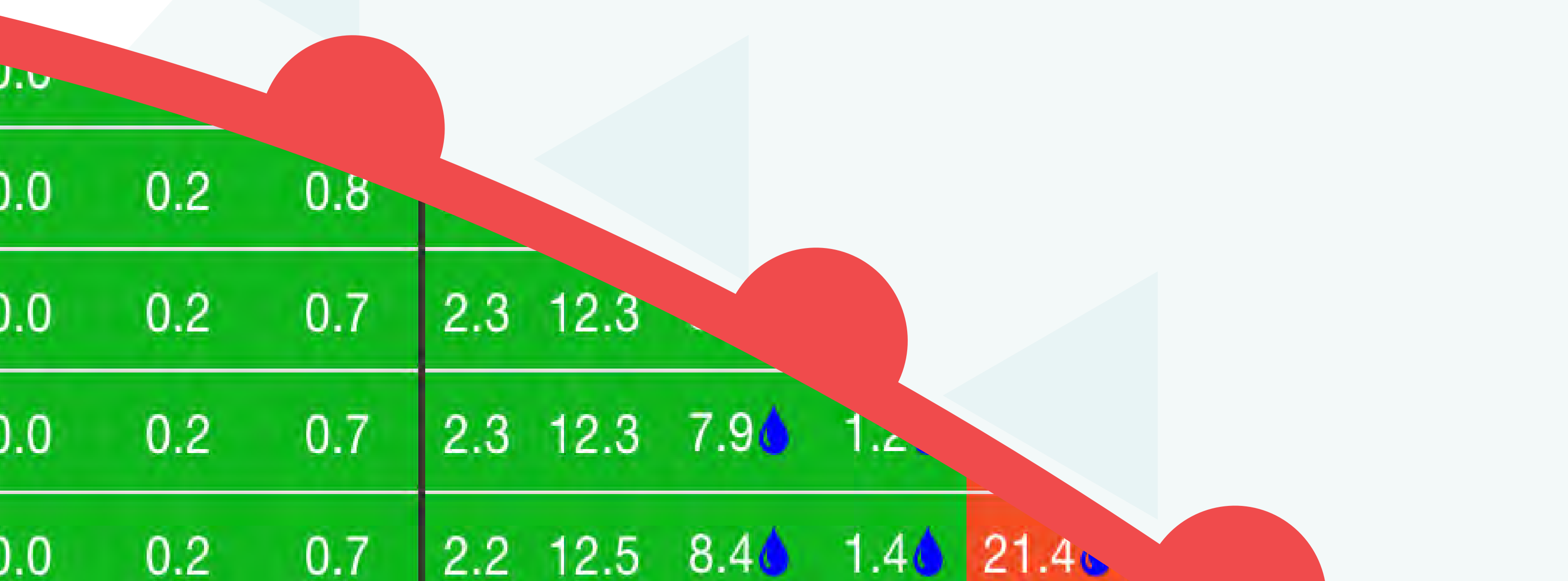


Figure 15
South East, mean daily maximum temperature change (˚C) (RCP 6.0 90th percentile)

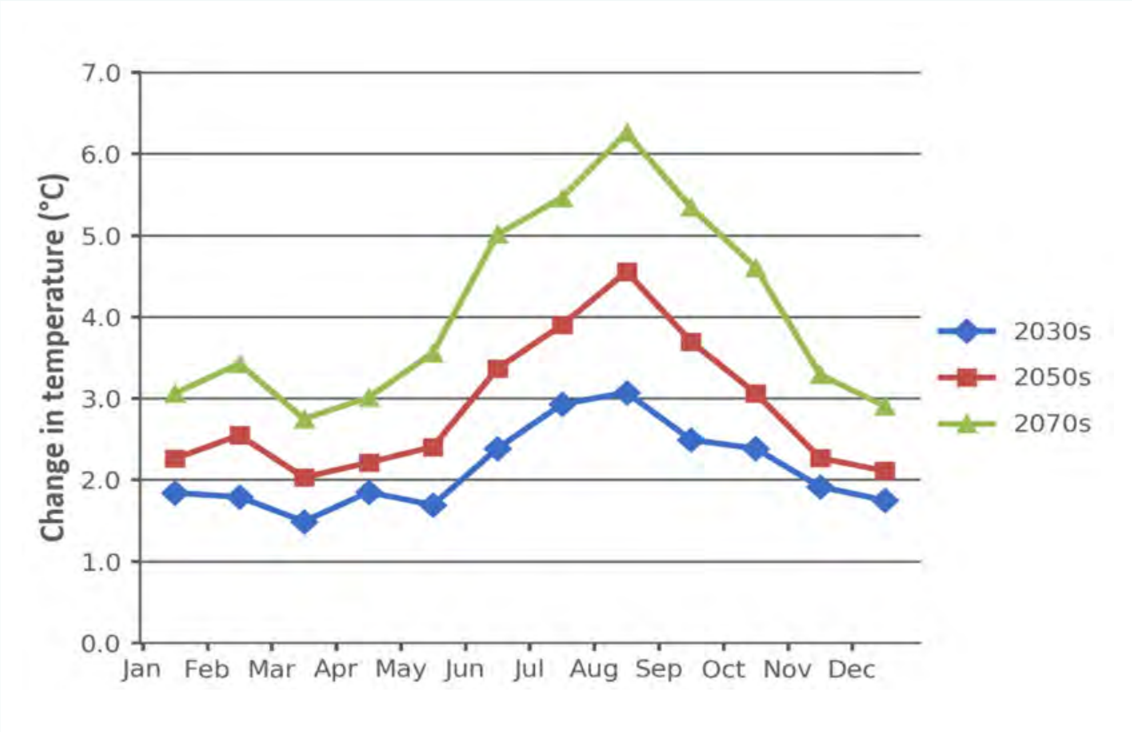


Figure 16
South East, mean daily minimum temperature change (˚C) (RCP 6.0 90th percentile)

South East Route vulnerability assessment continued

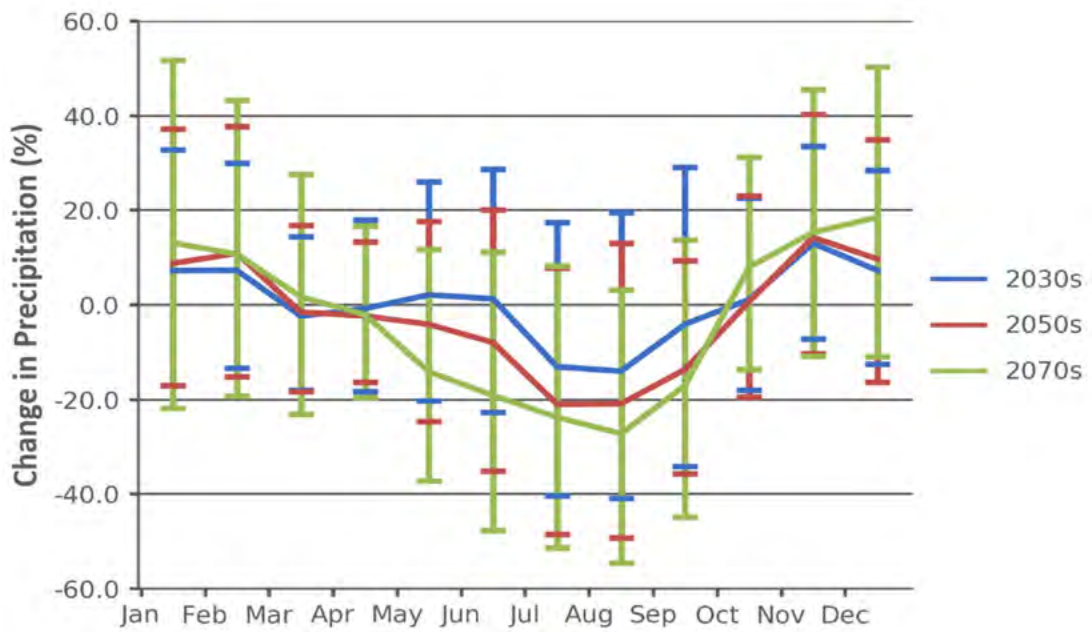
Mean daily precipitation

The UKCP18 narrative for mean daily precipitation in South East England is of significantly wetter Winters and drier Summers. Network Rail's chosen climate change planning scenario (RCP 6.0 90th percentile) shows the upper range of Winter rainfall increases, but does not illustrate the highest potential Summer rainfall reductions. These are best represented by the RCP 6.0 10th percentile projections.

Figure 17 therefore plots the RCP 6.0 50th percentile projections with error bars that indicate the wider range of change associated with the 10th and the 90th percentiles.

In the 2050s and 2070s December will be the wettest month with mean daily rainfall increases of 34.8 % to 3.8mm/day and 50.3 % to 4.2mm/day respectively. The driest month will be July showing decreases of 48.6 % to 0.8mm/day by the 2050s and 51.3 % to 0.7mm/day by the 2070s.

Figure 17
South East, mean daily precipitation change (%) (RCP 6.0 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 will 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 South East 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 South East Route are shown in Table 1.

Table 1
River flow uplifts (UKCP09)

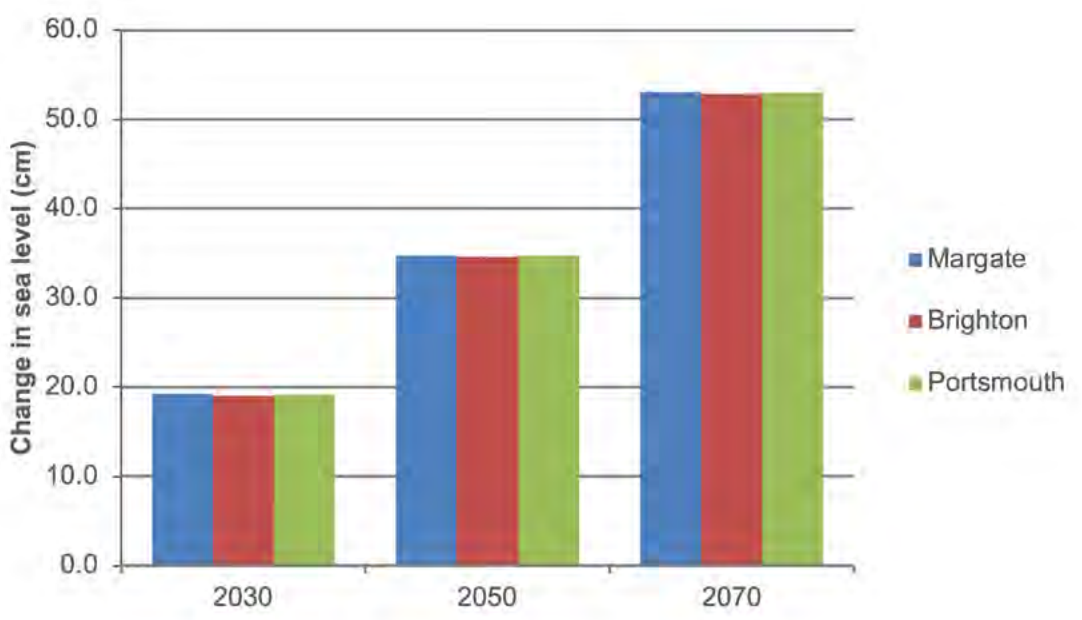
River basin	2050s uplift	2080s uplift
Thames	25 %	35 %
South East	30 %	45 %

Sea level rise

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

Margate will see the highest rises by 2050 and 2070 of 34.8cm and 53.1cm respectively and Brighton will see the lowest at 34.6cm and 52.9cm.

Figure 18
Sea level rise projections for South East England (cm), RCP 4.5 95th percentile



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

[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.

South East Route impact assessment

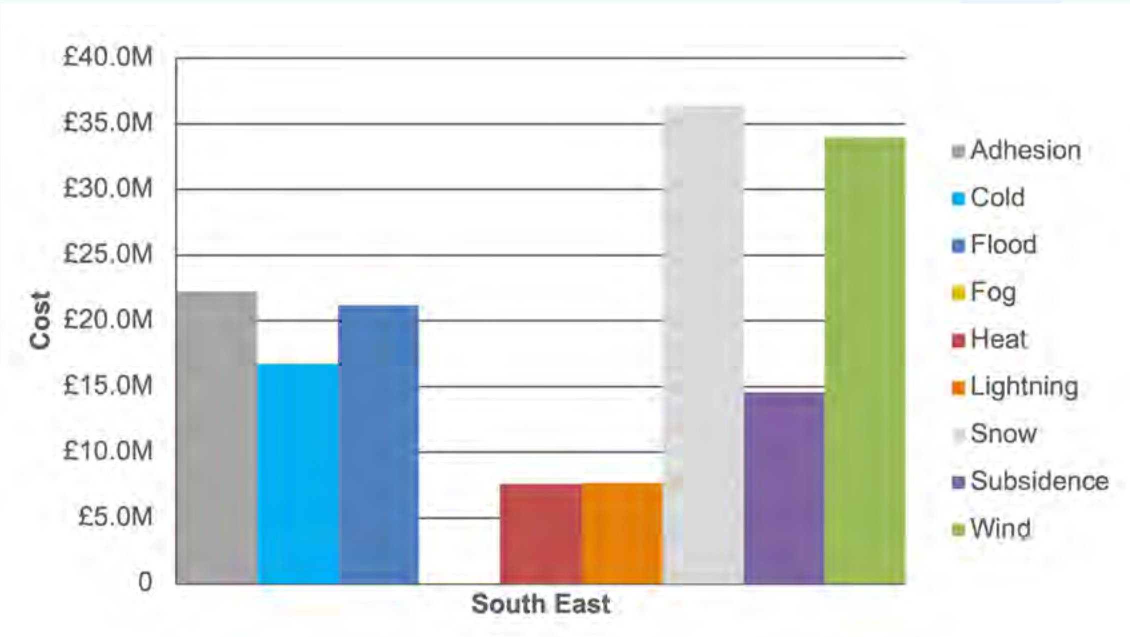
This section provides an update of the South East Route weather impact assessment findings published in the 2014 South East Route WRCCA Plan, including annual performance impacts and identification of higher impact locations on the Route.

Performance impacts

The impact of weather events on the performance of our network is monitored by using delay minutes and Schedule 8 delay compensation costs as a proxy. As the recording of these includes the duration and location of each disruption, and attributes 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 South East Route. This Plan updates that assessment using additional data from the past 5 years, see Figure 19.

Figure 19
South East Route weather attributed Schedule 8 costs – 2006/07 to 2018/19



The updated analysis shows that Snow continues to be the most significant weather impact incurring 1,235k of delay minutes and costing a total of £36.7m in the last 13 years. This is £466.2k delay minutes more than wind related incidents which cost £32.3m 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 South East 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.

Table 2
Prioritisation of weather-related impacts on South East Route

Impact	Schedule 8 Cost per year[12]	Climate projection[13]	Prioritisation
Wind	Average £2.62m Highest £10.23m	Changes difficult to project, however generally expected to increase	High
Adhesion	Average £1.71m Highest £2.82m	Complex relationship between multiple causes and their climate projections	Medium
Snow	Average £2.80m Highest £10.70m	Changes difficult to project, but increases in Autumn, Winter and Spring minimum temperatures suggest reduced snow days	Medium
Lightning	Average £0.59m Highest £1.75m	Changes in storms difficult to project, however generally expected to increase	Medium
Cold	Average £1.29m Highest £3.95m	Increases in mean daily minimum temperatures in Autumn, Winter and Spring ranging from 1.8˚C in April to 2.8˚C in January and September for the 2050s and 2.7˚C in April to 4.4˚C in September for the 2070s	Low
Subsidence	Average £1.12m Highest £4.05m	Increases in mean daily rainfall across late Autumn, Winter and early Spring months, for example; 13.2 % in April and 40.3 % in November by the 2050s becoming 16.7 % in April and 51.7 % in January by the 2070s. Increased frequency and intensity of Winter and Summer storms. Decreases in mean daily rainfall for late Spring through to early Autumn, for example; 24.7 % in May and 49.3 % in August by the 2050s becoming 37.2 % in May and 54.6 % in August by the 2070s	High
Heat	Average £0.58m Highest £1.4m	Increases in mean daily maximum temperatures range from 2.1˚C to 2.5˚C (Winter) and 3.4˚C to 4.6˚C (Summer) by the 2050s. In the 2070s this becomes 2.9˚C to 3.4˚C and 5.0˚C and 6.3˚C respectively	Medium
Flooding	Average £1.63m Highest £7.57m	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 <£0.01m Highest <£0.01m	This is a complex picture with low confidence[14], however possible seasonal changes for the 2080s have been indicated as: Winter +7 %, Spring -42 %, Summer -70 % and Autumn -31 %	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 does not affect their relative impact rankings.

[12]Based on Schedule 8 costs per year over the last 13 years from 2006/07 to 2018/19.
[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.

South East Route impact assessment continued

Identification of higher risk locations

Since the publication of the last Plan the South East 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 South East 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 in 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 8,354 delay minutes and £0.58m in Schedule 8 costs per year. This is 2.7 % of South East's annual average weather-related delay minutes and 4.7 % of the annual average cost.

In general, the weather will become hotter on average in all seasons. Spring will move to be earlier and Autumn will move later. Winter will be shorter. Average and daily maximum temperatures will increase, and heatwaves will become more frequent, longer and more severe (see climate data). Growing seasons will lengthen, droughts will become more common.

Several, if not all, assets on the railway are affected by heat. Buildings and structures are perhaps the least affected with the main concern being overheating of station buildings. This requires more cooling equipment and increases electricity demand.

Signalling suffers from overheating of equipment cabinets/buildings, and they therefore require better insulation and more cooling equipment, which also increases electricity demand. Electronic equipment, such as printed circuit boards, may need to be more robustly manufactured to maintain functionality at higher temperatures. The Route is advanced in testing all signalling equipment to deal with changes in temperature (diurnal range rather than maximum). Whilst this has been a weakness software systems have been upgraded to counter this.

Rail buckling is one of the main issues for track and requires increased vigilance and resources to manage it safely through heat speeds and extra tamping. Increased risk of lineside fires will require increased efforts to minimise litter and clear vegetation. There were several instances of this in the hot Summer experienced in CP5 and several initiatives have now been put in place to mitigate this in future including ensuring adequate ballast provision.

It is estimated that over 65 % of embankments in the South East Route are composed of moisture sensitive clays. The remainder of are made of less moisture sensitive granular soil types with varying susceptibility to shrink-swell or chalk, which is not quite so moisture sensitive. The rate at which the clay moves is proportional to the seasonal variations from wetting to drying (desiccation), and climate change will increase the range causing acceleration in the demise of clay banks. The desiccation effect, which causes deteriorating track geometry, is exacerbated in the presence of high water demand trees (such as Oak) which draw extra water to keep alive, especially late Summer to Autumn.

In CP5 significant effects of desiccation took place in 2016 and 2018 where 25 and 16 temporary speed restrictions were put in place to manage the poor track quality. In addition, a number of long temporary speed restrictions were put in place along the Redhill to Tonbridge line causing significant delays.

Some rationalisation of track assets is underway to make the track more heat resilient. This includes:

- Removal of Jointed track,
- Removal of Obsolete fastenings, and
- Use of geogrid on Cat 14 renewals.

The Route is mindful of the impact that extremes of weather have on our staff, particularly during travelling and those working trackside. Staff can quickly become fatigued and loose concentration, which is exacerbated by becoming too cold, too hot or wet. The loss of concentration can lead to safety incidents. The Route safety team has produced an online survey to assess impact. A plan can then be put together to improve factors affecting fatigue such as sleep, nutrition, stress, hydration and exercise. The right personal protective equipment (PPE) for the right weather conditions is also important, and the Route has made available different options for different seasons and weather conditions. The Route is also improving welfare facilities at a number of locations trackside.

South East Route impact assessment continued

Cold and snow impact assessment

Between 2006/07 and 2018/19 cold related incidents accounted for an average of 38,276 delay minutes and £1.29m in Schedule 8 costs per year. This is 12.4 % of South East's annual average weather-related delay minutes and 10.4 % of the annual average cost. Over the same period snow related delays averaged 94,663 delay minutes and £2.80m in Schedule 8 costs per year. This is 30.6 % of the annual average weather-related delay minutes and 22.7 % of the annual average cost.

The weather will become hotter on average in all seasons. Spring will move earlier, and Autumn will move later. Winter will be shorter. Average and daily maximum temperatures will increase (see climate data). Frost and snow days will reduce. The likelihood of severe Winters will decrease, but current levels of severity will remain possible.

Measures taken to mitigate the effects of snow and cold at these locations include installing conductor rail heating, no splitting of trains in cold conditions and staff on the ground to react to incidents. While this is not sufficient to completely mitigate the risk, there has been an improvement in delays in the last few years, as the figures show. It is not planned to install more conductor rail heating at additional locations, but existing locations will need to be maintained.

While the climate change projections would suggest an improving situation for frequency of cold days, the fact is, that even the shortest periods of cold and/or snow have a debilitating impact on the network. To mitigate this, we have increased the amount of conductor rail heating in both Kent and Sussex, we run anti-ice MPVs and we have a Key Route Strategy (KRS) which involves the use of Snow Ice Treatment Trains (SITTs). However, the "Beast from the East" in March 2018 still had a significant impact on the Route. Following the incident at Lewisham an independent investigation was undertaken by Arthur D. Little and Southwood Rail Consulting and the results of this were announced in August 2018.

This recommended better weather prediction, improved rail head treatment, improved response and processes to manage similar situations and testing of those processes by scenarios. At the time of publication of this document a report on the incident from the Rail Accident Investigation Branch was awaited.

Most assets are impacted by the effects of snow and cold, and measures are taken to reduce these impacts on all fronts. A concern for structures and buildings is the risk of shrinkage and fracture of metal components, leaks from accumulating snow on and around buildings, slippery conditions around buildings and on walkways, and snow and wind blowing platform copers out of alignment. Ice formation in tunnels also poses a risk to the running of trains, as sheets of ice can form icicles in front of the path of the train and cause damage or break off without warning.

To mitigate this, tunnel checks are carried out by track patrollers, who have equipment to remove ice sheets if found. The Civil Engineering Adverse and Extreme Weather Plan was revised in December 2018 to incorporate tunnels at risk of ice, following the extreme cold weather in March 2018.

Cold weather poses perhaps the biggest risk to track; ice formation on the third rail prevents trains from accessing the power supply via the shoe gear and often results in arcing and sparking which damages the train and the track. Points can become frozen which prevents paths from being set by signallers, and a build-up of snow on the track simply means that trains cannot run until cleared by the SITT, much as roads need to be cleared by a snowplough before cars can drive through them.

While conductor rail heating, points heating, the running of SITTs and ghost trains go some way towards mitigating the effects of ice, a large amount of snow does render these ineffective.

Figure 20
Snow in the Sussex part of the Route affecting a Southern train

Further costs are often incurred in repairing the equipment. There was also an incident where disruption of services was exacerbated in the Kent snow of December 2010 because trains could not pass trees which had lent over the tracks due to the weight of snow on their branches. This has not occurred again in CP5.

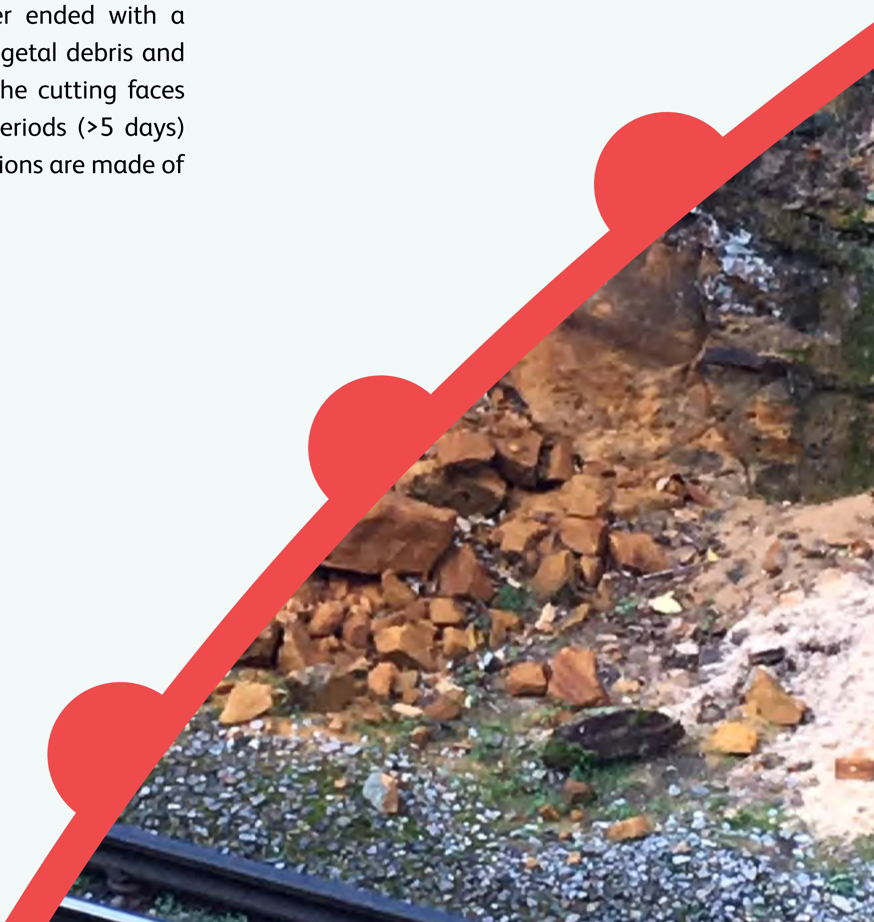
Apart from snow melt, snow and cold has limited impact on earthwork stability. The more significant impact is from the freeze-thaw process which damages rock and in particular chalk cuttings. The lines through the Hooley cuttings were closed for several days in 1947 when a long period of freezing weather ended with a rapid thaw, which caused the vegetal debris and weathered chalk to slough off the cutting faces and block the lines. Following periods (>5 days) of sub-zero temperatures inspections are made of the rock cuttings.

The following mitigation will reduce the impact from snow and cold:

- Better forecasting of snow conditions so that emergency timetables can be instigated in good time,
- Removal of lineside trees to prevent line blockage,
- Ensure adequate de-icing arrangements and material supplies in conjunction with train operating companies etc,
- 24/7 availability and full coverage of 10 SITTs,
- Use of 10-8 car trains which allows ability to move incapacitated trains, and
- Use of the Network Rail Weather Website and Extreme Weather Action Teleconferences (EWATs) to be more proactive in forecasting and managing weather events.

During 2014/15 the Route invested £1.9m in Winter preparation. Previously in CP4 we invested £50m and deployed Conductor Rail Heating (CRH) at a number of locations, developed and delivered six snow and ice treatment trains and fitted anti-icing equipment to 20 class 375 trains.

In addition, the 2014/15 CRH installation included developing remote condition monitoring for the CRH and detailed pre-Winter checks on CRH.



South East Route impact assessment continued

Flooding and sea level rise impact assessment

Between 2006/07 and 2018/19 inland and coastal flood related incidents accounted for an average of 31,936 delay minutes and £1.63m in Schedule 8 costs per year. In combination these represent 10.3 % of South East's annual average weather-related delay minutes and 13.2 % of the annual average cost.

Flooding

Flooding includes river, groundwater and surface water flooding (sea flooding is dealt with below). Winters are expected to become significantly wetter on average and the frequency and intensity of Winter storms will increase. Summers will become significantly drier, but the intensity and frequency of Summer storms is expected to increase markedly. Summer storm rainfall will be more severe than in Winter. Intense Summer rainfall after droughts/dry periods will increase the surface/flash flood risk and peak river flows will increase (see climate data).

Flooding remains an increasing challenge as frequency and severity is projected to increase with climate change.

Flooding can generally be divided into river (fluvial), surface water (pluvial), tidal and groundwater. Pluvial flooding is a secondary impact of prolonged heavy rain or cloudbursts which can overwhelm rail drainage systems. Groundwater is where the geology is porous and acts as a sponge, or aquifer, which fills up in response to prolonged heavy rainfall, such as the chalk of the North and South Downs escarpments.

River and surface water flooding is the more common. Groundwater flooding only affects locations where the railway has been constructed in the floor of river valleys within chalk bedrock (e.g. at Shalmsford Street on the Ashford line) or has been placed in deep cuttings or tunnels within chalk bedrock (e.g. at Pangdean, Woodplace on the Brighton line and Higham-Strood Tunnel on HDR).

Flooding can cause minor damage to station and lineside buildings through entering the building and leakage of flat roofs, while the impact on structures can be more severe where increased scour occurs around bridge abutments. Except for those tunnels passing through the permeable chalk of the North and South Downs, water ingress and disposal is becoming an increasing challenge. Costly seepage interception systems are required as is the renewal of six foot drainage systems where their functionality has become compromised by track lowering schemes leading to repeated track flooding and service interruption.

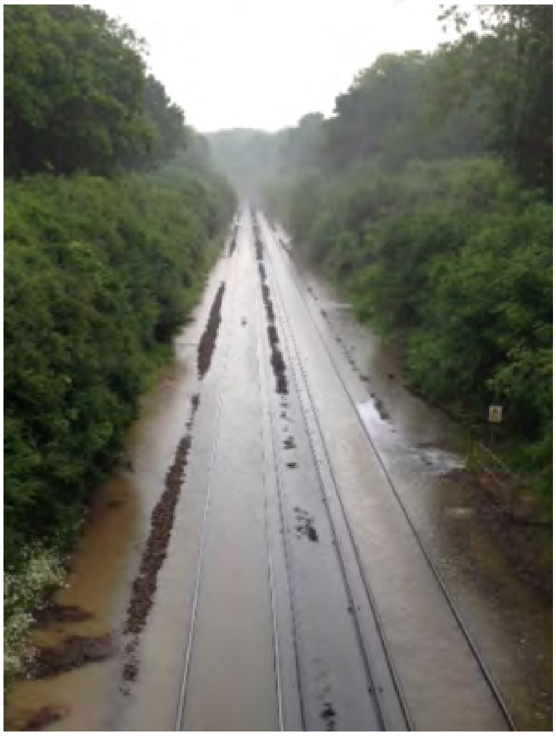
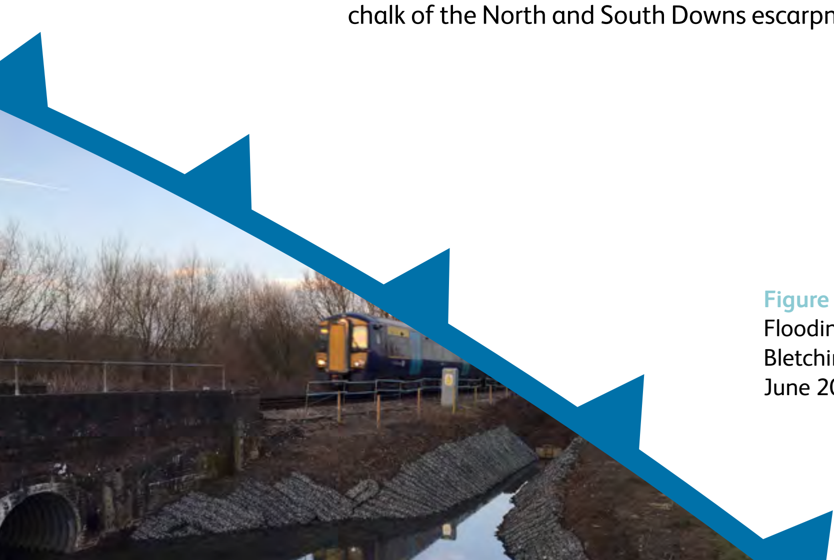


Figure 21
Flooding at Bletchingly – June 2016



Both signalling (S&T) and power (E&P) are vulnerable to damage to equipment from surface or groundwater flooding and measures are being taken to enhance the protection of sensitive equipment. Where possible equipment is being relocated away from locations prone to groundwater flooding, such as in Pangdean cutting. The relocation of Pangdean substation to the top of the cutting was completed in 2017.

The propensity for earthwork failure is raised during periods of wet weather and flooding through the raising of inter-granular pore water pressure, and mobilisation of material and through the physical removal of materials (e.g. scour). A further process experienced recently was the re-activation of sinkholes, both natural solution features and man-made chalk mines or 'dene holes'. The impact at one particular location (Newington) can be significant, especially when holes open in the track area. Our experiences were mirrored across southern Britain, which experienced a four-fold increase in reported collapses.

The following mitigations will reduce the impact from flooding:

- Raise sensitive equipment above flood levels,
- Develop, instigate and review Drainage Management Plans. These will be issued annually from 2019,
- Ensure cesses are kept clear to allow free discharge of floodwater caused by rising groundwater,
- Ensure 'six foot' carrier drains are fully functional and refurbished where necessary. A programme of inspection of the Route's drainage is currently underway associated with the Watford RAIB investigation report,
- Purchase standby pumps to alleviate minor flooding, and
- Incorporation of an additional 20 % capacity in drainage designs to allow for climate change.

Sea level rise

Sea level will rise along the South East Route coast with small variations depending on the location (see climate data). Storm intensity and frequency will increase. The risk of coastal erosion and defence overtopping will increase. Discharges to estuaries and the coast will become more difficult.

The impact of rising sea levels alone is not identified in terms of train delays. However, the Route has a number of coastal and estuarine sections which could become increasingly exposed to storm events as sea levels undergo a gradual rise. These include:

- Seasalter/Whitstable,
- Folkestone to Dover,
- Glynde Gap,
- Cooden Beach, and
- Arun Valley.

All of these locations benefit from various forms of coastal protection installed at the time of railway construction. However, in most cases these defences have been incorporated into ongoing coastal protection schemes carried out and maintained by the EA.

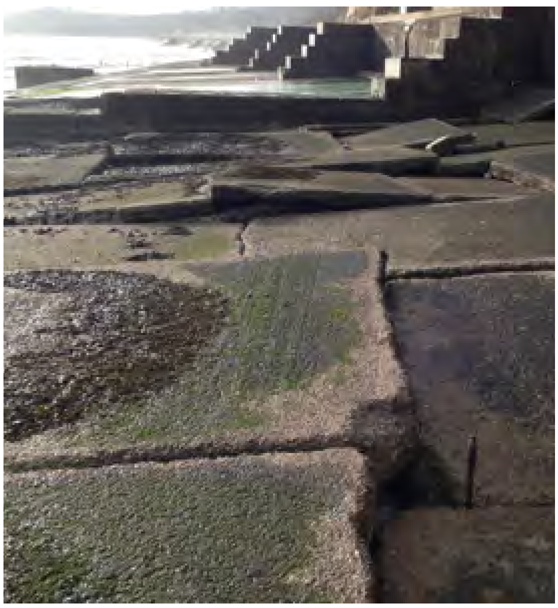


Figure 22
Damage to the sea defence at Folkestone Warren – 2014

South East Route impact assessment continued

The main exception to this is the coastal section between Folkestone and Dover where the railway was built at the foot of the sea cliff or within tunnels just behind the sea cliff. However, the railway is at an elevation such that it is not affected directly by storm conditions affording a delay between any damage to the sea defences and any impact on the safety of the line.

Scour caused a section of the seawall at Dover to collapse in December 2015 leading to a line closure until September 2016. £40m was spent on this location underpinning the line which effectively means the location now sits on a piled viaduct.

Storms on the south coast have caused recent overtopping of coastal defences at Bulverhythe, where shingle was washed on to the tracks causing minor delays to train operations.

There has been little direct impact from sea level rise on earthworks apart from the Folkestone Warren landslide, which falls within the coastal section between Folkestone and Dover. The impact here will be from accelerated ground movements caused by a combination of inability to maintain ground water lowering within the slipped mass and increased ground water entering the slip surfaces from the Folkestone – Dover chalk block behind. The landslip is extensively monitored.

The following mitigation will reduce the impact from sea level rise:

- Raising or strengthening of coastal defences,
- Maintain liaison with the EA and relevant coastal groups regarding Coastal, Estuarine and River Defence (CERD) plans, and
- Further coastal defence works to extend the life of the Folkestone Warren protective apron. This was last repaired in 2018.

Subsidence impact assessment

Between 2006/07 and 2018/19 subsidence related incidents accounted for an average of 22,941 delay minutes and £1.1m in Schedule 8 costs per year. This is 7.4 % of South East's annual average weather-related delay minutes and 9.1 % of the annual average cost.

Winters are expected to become significantly wetter on average and the frequency and intensity of Winter storms will increase. Whilst Summers will become significantly drier the intensity and frequency of Summer storms is expected to increase markedly. Summer storm rainfall will be more severe than in Winter (see climate data).

Many of the earthslip issues in Sussex and Kent have been remediated by the completion of both planned works and reactive remedial works. Those locations where emergency response was limited to removal of debris following the 2013/14 weather event will be fully remediated in CP6 to reinstate the earthworks back to their pre-failure condition with additional protection and mitigation measures included, as necessary.

The Route reissues its adverse and extreme weather plans every year which are used as a part of the EWAT process for the management of adverse or extreme weather events. In terms of earthwork stability, the plan makes use of the 'Earthworks Watch' system, which provides forewarning of conditions which could facilitate earthslips during extreme weather events. The system uses Soil Moisture Deficit and more recently Soil Moisture Index to identify times when earthslips are more likely. This helps with the management of resources required for checks on sensitive earthworks which have been subjected to intensive rainfall, so that the safety of the line is not compromised.

Remote condition monitoring has been trialled successfully on a number of our most vulnerable cuttings including at St Leonards, Hooley and Barnehurst. The Route intends on rolling out further remote monitoring during CP6 at 500 locations at a cost of £5.2m.

The Route has two major earthworks, at Folkestone Warren and at Hooley. Both of these locations are complex with long histories of issues and extensive monitoring. They are both subject to "expert eye" walkovers and the management of these locations is detailed in Major Earthworks Management plans.

The Route plans to spend £121m on earthworks and £40m on drainage throughout CP6. This will target earthworks based on assessed condition, safety risk and location, focusing on criticality 1 and 2 Route's where the consequence of failure is high. It will improve asset data, increase monitoring and intervene before the asset fails, using technology such as remote condition monitoring and remote sensing. This will reduce the likelihood of outside parties causing unexpected failures through drainage condition inspections and introducing more proactive maintenance.

The funding will also allow a gradual reduction in the number of earthworks prone to adverse and extreme weather failure. This total listed in Kent is currently 89 and in Sussex is 50. This is expected to drop by 10 by 31st March 2020.

Wind impact assessment

Between 2006/07 and 2018/19 wind related incidents accounted for an average of 61,759 delay minutes and £2.62m in Schedule 8 costs per year. This is 20 % of the South East's annual average weather-related delay minutes and 21.2 % of the annual average cost.

Wind is difficult to model into the future, so there are no projection figures, however the expected trend is for increased gust speeds and increases in the frequency and intensity of storms.

While our structures team have not reported any impact from high winds, the buildings team reported dislocation or damage to station canopies that have required immediate attention during storms.

The impact on signalling and power systems relates principally to damage to equipment from wind-blown debris and uprooted trees. Being almost exclusively third rail traction current supply, the South East Route is not as vulnerable to winds as those reliant on catenary (overhead line). However, debris caught up in the pantograph equipment on the train roof can be conveyed out of the Route leading to problems when entering OLE areas.

Line blockage from fallen trees and poor adhesion are the main issues to track, and serious damage to rolling stock has required removal from service for repair. In the last 5 years the adhesion issues have caused on average 47,000 minutes delay per annum and trees on the line have caused 23,000 minutes delay per annum.

The following mitigation will reduce the impact from high winds:

- Greater emphasis on the removal of trees within toppling range, including third-party trees with hazardous trees currently being identified by survey (to be completed by 2020); and
- New approaches the management of the lineside vegetation following the Vegetation Management Review by John Varley in 2018 will see identified trees and other vegetation managed to improve safety and performance whilst protecting and enhancing biodiversity with total of £15.3m will be spent managing lineside vegetation during CP6.

Figure 23
Fallen tree at Woldingham – February 2018

South East Route impact assessment continued

Lightning impact assessment

Between 2006/07 and 2018/19 lightning related incidents accounted for an average of 13,006 delay minutes and £0.59m in Schedule 8 costs per year. This is 4.2% of South East's annual average weather-related delay minutes and 4.8% of the annual average cost.

Lightning protection systems for buildings are generally adequate. However, one must be mindful of local changes, such as at Ashford depot, where the removal of lightning towers reduced the protection to the surrounding facilities.

Power systems can be tripped out by lightning surges, but this is currently managed by adequate supply protection arrangements. The main issue is in the cost of recovery, the capital cost of restoring Continental Junction after a recent lightning strike was around £0.8m.

The following mitigation will reduce the impact from lightning:

- Improved earthing arrangements – carried out under the SIN119 programme, and
- Rapid response to reinstate damaged signalling or power equipment.

Adhesion impact assessment

Between 2006/07 and 2018/19 adhesion related incidents accounted for an average of 37,968 delay minutes and £1.71m in Schedule 8 costs per year. This is 12.3% of South East's annual average weather-related delay minutes and 13.9% of the annual average cost.

Changes in the rainfall and temperature patterns will alter the growing season by lengthening it and therefore, changing the timing of Autumn. Increased storminess may also remove more leaves at additional times of year. These may change the pattern of leaf fall.

In the last 5 years the adhesion issues have caused on average 47k minutes delay per annum and trees on the line have caused 23k minutes delay per annum. This equates to approximately £7m of delay costs per annum.

It is difficult to pinpoint locations which are severely affected by adhesion, as often the worst cause of delays is the reactionary impact. Safety incidents are a far greater risk from contamination on the line than delay minutes, and this is what the Route attempts to mitigate.

Adhesion loss can be caused by leaf mulch, snow, ice, or heavy dew creating contamination on the line. The train loses traction as it passes over the contaminated track and this can result in a variety of incidents such as:

- Station overshoots – in case of severe contamination, the train may not have sufficient friction between the wheel and the rail to brake in time, resulting in it slipping past a station,
- Wrong side track circuit failures (WSTCFs) – contamination of the railhead may prevent the wheel and the rail from touching, effectively causing the train to 'disappear' from the signalling system as the circuit is broken, and
- Signals Passed At Danger (SPADs) – again, this occurs when a train cannot gain enough traction to stop at a red signal and slips past it; this is a particular risk at junctions and level crossings, where a train being unable to stop at a red signal could cause a collision with an oncoming train or car.

Contamination caused by leaf mulch is most effectively mitigated by removing the source of the issue, i.e. clearing lineside vegetation. This has been seen to have a direct impact on the number of safety incidents encountered on the Route. For instance, 2017 and 2018 were particularly successful years for vegetation management in the Kent and Sussex area resulting in a reduction in station overshoots and wrong side failures.

Several forms of mitigation need to be in place to combat the issue of adhesion. Vegetation is one that has already been mentioned, other forms include:

- Running treatment trains (multi-purpose vehicles and railhead treatment trains) which water jet the tracks and 'wash off' any contamination build up. MPVs also lay sandite, a gluey sandy substance, in some locations which helps trains gain traction. It is important to run these trains before the start of service where possible, to remove any build up from the previous night,
- Maintaining assets on the network to ensure that they can be relied upon. Work is ongoing in conjunction with re-signalling schemes to fit axle counters where possible as these aid train detection,
- Working with train operating companies to; run longer formations where possible, terminate late running trains early to minimise the impact of reactionary delay during Autumn and train drivers to drive to conditions experienced on the track and report when they experience low contamination,
- Installation of traction gel applicators where there are known issues with adhesion,
- Installation of intelligent infrastructure which allows for targeted jetting and remote monitoring of track circuits, and
- The gradual replacement of track circuits with axel counters.

A comprehensive strategy has been put together for CP6 to ensure that once sites are cleared, they do not become an issue again.

Previously, the South East Route only used multi-purpose vehicles (MPVs) to treat the tracks but now uses six rail head treatment trains (RHTTs). Not only does this greatly enhance the resources available to us, but it is also believed that RHTTs are more effective than MPVs in clearing contamination off the track due to the higher pressure water jetting sprays and their larger water capacity, meaning they can run for longer. We therefore expect to see adhesion having a greatly reduced impact on the Route this year. Train operating companies also make minor changes to their timetables during Autumn to allow for treatment trains to run on the network, and also to reduce the impact of reactionary delays.

New weather systems are also going to be used to forecast low adhesion, taking into account factors such as vegetation, microclimates, and dew or the 'wet rail syndrome'. These will help to understand where our resources and efforts to mitigate adhesion should be focused.

Fog impact assessment

Between 2006/07 and 2018/19 fog related incidents accounted for an average of 44 delay minutes and less than £0.03m in Schedule 8 costs per year. This is less than 0.1 % of South East's annual average weather-related delay minutes and less than 0.1 % of the annual average cost.

Fog is more difficult to model than the other weather parameters referenced in this plan and UKCP09 does not provide modelled projections in its User Interface. An additional report did however provide some low confidence seasonal projections. Spring, Summer and Autumn will see significant reductions in fog days, whilst Winter will see a small increase.

Fog is not expected to become an increasing problem as current controls are considered adequate for now and the future.

The Route has implemented a programme of installation of LEDs within signalling systems from CP5 and VTB will shortly have all LED signals. LED signals are easier to see in foggy conditions.

South East Route WRCCA actions

As the impacts of weather events are location specific South East 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 South East Route in this by providing asset policies and design standards that have weather resilience and climate change considerations embedded within them, by carrying out root cause analysis of national weather and asset data and through the review and adoption of appropriate new technologies.

This section summarises the WRCCA actions undertaken by the South East 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 3), and
- WRCCA actions planned for CP6 (Table 4).

The third table, Table 5, contains potential additional actions that the South East 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 South East Route, in the Defra NAP. Some of these will align with CP6 planned and funded actions (Table 4), some will align with the actions in Table 5 and others will require further consideration in CP6 and beyond.

Table 4 and Table 5 cross reference with Table 6 to indicate the relationship between the South East Route actions and the delivery of the NAP actions.

Table 3
2014 WRCCA Plan CP5 actions review

Action name	Target completion date	Actual completion date	Comments
Level of engagement with flood risk management authorities is not supporting effective discussions	2015	Ongoing	Improvements made to liaison between the EA and NR facilitated by our Asset. Protection team with access to Route Asset experts to ensure EA work can proceed unhindered.
Improved Weather Alert and Information System	2015	2015	Network Rail Weather Web system in operation and allowing advance warning and mitigation of weather events.
Earthworks Remote Condition Monitoring pilot	2015	Ongoing	Route is not part of the national trial, but has 9 locations monitored by trial RCM.
Works on Folkestone Warren sea defences	2019	2018	Works completed to repair the sea defences at Folkestone Warren
Balcombe Tunnel Junction	Additional	2018	Works completed to improve the drainage around Balcombe Tunnel North Portal.
Stoats Nest Jn : Earlswood	Additional	2017 - 2019	Optic Fibre monitoring installed. Flyover Cutting Drainage improvements ongoing.
Weather review following 2013/14 wet weather event	Additional	2015	Carried out by Arup and focussed on some of the human impact of the event.

Table 4
Planned WRCCA investment for CP6 (2019 to 2024)

Vulnerability	Location	Action to be taken	Cost of action	Expected benefit	Target completion date	Resilience change	NAP action reference
Rain	Various	Earthworks Remote Condition Monitoring	£5.2m	Reduction in risk and delay minutes (not quantified) associated with earthslip	31/03/24	Better warning of landslips	NRNAP4
Wind	Route	Vegetation Inspections	£0.2m	Reduction in risk and delay minutes (not quantified) associated with trees on the line	31/03/21	Identification of dead, diseased or dying trees before they fall.	-
		Vegetation Removal	£15.3m		31/03/24	Sustainable management	-
Rain	Route	Reduction in number of Adverse and Extreme Weather sites	Part of £112m earthworks funding	Additional resilience to weather events	31/03/20	Reduction in number of sites from 139 to 129	-
Staff	Route	Improvements to reduce risk to staff from extreme weather conditions	-	Reduction in absence due to sickness and non-lost time and lost time injuries	31/03/24	-	-

Table 5
High priority actions not funded in CP6

Vulnerability	Location	Potential action	Target completion date	Predicted benefit	NAP reference
Flooding	Shalmsford Street (Chartham)	Continue drainage resilience works	2019	Reduction in line closures and flooding delay minutes	-

Table 6
NAP actions

Objective	Action	Timing	NR 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.

South East Route management and review

The Weather Resilience and Climate Change Adaptation Plan will be reviewed annually at the Director of Route Asset Management Periodical Business Review. Significant weather events may prompt an interim update to the plan, but it is expected that the next full update will be in CP7 (2024).

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