2019 – 2024

Western

Route CP6 Weather Resilience and Climate Change Adaptation Plans

Contents

Purpose of this document

This document defines the Western 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.

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

Director of Route Asset Management statement

Over the last decade Western Route has faced periods of major service disruption and infrastructure damage at multiple locations resulting from the effects of extreme weather.

The vulnerability of the Route to weather-induced disruption continues to be at an elevated status and weather-related issues at locations such as Dawlish and the Somerset Levels have become nationally totemic symbols of the vulnerability of the rail network to weather-related issues.

Following a programme of major resilience works in CP5, the start of CP6 sees Western Route continue to be focused on delivering significant and long-term improvements in infrastructure resilience and service recovery in response to both extreme weather events and the strategic changes brought about by climate change. Several long-term programmes, including work to increase the resilience of the railway between Dawlish and Teignmouth, continue to be developed and implemented. However, the primary strategic approach adopted in CP6 is to ensure that consideration of weather resilience is incorporated into the remit of all projects is being delivered across the Route.

The following report documents the effects of extreme weather and climate change on Network Rail infrastructure and demonstrates the close working relationships Network Rail has made to manage extreme weather and climate change risks with the Environment Agency and Local Government organisations in the Thames Valley, the West Country and the South West Peninsula.

Tim Laverye
Director of Route Asset Management –
Western Route – November 2019

Executive summary

Adverse and extreme weather events can cause significant damage to rail infrastructure, the effects of which can cause major disruption to the operation of train services.

The UK Climate Change Projections 2018 (UKCP18) indicates the continuation of the shift to a warmer climate, significant changes in sea level and an increase in intensity of precipitation across the year. The frequency and intensity of adverse and extreme weather events are expected to increase causing additional stress to our infrastructure.

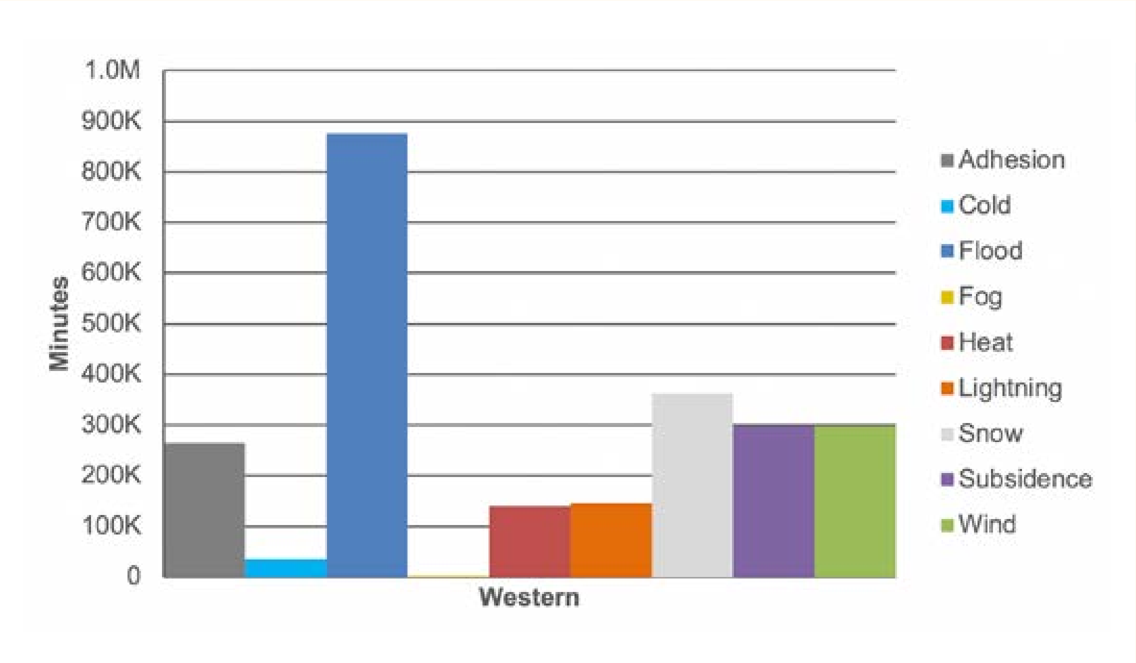
With a renewed focus on train performance and passenger experience through the 'Putting passengers and freight first' initiative, it is critical that the vulnerabilities of rail assets to weather events and potential impacts from climate changes are understood and addressed in order to maintain a performing and resilient railway system; as such, Western Route is fully and firmly committed to delivering our weather and climate change adaptation action plan through CP6 and beyond.

The CP5 WRCCA plan saw successful development and implementation of weather resilience and climate change adaptation schemes, including:

- Large scale flood resilience projects,
- Network Rail Weather System (NRWS),
- Training and equipment provision for maintenance teams,
- Increased use of suitable technology including Remote Condition Monitoring (RCM) in earthworks and track monitoring, and
- Strengthening of relationships with the Environment Agency and other 3rd party bodies.

We have developed an understanding of our risks by assessing our weather-related vulnerabilities (Figure 1) and identified root causes of historical performance impacts.

Figure 1
Western Route weather attributed delay minutes 2006/07 – 2018/19



Western Route's CP6 WRCCA plan will build on the development of the CP5 plan noting a fundamental change of delivering the majority of actions through 'Business As Usual' (BAU) activities. Using the predictions of UKCP18, focus will be given to improving and updating vulnerability assessments and the delivery of appropriate works – including vulnerability of structures to coastal and estuarine scour; earthworks to high and persistent rainfall in addition to heat and prolonged dry periods, and trees and consequential tree strike from high winds. 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 Network Rail WRCCA strategy and guidance.

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

Introduction

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

Weather events such as extreme rainfall, wind, snow and high temperatures reveal the vulnerability of the rail network and the severe impact these weaknesses in resilience has on train services and our resources as detailed throughout this report.

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

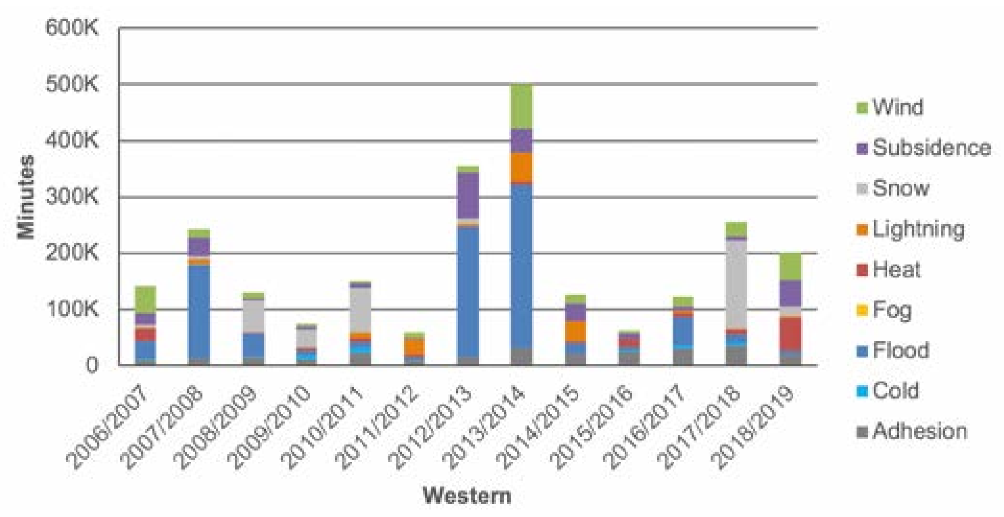
Weather-related costs can also be captured within Schedule 4 payments, compensation to train and freight operators for Network Rail's possession of the network, and capital expenditure required to reinstate the asset.

In the past 13 years (2006/07 to 2018/19) the average annual number of delay minutes attributed to weather for the Western Route network was 176,923.

The impacts of severe weather events on the Western Route can be clearly seen in Figure 2, for example:

- Snowfalls of 2009 through to 2011 and 2017/18,
- Wind in a number of years, but particularly 2013/14,
- Severe flooding in 2007/08, 2012/13 and 2013/14,
- Subsidence in events in 2012/13, and
- Heat impact in 2018/19.

Figure 2
Delay minutes across 13 years (2006/07 – 2018/19) with relation to weather type



The costs, in addition to the wider socio-economic impacts, justify Network Rail's enhanced investments to increase weather resilience. The interdependencies within transport and infrastructure systems similarly justifies Network Rail's continued efforts to improve collaborative understanding of the wider impacts of weather-related events and our role in supporting 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 3 illustrates the projected changes in frequency and severity of Atlantic winter storms.

Historical temperature records indicate that a significant, relatively recent shift in climate has occurred. The Hadley Centre Central England Temperature (HadCET) dataset is the longest instrumental record of temperature in the world, Figure 4 clearly shows a rising trend in temperature over the past century.

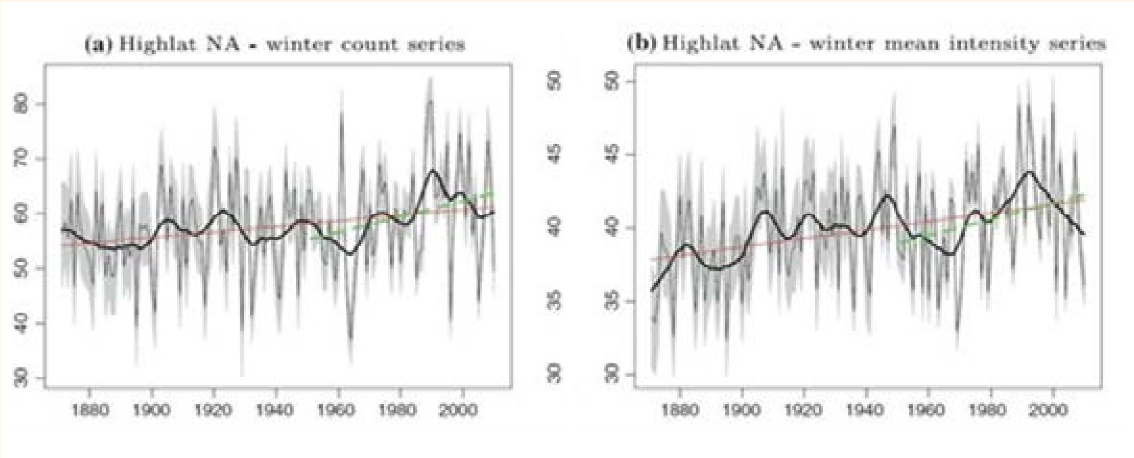


Figure 3
Intensity and frequency of high latitude Atlantic winter storms[1]

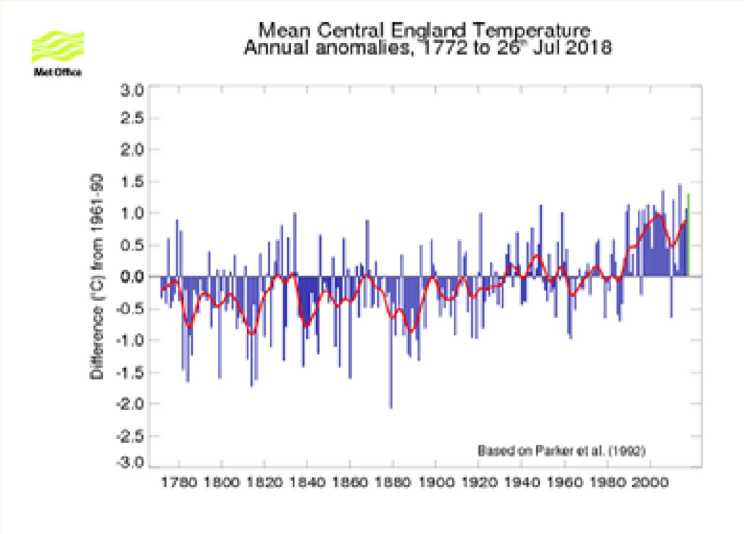


Figure 4
Mean Central England Temperature record[2]

[1]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.
[2]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

To ensure a consistent approach to WRCCA consideration and action across Network Rail an iterative framework of key management stages is used (see Figure 5). The same framework has been applied to develop this Route WRCCA plan.

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.

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

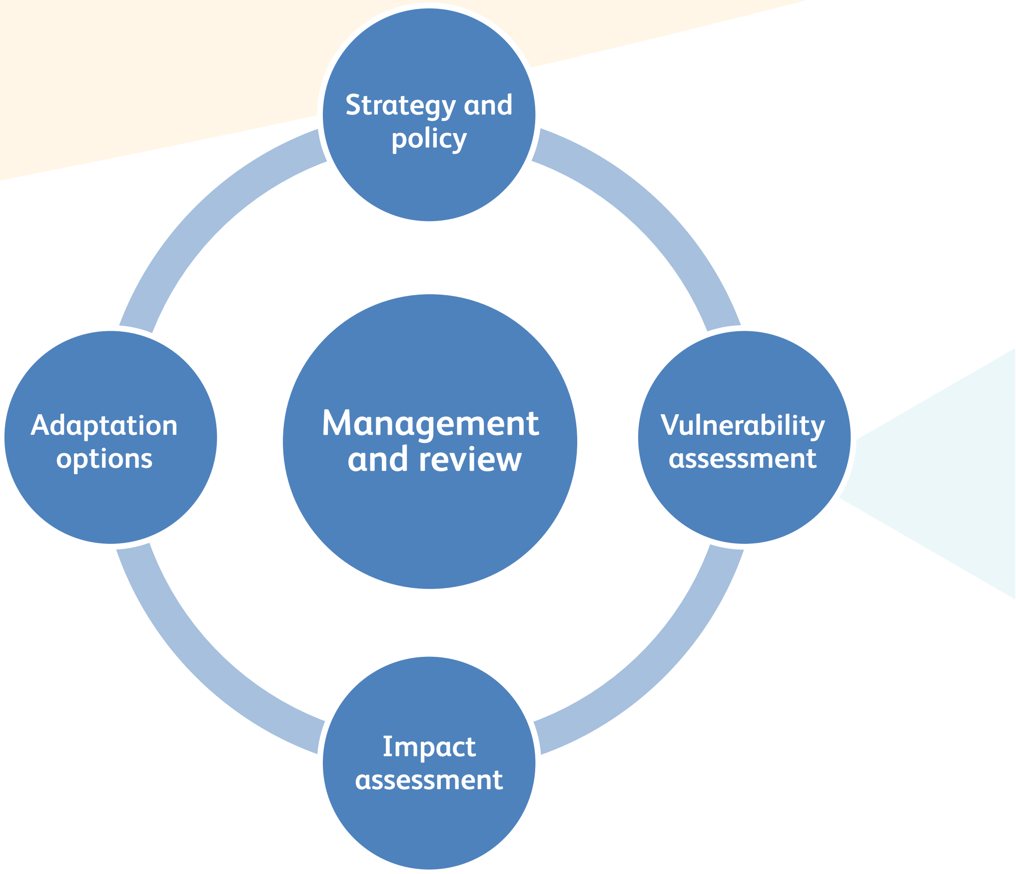


Figure 5
Weather resilience and climate change adaptation framework

Climate change projections

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[3]

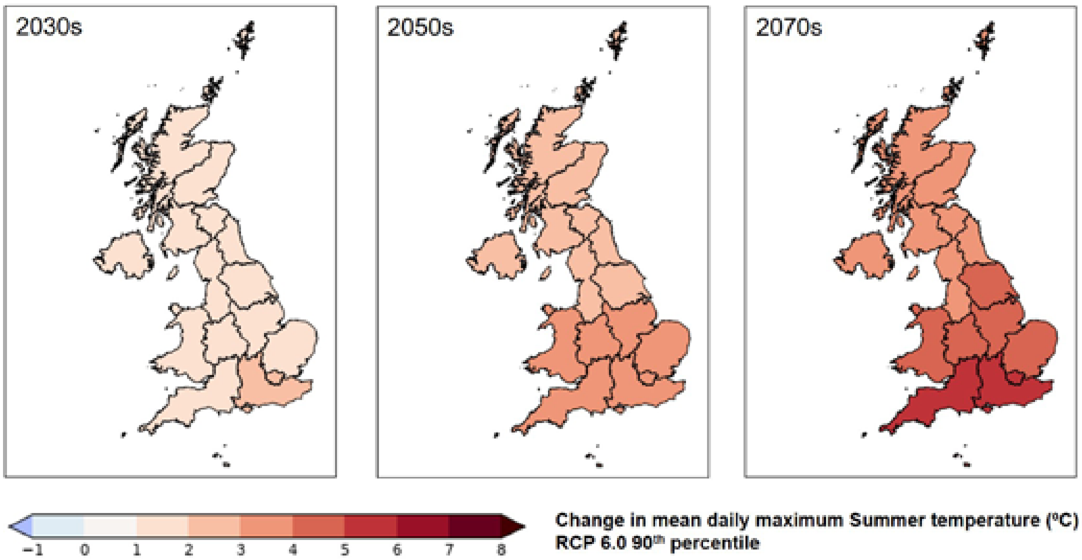
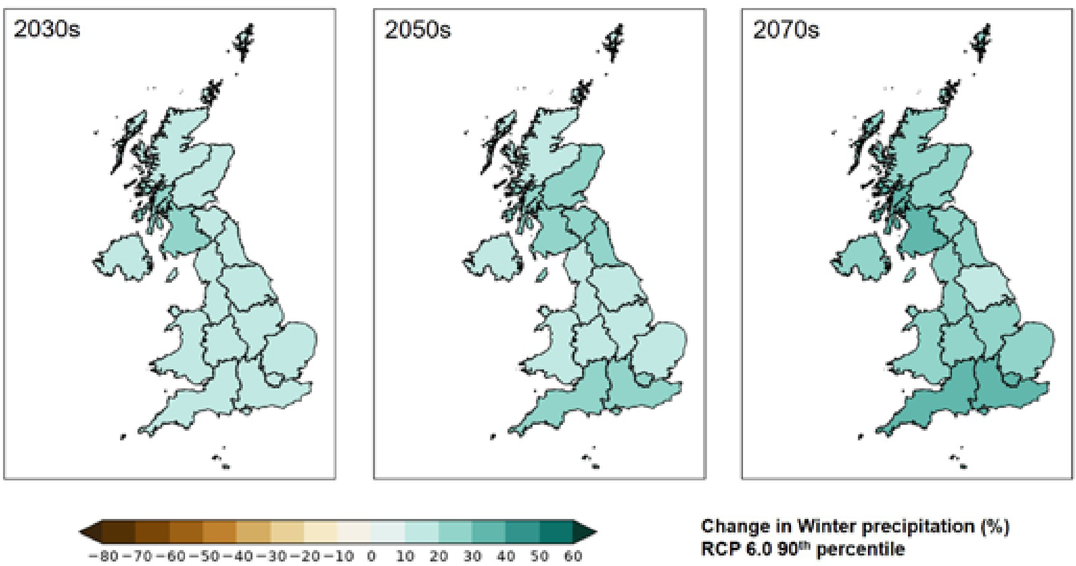


Figure 7
Change in winter precipitation (%) (left to right; 2030s, 2050s and 2070s) based on a 1981-2000 baseline[4]



[3]© UK Climate Projections, 2018.
[4]© UK Climate Projections, 2018.

Climate change projections continued

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. Of these the most critical to Network Rail and the Western 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 Assessments (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 considering 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[5] 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 evaluation 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.

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 Western Route, are included in the Western Route WRCCA Actions section of this Plan.

It must be noted that climate change projections include inherent uncertainties, associated with natural climate variability, climate modelling and future emissions, and these uncertainties increase with downscaling to local levels; however, the projections can be used by Network Rail to provide a direction of where the UK climate is heading, and the Route Weather Resilience and Climate Change Plan (WRCCA) uses these projections to support the prioritisation of weather resilience actions.

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

Future climate change vulnerability

The relationship between weather events and climate is complex, Network Rail must therefore, use the climate projections to understand the risks from future weather and make informed strategic decisions to weather resilience.

UKCP18 provides regional climate change projections across 13 administrative regions in Great Britain, Figure 8. The South West England region of UKCP18 is predominantly representative of Western Route but the London 'Thames Valley' end of the Route falls within the South East England region. Projections for these two areas are considered to be representative of the future climate changes within the Route.

In the 2014 Plan charts were generated using the UKCP09 High emission 50th percentile probability scenario for the two 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 associated narrative have been updated to match the current Network Rail climate change planning projections. that uses the updated climate projections (UKCP18) where available. UKCP18 moves to a new 1981-2000 baseline and new future 20-year average time periods (2030s, 2050s, 2070s) with comparable climate scenarios RCP 6.0 for Network Rail's Primary Climate Change Scenario and RCP 8.5 for the Higher scenario for temperature and precipitation variables, For UKCP18 sea level rise data, RCP 4.5 and RCP 8.5 are used as Network Rail Climate Change Scenarios Primary and Higher respectively. RCP 4.5 is used in place of RCP 6.0 (which is not available) and the future time periods are shown as up to that year (e.g. by 2050) rather than 20-year averages. Sea level rise (in cm) is expressed as the 95th percentile that shows the higher end of the range projected for each location.

Figure 8
Map of UK administrative regions used in UKCP18[6]

[6]Source: 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]

Climate change projections continued

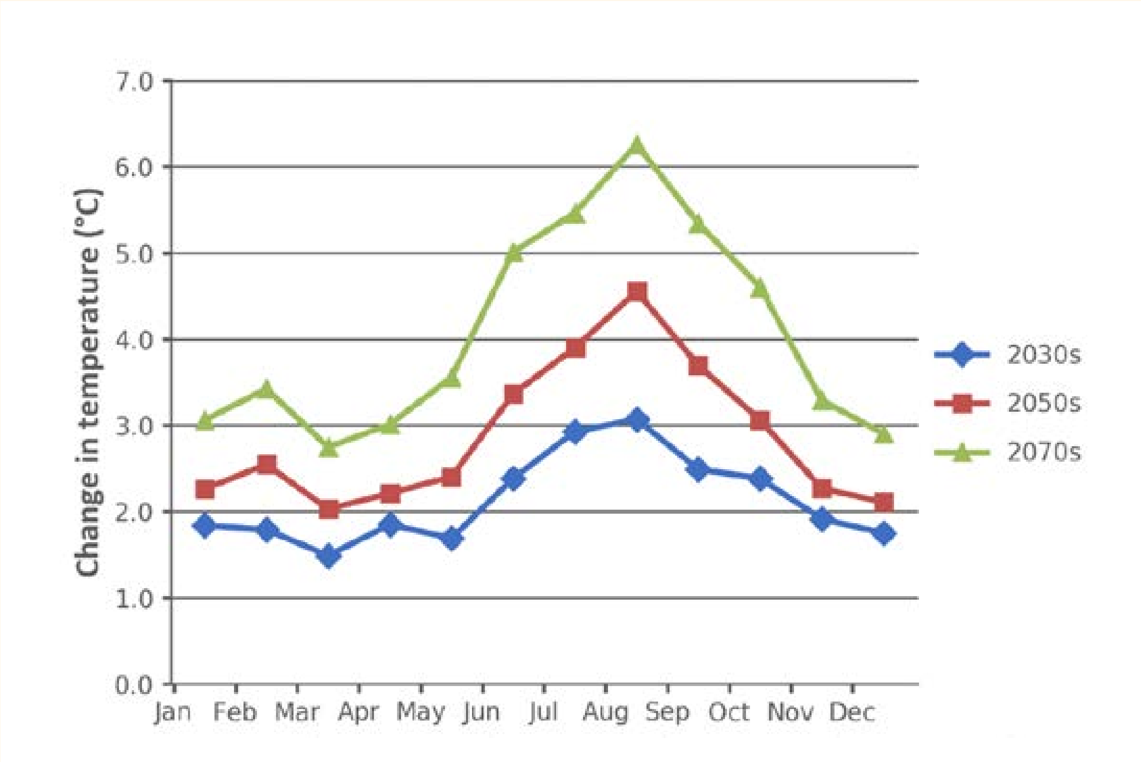
Mean Daily Maximum Temperature change

The mean daily maximum temperature for both regions 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.

South East England

The highest mean daily maximum 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.

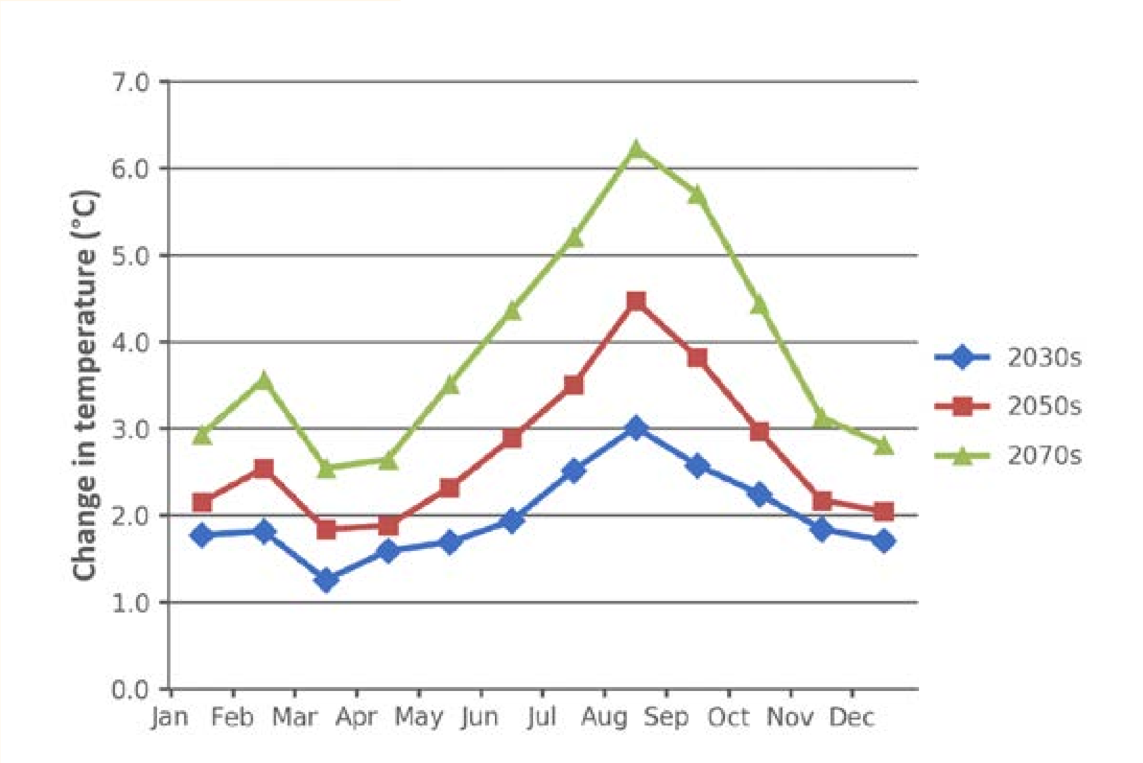
Figure 9
South East England, mean daily maximum temperature change (˚C), (RCP 6.0 90th percentile)



South West England

The highest mean daily maximum summer temperatures are expected to be in August for both the 2050s and 2070s, with increases of 4.5°C to 25.0°C and 6.2°C to 26.8°C respectively. In winter the highest mean temperatures will be seen in December for the 2050s, with increases of 2.0°C to 10.4°C and February by the 2070s with increases of 3.6°C to 11.3°C respectively.

Figure 10
South West England, mean daily maximum temperature change (°C), (RCP 6.0 90th percentile)



Climate change projections continued

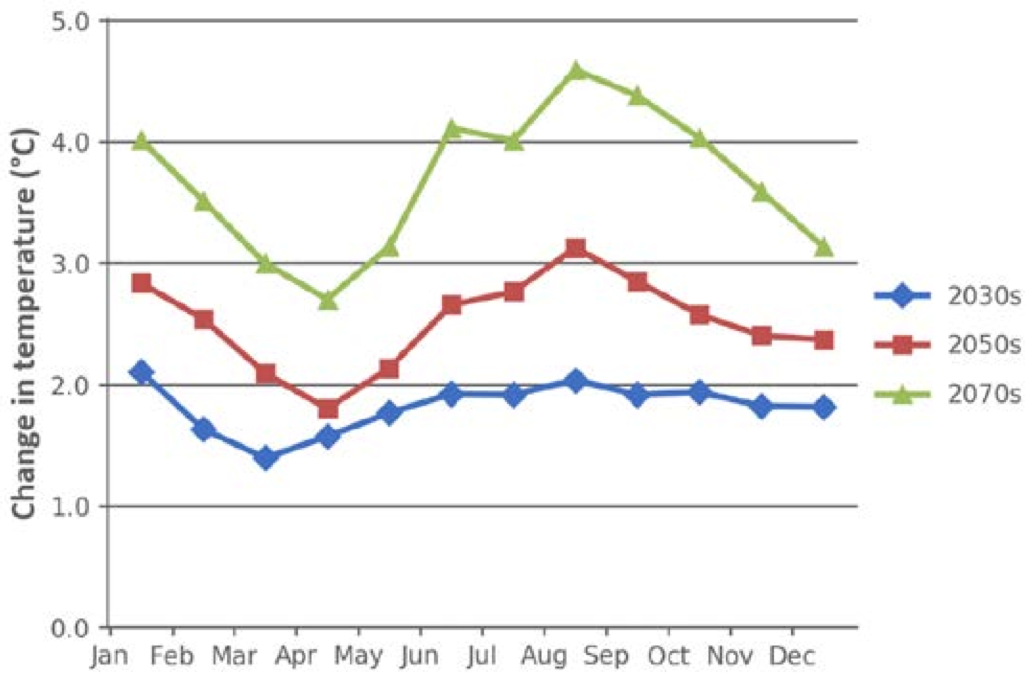
Mean Daily Minimum Temperature change

The mean daily minimum temperature for the regions 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.

South East England

The highest mean daily minimum temperatures for summer are expected to be in August, with an increase of 3.1°C to 15.0°C by the 2050s and increase of 4.6°C to 16.5°C by the 2070s. The lowest mean minimum temperatures will still occur in February with expected increases being 2.5°C to 3.6°C by the 2050s, and by 3.5°C by the 2070s to 4.5°C.

Figure 11
South East England, mean daily minimum temperature change (°C), (RCP 6.0 90th percentile)



South West England

The highest mean daily minimum temperatures for summer are expected to be in August, with increases of 2.9˚C to 14.7˚C by the 2050s and an increase of 4.5˚C to 16.3˚C by the 2070s. The lowest mean minimum temperatures will still occur in February with expected increases being 2.7˚C to 4.3˚C by the 2050s, and 3.8˚C by the 2070s to 5.5˚C.

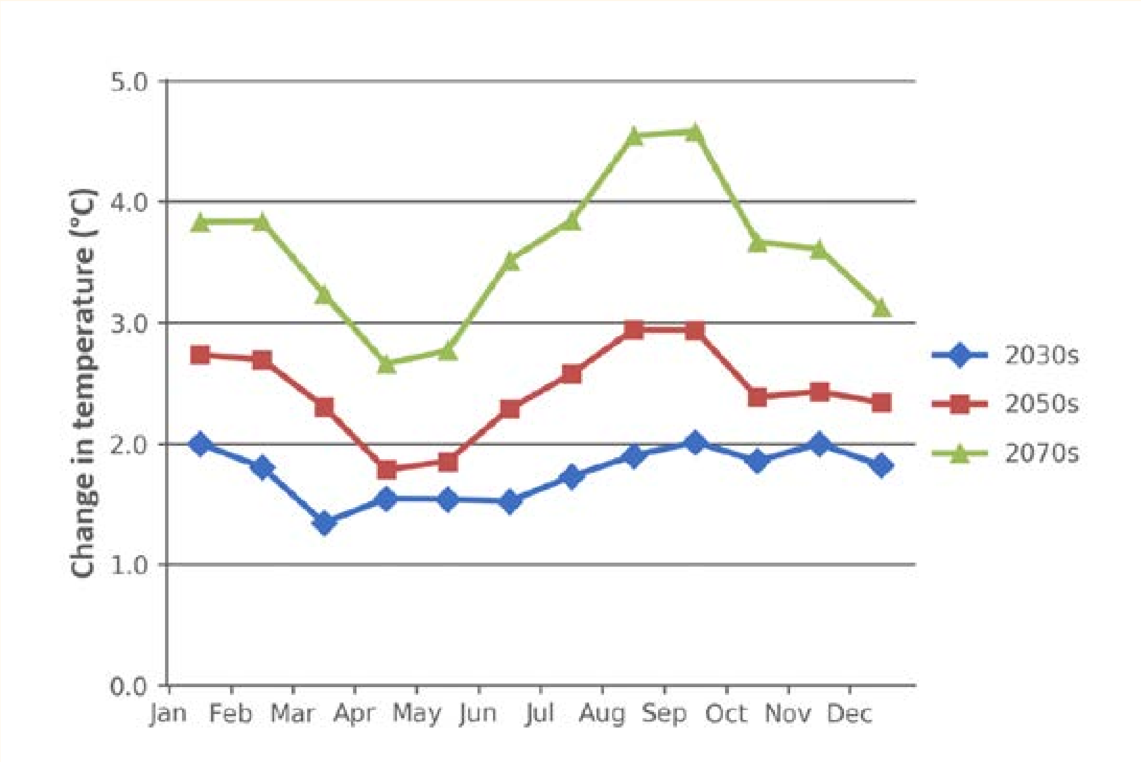


Figure 12
South West England, mean daily minimum temperature change (˚C), (RCP 6.0 90th percentile)

Climate change projections continued

Mean daily precipitation

The UKCP18 narrative for mean daily precipitation in the regions 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 it does not illustrate the highest potential summer rainfall reductions. These are best represented by the RCP 6.0 10th percentile projections Figures 13 and 14 therefore plot the RCP 6.0 50th percentile projections with error bars that indicate the wider range of change associated with the 10th and 90th percentiles.

South East England

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.

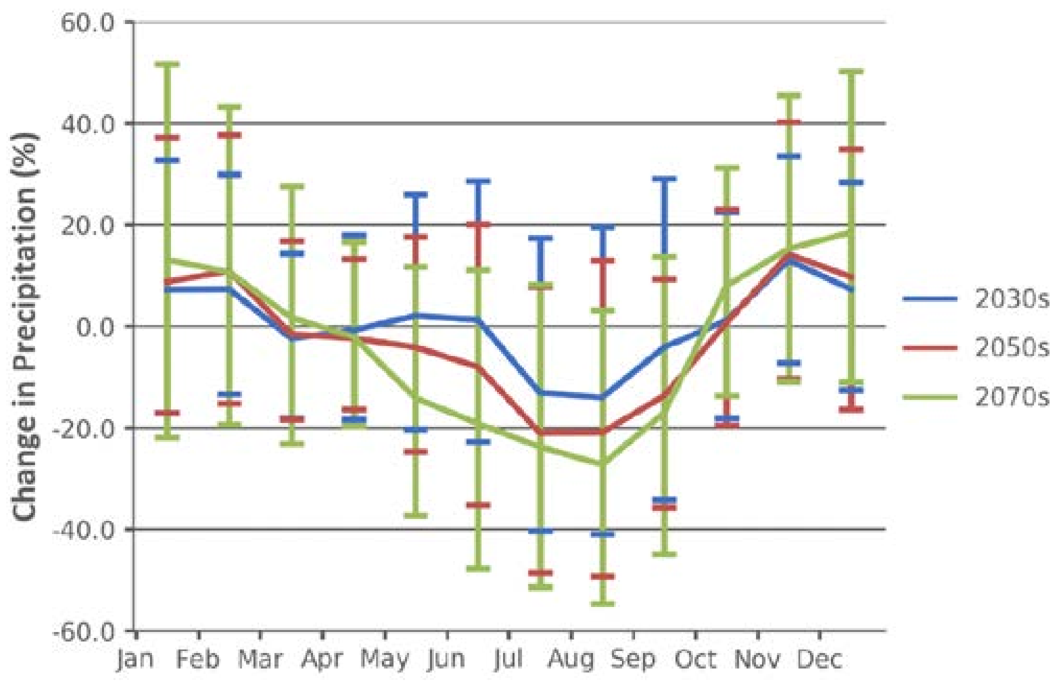
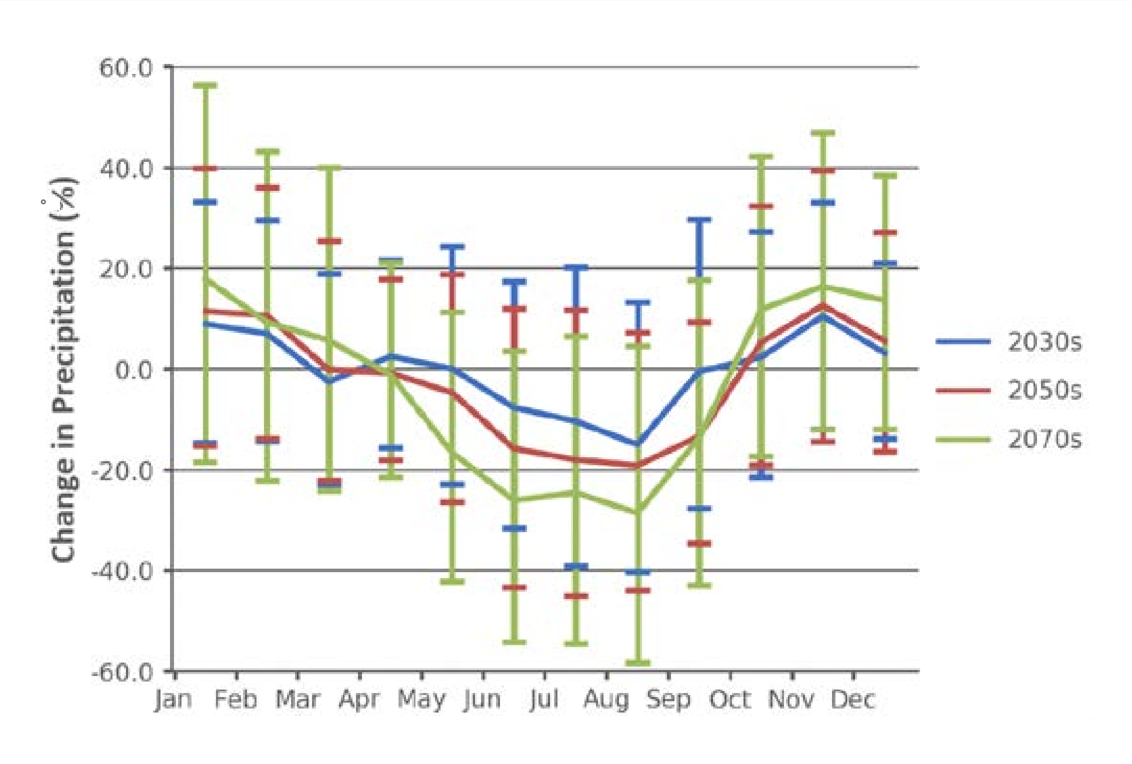


Figure 13
South East England, mean daily precipitation change (%), (RCP 6.0 50th percentile with the wider range showing the 10th and 90th percentiles)

South West England

In the 2050s and 2070s December will be the wettest month with daily rainfall increases of 27.2 % to 5.4mm/day and 38.4 % to 5.8mm/day respectively. The driest month will be July showing decreases of 45.1 % to 1.0mm/day by the 2050s and 54.5 % to 0.8mm/day by the 2070s.

Figure 14
South West England, mean daily precipitation change (%) (RCP 6.0 50th percentile with the wider range showing the 10th and 90th percentiles)



Climate change projections continued

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 Environment Agency 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 Western Route area should be increased by 10 % for the 2050s and 20 % for the 2080s. Climate uplifts[7] for river flows are provided by river basin and those relevant to the Western Route are shown in Table 1.

Table 1
River flow uplifts (UKCP09)

River basin	2050s uplift	2080s uplift
Thames	25 %	35 %
South West England	30 %	40 %

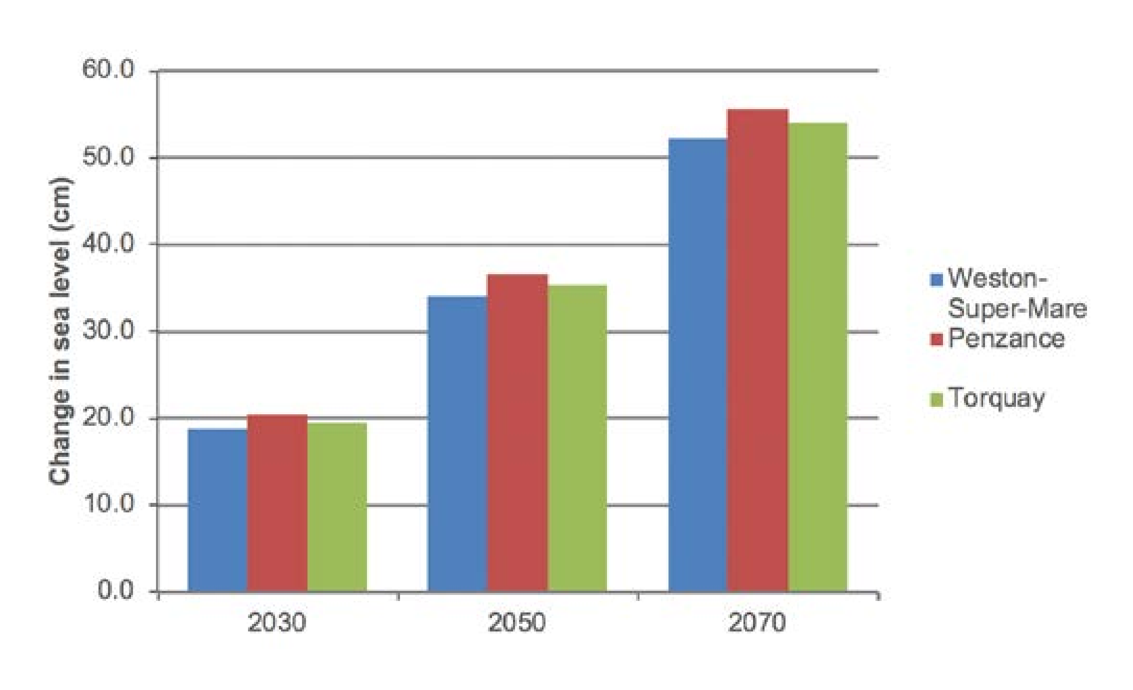
Sea level rise

Sea level varies around the coast which will also affects the degree of sea level rise. UKCP18 projections have been obtained for coastal locations covered by the Western Route[8].

South West England

Penzance will see the highest rises by 2050 and 2070 of 36.5cm and 55.6cm respectively and Weston-Super-Mare will see the lowest at 34.1cm and 52.2cm.

Figure 15
Sea level rise projections for South West England (cm) (RCP 4.5 95th percentile)



[7]Environment Agency higher central climate change estimate as the most comparable to Network Rail's climate change planning scenario.
[8]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.

Western Route vulnerability assessment

Network-wide weather vulnerability

The rail network and its component assets are sensitive to the effects of several 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 – Figure 16.

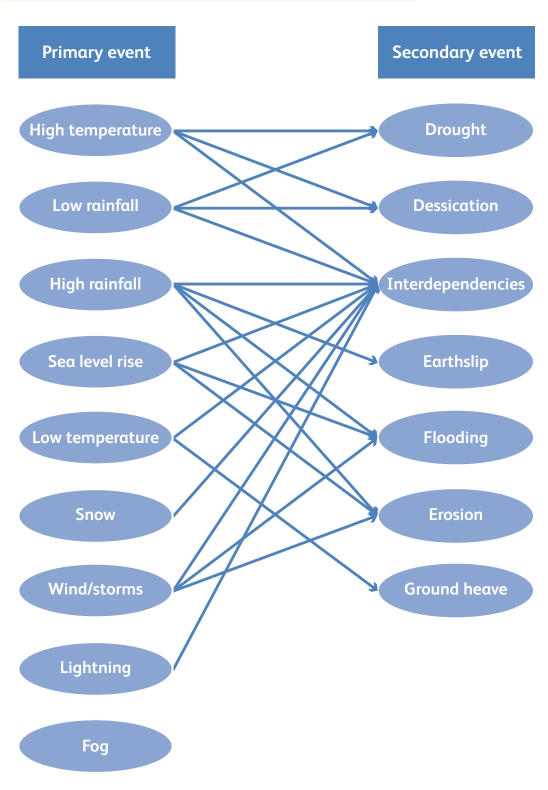


Figure 16
Diagram showing the link between primary weather events and secondary event consequences

Managing an intricate array of assets of varying ages, condition and weather vulnerabilities across a wide range of bio-geographic regions in a variety of climates is a complex challenge for Network Rail, additionally so when considering interdependencies with other infrastructure sectors e.g. power and telecoms.

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

We have monitored the impact of weather on the performance of our network and analysed this data to understand:

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

Western Route vulnerability assessment continued

Performance impacts

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. 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.

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

Figure 17
Network wide potential consequences of weather-related hazards (NR/L2/OPS/021, 2019)

Flooding/High seas (Topping)/Heavy Rain	a) Obstructions on the line b) Scour action c) Land-slide, slope failure or washout d) Inundation (flooding), including equipment failure e) Sea spray f) Erosion
Ground Saturation	a) Surface water flooding b) Land-slide, slope failure or washout c) Erosion
High Wind Speeds	a) Overhead line damage b) Structural damage, including station roofs and canopies c) Fallen trees (or parts therof) d) Leaf fall (includes railhead contamination and loss of Track Circuit Detection [wrong side failures]) e) Debris f) Shifted load or loose sheeting
Railhead Contamination	a) Category A SPAD b) Station over-run c) Low rail adhesion d) Loss or Track Circuit Detection (wrong side failures) e) Rail/wheel defects
Extremes of temperature	a) Rail buckles b) Track circuit failures c) Point failures through loss of detection, especially switch diamonds d) Overhead line sag e) Overheating relay rooms f) Swing bridge expansion g) Rock-fall resulting from prolonged periods of cold weather
Thunderstorms/lightning	a) Failure of electrical and electronic equipment b) Structural/tree damage c) Lineside fires
Fog/Mist/Low Level Ground Cover	a) Signal passed at danger b) Level crossing collision
Snow/Hail/Ice/Frost, including Freezing Rain and Freezing Fog	a) Points failure b) Signal failure c) Structural/tree damage d) Ground heave during extended periods of low temperatures e) Icing of electrical equipment, including conductor rails and OLE f) Icicles, including in tunnels g) Signal passed at danger h) Level crossing collision i) Platforms or walkways covered by snow or ice j) Track circuit failures at level crossings caused by applications of road salt
Long Periods of Dry Weather	a) Desiccation (shrinkage) of sensitive clay embankment from moisture removal leading to serviceability issues with formation and track b) Lineside fires – Fires on land/premises adjoining the railway – Fires resulting from the operation of steam locomotives

Route weather vulnerability

Western Route, along with the rest of the UK has experienced a number of significant weather events since publishing the CP5 Weather Resilience and Climate Change Adaptation action plan. Following several years of extreme winters involving the largest average winter rainfall for over a hundred years, the annual rainfall in the previous 3 years throughout the UK has been below the 1981-2010 average. CP5 ended with one of the hottest summers on record with a mean temperature of 15.75°C across the UK.

UK – Mean temperature – summer

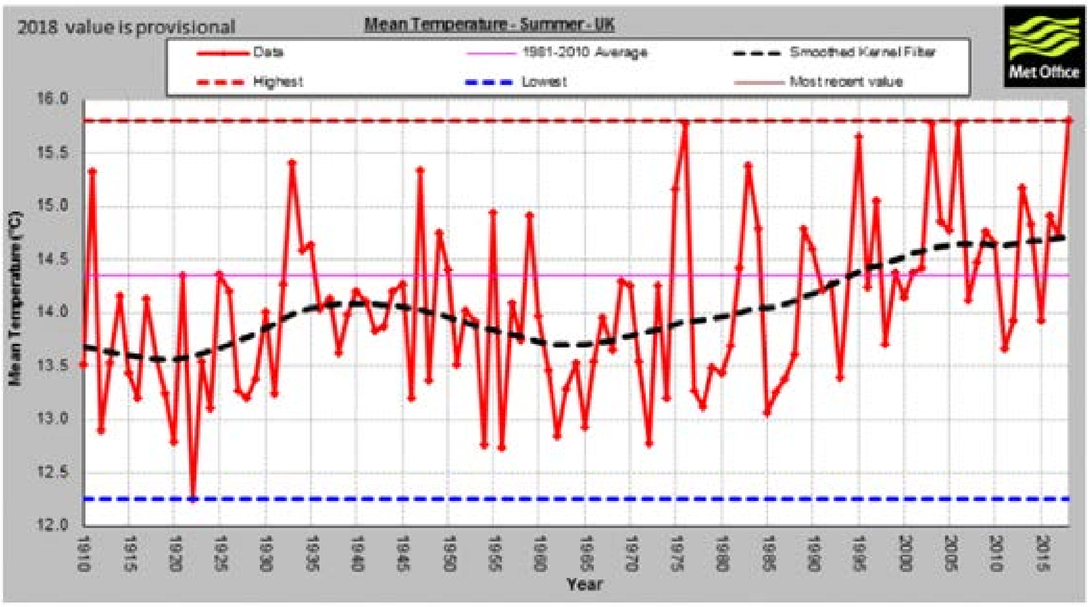


Figure 18
Graph showing the change in mean temperature in the UK during the summer months 1910–2018[9]

[9]Met Office, 2019, Climate graph, https://www.metoffice.gov.uk/datapoint

Western Route vulnerability assessment continued

Prior to CP5, flooding was by far the Route's primary weather vulnerability; however, over the last 5 years, the effect of flooding has been considerably less. In terms of delay minutes, snow has been the greatest vulnerability of the Route between 2014/15 and 2018/19, with over 100,000 minutes in 2017/18 alone, attributed mainly to the 'Beast from the east'. The record-breaking summer of 2018 showed the challenges faced by prolonged hot temperatures and dry periods causing stress on rail and high Soil Moisture Deficit (SMD) leading to shrinkage of embankments and subsequent speed restrictions being instigated across the Route.

Operational restrictions are often instigated preemptively when extreme weather conditions are expected. Figure 19 shows the thresholds for weather conditions to be considered Adverse and Extreme and where operational restrictions would be considered.

The variation of extreme weather throughout CP5 is evidence of the increasing challenges that Western Route must deal with to ensure a resilient railway. Below highlights some of the issues faced over the past control period due to adverse weather.

Figure 19
Table highlighting the national weather hazard identification (NR/L3/OPS/045/3. 17, 2017)

National Table				
Wind				
Category	**Normal**	**Aware / Level 1**	**Adverse / Level 2**	**Extreme / Level 3**
Sustained (mph)	29 or less	30 to 39.9	40 to 49.9	50 mph or more
Hourly Gusts (mph)	39 or less	40 to 49.9	50 to 59.9	60 mph or more
Rain				
Category	**Normal**	**Aware / Level 1**	**Adverse / Level 2**	**Extreme / Level 3**
Hourly (mm)				
3 Hourly (mm)	less than 3mm	3 to 4.9mm	5 to 9.9 mm	10mm or more
12-hour	less than 15mm	15 to 19.9mm	20 to 24.9 mm	25mm or more
12-hour on 100% Wet Soil (mm)	less than 5mm	5 to 7.9 mm	8 to 10 mm	10mm or more
Daily (mm)	less than 30mm	30 to 39.9	40 to 49.9	50 or more
Daily on 100% Wet Soil (mm)	less than 10mm	10 to 14.9 mm	15 to 19.9 mm	20mm or more
15 Daily (mm)	less than 70mm	70 to 99.9 mm	100 to 149.9 mm	150mm or more
Temperature				
Category	**Normal**	**Aware / Level 1**	**Adverse / Level 2**	**Extreme / Level 3**
Heat (°C)	less than 20 C	20 to 24.9	25 to 28.9	29 or more
Cold (°C)	warmer than -0	0 to -2.9	-3 to -7	-7 or colder
Frost (°C) (Minimum air temperature - wind >12 mph)	warmer than -0	-0 to -0.9	-1 to -2.9	-3 or colder
1 Day Diurnal Cycle (°C)	less than 13 C	13 to 15.9	16 to 17.9	18 or more
Snow				
Category	**Normal**	**Aware / Level 1**	**Adverse / Level 2**	**Extreme / Level 3**
Daily Snowfall (cm)	1.9 or less	2 to 4.9	5 to 14.9	15 or more
Accumulation	TBD	TBD	TBD	TBD
Drifting Risk	None	Low	Medium	High

Summer 2018 heatwave

The summer of 2018 proved to be the joint hottest summer on record for the UK as a whole and the hottest ever for England, experiencing twice as many days over 21˚C as the previous year (98 versus 47). The heat caused numerous issues to a variation of assets, including track, earthworks, signalling and Electrification and Plant (E&P).

Points failures formed the most significant proportion of disruptive incidents. No single failure mode stood out as the most common root cause, however, 34% of points related failures were classified 'No Cause Found'. Overheating Cyclon cell batteries were responsible for one major failure at Bristol East Junction, and three other points failures, making this the highest attributed failure mode for points failures. Train detection also experienced a number of failures at high temperatures above 21˚C – although it should be noted that there are a number of other issues that may have contributed to the axel counter failures.

Figure 20
Scrap rail left within 2m of heads (left) and poor installation of axel counter (right)

Overheating electrical assets was a critical underlying factor in many service affecting failures during the summer, including major datalink and battery failures. Much of the current air-con provision is specified by the area of the building being cooled rather than the heat generated by the equipment it houses.

The track itself is vulnerable to high temperatures as compressive forces which develop in rails expanding in hot weather can cause the rail to buckle, resulting in a short but severe misalignment. The incident shown in Figure 21 at Oxford resulted in emergency works being required and associated train delays.

Figure 21
Track buckle at Oxford, May 2018

Western Route vulnerability assessment continued

The long period of hot and dry weather lead to desiccation on clay cored embankments throughout Western Route, but notably in the Thames Valley and West Country (north) areas.

This was exacerbated by the dry and hot summer following a wet winter causing a significant differentiation in SMD from winter to summer.

Figure 22
Example of SMD tracking, updated weekly for TSR board

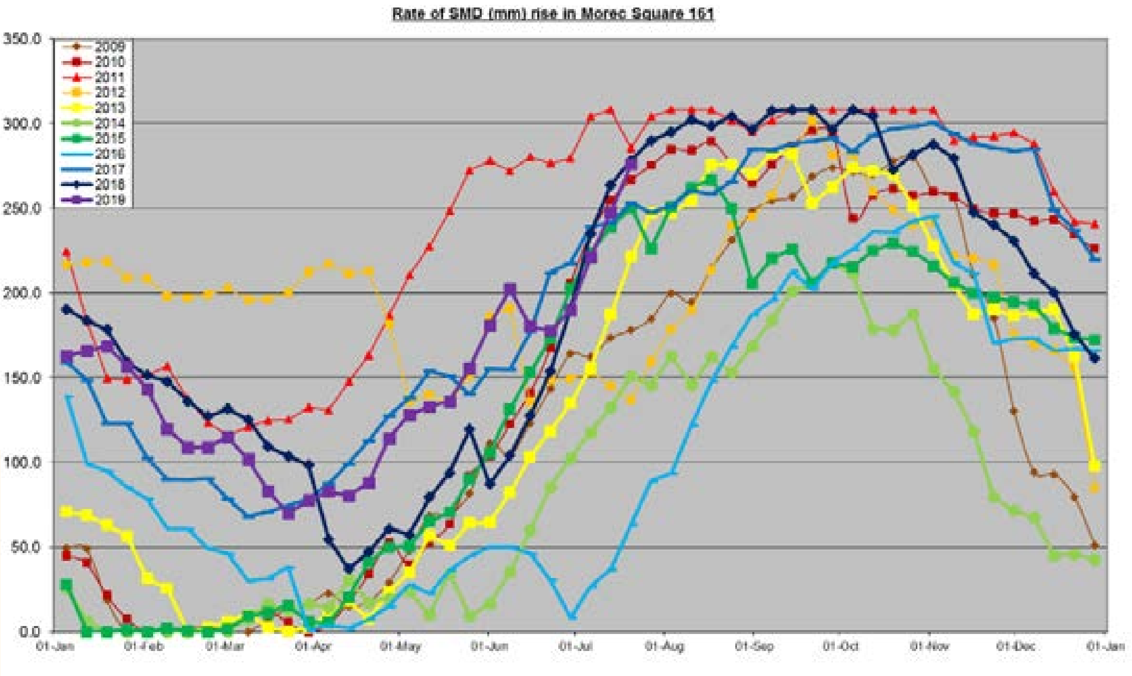


Figure 23
Image showing track alignment issues when transitioning to underbridge

Shrinkage in the embankment and subsequent movement of the track above led to a number of track alignment issues, especially on transition to underbridges and other underlying hardstandings. The track issues were exacerbated further by the very low levels of track maintenance undertaken due to the exceptionally high track temperatures and the risk of track buckling if disturbed – a total of 10 no. Temporary Speed Restrictions (TSRs) were imposed due to underlying desiccation issues.

Southall Uninterruptible Power Supply (UPS) (2015)

During hot weather in August 2015 all Signaling was lost in the Southall area due to a power failure. The train service in and out of Paddington station was severely affected with over 8000 minutes delay attributed to the event. The UPS at Southall had overheated and shutdown. The overheating was due to a complete failure of the air conditioning in the equipment room and technicians attending the fault stated the room was initially too hot to enter. The UPS batteries expanded in the excessive heat and all had to be scrapped. This incident prompted a change in cooling philosophy in UPS rooms and new installations are now cooled by forced air cooling which is more reliable than air conditioning.

Figure 24
Overheated batteries, Southall UPS, August 2015

Winter storms

A number of storms have hit the Route during CP5, the most damaging of which occurred in 2016 – notably, Storm Katie (March 2016), Storm Imogen (Feb 2016) and Storm Angus (Nov 2016). All caused significant damage to infrastructure and train delays due to issues such as flooding, washouts and fallen trees.

Storm Imogen struck the West Country area of Western Route (0700hrs 8th February 2016) with estimated wind speeds in excess of 70mph and heavy rainfall showers. Disruption to service was experienced and a number of weather-related incidents occurred. As summary of the incidents and associated disruption is listed below.

Figure 25
Fallen tree at Bodmin and damage to Voyager

Western Route vulnerability assessment continued

Table 2
Summary of incidents directly associated with Storm Imogen (Feb 2016)

Incident location	Incident description	Short term mitigations	Medium term mitigations	PfPI minutes	PfPI costs
Bodmin	1S47 disabled after striking fallen tree. Tree was from 3rd party (National Trust) land. Both lines blocked. Train was evacuated.	Pway removed fallen tree. Single line working introduced. Train removed under own power.	N/A	638	£91,961.00
Pilning to Patchway	Patchway – Flowing water from adjacent bank potentially eroding ballast.	Pway visited site and reported that water was not disturbing ballast.	Investigation to be completed to determine whether the drainage measures currently in place are adequate and serviceable.	593	£40,925.24
Gunnislake Branch	Fallen tree on the Gunnislake Branch line	Pway removed fallen tree.	N/A	0	£0.00
Tiverton	Closure of line due to overhanging 3rd party tree at risk of falling onto track.	Tree removed and normal service resumed.	N/A	392	£79,525.12
Par	Train stuck fallen tree.	Pway removed fallen tree and temporary repair to fence.	N/A	7	£611.00
Yate	Very large bush brushing side of trains.	Off-track cut back branches.	N/A	12	£1,086.00
Chenson	Low branch striking front of train.	Trains were run at caution until tree was cleared.	N/A	0	£0.00
Charfield	Small tree online approaching Charfield.	Driver removed tree.	N/A	0	£0.00
Bristol DU	Flooding causing multiple Track Circuit Failures.	Flood waters to be allowed to recede. S&T Maintenance mobilised to rectify fault.	Investigation to be completed to determine whether the drainage measures currently in place are adequate and serviceable.	7065	£849,745.29
Plymouth DU	Flooding causing multiple Track Circuit Failures.	Flood waters to be allowed to recede. S&T Maintenance mobilised to rectify fault.	Investigation to be completed to determine whether the drainage measures currently in place are adequate and serviceable.	3276	£422,756.98

Storm Emma and other unnamed storms in the winter of 2018 caused damage to the Dawlish Wall. The damage was mainly damage to the walkway, missing and dislodged copings and the loss of fencing adjacent to King Harry's Walk. There were no major defects to the fabric of the wall through CP5.

Figure 26
Image showing effects from storms at Dawlish during the winter of 2018

In the winter of 2018, severe snow and cold hit Western Route in addition to the majority of the UK – this storm was known as the 'Beast from the East'. The storm caused significant disruption due to the snow drifts on the line and closure of railway platforms. The deep snow covered the rail head stopping the Train Operating Companies (TOCs) and Freight Operating Companies (FOCs) running their fleet until snow ploughs could be deployed to clear the paths and to enable the safe running of the railway.

Figure 27
Snow fall covering the rails during the 'Beast from the East' (2018)

Western Route impact assessment

This section provides an update to Western Route's weather impact assessment findings published in the 2014 Western Route WRCCA action 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 (APL – average passenger lateness) compensation costs as proxies. As this data includes the duration and location of each disruption, and attributes cause, it provides a high degree of granularity for use in analysing weather impacts and trends.

Compensation costs for the past 13 financial years for Western Route have been analysed to provide an assessment of weather impacts, see Figure 28.

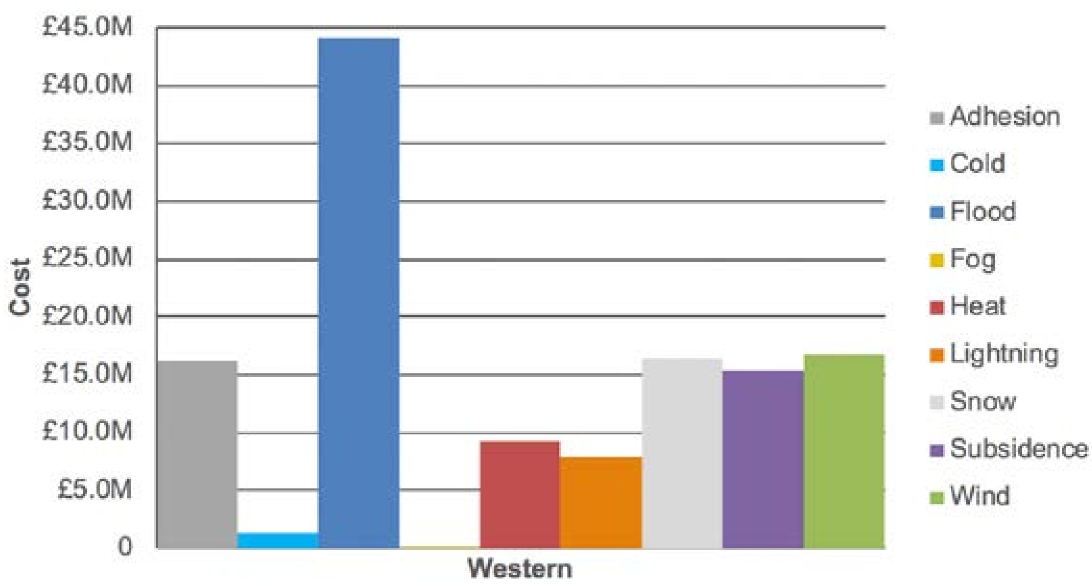


Figure 28
Western Route weather attributed Schedule 8 costs 2006/07 – 2018/19

The updated analysis shows that, with a cost of £44.7m over the last 13 years, flooding remains the greatest impact by far. Wind and adhesion are next with individual costs of roughly one third of those for flooding; however, both of these impacts have shown a marked growth in cost over the last 4 years relative to the remainder of the impact types.

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 on the Western Route.

From early review of UKCP18, there is a high degree of confidence in the projections for temperature, rainfall and sea level rise, but lower levels of confidence 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 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 3 – Prioritisation of weather-related impacts on Western Route.

Table 3
Prioritisation of weather-related impacts on Western Route

Impact	Compensation costs per year[10]	Climate projection[11]	Prioritisation
Wind	Average £1.09m Highest £3.96m	Changes difficult to project, however generally expected to increase.	High
Adhesion	Average £1.22m Highest £2.51m	Complex relationship between multiple causes and their climate projections.	High
Snow	Average £1.26m Highest £9.21m	Changes difficult to project, but increases in autumn, winter and spring minimum temperatures suggest reduced snow days.	Medium
Lightning	Average £0.63m Highest £3.21m	Changes in storms difficult to project, however generally expected to increase.	Medium
Cold	Average £0.11m Highest £0.44m	Increases in mean daily minimum temperatures across the regions in autumn, winter and spring ranging from 1.8˚C in April to 2.9˚C in September for the 2050s and 2.7˚C in April to 4.6˚C in September for the 2070s.	Low
Earthwork Failure / Landslip	Average £0.96m Highest £3.51m	Increases in mean daily rainfall across the regions for late autumn, winter and early spring months, for example; 17.8 % in April and 39.8 % in January by the 2050s becoming 21.2 % in April and 56.3 % 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; 26.3 % in May and 43.9 % in August by the 2050s becoming 42.2 % in May and 58.4 % in August by the 2070s.	High
Heat	Average £0.43m Highest £1.48m	Increases in mean daily maximum temperatures across the regions range from 2.0˚C to 2.5˚C (winter) and 2.9˚C to 4.5˚C (summer) by the 2050s. In the 2070s this becomes 2.8˚C to 3.6˚C and 4.4˚C to 6.2˚C respectively.	High
Flooding	Average £3.65m Highest £15.26m	Increases in mean daily rainfall for late autumn through to early spring and increased intensity and frequency of winter and summer storms (see Earthwork Failure/Landslip)	High
Sea level rise	Average (schedule 8 effect not currently known)	Sea level rise ranges from 34.1cm (Weston-Super-Mare) to 36.5cm (Penzance) in the 2050s and 52.2cm to 55.6cm in the 2080s. This and increases in storminess raise the risk of overtopping and erosion[12].	High
Fog	Average <£0.01m Highest £0.04m	This is a complex picture with low confidence[13],however possible seasonal changes across the regions for the 2080s have been indicated as: winter -+7 % to -+4 %, spring -40 % to -42 %, summer -69 % to -70 % and autumn -28 % to -31 %.	Low

It should be noted that the compensation cost rate charged for Schedule 8 delays increased in 2015, as such, costs associated with CP5 are augmented in comparison with pre-CP5 events.

Identification of higher risk locations

Throughout CP5, Western Route has continued to experience extreme weather events that have challenged weaknesses in our assets and operations. More frequent and intense extreme weather events are projected due to climate change; understanding the impacts of current and future events is critical to investment decision making.

Western Route has identified potential future risks and resilience actions based on climate change projections and Route knowledge but is also supported by data captured, via the schedule 8 compensation cost data.

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 creating a railway that is safer and more resilient to weather impacts now and in the future.

[10]Based on Schedule 8 costs per year over the last 13 years from 2006/07 to 2018/19.
[11]UKCP09 projections still used for wind, snow, lightning and fog as UKCP18 does not contain updates.
[12]UKCP18 RCP 4.5 95th percentile.
[13]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.

Western Route impact assessment continued

Weather impact assessments

Understanding the impact of adverse weather and the effects it has on the infrastructure is vital for preparation for the projected changes in climate. Temperatures 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, and heatwaves will become more frequent, longer and more severe and droughts will become more common. This will lead to a decline in frost and snow days and the likelihood of severe winters will decrease, but current levels of severity will remain possible. Winters are, however, expected to become significantly wetter, and the frequency and intensity of summer storms are expected to markedly increase.

Summer storm rainfall will be more severe than in winter. Intense summer rainfall after droughts/dry periods will increase the surface run-off and flash flood risks as well as an increase in peak river flows. Due to climate change sea level rise along the Western Route coast is expected with small variations depending on location. Storm intensity and frequency is all expected to increase, growing the risk of coastal erosion and sea defence overtopping causing difficulties in discharging to estuaries and the coast.

Earthwork impact assessment

Within the Western Route boundary there are long sections of earthworks known to be vulnerable to adverse weather, and where earthwork failures or proactive safety measures have restricted the running of trains.

Landslips & washout failures

The vulnerability of earthwork assets to adverse weather events can be linked to the type of underlying geological material cut through or used to fill during the construction of the railway. Weathering and the resultant reduction in the strength of the soils and rock forming the earthworks over the c.180 years since construction has left certain slopes susceptible to intense and/or sustained rainfall.

Earthwork failures are often triggered by water. This can be by direct rainfall and saturation of the earthwork, a failure of a drainage system at the crest or the toe of the earthwork, third party inflows or groundwater level changes.

Network Rail's steep soil cuttings, often cut into steep and large catchments, will always be at risk of failures in adverse or extreme rainfall as the high moisture content can reduce the soil's shear strength, and/or lubricate pre-existing slip surfaces within the slopes. Western Route contains a high percentage of high plasticity clays which are particularly susceptible to weakening in high moisture content.

Due to the relatively drier weather in CP5 in comparison to other control periods, in addition to targeted earthwork drainage enhancements over the last control period, there were fewer earthwork failures in total with no failures similar to the magnitude of which occurred in Teignmouth in CP5. Numerous smaller scale washouts and slope failures have occurred as a result of heavy and prolonged rainfall, including the slope washout at Chipping Sodbury Aqueduct and washout at level crossings in the Golden Valley, near Stroud.

Continued delivery of earthwork stability and drainage schemes is required to ensure resilience to adverse and extreme rainfall throughout CP6 and the projected increase rainfall magnitude and intensity due to climate change.

Figure 29
Washout failure and adjacent field at Chipping Sodbury Aqueduct (SWB 103m 74ch Dn)

Rockfalls

Rock cutting failures can occur quickly with very little warning (known as brittle failure) and can have catastrophic circumstances. During CP5 there were a number of these incidents on the Western Route. Freeze-thaw within rock cuttings can cause issues, by increasing the dilation of the joints which can in turn lead to failure. Below shows evidence of the damage that can be caused by just a light rain and a prolonged period of temperatures below zero.

There was also a large presence of vegetation on the rock face causing root jacking to occur which will have contributed to the planar failure.

Figure 30
Rockfall failure occurring on MLN3 in 2018

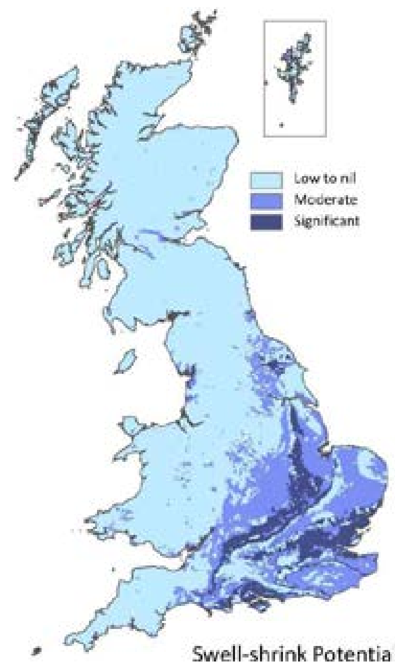
Western Route impact assessment continued

Dry weather impact to embankments and track quality

The CP5 WRCCA plan focused heavily on rainfall and storm events following the, at the time recent, damage caused at Dawlish and Teignmouth in addition to the large schedule 8 payments attributed to rainfall throughout CP4. In contrast, 2018 saw a prolonged period of very warm weather with highs of 35°C making it the joint hottest summer in the UK since records began. Much of the Route's embankments are formed of clay material which in periods of hot and dry weather lead to shrinkage, known as desiccation. Where there is an embankment made up of predominantly clay material then there is potential for volume change when the moisture content changes.

Clay material is susceptible to both shrinkage and swelling and embankments with a high proportion of expansive clay minerals are most likely to experience the greatest volume change. The movement of the embankment causes a consequential movement of the track above and differential shrinkage in the embankment can contribute to significant track misalignment, especially on transition to underbridges and other underlying hardstandings. Additionally, the continued and increasing shrink/swell process can lead to a reduction in strength of the embankment and ultimately lead to an earthwork failure.

Figure 31
UK shrink-swell potential map and a table of Western Route earthwork 5 chain lengths with high potential



MLN1	WEY	SAL	DCL	SWB		BAG2
7.1100	104.1210	110.1540	55.0990	84.0220	88.0990	80.0770
51.1320	107.1320	110.1650	57.0660	84.0330	88.1100	84.0330
51.1430	107.1430	111.0000		84.0440	88.1210	91.1100
83.1430	108.0000	111.0110	OWW	84.0550	88.1540	
84.1650	108.0110		79.0990	84.1320	88.1650	SWM1
90.0330	108.1210	SWY	92.1540	84.1430	89.0000	86.0660
	108.1320	84.0550	98.0880	84.1540	89.0110	88.0330
ANL	108.1430	84.0770	98.1100	84.1650	89.0220	105.0000
6.0000	112.0770	84.0880		85.0000	89.0330	105.0440
	112.0990	84.0990		85.0110	89.0440	
BRB	112.1100	85.0000		85.0220	89.0550	BGL2
1.1320	117.0660	85.0110		85.0330	89.0660	96.0440
	117.0770	86.0110		86.0000	89.0770	96.0550
	117.1100	86.0220		86.0110	89.0880	97.1540
	117.1210	86.0330		86.0660	90.0440	101.1650
	118.1430			86.0770	90.0550	104.1320
	119.0000			86.0880	90.0660	106.0660
	119.0110			86.0990	90.0880	106.1540
	119.1100			87.0220	90.1100	106.1650
	124.1540			87.0330	90.1210	
				87.0440	91.0330	
				87.1650	91.1430	
				88.0880		

https://www.bgs.ac.uk/products/geosure/shrink_swell.html

The best indicator for desiccation occurring is Soil Moisture Deficit (SMD) which is the measure of how much water the ground can absorb before becoming saturated. As a rule, once the SMD levels exceed 200mm, impacts from clay shrinkage are expected to materialise in the track formation. In 2018 all susceptible areas along the Western Route went above the 200mm limit with some nearly reaching 300mm and most for prolonged periods of time.

Many Emergency and Temporary Speed Restrictions (ESRs) and TSRs were required due to the extreme heat and dry weather experiences in the summer 2018.

It is impractical to totally remove shrinkage from embankments, however preventative techniques such as planning an active high frequency track maintenance programme to manage the changes to the track geometry; and early targeted tree removal to reduce the increase and differential in SMD, can be used to lessen the symptoms.

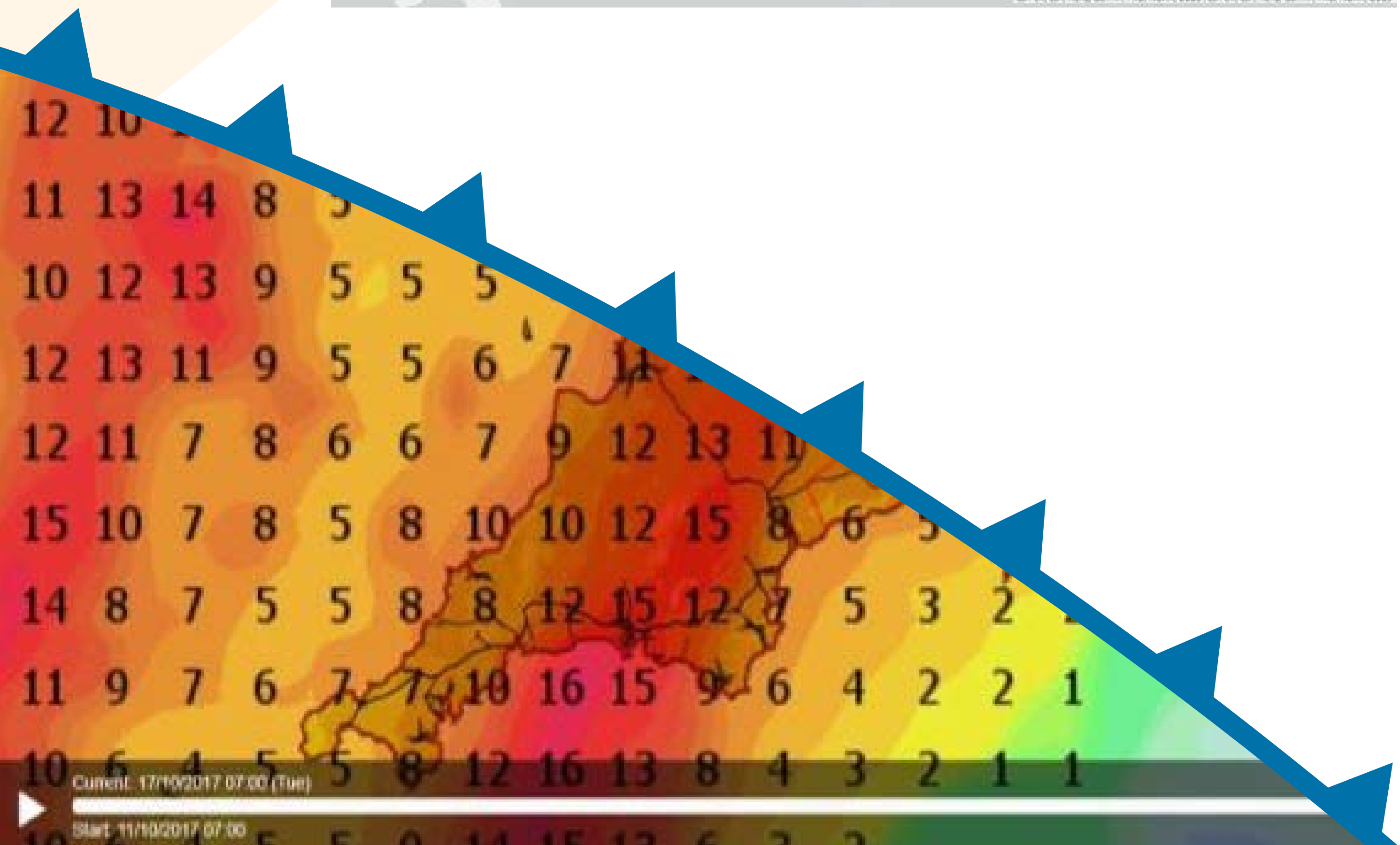
Generally, only rainfall can truly mitigate shrinkage through natural swelling in the embankment. Customarily this occurs in the winter, however due to the exceptionally high SMD in the summer months and relatively dry winters in recent years, earthworks have been remaining in a moisture deficit all year round. UKCP18 projections that winters will be wetter and summers will be hotter, drier and longer suggests that large differentials in SMD between winter and summer seasons will become the norm.

Western Route impact assessment continued

Heat impact assessment

Between 2006/07 and 2018/19 heat related incidents accounted for an average of 11,965 delay minutes and £0.786m in Schedule 8 costs per year.

Figure 32
Heat related incidents in CP5 (2014/15 – 2018/19)



Track

The rails are vulnerable to the effects of heat as the rail expands and induces additional forces into the track system.

The expansion of steel rails in hot weather is accommodated either through gaps at the end of jointed rails or through a pre-tensioning or stressing of continuously welded rail. Both scenarios are closely managed with any deficiencies corrected in the spring.

Where possible, normal maintenance activities such as packing of ballast to correct poor track geometry are avoided at very high temperatures as this can reduce the stability of track. If delaying the works is not possible, additional risk controls are applied which can include reducing the speed of trains over the affected area. Prolonged periods of hot weather can be particularly difficult due to this issue, with potential for a backlog of work to develop. This is being addressed through an increase in preventative work.

Certain track assets are inherently less resilient to the effects of heat, an example being point work at junctions constructed using hardwood timber bearers. Renewal with modern prestressed concrete bearers is more reliable in hot weather and has been gradually installed on main lines. The last principal main line junction to be relayed between London and Bristol is at Southall East where works will be completed in CP6.

Figure 33
Poor track geometry due to heat impact

Western Route impact assessment continued

Points

Currently, in conjunction with the Critical Rail Temperature (CRT) mitigations, the movement of points is minimised during hot weather to reduce the risk of failure. A Key Route Strategy (KRS) is applied to enable through traffic to pass without delay from point failures. The general track mitigations for heat stated above are also being considered for points and the immediately adjacent sections to reduce the need for restricted points operations.

Vegetation (off track failure, fences etc.)

During hot and dry weather, high water demand trees, such as Oak, Hawthorn and Willow can cause additional reduction of moisture in embankments. The differential shrinkage can cause localised track misalignment if support for the track is reduced, especially where the embankment crest to track stand-off is narrow. Although high water demand trees can be easily identified, determining which trees are likely to cause shrinkage issues prior to the differential shrinkage occurring is difficult and as such, felling of issue trees generally only occurs reactively.

Buildings

Heat causes problems and train disruption at all three of the managed stations on the Western Route.

Expansion of coping stones can cause damage to structures and eventually dislodge; this is principally due to the historic stones not having sufficient expansion joints, which would now be required under standard specification. The masonry walls and concrete flat roofs also expand in the heat creating a ratchet effect which directly damages the asset and creates a risk of subsequent issues such as water ingress and structural failure; this is a reactive issue requiring monitoring to identify.

Issues also arise when using containerised REBs (relocateable equipment buildings) that in certain operational conditions, can increase the likelihood of overheating and failure of critical equipment; this can lead to the need for artificial cooling which in turn creates a maintenance and energy liability. Management options can include colour, shading or compartmentation of heat generating equipment e.g. batteries from heat sensitive equipment.

Electrification and Plant (E&P)

Most E&P assets are relatively unaffected by heat. Long lengths of OLE do expand and contract with temperature variation but the new OLE system is fitted with the latest automatic tensioning devices which manage this and keep the contact wire from drooping excessively. Additional checks of older balance weight tensioners in 0-12 mile take place during periods of high temperatures. Current OLE design allows for ambient temperatures of up to 40˚C.

Figure 34
PSP roof painted with reflective paint to reduce solar gain

Uninterruptable Power Supplies (UPS) batteries are susceptible to heat; ideally, they should be kept at a steady 20˚C and historically they have been kept in air-conditioned environments. Current policy however for Principal Power Supplies (PSPs) supplying signaling power to lineside equipment is to rely on forced air cooling. This relies on air at ambient outdoor temperature to cool equipment rooms and during the warmer months temperatures within these rooms are inevitably higher than ideal. The effects of heat on batteries is to reduce their operational life. The warmer the environment they are kept in the sooner they will need to be replaced. All battery rooms are fitted with high temperature alarms. We are experimenting with painting equipment room roofs with reflective paint to reduce solar gain and fitting full remote temperature monitoring to better respond to high temperature incidents.

Structures

Expansion of structures in high temperature can cause damage to structures where the expansion joints are insufficient or ineffective; in the case of overbridges, subsequent damage to road surfacing above can occur e.g. the damage at Ranelagh bridge.

Western Route impact assessment continued

Cold and snow impact assessment

Between 2006/07 and 2018/19 cold and snow related incidents accounted for an average of 26,756 delay minutes and £1.147m in Schedule 8 costs per year.

With climate change, South West England is predicted to experience less snow and cold overall and a general increase in daily winter temperatures, however natural variability, the complexity of the UK weather system mean that severe cold weather events cannot be ruled out. As such, Network Rail will still need to invest, maintain and prepare vulnerable assets for cold weather conditions.

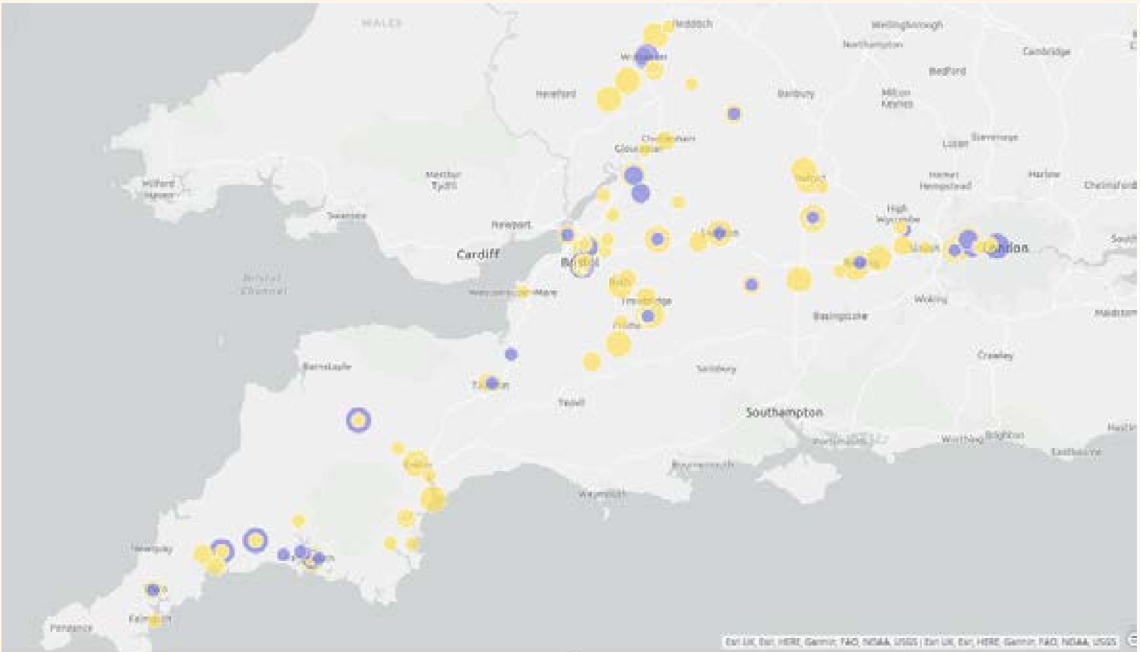


Figure 35
All cold (yellow) and snow (blue) related incidents in CP5 (2014/15 – 2018/19)

Buildings

Typically, low temperatures cause embrittlement of materials and icing of surfaces. while ice formation around or within a material can cause freeze/thaw action. This is a significant cause of stonework erosion and failure leading to objects falling from height. Cold combined with poor or historic design can also create 'cold bridging' resulting in higher fuel bills, and surface or interstitial condensation.

Surface condensation can be a significant issue, either promoting mold growth, or creating slip hazards on smooth paving surfaces, while interstitial condensation in the wall can cause building defects in concealed areas that can lead to structural failure.

Snow in the UK generally is denser and wetter than other countries. Suitable snow loading is required to be considered in the design of structures.

Snow has also been responsible for the closing of several stations due to the slipping hazard and other health and safety implications. Even though the use of salt or 'ice melt' can be used to remove the snow, the chemicals can cause corrosion within the structure, particularly to steel and concrete without careful management. The partial thawing and refreezing can create icicles and ice plugs that block the building's drainage.

Points

One of the Route's primary cold weather weaknesses is the failure of points. There are several failure modes for points: compacted snow between the switch rail and the stock rail; frozen point ends due to failed points heating; and frozen Points Operating Equipment (POE).

With potentially wetter winters and the continued risk of severe cold and snow events, it is imperative that points are reliable to maintain an operational railway. Reliability is currently monitored; the root cause of failures is established to improve asset knowledge and there is an appropriate action plan.

Snow compacted into point ends is cleared by maintenance when snowfall is predicted to overwhelm the points heating capability.

Points heating may fail due to detachment from the temperature sensor, detachment from the rail, or no power supply. The power supply is monitored remotely which allows for prompt maintenance if cold weather is expected.

Currently during snowfall or freezing events, Key Route Strategy (KRS) is implemented to reduce the movements of points and minimize service disruption. Points are maintained in a position for through traffic to minimise delay to main Routes, as points moved during snowfall fail more easily due to compacted snow or ice. Robust, reliable and powerful points-heating is essential to maintain performance regardless of the KRS. The Route is planning to specify these robust minimum design features for all new and renewed points.

Electric points heating is fitted to most main line S&C (Switches and Crossings) to keep them clear of snow and ice.

Track

Cold weather can lead to broken rail as the rail contracts. The Route will continue to mitigate the risk through normal maintenance and inspection

Electrification and Plant (E&P)

Automatic OLE tensioning also accounts for contraction in cold weather; current design allows for ambient temperatures down to -18°C. Icicles tend to form around the OLE at tunnel portals which can damage pantographs, as such maintenance teams must be sent out to knock these down in cold weather.

All lineside cabinets and equipment rooms are fitted with anti-frost and condensation heaters which protect against the effects of cold.

Figure 36
Icicles formed around OLE equipment, (note –picture not on Western Route)

Western Route impact assessment continued

Structures

In wet tunnels, ice can form. Formation of ice in tunnel shafts results in large sections of ice suspended over the railway, which can and have fallen resulting in a train striking the dislodged ice and derailing in the tunnel.

Table 4
Tunnels with known issues of ice formation

Name	Location
Luxulyan Tunnel	NEW 285m 44.5ch
Box Tunnel	MLN1 99m 12ch
Rainbow Hill Tunnel (Worcester Hill)	OWW 120m 78.25ch
(Chipping) Campden Tunnel	OWW 97m 47ch
Sapperton Long Tunnel	SWM1 94m 70ch

Table 5
Shafts with known issues of ice formation

Name	Location
Wickwar Tunnel	BGL 115m 28.25ch
Patchway New Tunnel	BSW 6m 56ch
Somerton Tunnel	CCL 126m 58.5ch
Clifton Down Tunnel	CNX 4m 7ch
Box Tunnel	MLN1 99m 12ch
St Annes No.3 Tunnel	MLN1 115m 58.5ch
Chipping Sodbury Tunnel	SWB 101m 6.5ch
Sapperton Long Tunnel	SWM1 94m 70ch
Colwall New Tunnel	WAH 130m 48ch
Ledbury Tunnel	WAH 135m 15ch

Sea level rise and flooding impact assessment

Sea level rise

Sea level will rise along the Western 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 and discharges to estuaries and the coast will become more difficult.

Western Route has experienced a number of high-profile coastal flooding events; however, with sea levels due to rise by the end of century, relative to 1990 levels (based on UKCP18), water inundation will become more prevalent within coastal sections of the Route.

Western Route has 245 miles of coastal boundary, which accounts for 41% of the Route boundary miles. With sea level rise, there are numerous branch lines to coastal resorts that are inherently more vulnerable to more flooding, coastal erosion and loss of the railway.

There are main lines that are susceptible to more frequent and more extensive flooding as the sea level rises:

- Penzance,
- Par and Lostwithiel,
- Exeter to Teignmouth (Powderham Banks to Newton Abbot),
- Bristol to Bridgwater (Highbridge & Burnham on Sea), and
- Severn Tunnel approach (from Bristol to Wales Route).

There are also branch lines at risk from sea level rise, namely:

- St Ives (Lelant),
- Falmouth,
- Fowey Docks,
- Looe,
- Torquay,
- Newquay,
- Clifton Down – Avonmouth,
- Exmouth Branch (Lympstone on East Exe Estuary), and
- Bere Ferrers (Gunnislake Branch).

In recognition of the potential risks that sea level rise will bring to connectivity West of Exeter, works are ongoing to improve resilience at Dawlish and Teignmouth. These works will examine the short-term impact of storm surge and flooding and long-term impact of sea level rise for the Route from Exeter St Davids to Newton Abbot.

In CP5 the initial asset management plans for Western Coastal, Estuarine and River Defences (CERDs) was produced (excluding Dawlish – Teignmouth a separate plan for this area is being developed under the South West Rail Resilience Project (SWRRP)). These plans looked at the current condition of the asset, defects on the asset, risk of over topping and the effects of predicated sea level rise. In CP6 an update of the management plans will be undertaken and hosted on an internet platform.

Western Route impact assessment continued

Flooding

Between 2006/07 and 2018/19 inland and coastal flood related incidents accounted for an average of 65,252 delay minutes and £3.42m in Schedule 8 costs per year.

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).

Figure 37
All flooding related incidents in CP5 (2014/15 – 2018/19)

It is important to analyse the water source of the flooding in order to develop the appropriate mitigations. Flooding affecting the railway takes a number of forms:

- Pluvial – directly resulting from rainwater overwhelming local drainage systems,
- Fluvial – from rivers or streams adjacent to or crossing the railway reaching 'bank full' or leaving their normal course – for the purpose of this report, this will include flood plains,
- Groundwater – groundwater levels rise on to the railway, usually over an extended length, of track and for an extended period,
- Estuarine – where natural periodic tidal variation and rainfall combine into a flood event, and
- Storm surge – on coastal sections, where the combined effects of tide and wind form unusually large waves.

Cuttings: pluvial flooding and groundwater flooding

Railway cuttings are naturally vulnerable as 'low points' attracting both groundwater flooding (dependent on the geology) and pluvial flooding (many drainage systems direct rainwater into cuttings).

Many flood resilience schemes have been successfully delivered throughout CP5 based on analysis undertaken as part of Western Route's Geo-Environmental Resilience Study, including drainage upgrades at Curry Road, and Whiteball cutting, and a signalling renewal with increased aquifer monitoring at White Waltham.

Chipping Sodbury, between Bristol Parkway and Swindon, has been Western Route's most frequently flooded cutting. Ongoing flood resilience works including construction of a flood alleviation lagoon is due for completion in early CP6. Other high-risk sites will be developed to detailed design stage which can be delivered if funding is granted.

There are widespread locations across the network where intense rainfall can overwhelm track drainage systems or, more often, their outfall to other watercourses or off-track systems. These sites are presently tracked and addressed on a case-by-case basis when flooding occurs, or damage/defects are found during inspection.

River valleys or flood plains: fluvial flooding

A number of lines across the Route follow river valleys, these often being level, and therefore cost-effective, Routes for railway construction. Similarly to pluvial and groundwater flooding, a number of the highest priority fluvial flooding schemes were developed and delivered in CP5 including Hinksey and Cowley Bridge Junction culvert enhancements.

Hele and Bradninch and Staffords bund flood prevention schemes will be developed and are planned for delivery in CP6.

Figure 38
Moreton in Marsh (Storm Katie 2016)

Western Route impact assessment continued

Estuaries: estuarine flooding

Estuarine flooding typically causes less damage to rail infrastructure than fluvial flooding as larger areas are submerged and peak flow rates at individual points are lower. However, persistent estuarine flooding can still cause significant disruption to rail services through damage to earthworks and trackside equipment e.g. signalling equipment.

Flooding on the Somerset Levels in 2014 was extensive and, as reported in press coverage during the event, long-lasting with the duration hard to predict. A section of the two-track line from Bristol to Taunton was submerged for a month, with damage to signalling further disrupting services for a second month. Although no similar events of this scale have been experienced in recent years, the sea level rises and more intense rainfall events projected due to climate change, we expect that similar levels of flooding will reoccur in the future.

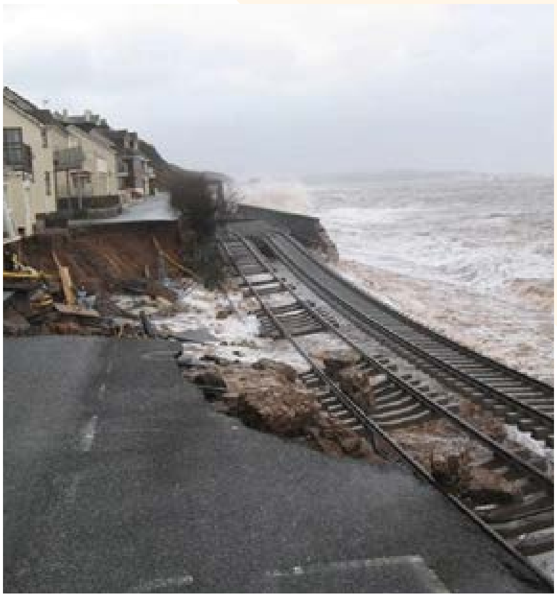


Figure 39
Damage caused by the storms in 2014 in Dawlish

Coastal railway: storm surge

Sea defences can be adversely affected by wave damage and potential overtopping, a risk that is expected to increase due to the rising sea levels projected due to climate change.

Dawlish sea wall was overtopped in 2014, causing water to wash out fill and the wall to fail resulting in loss of support to the track and numerous areas of damage to the coping stones and boundary wall. New vulnerabilities are likely to develop due to the projected sea level rise.

Ongoing sea wall resilience works are ongoing at Dawlish with further resilience works being developed as part of the South West Rail Resilience Project (SWRRP).

Figure 40
Flooding at Didcot Station

Buildings

In Paddington, the rise in the water table causes water to ingress into the basement area, believed to be mainly caused by the retirement of historical pumps as well as the increase of sub surface structures such as Crossrail. In such cases, consideration must be given to the risk of water contamination and sewage etc.

When considering risk to Buildings, the decision is required whether to manage the risk through resistance measures or resilience is most effective.

Electrification and Plant (E&P)

Lineside flooding can affect cable routes and equipment cabinets. If a power cabinet is flooded, then we would normally isolate it for safety reasons which would affect operational/signaling equipment. There were some notable incidents in CP4 included in the last report.

Cable routes can become waterlogged and old rubber insulated cables can become saturated over time, reducing the cable insulation resistance until eventually power cables fail in service. There is an E&P renewal project in CP6 to replace our oldest 650V power cables.

Structures

During flood conditions river levels rise to an extent where the openings of bridges and culverts run at full bore – this can give rise to dangers. Particularly at risk are metal bridge decks that may be displaced by the force of the water itself or debris carried downstream. When enclosed culverts run at full bore, the water can be put under pressure and hydraulic capacity can be reached. This can lead to water backing up, causing further flooding upstream with attendant dangers.

Figure 41
Debris washed up against a metal bridge deck

Rainfall

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.

Buildings

The projected increase in average rainfall and the intensity of severe events associated with climate change is a significant concern. Overwhelming of existing historic roof drainage systems can result in water ingress to buildings through overtopping of gutters and flashings, downpipe joints being placed under increased pressure and water taking routes to ground level that were not designed to do. Large quantities of water taking these routes at stations also creates problems for electrified lines as it can cause arcing. Even moderate water can cause problems for certain material specifications; e.g. at Bristol Temple Meads and Reading stations, where the polished limestone platform surfaces become slick when wet resulting in slips and falls.

Structures

Increased water percolation through structures, particularly where ageing profile of the structure has resulted in failure of the waterproofing or protective paint systems. This results in an increased rate of deterioration to both metallic elements (formation of rust and eventual loss of section, particularly around water traps, e.g. truss bridges) and masonry bridges (loss of mortar, open joints).

Western Route impact assessment continued

Wind impact assessment

Between 2006/07 and 2018/19 wind related incidents accounted for an average of 22,864 delay minutes and £1.32m in Schedule 8 costs per year.

Figure 42
All wind-based incidents throughout CP5 (2014/15 – 2018/19)

Buildings

The brute force of wind can cause structural damage to buildings through overturning, uplift etc. Wind can also create positive or negative wind pressure causing slight lifting of roof slates or bowing of finishes allowing water ingress. It can also contribute to and exaggerate problems from all the other weather types, such as wind chill; moving of water across a surface away from a drain or onto OLE; snow drifting and storm surges.

Vegetation

The impact of wind on vegetation can affect the running of railways in different ways. One of the most common causes is through leaves being blown onto the line, whether it be from trees within the Network Rail boundary or from third party land, this persistently causes a significant percentage of annual delay minutes. Another is a more serious and direct risk to safety due to potential derailment; the force that wind can create when acting on a tree could cause it to collapse onto the line, which, if not detected in time, could lead to a collision and derailment. Fallen trees can damage or destroy boundary fences raising opportunity for trespass – notably from livestock.

Figure 43
3rd party tree obstructing the LOO Line, June 2019

Electrification and Plant (E&P)

Lineside vegetation is a problem in OLE areas; storms and high wind events can damage trees which can fall on to the OLE equipment. Inadequate vegetation management is a risk in CP6. The Series One OLE itself is of a lightweight, wind resistant design and structure spacing and contact wire stagger is designed to reduce pantograph blow off in high winds in accordance with BS EN 1991-1-4 and BS EN 50119.

External DNO power supplies are also affected by high winds and storm events leading to short duration interruptions to Low Voltage Network Rail supplies. Critical operational equipment is backed up by standby generators and UPS systems to mitigate against this.

Structures

Although not a direct impact to structures, during construction works wind can be particularly disruptive. Where crane use is required, this can be delayed by high winds with implications to cost and programme. Where bridges are encapsulated to facilitate paint removal and reapplication, sheeting can act as a sail and impose significant loads on a structure. A safe wind level must be determined and contingency measures, such as slashing sheeting, put in place to ensure the safety of the structure.

Seawater spray

The south west coast can be significantly impacted by spray caused be wind over the sea. For Western Route, this is primarily the Dawlish and Teignmouth stretch of line. Spray can affect signaling and train fleet reliability; special operation arrangements are invoked when this risk is identified which lead to train delays and cancellations.

An industry weakness with regards to seawater spray is that some rolling stock is more unreliable in these conditions, particularly the class 220 and 221. With climate change, increased winds and potentially more forceful sea spray, modern rolling stock fleets must themselves become more resilient to these conditions in order to operate without restriction.

Western Route impact assessment continued

Lightning impact assessment

Between 2006/07 and 2018/19 lightning related incidents accounted for an average of 10,972 delay minutes and £0.603m in Schedule 8 costs per year.

The Route experiences a high number of lightning incidents in comparison to other Routes. Cornwall is particularly prevalent for lightning strikes, accounting for 50 per cent of the lightning strikes in the Route over the past eight years, primarily due to the granite-based geology and extremely high soil resistivity. Climate change projections are not available for lightning strikes, however as storm events are likely to increase in intensity and frequency, lightning will also potentially increase; however, this remains unpredictable.

Figure 44
All lightening related incidents throughout CP5 (2014/15 – 2018/19)

Buildings

Lightning strikes cause power surges or fires if the infrastructure is not sufficiently protected. All buildings should be risk assessed and have lighting protection installed and maintained as necessary.

Vegetation

Trees adjacent to the track are often the tallest point in the local area; this increases the risk of a lightning strike during a storm. Such a strike could lead to the tree collapsing onto the railway or for it to catch fire, which in turn could set fire to other adjacent vegetation.

Electrification and Plant (E&P)

OLE bonding has been sufficiently designed to dissipate lightning strikes down to earth.

Lineside power PSP equipment is all fitted with lightning protection devices. These are very high impedance connections to earth which are designed to short to earth if the equipment is struck by lightning, dissipating the energy.

Adhesion impact assessment

Between 2006/07 and 2018/19 adhesion related incidents accounted for an average of 20,286 delay minutes and £1.23m in Schedule 8 costs per year.

Vegetation

As stated in Wind, leaves being blown onto the line, whether it be from trees within the Network Rail boundary or from third party land persistently causes a significant percentage of annual delay minutes. An adhesion assessment is undertaken annually.

Figure 45
All incidents regarding adhesion in CP5 (2014/15 – 2018/19)

Fog impact assessment

Between 2006/07 and 2018/19 fog related incidents accounted for an average of 166 delay minutes and less than £10,000 in Schedule 8 costs per year.

Signalling

The Worcester area is still predominantly signalled by semaphore signals and therefore can still be significantly affected by foggy conditions. The resignalling of the Worcester area is programmed for CP6, which will reduce the impact of fog on the Route.

Figure 46
Fog in South Devon (Feb 2017)

Western Route impact assessment continued

Subsidence

Buildings

Any buildings on vulnerable geology, both natural and re-worked, have the potential to suffer subsidence e.g. the platforms in Bristol Temple Meads. That is increased by other issues such as the local ground conditions and presence of high water demand trees; it needs to be managed on a risk assessment basis with problems pre-empted or dealt with reactively.

Vegetation

As stated in heat, during hot and dry weather, high water demand trees, such as Oak, Hawthorn and Willow can cause additional reduction of moisture in embankments. The differential shrinkage can cause localised track misalignment if support for the track is reduced or to building and structures when founded on clay material. Although high water demand trees can be easily identified, determining which trees are likely to cause shrinkage issues prior to the differential shrinkage occurring is difficult and as such, felling of issue trees generally only occurs reactively.

Weather Resilient Rolling Stock

Rolling stock equipped to handle poor weather is becoming increasingly valuable as it reduces the requirement for operatives to work on or near the line. It can also perform more efficiently, covering larger distances and with a higher output. Due to the unpredictability of weather some of the rolling stock isn't mobilised unless needed however some is planned in seasonally for near daily time slots due to the known risk to the running of the network.

Autumn

Leaves on the line is a constant problem in the autumn months, with the leaves falling from surrounding vegetation and landing on the rail heads to then be crushed by the passing trains. This creates a gelatinous like film over the head of the rail leading to poorer traction between the rail head and the wheel of the train. This can lead to delays as well as creating a safety risk.

Rail Head Treatment Trains (RHTT) are used on the Western Route between the autumn months (late September to early December) to help reduce the risks of leaves on the line. RHTTs work by jetting high pressured treated water to clean the rails, improving the wheel-rail adhesion and the track circuit activation. Operating out of four separate depots over the Western Route the RHTTs operate every night of the week within the autumn apart from Saturday, covering all the Route as well as some of Wales.

As part of moving forward and improving the RHTT's service to the Route, there are several potential advancements to its operation during CP6, such as the way treatment is reported. Moving towards a more real time digital system would aid this heavily with the likes of digital tick sheets so that Routes are advised quickly about missed treatment; live GPS tracking showing which sites have/haven't been treated and other useful stats such as the percentage of the circuit treated; as well as producing reports later to accurately reflect the previous night's circuits once all the data has been collated.

The improvement in availability and planning of the RHTTs will reduce the inefficiency of the treatment plans which currently rely on one replacement water pump module nationally.

Planning of treatment is also to be improved within CP6 with more robust pre, mid and post season plans in order to provide a better service. Chlorophyll sensors will potentially be fitted to the RHTTs in order to trigger treatment based on the presence of leaf contamination as well as generating heat maps of the worst locations, so that sites can be located for which additional mitigations might be beneficial.

Winter

Winter is normally when the more reactive side of the fleet responds, such as when having to deal with ice and snow. When deep snowfall covers the rail head, the TOCs and FOCs cannot run their fleet, in these circumstances, the snow plough from the fleet is deployed to clear the paths and to enable the safe running of the railway.

With the recent completion of the Great Western Electrification Programme (GWEP) within the Western Route OLE is now a concern in the winter due to it icing up and not allowing the pantograph to connect properly or even damaging it. It is proposed that the TOCs operate ghost trains and icebreakers to keep the OLE clear of ice or to safely remove ice from the OLE, this method is proposed to prevent incidences of trapped trains and the inherent risk to the travelling public.

Summer

During the summer months Supply Chain Operations (SCO) runs weed spraying throughout the network including hand weed spraying of the more complex track layouts e.g. between platforms, to control the vegetation which grows at a rapid rate during these months. The challenge of dealing with weed growth is likely to increase as weather becomes wetter and warmer.

Western Route WRCCA Plan

Western Route's CP5 WRCCA plan saw successful development and implementation of weather resilience and climate change adaptation schemes, including large scale flood resilience schemes, the implementation of NRWS (Network Rail Weather Service), training and equipment provision for maintenance teams, the increased use of suitable technology including RCM in earthworks and track monitoring, and the strengthening of relationships with the Environment Agency and other 3rd party bodies – notably the creation of an Environment Agency/Network Rail liaison officer.

Western Route's CP6 WRCCA plan will build on the development of the CP5 plan noting a fundamental change of delivering the majority of actions through BAU and renewal activities.

Examples include the continuation of strategic vegetation management programs, structural scour and earthwork adverse/extreme weather schemes. Using UKCP18, focus will be given to improving and updating vulnerability assessments and the delivery of appropriate works – including:

- Vulnerability of structures to coastal and estuarine scour,
- Earthworks to high and persistent rainfall in addition to heat and prolonged dry periods, and
- Trees and consequential tree strike during high winds.

These schemes have been referenced in the Route Strategic Plan with specific funding allocated to their delivery.

Weather resilience schemes that were not included within the CP5 plan will also be developed as BAU throughout CP6, including building lightening resilience into renewal designs for buildings and S&T equipment.

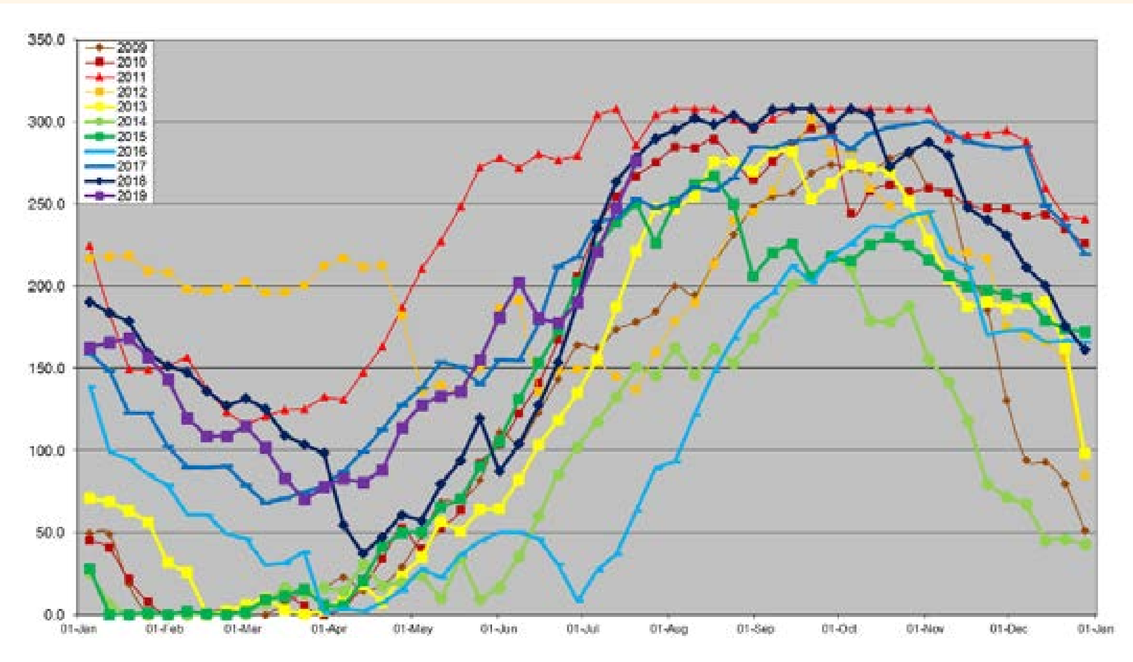


Figure 47
Example of SMD[14] analysis currently undertaken in the Route

[14]SMD is a measure of how much water the ground can absorb before reaching it maximum field capacity, the higher the calculated number the drier the soil profile. SMD is calculated by the Met Office at 40km^2 grids and considers a range of factors that include rainfall, solar intensity, wind exposure and vegetation cover.

An increased focus will be put on climate change adaptation in the CP6 plan. We intend to create a climate change vulnerability heat map based on UKCP18 and use the results to determine potential studies and schemes for CP7 and beyond.

The requirements of the Environment and Social Responsibility standard will be implemented in CP6 for all applicable enhancement and renewal schemes delivered by IP and Works Delivery.

Additional flood resilience funding received in CP5 allowed a number of schemes to be developed and delivered within the control period (e.g. Cowley Bridge Junction and Hinksey) however; without similar funding in CP6 it is not proposed to develop as many such schemes (with the exception of works undertaken as part of the South West Rail Resilience Programme) as part of this plan. As such, and in line with Department for Transport (DfT) and Defra aspirations, Western Route will seek to engage with other statuary bodies and communities in order to deliver mutually beneficial schemes; this will include provision of expertise, information and when appropriate, funding.

We are actively working with Somerset Council on the early stages of 'Adaptation Pathways in Somerset (APIS): Climate Adaptation Planning for Flooding in Somerset'; and are collaborating with the East Devon Catchment Partnership in the Connecting the Culm scheme, including sharing of drainage mapping and the intention to share flood modelling of the Culm and Exe rivers that was undertaken as part of the CP5 flood resilience schemes.

Resilience of the railway between Dawlish and Teignmouth, accounting for climate change and latest sea level rise predictions will be developed in sections, in line with specific DfT granted enhancement funding through CP6.

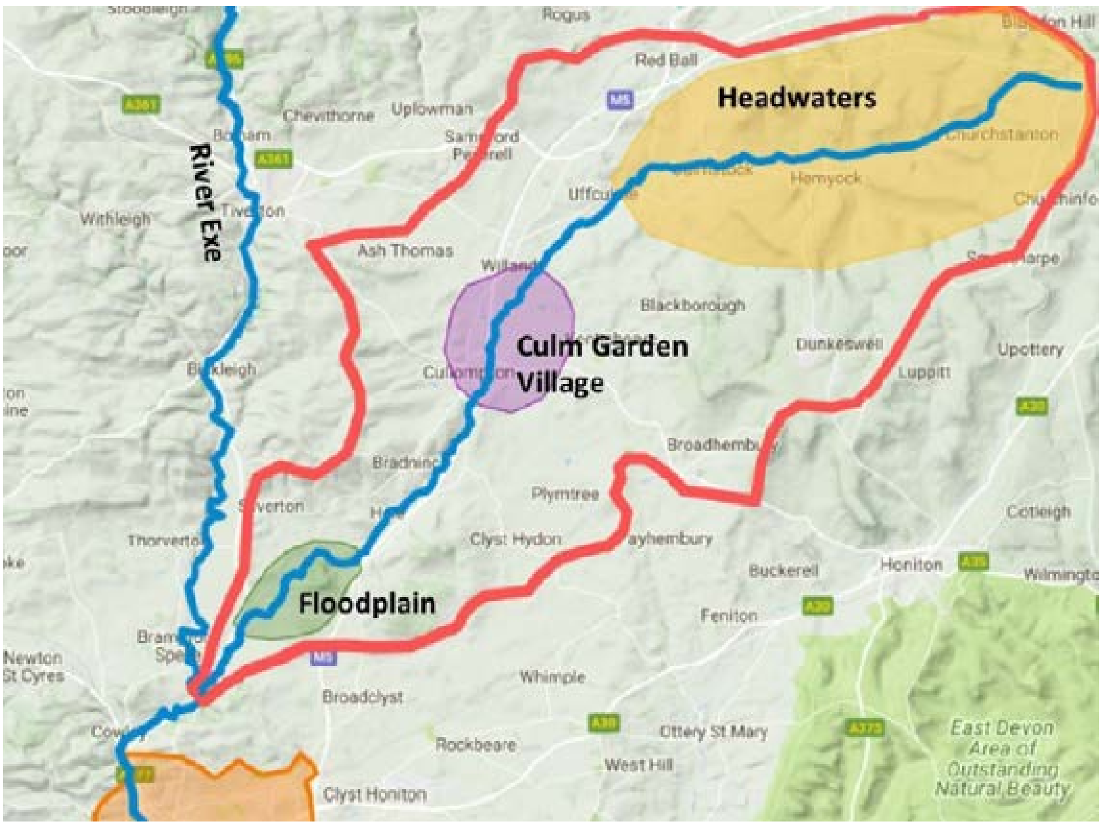


Figure 48
Image showing extent of Connecting the Culm

Western Route WRCCA Plan continued

Vegetation Management

Lineside vegetation has been neglected over several decades with very little proactive removal undertaken. The failures and associated delay minutes, in addition to damage to infrastructure and rolling stock, has led to a serious evaluation of the adverse effect that poor vegetation management can have on performance and safety of the rail network.

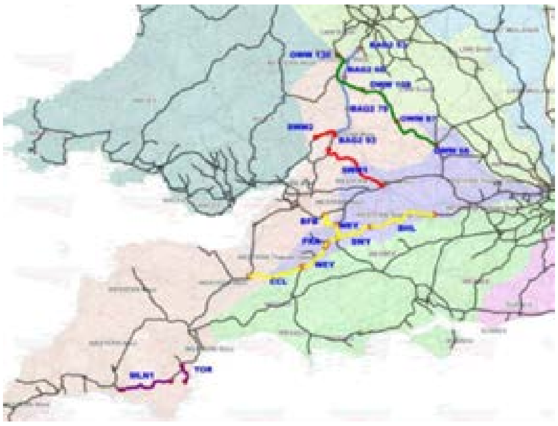


Figure 49
Map showing CP6 vegetation removal extents

In CP5, vegetation management began with the focus predominantly on the cutting back and maintaining of the vegetation adjacent to the soon to be electrified areas of the railway. Western Route authorised £12m of funds for lineside vegetation management in order to return the asset to a compliant standard – this was primarily driven by the introduction of the new hybrid IETs on the Route, to accommodate the installation of OLE installation, and for Crossrail. In total, 250 miles of vegetation was cleared to a compliant standard. In addition, a further 280 miles of vegetation was cleared beyond compliance due to the risk to the pantographs on the new fleet where OLE is not present.

The Varley report was conducted in CP5 and released in early 2019. The report considered the way Network Rail conducted its management of vegetation and produced 6 different recommendations, outlining Network Rail's responsibilities as a land owner as well as stating that Network Rail should lead cultural change for valuing nature across the organisation.

Alongside the Varley report, the new lineside vegetation management standard (NR/L2OTK/5201) was released in March 2019, outlining a 'new way to manage vegetation', including guidance on protecting OLE. The new standard has removed the previous 'blanket distance from the rail' approach and instead considers the danger of falling trees reaching the track, OLE and other critical equipment, as shown in Figure 50, where in addition to the standard 6m clearance from the cess rail, an 'infinite' clearance above 45˚ from the end of the sleeper is also required.

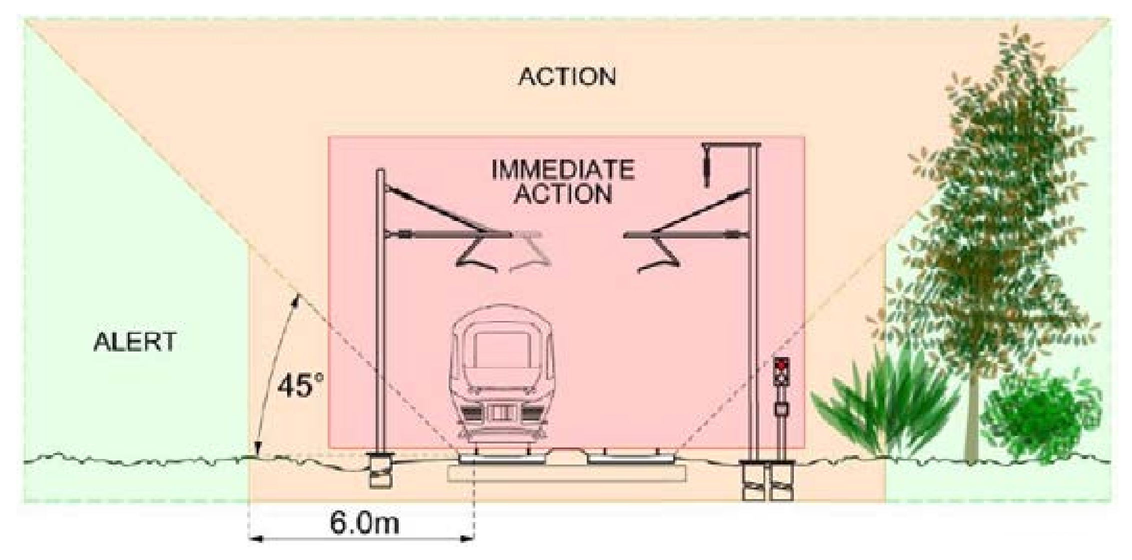


Figure 50
New lineside vegetation management standard (NR/L2/OTK/5201) – clearance cross section profiles

In CP6, the Route is funding a further £23m of vegetation management in order to increase compliance percentage against the updated standards, focusing on the mainline areas of the Route west of Swindon and into Cornwall. Funding has also been included within the CP6 Strategic Business Plan for a vegetation LiDAR survey. A Route wide tree survey on high criticality ELRs, where priority will be given to areas where major vegetation clearances haven't been completed, will be undertaken within Year 1 and Year 2 of CP6 at an estimated cost of £1m.

Figure 51 below shows the 250 Route miles of vegetation to be cleared to compliance with the standard (NR/L2/OTK/5201) throughout CP6 in addition to a maintenance regime implemented to maintain clearance on all previously de-vegetated areas.

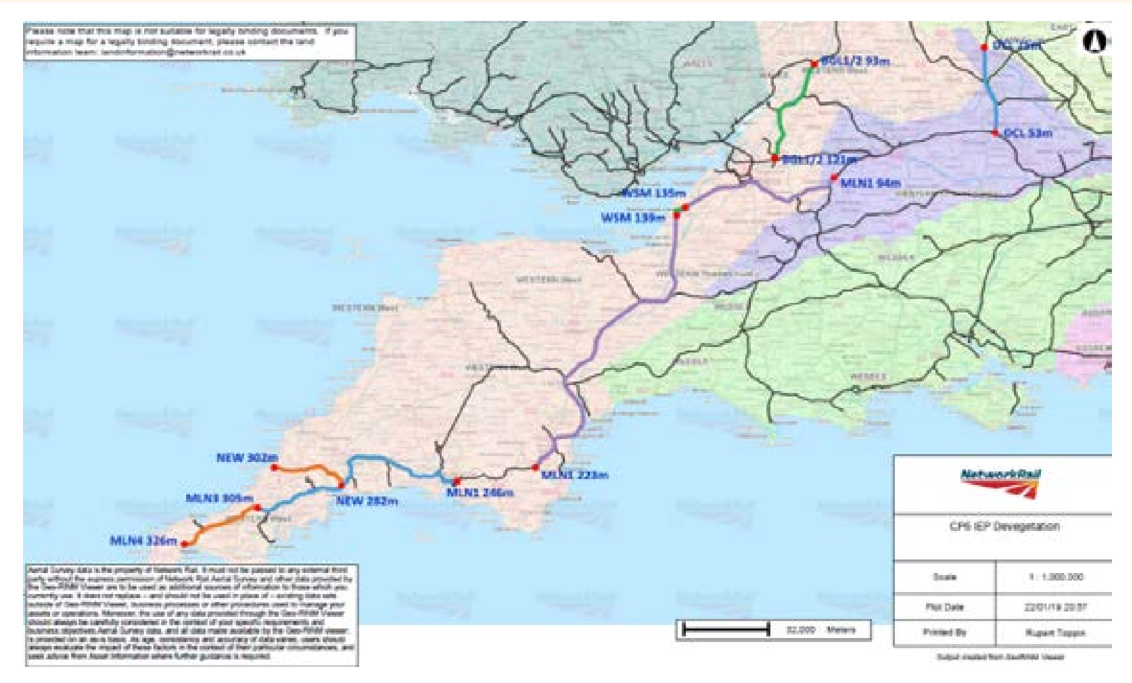


Figure 51
CP6 Vegetation Clearance Sites

Western Route WRCCA Plan continued

The Route will continue improving the competence of maintenance Delivery Unit (DU) staff through continued tree awareness workshops and engaging with Safety, Technical and Engineering (STE) department on the competence matrix update for Off-Track Competences. Resourcing and OPEX spend within the maintenance organisation will increase in CP6 with increased staffing to deliver a more robust and sustainable approach to the off-track inspection and maintenance activities.

The CP6 strategic plan for Off Track is illustrated in Figure 52, including detailing the approach for all Activity Base Planning (ABP) volumes that will assist with maintaining general branch line vegetation, signal sightings and Service Requests, faults etc.

Vegetation clearance will play a significant part in reducing the risk to the running railway as well as the reduction of schedule 8 compensation payments and will provide a vital step in reducing the risk from adverse weather.

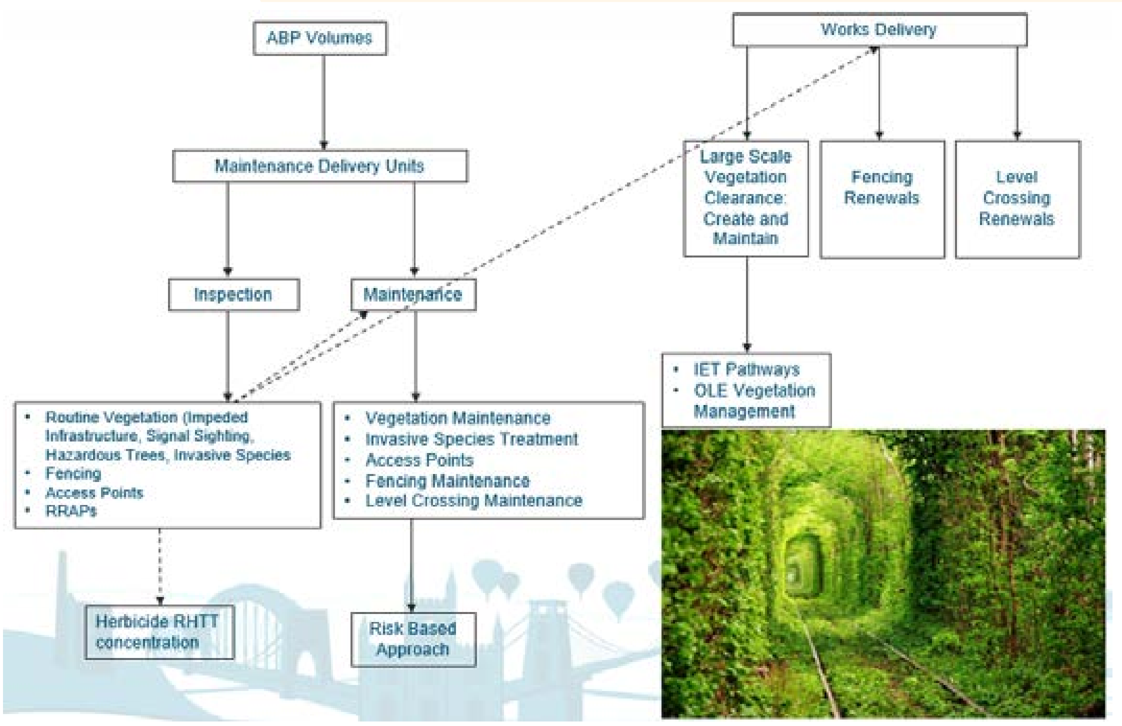


Figure 52
Off Track CP6 ABP Volume Strategic Plan

South West Rail Resilience Project (SWRRP)

The destruction of the Dawlish sea wall and the failure of the sea-cliffs at Teignmouth in the winter of 2014 brought the attention of the Nation to the severe risks posed from adverse weather. UKCP18 has predicted several weather changes, with 1 in 100 storms trending towards becoming 1 in 50 and the winters becoming wetter, more events comparable to the extreme weather experienced prior to the Dawlish and Teignmouth incidents are expected. Planning for the projected increase in intensity and frequency of such weather events, is vital.

Through CP5 and into CP6 and beyond, the South West Rail Resilience Project (SWRRP) is tasked with increasing resilience of the railway between Exeter and Newton Abbot to current and projected climates over the next 100 years. The scheme is currently focused on 4 main areas – Cliff Behaviour Unit 17 (CBU17), Parsons Tunnel to Teignmouth, Marine Parade and Colonnade to Coast Guards which will be developed in CP6.

Figure 53
Current image of the CBU17 and Parsons Tunnel portal (left) and Mock-up of rock fall shelter solution at CBU17 (right)

CBU17 covers the cliffs around the low mileage entrance into Parsons tunnel where there is substantial risk of rock slope failure due to its natural fall towards the railway, the formation of a gully around the tunnel portal and the risk of erosion of the cliff face in large storms. The proposed resilience scheme is to construct a rock fall shelter which will protrude for 85m out of Parsons Tunnel running along the base of the cliff face, accompanied by soil nailing and netting of the upper.

Parsons Tunnel to Teignmouth runs along the coast line until the railway moves inland towards Teignmouth station and encompasses the area of sea-cliff known as ‘Woodlands’ where in 2014 an extreme failure occurred. Large sections of the cliffs here are deemed high risk, with numerous largescale failures the past 20 years.

The proposed development for this section of the railway is one of the biggest railway engineering projects conducted by Network Rail. It will require land reclamation into the sea in order to move the railway away from the cliffs, a mix of sea wall and revetment to optimise the coastal protection as well as retaining as much of the beach running along that area as possible.

The repositioning of the track away from the cliffs will allow for a series of buttresses to be constructed at (CBU 4,6,8,10 and 12) to reinforce the high-risk cliffs situated behind them. Other areas will be strengthened by large dowels to prevent a large wedge failure and a rock fall shelter will be installed to the high mile (west) of Parsons tunnel to protect the line from the cliffs around the portal.

Figure 54
Extent of Parsons Tunnel to Teignmouth Site (Arcadis, 2019)

Western Route WRCCA Plan continued

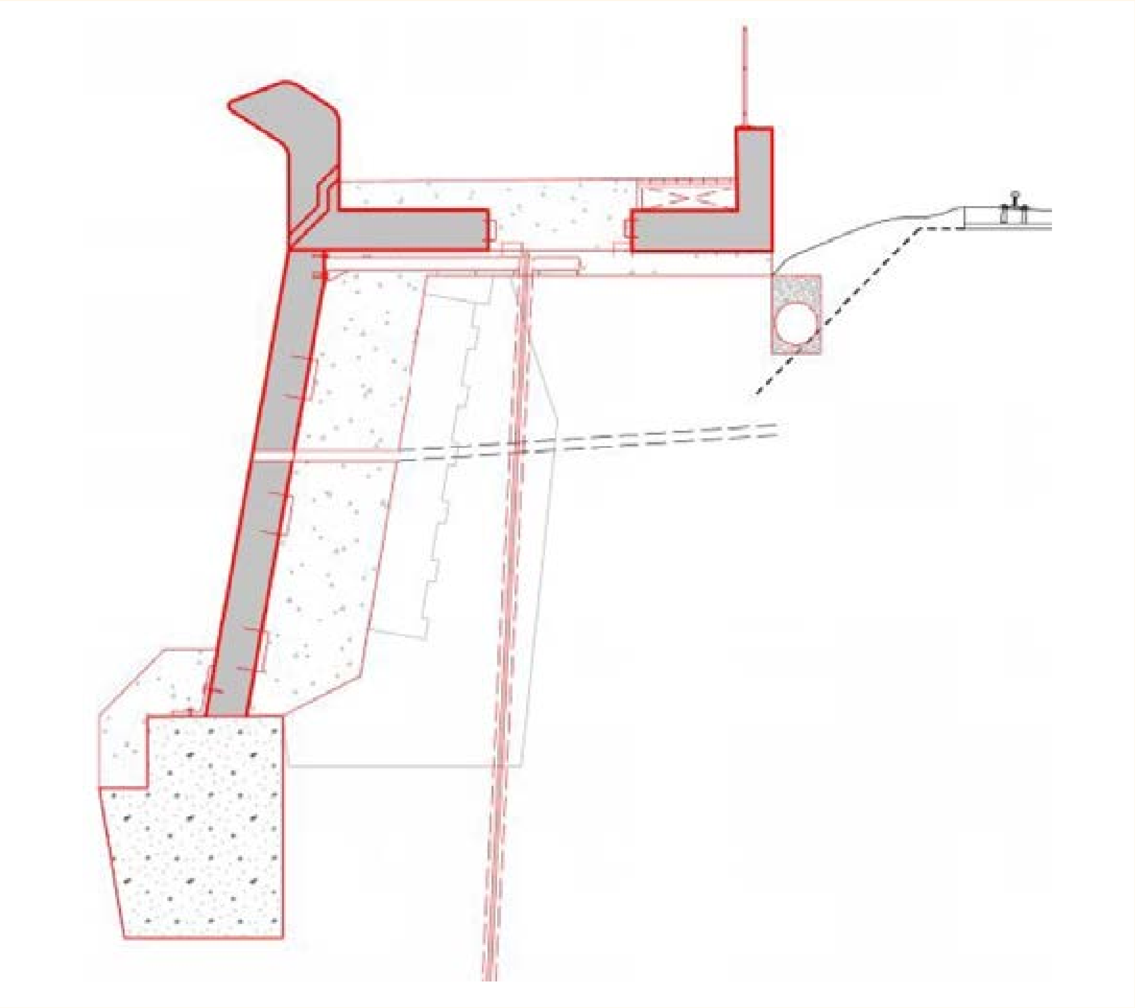
Marine Parade and Colonnade to Coastguards covers the main sections through Dawlish with Colonnade underpass being the separator between the two schemes. The proposed solution will consider the predicted sea level rise over the next 100 years to protect the town from sea level rise and to prevent a similar failure to that experienced in 2014.

The section known as Marine Parade is split into three sections; Town Gateway which covers the Colonnade underpass, Marine Parade Promenade, and Boat Cove, which is at the far end of the section providing protection to Kennaway tunnel portal.

There have been three main areas of focus which have been considered throughout the design process; improving resilience, safety and amenity. The proposed design encompasses all of these with the height of the sea wall being raised by 5m, creating a 90% reduction in the volume of water reaching the railway. Due to the increased height it allows for a 1.1m high parapet along the edge of the promenade to prevent members of the pubic falling as well as an upstand between the walkway and the railway preventing vehicle incursion in the event of collision. Finally, the public amenity along the promenade has been increased, with textured concrete and colour finishes adding interest and a 1m wide amenity strip at the back of the promenade provides space for seating.

The whole of the SWRRP is focused on maintaining the safe and reliable running of the railway into Cornwall.

Figure 55
Form 001 Design of the new promenade at Dawlish



Western Route WRCCA actions

Western Route is committed to reacting to the challenges of climate change to ensure the long-term resilience and sustainability of all assets.

The tables below summarise the WRCCA actions undertaken by Western Route in CP5 and their current status, followed by the actions that planned and agreed for CP6, and potential additional actions that have been identified as potential actions to deliver in CP6, but which are not funded in the current CP6 business plan.

The final table details actions that have been apportioned to Network Rail, in the Defra NAP. Some of these will align with CP6 planned and funded actions.

CP5 WRCCA Plan CP5 actions – Review

Table 6
CP5 WRCCA Plan CP5 actions – Review

Action name	Target completion date	Actual completion date	Comments
All impacts			
Staff trained to use and supplied with appropriate equipment, e.g. life vests for flooding events, seasonal PPE	Continually Reviewed	Ongoing through BAU activity	Staff have been supplied and trained to use appropriate equipment. Specialist equipment and training can be limited to specific locations e.g. Inflatable dam and Cowley Bridge – Exeter
Include clear requirements for climatic conditions and resilience levels in Route Requirements Documents	December 2014	Not completed	Not completed in CP5 – action to be addressed in CP6 through the Environment and Social performance policy
Weather information			
Use real-time Met Office weather data to confirm actual weather conditions and assess asset vulnerability	August 2014	August 2014	Met desk weather has replaced Met Office as weather service provider for Network Rail. The NRWS provides a 1 stop shop system for weather and specific asset risk information (such as rainfall, Soil Moisture index (SMI) and lightning risk)
Flooding			
Provision of water safety equipment (lifejackets, lifesaving rings) at repeat flood sites which require staff attendance	October 2014	October 2014	Water safety equipment at repeat flood sites are now provided
Staff who respond to flooding and assess flood risk to receive Water Awareness Training	End 2014	End 2014	Training was provided and completed for required maintenance personnel
Strengthen relationship with the Environment Agency through setting up of a Local Liaison Group on flood risk management to share information and resolve issues	March 2014	March 2014	Steering group and working group have been set up and are attended quarterly
Engage with Local Flood Resilience Forums	March 2015	March 2015	Achieved through strategic approach from Environment Agency/ Network Rail Liaison Officer and Senior Asset Engineer – Drainage
Appoint a shared, co-funded member of staff between the Environment Agency in the South West and Network Rail Western Route to facilitate closer working	End 2014	End 2014	Network Rail/Environment Agency Liaison Officer has been employed – role currently as secondment
Flooding			
Deliver the major projects identified in the 2013 Flood Resilience Study and funded in February 2014	Three-year programme with staged completion 2014, 2015 and 2016	See comments	Whiteball scheme – completed CP5 Year 1 Patchway Tunnel Up – completed CP5 Year 2 Hinksey – completed CP5 Year 2 Exe and Culme Study – Completed Study P1 July 2014 – Completed Study P2 April 2015 Athelney – Cogload – On hold Hele & Bradninch – Deferred CP6 Flax Bourton – Progressing to GRIP 5 in CP6 Catchment Monitoring – Deferred CP6 Cowley Bridge Weirs – Cancelled Cowley Bridge Culverts – Completed CP5 Year 5 Chipping Sodbury Lagoon – Ongoing – Expected completed date May 2020
Review new flood sites and prioritise them for design development and remedial works	End 2014	End 2014	Initial action has been completed and priority sites determined based on 12/13 season flood data. The RAM Geotechnics, Drainage and Off-Track (GDO-T) team will continue to review and develop flood resilience sites based on flooding events and climate change projections
Install Remote Condition Monitoring (RCM)	End 2014	End 2014	Western Route will continue when deemed necessary, to enhance the frequency of preventative maintenance at high risk drainage locations considered for RCM fitment; such that a proactive risk management philosophy is adopted
Review latest flood risk projections against updated rail network elevation model	End 2015	End 2015	Western Route has been mapped onto ArcGIS and superimposed onto various data maps. The following data is available to view: • BGS Geosure Slope Instability – Landslides (Categorised from E to A – find attached guidance to categories), • BGS Geosure Shrink-swell – Subsidence (Categorised from D to A– find attached guidance to categories), • ESI Groundwater flooding (Categorised from High to Negligible Risk – with 'other' not being at any risk), • NaFRA River & Coastal flooding (Categorised from High to very low – with 'other' not being at any risk), and • Environment Agency surface water flooding 1in 30, 1 in 100 and 1 in 1000-year flooding (categorised into 'Yes' or 'No' if at risk of flooding)
Install RCM on the most frequently monitored bridge structures in the 'flood plan' to reduce requirement for staff response	Potential addition	N/A	Structures team working in accordance with STE guidelines to manage risk, profile and compliance of their vulnerable assets

Table 6
CP5 WRCCA Plan CP5 actions – Review

Action name	Target completion date	Actual completion date	Comments
Earthworks			
Actively monitor Met Office rainfall data to implement an Adverse Weather Earthworks Plan and ensure safety. Continuously revise the plan to take into account earthwork condition	Strategy completion autumn 2014 Implementation 2015-2017	Strategy completion autumn 2014 Implementation 2015-2017	Adverse weather sites are determined based on the Earthwork Hazard Category (EHC), Risk and Earthwork Asset Criticality Band (EACB) of each 5-chain length and supplied to the earthworks RAM team. Through risk assessment of the 'Very High Risk' sites by the earthworks RAM team, a decision was taken whether an ESR would be required during adverse weather. Where ESRs were deemed necessary, the sites were added to the Earthwork Adverse Weather Implementation plan, detailing the location and type of speed restriction to be used, and under what conditions the ESR would be implemented. The earthworks included in the Adverse Weather Plan are updated annually following a risk assessment of all earthworks, undertaken by the earthworks RAM team
Remediate the highest risk earthworks as planned within the renewals work bank	March 2017	March 2017	Intervention works have been delivered or are planned for a number of the highest risk earthworks in CP5. Enhanced monitoring and Adverse Weather ESRs are implemented on high-risk sites that have been deferred until CP6 due to budget constraints
Install RCM on select high-risk earthworks	End 2017	End 2017	RCM installed at the following suitable high-risk earthworks: • Teignmouth Sea Cliffs Early Warning System, and • Smugglers to Woodlands Catchfence accelerometer and cliff Inclinometers Earthwork Detection Failure (EDF) installed at 102 5ch lengths at 33 no. sites: • Intelligent Infrastructure led Pilot scheme – 65 5ch lengths at 22 no. sites, and • Western Route funded scheme – 37 5ch lengths at 11 no. sites
Prioritise and include adverse weather sites in the Civils Adjustment Mechanism (CAM) submission, for remediation in Years 3-5 CP5	March 2015	March 2015	Adverse weather sites were prioritised and included in CAM submission
Remediate additional earthworks at adverse weather sites	Potential addition	Ongoing delivery	Earthwork drainage refurbishment and maintenance work bank was developed by the earthwork and drainage RAM teams to improve the resilience of earthworks and reduce risk of failure in adverse weather. Locations of the works have been prioritised based on risk to track, risk to Network Rail personnel (that currently have to manually erect ESR boards) and potential disruption to the effective running of TOC timetables
Heat			
Install RCM of rail temperature on some of the high-risk, highest delay impact locations	Potential addition	N/A	CoRCM units are thermometers set across the Route and are controlled by Delivery Units (DUs). Critical Rail Temperature (CRT) is set for each unit by Asset Management (track) or Maintenance team. When the CRT is reached an 'alarm' (email) is sent to Maintenance and Asset teams. Although the units continually measure temperatures, an alarm will only be sent in units that are set to do so; track temperatures may not be deemed an issue if the sleepers are heavy (concrete) and in good condition, and a full ballast shoulder is in place, restricting movement of the track itself. When an alarm is sent, a TSR will be put in place, the severity of the TSR is dependent on the extent the temperature has passed the CRT. Watchmen will be put in place, for the duration of the TSRs, to check for buckling of rail. comments required
Coastal and estuarine			
Support regional resilience proposals developed by Somerset County Council and the Environment Agency	Ongoing	Ongoing	Support is provided and coordinated by Environment Agency/ Network Rail Liaison Officer
Develop and publish proposals for increasing the resilience of the coastal railway at Dawlish	End 2015	End 2015	Multi-control period resilience programme estimated to cost up to £600m over 20 years. The Exeter to Newton Abbot resilience scheme shall be developed through CP5-CP8. Meetings to be held with DfT to determine funding and programme

CP5 WRCCA Plan CP5 actions – Review continued

Table 6
CP5 WRCCA Plan CP5 actions – Review

Action name	Target completion date	Actual completion date	Comments
Coastal and estuarine			
Develop individual Asset Management Plans for Coastal Estuarine and River Defences (CERDs) which detail vulnerable coastal assets and their management plan for inspection, maintenance, renewal and upgrade	March 2019	March 2019	JBA will develop and deliver CERD analysis. JBA surveying assets as part of development of the database
Combined with Cornwall Signalling Renewal, relocate signalling equipment into storm resilient cases and buildings	Potential addition	N/A	Action delivered as part of Cornwall Signalling Renewal
Following the development of proposals by end 2015, consider investing in a rolling programme of resilience improvement work for Powderham Banks – Dawlish – Teignmouth over a 4 Control Period cycle (mid CP5 to end CP8)	Potential addition	N/A	Exeter to Newton Abbot (EX2NA) resilience study is ongoing. Ground Investigation (GI) of Teignmouth sea cliff has been completed. Intervention options report completed, preferred option selected
Wind			
Review and catalogue the results of the national LIDAR survey	End Q1 2015	End 2020	Survey release date was delayed to CP6 – Analysis ongoing with Airbus to allow pertinent information to be obtained from LiDAR survey data
Undertake autumn 2014 tree clearance programme (£5m)	End 2014	End 2014	Completed during the autumn 2014 season
Series 1 (overhead line system to be installed in Western Route) has improved design parameters for wind loading compared to previous high-speed overhead line systems	N/A	Series 1 Reference Design signed off June 2014	Series 1 OHL installed on electrified areas of Western Route
Vegetation clearance as part of Great Western Electrification Programme (GWEP)	Staged completion 2014-2018	Ongoing	GWEP de-vegetation was completed under extended license. Volume targets were revised and change controlled. Revised volume targets were met
Maintain new reduced levels of vegetation (following clearance during 2014 and the Electrification Programme)	Potential addition	N/A	Great Western Route Modernisation (GWRM) continued to maintain de-vegetation levels until hand back to RAM team following competition of GWRM. De-vegetation extents and volumes were reported to RAM. Maintenance teams to maintain vegetation and upload data to ELIPSE, allowing detailed records to be kept on time and location of de-vegetation
Cold and snow			
On extreme snow/cold days, consider running a maintenance train ahead of the first passenger trains to clear icicles, or other mitigation	Potential Addition	N/A	In extreme cold, Control shall contact the TOCs to request a 'Ghost' train be sent prior to any passenger trains. Process delivered through Disruptive Management Conference (DMC)
Inspect and monitor wet structures/tunnels for icicle growth	Potential Addition	N/A	Inspection and monitoring of wet structures/tunnels for icicle growth is being completed by control through Disruptive Management Conference (DMC)
Increase the number of Points Operating Equipment (POE) with internal heating as part of the renewals process	Potential Addition	N/A	Only a very few POEs do not have internal heating. Upgrade to be completed as part of BAU renewal process
Use train borne monitoring where possible. Review inspection frequencies during winter preparation	Potential Addition	No further works currently planned	Discussion held with Asset Information at STE concerning how the very large amounts of data that would be gathered by the cameras will be collected and processed. Funding for R&D required – no single product available. Investigation required to determine if the standard of the current on-board camera is sufficient to assess the heating strips. Potential that RCM technique – measuring current induction within the heating strips – would be more effective system of detecting detached heating strips. No further works to progress as this stage

Table 6
CP5 WRCCA Plan CP5 actions – Review

Action name	Target completion date	Actual completion date	Comments
Adhesion			
Undertake autumn 2014 tree clearance programme (£5m) – as noted in Wind	Undertake autumn 2015 tree clearance	End 2014	The Western Route Season Delivery Specialist (SDS) completed assessments of rail adhesion sites - updating the Hazard Directory, and the TGA's sandite and RHTT treatment programme accordingly.
Improved management of adhesion and development of autumn timetables	Ongoing	Ongoing – continual improvement	The autumn timetable for 2015 included many successful treatments that were trialled during 2014; mainly MLN3 WCS, where the RHTT was slowed and treated in shorter more intense bursts, this reduced the number of low adhesion reports that were received.
Lightning			
Include lightning risk in the business case for the proposed accelerated Cornwall Signalling Renewal and install lightning protection measures in the new signalling system	Potential addition	N/A	Lightning protection measures have been included in the Cornwall Signalling renewal

Planned WRCCA actions for CP6 (2019 – 2024)

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/ action lead	Expected benefit	Target completion date	NAP action reference
All impacts							
General	N/A	Compliance with the Environment and Social minimum requirements standard for all Infrastructure Projects and Works Delivery schemes	N/A	RAM/ Sponsor	Improve Network Rail's environment and social performance through the mitigation of risks and the improved delivery of environment and social management to leave a sustainable legacy for future generations.	December 2019	-
Earthworks							
Earthworks are at increased risk from failure in heavy and persistent rainfall	Various locations across the Route – determined through assessment of earthwork condition and risk following heavy rainfall	Undertake (minimum) annual adverse weather (rainfall) risk assessment to determine highly vulnerable sites to heavy and/or persistent rainfall that require operational restriction during adverse/ extreme rainfall	Time spent only	RAM GDO-T	Reduction of risk to rolling stock and passengers in case of earthworks failure in adverse/extreme rainfall	CP6 Yr1 – October 2019 CP6 Yr2 – October 2020 CP6 Yr3 – October 2021 CP6 Yr4 – October 2022 CP6 Yr5 – October 2023	NRNAP1
		Implement adverse weather (rain) protocol when pre-defined trigger levels of rainfall and SMI are met	Schedule 8 costs acquired per event			BAU activity	NRNAP1
		Enhance earthwork drainage at Adverse Weather sites	£9 million			Delivered as per programme in CP6 Business Plan	NRNAP5
		Remediate the highest risk earthworks as planned in the renewal workbank	£45 million				NRNAP5
		Increase coverage of Earthwork Detection Failure (EDF) in the Route	£200k	RAM Geotechnics	Near real-time detection of earthwork failure allowing operational restrictions to be put in place	March 2021	NRNAP4

Planned WRCCA actions for CP6 (2019 – 2024) continued

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Earthworks							
Earthworks are at increased risk from failure in heavy and persistent rainfall	Bath Road cutting	Earthwork drainage enhancement at Bath Road cutting	£1.5m	RAM GDO-T	Increased resilience to surface and sub-surface water flow and removal of ESR in adverse weather (rain)	March 2021	NRNAP5
	Sites at risk from failures on 3rd party land	Undertake 3rd party slope risk evaluations making use of 'Classification of Hazards on Outside Party Slopes' (CHOPS) assessment	Time spent only	RAM Geotechnics	Reduction of risk to rolling stock and passengers in case of earthworks failure in adverse/extreme rainfall	March 2021	NRNAP1
Clay cored embankments susceptible to desiccation following dry and hot periods	Various – determined through earthwork assessments and track performance issues	Develop high risk desiccation embankment register and monitor	Time spent only	RAM GDO-T	Targeted track and vegetation management during dry and hot periods (high SMD)	March 2020	-
		Removal of high water demand trees on clay embankments that are particularly susceptible to desiccation	As required		Reduce effect of desiccation on track performance	BAU activity	-
		Undertake ground investigations and install inclinometers and piezometers at embankments known to be susceptible to shrink/swell	£2m	RAM Geotechnics	Develop early warning system using monitoring information to undertake targeted track maintenance regime and earthwork interventions	March 2020	-
		Develop cyclic tamping strategy with ringfenced shifts to take place twice a year	TBC – predicted costs to be determined as part of development of strategy	Head of Maintenance	Tamping shifts in spring time aimed at preventing issues occurring by tamping to a fixed design tamping shifts in autumn available to recover track position if it has dropped during the summer		-
Flooding							
Lineside E&P equipment within flood zones	Westbury – Castle Cary (WEY); Castle Cary – Taunton (CCL, MLN1), Totnes – Liskeard (MLN1&2), and Penzance (MLN4)	Renew old rubber 650V power cables showing signs of significant insulation degradation. Assess position of lineside equipment cabinets and raise them onto platforms in high flood risk areas	£21.5 million	RAM E&P	Prevention of signal power cables failing in service, reduction in train delays	End of CP6	NRNAP3
Major repeat flood sites	Staffords Bund	Repair and enhancement of flood bund at Staffords Bridge	£800k	Western Route flood resilience – enhancement	Reduction of flow through Cowley Bridge culvert in flood conditions	October 2019	NRNAP3
	Hele and Bradninch flood resilience scheme	Track lift through level crossing and highway. Flood plain landscaping.	£8.0m		Increased resilience and reduction in frequency of flood events	March 2021	

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Flooding							
Major repeat flood sites	Flax Bourton flood resilience scheme	New crest drain to intercept runoff flows, new cross drains and possible enhancement to track drainage – Develop scheme to GRIP5 – Detailed design	TBC	-	Increased resilience and reduction in frequency of flood events – reduction in return flood period to be confirmed in detail design	March 2021	-
	Catchment monitoring	Installing telemetry at Exeter and Chipping Sodbury and improving the Exeter flood warning model	£365k		Improve flood warning for both sites leading to shortened periods of railway closure	March 2020	-
	Cowley Junction Demountable Barrier	Construction of demountable barrier – completion of Cowley Bridge flood resilience scheme to tie in with Environment Agency flood defence	TBC	RAM GDO-T	Protection of assets at Cowley Junction and along rail corridor to Exeter St. David's station	March 2020	-
Embankment damage from flood water	Athelney Embankment	Refurbishment and increased resilience of embankment damaged by flooding	£500k	RAM Geotechnics	Repair of damage caused by extreme flooding in 2014 and increased resilience to future flood events	March 2021	NRNAP5
Culvert can become overwhelmed in flood conditions	Various – determined through structures condition assessments	Renewals of prioritised high risk culverts	£4m	RAM Structures	Improved capacity of high criticality culverts allowing for increased flooding events due to climate change	March 2024 (End CP6)	-
Scour							
Damage caused to bridge structures from scour	River Cherwell	Undertake assessment and where required intervention works to reduce scour risk score to low	£230k	RAM Structures	Reduction in risk of scour damage during flood events	-	-
	Wharncliffe Viaduct		£250k				
	River Colne		£300k				
	Maidenhead Viaduct		£600k				
	St.James – R.Avon & towpaths		£280k				
	RBE UW: Huntspill Viaduct		£200k				
	RBE UW: Huntspill Viaduct 2		£200k				
	Huntspill Viaduct 3		£200k				
	River Dart		£300k				
	Liskeard Viaduct		£275k				
	Tregargle Viaduct		£275k				
	Truro Viaduct		£275k				

Planned WRCCA actions for CP6 (2019 – 2024) continued

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Scour							
Damage caused to bridge structures from scour	Yeo River – No.26	Undertake assessment and where required intervention works to reduce scour risk score to low	£200k	RAM Structures	Reduction in risk of scour damage during flood events	-	-
	Dart Bridge		£330k				
	Railway over R.Taw Downside		£150k				
	Weir Marsh Viaduct 63		£250k				
	Black Bridge 77		£360k				
	Pill – No.93 Over river		£300k				
	RBE UW: Rock Mill Viaduct		£250k				
	River Evenlode/ Fawler Manor Farm		£155k				
	River Avon		£675k				
	Pump House – River Severn		£250k				
	Blackpool Brook/ Cinderford Brook		£110k				
	Lavignton Viaduct		£200k				
	Lavignton Viaduct		£660k				
	Bourne End Viaduct		£400k				
	Sheep House		£300k				
Earthwork Scour	Various high-risk locations across the Route – determined by RAM-Geotech through examination/ evaluation process	Scour prevention and repair at high risk sites	£2.9m	RAM Geotechnics	Repair of existing scour damage and increased scour resilience at high risk and criticality sites	March 2024 (End CP6)	-
Heat							
Track vulnerable to buckling in high temperatures	Southall East Junction	Renewal involving replacement of timber bearers with concrete bearers	£2.5m	Track renewals provision	Improved stability in hot weather	Jan 2020	-
Uninterruptible Power Supply (UPS) batteries are susceptible to heat	PSP buildings	Fit full remote temperature monitoring of battery rooms and painting of equipment room roofs with reflective paint	£200k	RAM E&P	Reduction in thermal solar gain and more efficient maintenance response to high temperature alarms	Completed through BAU	-

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Coastal and estuarine							
Damage to infrastructure from storms	Exmouth Sea Defences	Repair and reinstate sea defences in Exmouth area with consideration given to projected increase in sea levels	£850k	RAM Structures	Increased sea defence resilience	March 2024 (End CP6)	-
	Lostwithiel to Fowey Sea Defences	Repair and reinstate sea defences	£1.2m	RAM Structures	Sea defence resilience	March 2024 (End CP6)	-
Damage from waves, storm surge and subsequent cliff instability	Exeter to Newton Abbot	South West Rail Resilience Programme – Exeter to Newton Abbot resilience – Works to keep the Route open during extreme weather including the following CP6 schemes:	£286.2m (total)	South West Rail Resilience Project	120-year design life and enhanced resilience to climate changes	Rolling programme of resilience improvement work for Powderham Banks – Dawlish – Teignmouth over a 4 Control Period Cycle (mid CP5 to end CP8) – subject to DfT funding	NRNAP5
		Rock fall shelter	£10m				
		Seawall strengthening	£26.2m				
		Cliff face remediation, track realignment and beach reclamation	£250m				
Structures at risk from flooding and damage from storms due to sea level rise	Various vulnerable coastal locations	Manage Asset Management Plans for Coastal Estuarine and River Defences (CERDS) which detail vulnerable coastal assets and their management plan for inspection, maintenance, renewal and upgrade	TBC	RAM Structures	Targeted increase in CERD resilience	March 2024 (End CP6)	-
	(ELR:) FOY & EMT	A series of major works are planned for the CERDs on the FOY and EMT. These works are a combination of repair works and enhancements	£4m				
3rd party engagement							
Improve relationships and increase liaison with 3rd party and other government organisations	Connecting the Culm	Sharing of flood modelling undertaken for the Cowley Weirs and Hele and Bradninch flood resilience schemes	N/A (modelling undertaken through CP5 flood resilience schemes)	WRCCA lead	Reduction of flooding in Cowley Bridge area	June 2019	-
	Somerset County Council	We are actively working with Somerset Council on the early stages of Adaptation Pathways in Somerset: Climate Adaptation Planning for Flooding in Somerset'	N/A	WRCCA lead	Improved flood resilience in Somerset levels	March 2021	-
	N/A	Continue local liaison group with Environment Agency	N/A	Environment Agency/ Network Rail liaison officer	Allow liaison on flood risk management to share information and resolve issues	Active	-

Planned WRCCA actions for CP6 (2019 – 2024) continued

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Cold and snow							
Formation of ice on OLE not allowing the pantograph to connect properly	OLE	Formalising the process of TOCs operating 'ghost trains' and icebreakers to keep the OLE clear of ice or to safely remove ice from the OLE	To be agreed with TOC	SDS	This method is proposed to prevent incidences of trapped trains and the inherent risk to the travelling public	September 2020	-
Freeze thaw in rock cuttings causing rock slope failures	Various locations across the Route – determined through assessment of earthwork condition and risk	Targeted and appropriate interventions at the highest risk and criticality sites – including scaling and installation of netting, and maintenance of existing netting	£17.4m	RAM Geotechnics	Increased resilience to failures due to freeze-thaw	March 2024 (End CP6)	-
Wind							
Trees falling onto the line causing risk to safety and performance	Focusing on mainline areas to the west of Swindon	Undertake additional vegetation management to increase compliance to standard NR/L2OTK/5201	£23m	RAM GDO-T	Increased resilience to falling vegetation from Network Rail and adjacent 3rd party land	Compliance by end of CP7	-
	Route wide	Undertake vegetation LIDAR survey	£1m			March 2021	-
		Review and catalogue the results of the national LIDAR survey	N/A	RAM GDO-T		March 2021	-
	N/A	Continue improving the competence of maintenance DU staff through continued tree awareness workshops and engaging with STE on the competence matrix update	N/A	N/A	Improved competence of maintenance DU staff to recognise and mitigate risk from falling trees	Continued improvement	-
Cables can become detached from OLE gantries in strong winds	OLE zones within the Route	Use train borne cameras to detect potential or active OLE failure	£500k	DfT/GWR/Paul Barnes lead	Reduction in OLE failures	July 2021	-
Lightning							
Lightning can cause significant damage to S&T equipment		Build lightning resilience into renewal designs for buildings and S&T equipment	BAU	N/A	Increased resilience of S&T equipment and buildings against lightning	Completed through BAU	-
Lightning strikes cause power surges or fires if the infrastructure is not sufficiently protected	Route wide	All buildings will be risk assessed and, if necessary, have lighting protection installed and maintained	As required subject to risk assessment output	RAM Buildings	Reduced power surges, blackouts and fires	March 2024 (End CP6)	-
Trees can be struck by lightning causing trees to collapse and ignite	Various	Undertake vegetation management to increase compliance to standard NR/L2OTK/5201	£23m	RAM GDO-T	Reduction of hazard from trees during lightning event	March 2024 (End CP6)	-

Table 7
Planned WRCCA actions for CP6 (2019 – 2024)

Vulnerability	Location	Action to be taken	Cost of action	Funding source/action lead	Expected benefit	Target completion date	NAP action reference
Adhesion							
Leaves on the line, especially in the autumn, cause performance issues due to loss of adhesion between rail and train	Route wide	Rail Head Treatment Trains will be used on the Western Route in the autumn months (late September to early December). Operating out of four separate depots over the Western Route the RHTTs operate every night of the week within the autumn apart from Saturday	£14.7m	SCO/SDS	Reduce the risks of leaves on the line and subsequent performance issues	Ongoing through BAU	-
		Improved planning of treatment through undertaking robust pre, mid and post season plans	TBC	SDS	Reduce the risks of leaves on the line and subsequent performance issues through targeted treatment	Autumn 2019	-

High Priority WRCCA actions not funded in CP6

Table 8
High priority WRCCA actions not funded in CP6

Vulnerability	Location	Potential action	Action lead	Predicted benefit	Target completion date	NAP action reference
Climate change						
Understanding the potential effects of modal change of behaviour on transport infrastructure due to climate change	Various	Assessment to determine vulnerabilities and effect of modal shift due to climate change and create a climate change vulnerability heat map based on UKCP18	Western Route Environment Specialist	Use the results to determine potential studies and schemes for CP7 and beyond	March 2024	-
Earthworks						
Earthworks are at increased risk from failure in heavy and persistent rainfall	Sites within Adverse Weather Risk Register	Install geo-physics based RCM on high risk earthworks	RAM – Geotechnics	Increase understanding of high-risk earthwork behaviour and detect movement in real-time	October 2020	NRNAP1
Clay cored embankments susceptible to desiccation following dry and hot periods	Sites known to be vulnerable to desiccation	Soil moisture probes to be installed into embankments to determine accurate in-situ SMI		Targeted track maintenance	N/A	NRNAP1
Flooding						
Major repeat flood sites	Athelney-Cogload	Completion of cross-track drain at Lyng Overbridge (3rd party inflow) and flood risk study through Somerset Levels (£2.6m)	Western Route flood resilience-enhancement	Reduction of flood risk at site location – flood return period reduction to be confirmed during design	N/A	NRNAP4
	Flax Bourton	Development to GRIP 8 – Installation of new crest drain, cross drains and enhancement to track drainage (£2.2m)				
	Berkley Road Junction	Proactive heavy drainage maintenance to ensure that existing systems can accommodate increased volume during extreme weather events; and track lift to bring running rails above expected floodwater levels (£1.0m)				
	Plympton	Upsize the existing components within the 6ft track drainage system to deal with greater volumes of water (£0.5m)				

High Priority WRCCA actions not funded in CP6 continued

Table 8
High priority WRCCA actions not funded in CP6

Vulnerability	Location	Potential action	Action lead	Predicted benefit	Target completion date	NAP action reference
Flooding						
Major repeat flood sites	Chipping Sodbury – Track drainage	Track drainage clearance in Up and Down cess through Chipping Sodbury cutting from the west portal to the lagoon. 6ft carrier drain requires clearing and CCTV survey to prove condition and capacity (£4.0m)	Western Route flood resilience-enhancement	Reduction of flood risk at site location – flood return period reduction to be confirmed during design	N/A	NRNAP4
	Lawes Road	Jetting and CCTV work to existing piped drainage system through bridge and retaining wall section and potential replacement of piped system with new components and upsizing of pipe diameters (£0.5m)				
Scour						
Flood and scour damage to structures	All sites risk rated medium/ high scour risk	Scour protection works to reduce risk to low	RAM – Structures	Reduction in risk of closing railway during and after flood events	CP8	-
Coastal and estuarine						
Sea Level Rises	Various sea defences	Improved/repaired sea defences	RAM – Structures	Resilience to sea level changes	CP9	-
Damage from waves, storm surge and subsequent cliff instability	Exeter to Newton Abbot	Rolling programme of resilience improvement work for Powderham Banks – Dawlish – Teignmouth over a 3 Control Period cycle (CP6 to CP8)	South West Rail Resilience Project (SWRRP)	Enhance resilience to extreme weather and climate change	CP6-8	-
Adhesion						
Leaves on the line, especially in the autumn, cause performance issues due to loss of adhesion between rail and train	Route wide	Chlorophyll sensors to be fitted to the RHTTs	SCO	Treatment will based on the presence of leaf contamination as well as generation of heat maps showing the worst locations, so that sites can be located for additional and specific mitigation	March 2024 (End CP6)	-

NAP actions

Table 9
NAP actions

Objective	Action	Timing	Network Rail NAP action reference	Monitoring and metrics
Climate change				
Network Rail will continue to address flood risk across its network by:	Ongoing monitoring of adverse weather through visual and thermal imaging	CP6	NRNAP1	Network Rail 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 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 UKCCRA 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.

Western Route management and review

The projects and schemes included within the Western Route CP6 WRCCA plan have been agreed by the Director of Route Asset Management following detailed review of asset requirements by the individual Route Asset Managers and included within Western Route's CP6 business plan. To ensure that a tight control of delivery cost and volume is maintained a comprehensive governance process has been put in place to manage scheme delivery, deferral and scheme and business plan scope change with a rigid and peer reviewed change control process.

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