Route Weather Resilience and Climate Change Adaptation Plans

Western

Contents

Purpose of this document

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

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

Director Route Asset Management statement

Dawlish storm surge breaches sea wall, February 2014

Flooding at Hinksey (Didcot to Oxford), November 2012

Western Route has faced three years 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 is currently very high and weather-related issues at locations such as Dawlish, the Somerset Levels and Hinksey have become nationally totemic symbols of the vulnerability of the rail network to weather-related issues.

The start of CP5 sees Western Route 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. A major programme of flood resilience projects is being delivered for the Route at a range of vulnerable locations, whilst the Route's ability to predict and plan for extreme weather is being improved through greater use of specialist forecasting tools, catchment monitoring and remote condition monitoring.

This document articulates Western Route's strategic objectives to manage and mitigate the effects of extreme weather and climate change 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.

Mike Gallop
Director Route Asset Management, Western Route
September 2014

Executive summary

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

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

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

An analysis of Schedule 8 performance costs (the compensation payments to train and freight operators for network disruption) attributed to weather during the period 2006/07-2013/14 clearly shows flooding has had by far the most significant impact on Western Route. Wind and earthslips are also major contributors to weather-related disruption.

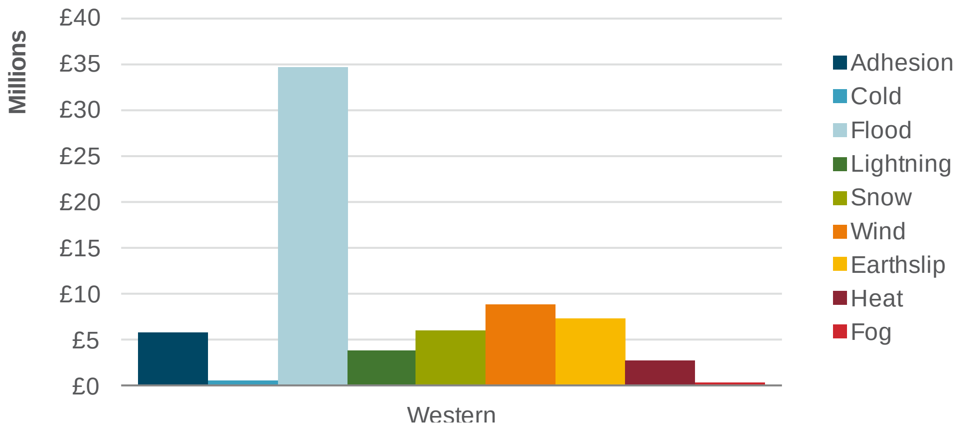

Figure 1 Western Route weather attributed Schedule 8 costs 2006/07-2013/14

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

- increase the understanding of weather and climate change impacts on the Western Route
- improve the knowledge of weather impacts through identification of root causes and trends to support the identification of cost effective resilience measures
- predict the impacts of weather and use weather forecasting and asset monitoring to manage locations vulnerable to adverse weather
- develop and manage a Route Weather Resilience and Climate Change Adaptation Plan to inform current and future Control Period investment plans and workbanks
- specify weather resilience and climate change adaptation in Project Requirements for renewals and new works
- support initiatives and demonstration projects aiming to deliver network wide resilience improvements
- engage with key regional stakeholders to communicate the Western Route strategy, planned programmes of work and identified weather resilience and climate change adaptation actions; including the South West Peninsula Railway Task Force and the Environment Agency.

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

- deliver the major flood resilience projects identified in the Route's 2013 Flood Resilience Study and funded in February 2014
- increase the use of real-time Met Office data to confirm actual weather conditions
- roll out a strategic programme of Remote Condition Monitoring for:
  - high-risk earthworks
  - frequent flooding sites and bridge structures
  - air conditioning in lineside equipment buildings
  - points operating equipment temperature
  - rail temperature
- develop a Route Coastal, Estuarine and River Defence (CERD) plan which details vulnerable coastal assets, their management plan, and future investment requirements
- maintain reduced levels of vegetation following an electrification-led clearance programme.

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

Introduction

Weather events can be a cause of significant disruption to the railway network. Recent prolonged periods of rainfall and extreme storm events demonstrated much of the network is resilient; however, asset failures such as the Dawlish sea wall, extended flooding such as at Hinksey and on the Somerset Levels, and the widespread tree fall during the St. Jude storm, reveal the vulnerability of the rail network and the severe impact these weaknesses in resilience have on train services and our resources.

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

Over the past eight years (2006/07 to 2013/14) the average annual Schedule 8 cost attributed to weather for the whole network was over £50m. The data clearly includes the impacts on train performance from the severe weather events during 2007, 2012 and 2013 from rainfall, and 2009 and 2010 from snowfall, Figure 2. In terms of the proportion of delay minutes, weather and seasonal events on average caused 12% of all delays experienced during this eight year period.

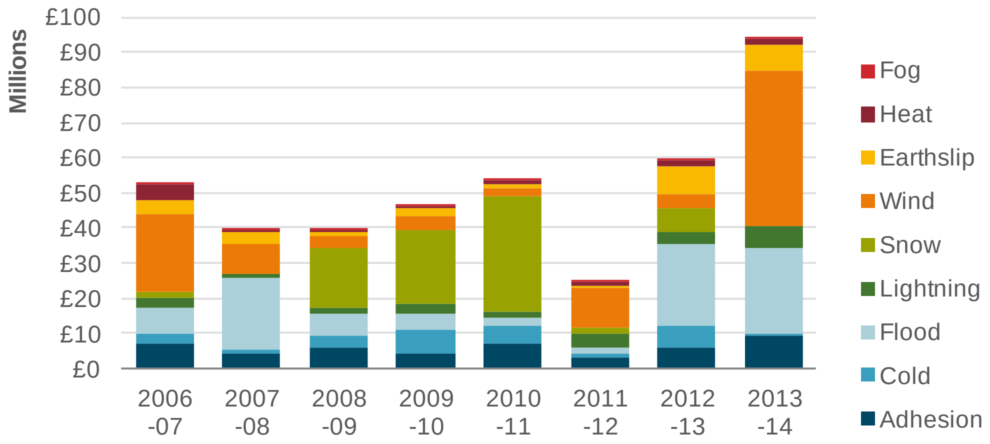

Figure 2 Whole network weather attributed Schedule 8 delay costs, 2006/07 to 2013/14

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

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

Potential escalation of these impacts from climate change supports the business case to increase weather resilience actions and presents a challenge to identify further actions to deliver a resilient rail network for the future.

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 3 and clearly shows a rising trend in temperature over the past century[1].

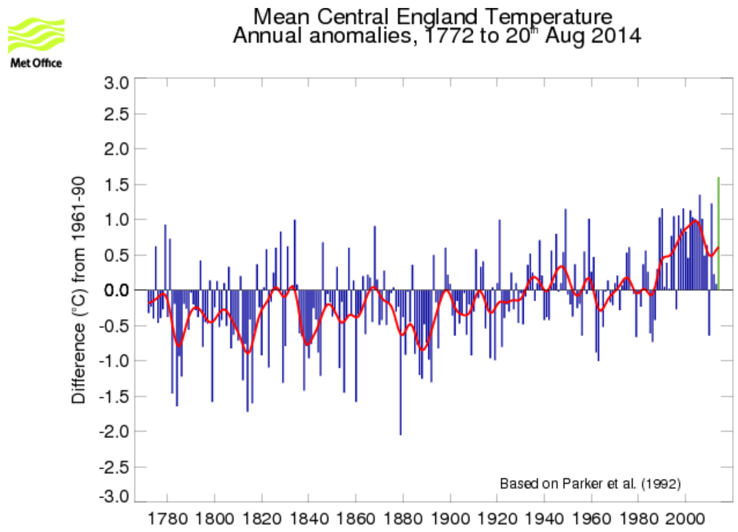

Figure 3 Mean Central England temperature record

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

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

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

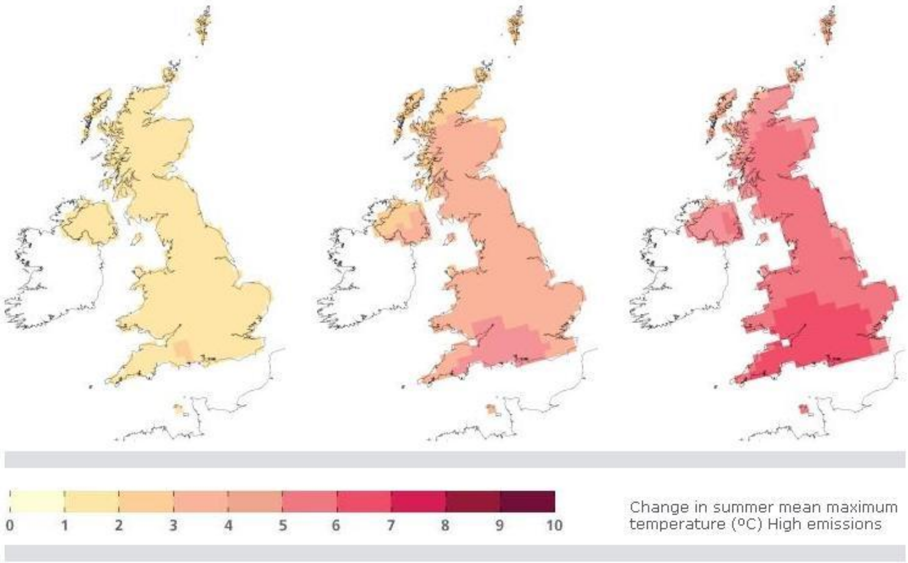

Figure 4 Change in summer mean maximum temperature (left 2020s, middle 2050s, right 2080s) (© UK Climate Projections, 2009)

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 this Route Weather Resilience and Climate Change plan (WRCCA) uses the projections to support the prioritisation of weather resilience actions.

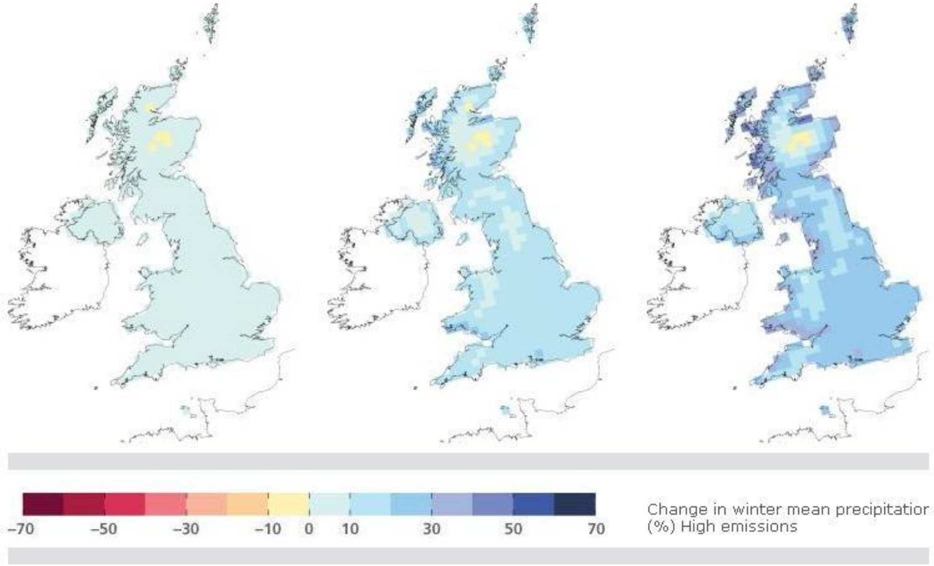

Figure 5 Change in winter mean precipitation (left 2020s, middle 2050s, right 2080s) (© UK Climate Projections, 2009)

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

Figure 6 Weather resilience and climate change adaptation framework

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

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

The following sections provide findings from the Western Route vulnerability and impact assessments, and details of the WRCCA actions; both completed and planned in Control Period 5, and potential additional actions, that aim to increase weather and climate change resilience.

Figure 7 Flooding at Hele & Bradninch level crossing, between Tiverton Parkway and Exeter St Davids, October 2012

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Western Route WRCCA strategy

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

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

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

Figure 8 The overtopping of an aqueduct demonstrates the importance of understanding surrounding water systems

Western Route strategy

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

- increase the understanding of weather and climate change impacts on the Western Route
- improve the knowledge of weather impacts through identification of root causes and trends to support the identification of cost effective resilience measures
- predict the impacts of weather and use weather forecasting and asset monitoring to manage locations vulnerable to adverse weather
  - install Remote Condition Monitoring on selected assets
  - combine this monitoring with Met Office and Environment Agency 'broader' data and intelligence
  - use triggers and action levels to apply operational restrictions based on asset condition and local weather observations
- develop and manage a Route Weather Resilience and Climate Change Adaptation Plan to inform current and future Control Period investment plans and workbanks
- specify weather resilience and climate change adaptation in Project Requirements for renewals and new works
  - ensure that the integration of Great Western Electrification into the Western Route does not import new climate and weather vulnerabilities
- support initiatives and demonstration projects aiming to deliver network-wide resilience improvements
- engage with key regional stakeholders to communicate the Western Route strategy, planned programmes of work and identified weather resilience and climate change adaptation actions; including the South West Peninsula Railway Task Force and the Environment Agency.

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

We have started to achieve these objectives through recent studies into weather impacts:

- Geo-Environmental Resilience Feasibility Study (April 2014)
- increasing climate change resilience (pilot study preceding this report, Spring 2014)
- the preparation and delivery of weather-related plans on Western Route during the St Jude's Storm high winds event of 27th and 28th October 2013 (operations report, March 2014)
- the effects of the severe weather of winter 2013/14 on the Western Route of Network Rail (operations report, May 2014).

Western Route vulnerability assessment

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

Network-wide weather vulnerability

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

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

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

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

Network Rail has moved from subjective and expert review-based knowledge of weather and climate change risks to more detailed internal analysis of asset failure and weather data to understand thresholds at which failure rates significantly change. Figure 9 provides an illustrative example of the analysis identifying assets with higher sensitivity to weather impacts. The horizontal lines are thresholds where there is 'no significant' (green), 'significant' (amber) or 'very significant' change in incident rates (red). This deeper dive analysis is critical to understanding the resilience of operational assets today and potentially in future climates.

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

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

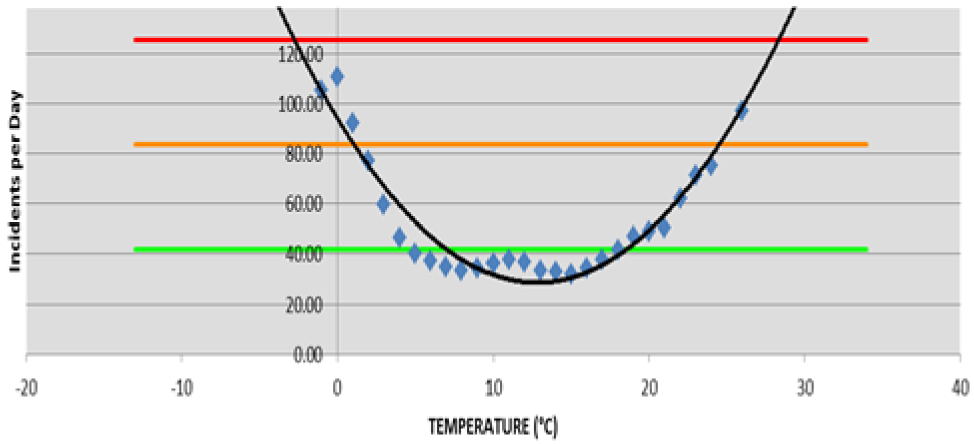


Figure 9 Example of asset failure rates varying with temperature

Managing operational response to weather vulnerability

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

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

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

Network Rail seeks continuous improvement of weather-based decision support tools, including flood, temperature, wind speed and rainfall alerts. A trial aiming to significantly improve real-time weather forecasting has installed approximately 100 weather stations on the Scotland rail network. In Western Route, there is wide coverage from Met Office weather stations and radar which is used to provide real-time weather information, Figure 10.

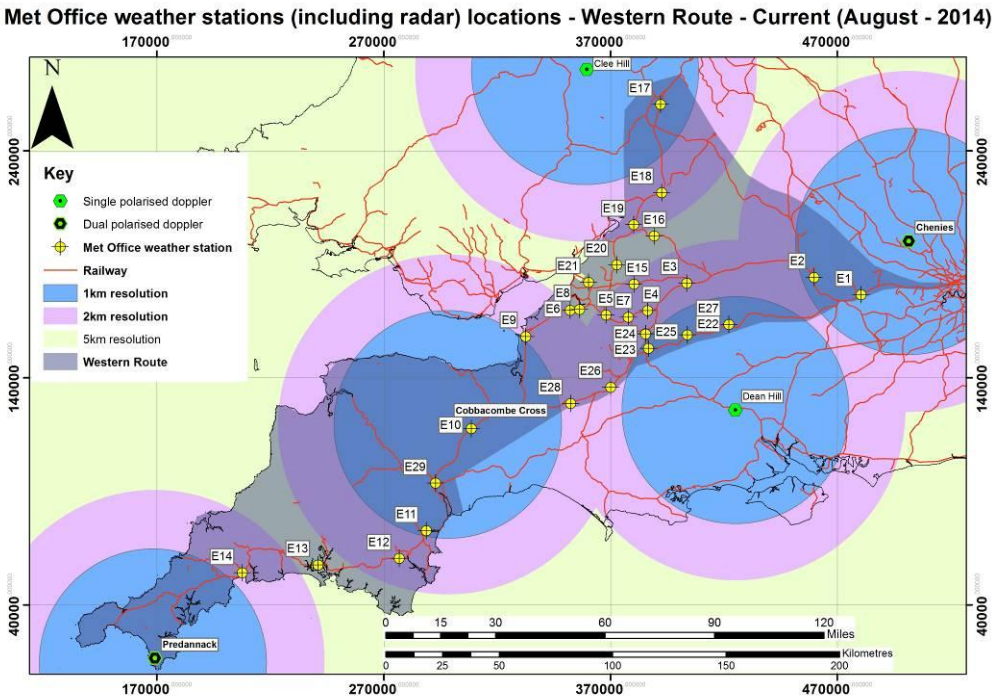


Figure 10 Met Office weather stations and radar covering Western Route (current in August 2014)

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

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

Improving our network wide resilience

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

The WRCC programme is founded on a bow tie risk assessment of weather-related disruption, Figure 11 – this risk assessment methodology is used widely across Network Rail. The bow tie assessment provides a detailed understanding of the adequacy of the controls that are in place to reduce the causes of disruption and consequences and highlights those controls that need to be enhanced.

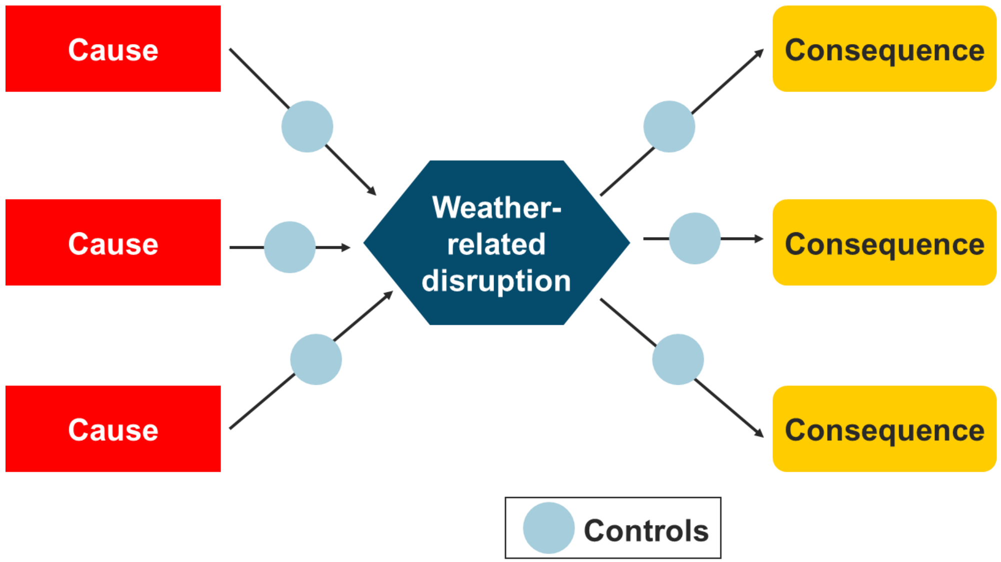


Figure 11 Bow tie risk assessment

The programme consists of six sub-programmes and their 23 constituent projects; these are described in Figure 12 below. Although the bulk of the outcomes that are currently defined expect to be delivered within the next 18 months, the programme is expected to extend throughout CP5.

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

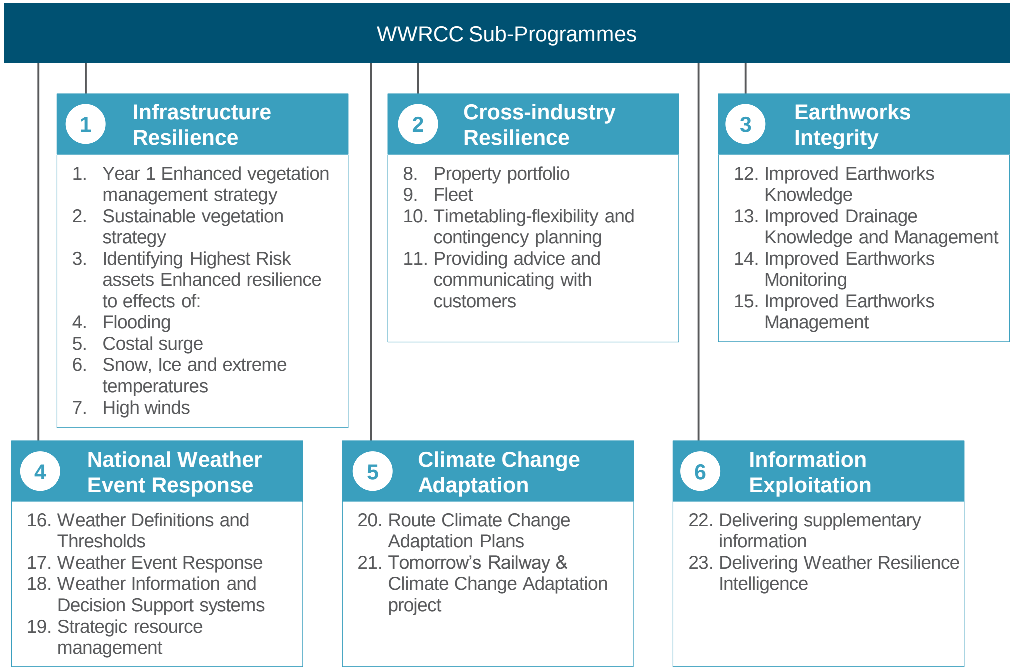


Figure 12 The constituent components of Network Rail's WRCC programme

The WRCC programme is currently supporting the delivery of:

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

Route weather vulnerability

The Western Route has seen worsening weather conditions over a number of years and has experienced two successive extreme winters and consequent disruption. The geographical location of the Route within the UK and the proximity to the Atlantic Ocean leaves it highly exposed to the weather conditions and particularly susceptible to flooding, landslips, sea level rise and wind.

Flooding remains the Route's primary weather vulnerability, accounting for 50 per cent of the Route weather attributed delay costs during 2006-2014. In 2014, Western bore the brunt of the UK's worst storms in 20 years[2] culminating in a breach in Dawlish Sea Wall, Figure 13, and the first ever flooding at Fordgate. This coincided with groundwater flooding on an unprecedented scale in the Thames Valley near Maidenhead.

Figure 13 Dawlish sea wall breach, February 2014

Figure 14 Stormy waves at Penzance, 14th February 2014

- along the Dawlish Sea Wall, the barrage of storm surges and winds caused a 100m breach of the wall, suspending train services for 58 days. In the previous 165 years, the Dawlish Sea Wall had been closed to traffic for 52 days total
- at Fordgate, the railway was inundated and was submerged for over a month
- Maidenhead saw the highest groundwater level in over 50 years and peak groundwater level 2.2m above the long-term average for January and February.

There were 26 other large-scale flooding sites across the Route during 2013/14, and 28 sites in 2012/13, including Hinksey in both years and Penzance in 2014, Figure 14. With coastal, pluvial, fluvial and groundwater sites, there is no single primary type of flooding on the Route, although many lines follow river valleys, making them more susceptible to river flooding.

The future management of coastal flooding and erosion is being developed within the Western Route Coastal, Estuarine and River Defence Plan.

[2] Met Office, "Winter storms, January to February 2014" at http://www.metoffice.gov.uk/climate/uk/interesting/2014-janwind

Figure 15 Chipping Sodbury flooding, December 2012

In association with flooding, the Route has suffered significant earthworks failures, particularly in 2012-13 and 2013-14. The worst Route sections for earthslips are Teignmouth and Chipping Sodbury to Badminton; both are in focus for the CP5 earthworks renewals programme.

Figure 16 Woodlands Avenue landslip, Teignmouth, February 2014

The Route also experiences significant wind-related delay, which accounts for 13 per cent of the Route delay costs over the eight-year period. Wind has played a large part in many coastal flooding events, but can impact on the Route directly as well. Wind from the Atlantic fetch blows debris on to the track, forces trees to fall on or near the line, and causes seawater spray across the track interfering with the signalling and rolling stock.

Future climate change projections

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

The UK Climate Change Projections (UKCP09) provides regional climate change projections across 13 administrative regions in Great Britain, Figure 17. The South West England region of UKCP09 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.

Figure 17 UKCP09 administrative regions

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

Mean daily maximum temperature change

The mean daily maximum temperatures for both South West England and South East England are projected to increase throughout the year, with greater increases expected in the summer months.

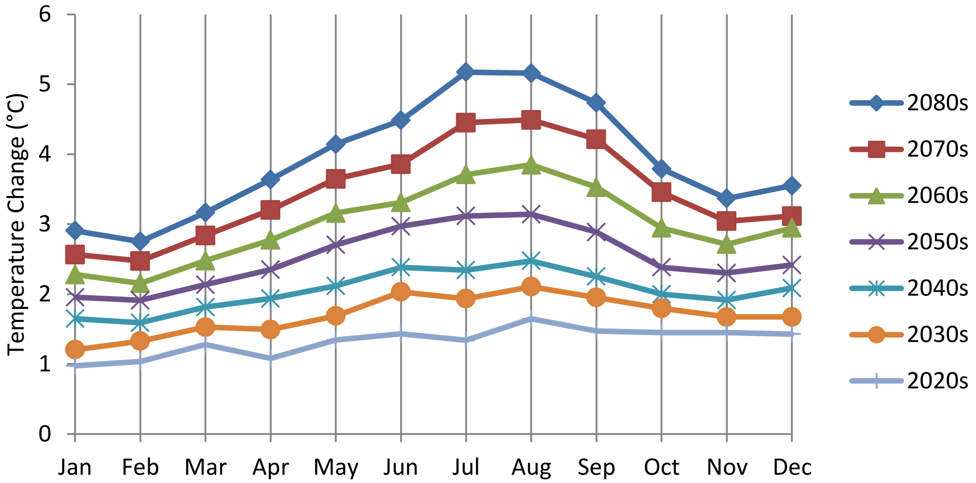


Figure 18 South West England, mean maximum temperature change (50th percentile)

In South West England the average maximum daily temperature in July is expected to increase by over 3°C, reaching 23.3°C by the 2050s, and by over 5.2°C, reaching 25.3°C by the 2080s. Average maximum daily temperature in January is expected to increase by 1.9°C, reaching 9°C by the 2050s, and by 2.9°C, reaching 10°C by the 2080s, Figure 18.

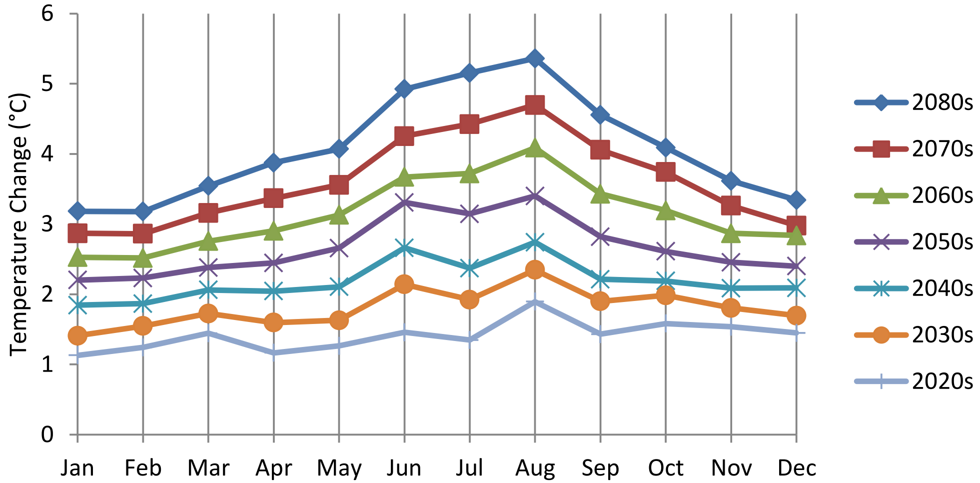


Figure 19 South East England, mean maximum temperature change (50th percentile)

The average maximum daily temperature in South East England in July is expected to increase by 3.1°C, reaching 24.3°C by the 2050s, and by over 5.1°C, reaching 26.3°C by the 2080s. Average maximum daily temperature in January is expected to increase by 2.2°C, reaching 8.7°C by the 2050s, and by 3.2°C, reaching 9.7°C by the 2080s, Figure 19.

Mean daily minimum temperature change

The mean daily minimum temperatures in both South West England and South East England administrative regions are also projected to increase throughout the year.

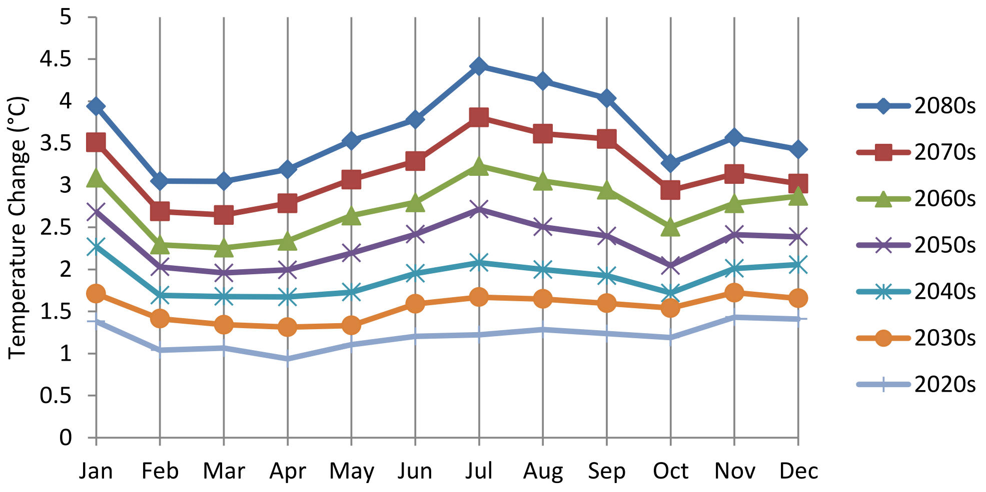


Figure 20 South West England, mean mininimum temperature change (50th percentile)

In South West England the average minimum daily temperature in July is projected to increase by 2.7°C, reaching 14.5°C by 2050s, and by 4.4°C reaching 16.2°C by the 2080s. Average minimum daily temperature in January is projected to increase by 2.7°C, reaching 4.6°C by 2050s, and by 3.9°C, reaching 5.8°C by 2080s, Figure 20.

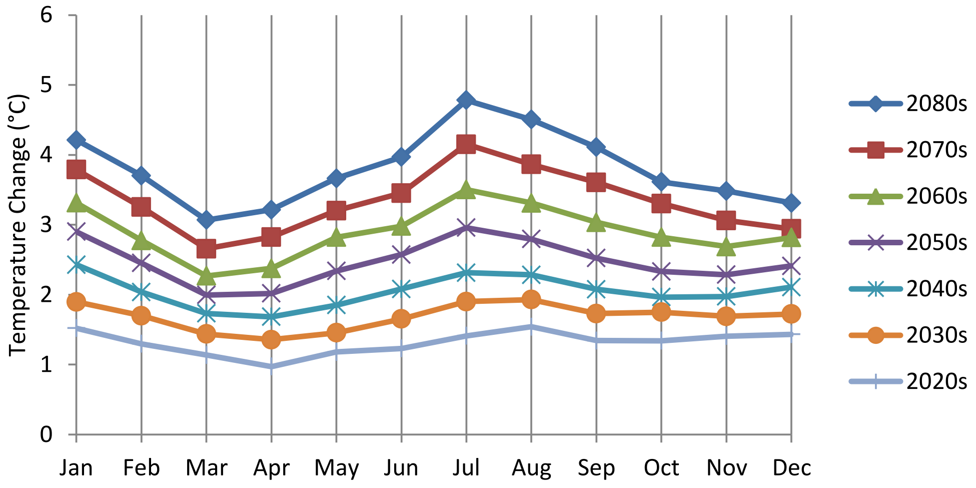


Figure 21 South East England, mean minimum temperature change (50th percentile)

In South East England the average minimum daily temperatures in July are projected to increase by 3°C, reaching 14.8°C by 2050s, and by 4.8°C reaching 16.6°C by the 2080s. Average minimum daily temperature in January is projected to increase by 2.9°C, reaching 4.3°C by 2050s, and by 4.2°C, reaching 5.6°C by 2080s, Figure 21.

Mean daily precipitation

Projections for mean daily precipitation for both South West England and South East England administrative regions show a significant increase in the winter months and a decrease in summer months. Generally, the greatest increase is projected to occur in February, while the greatest decrease is expected to occur in August.

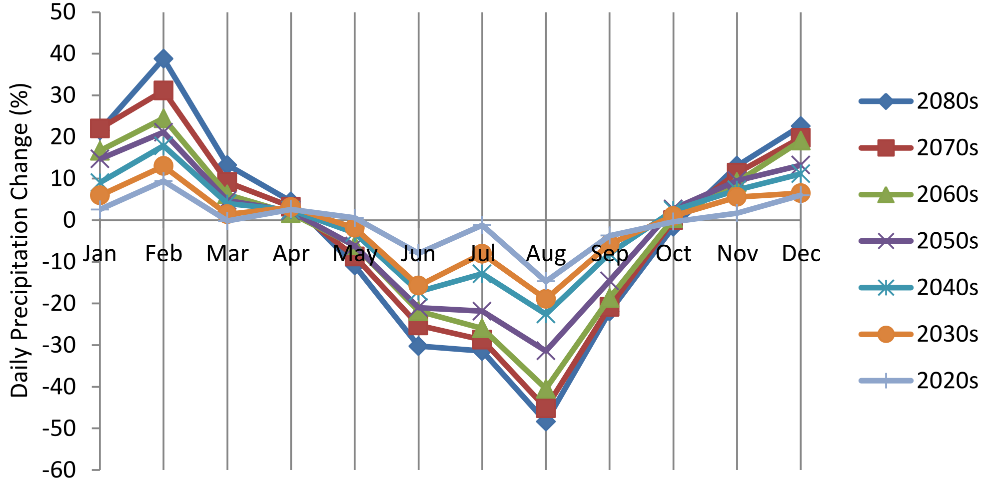


Figure 22 South West England, mean daily precipitation change (50th percentile)

In South West England the increase in daily precipitation in February is projected to be 21 per cent, reaching 3.5mm per day by the 2050s, and 39 per cent, reaching 4.1mm per day by the 2080s. The mean daily precipitation in August is projected to decrease by 31 per cent by the 2050s, to 1.6mm per day, and by 48 per cent, to 1.2mm per day by the 2080s, Figure 22.

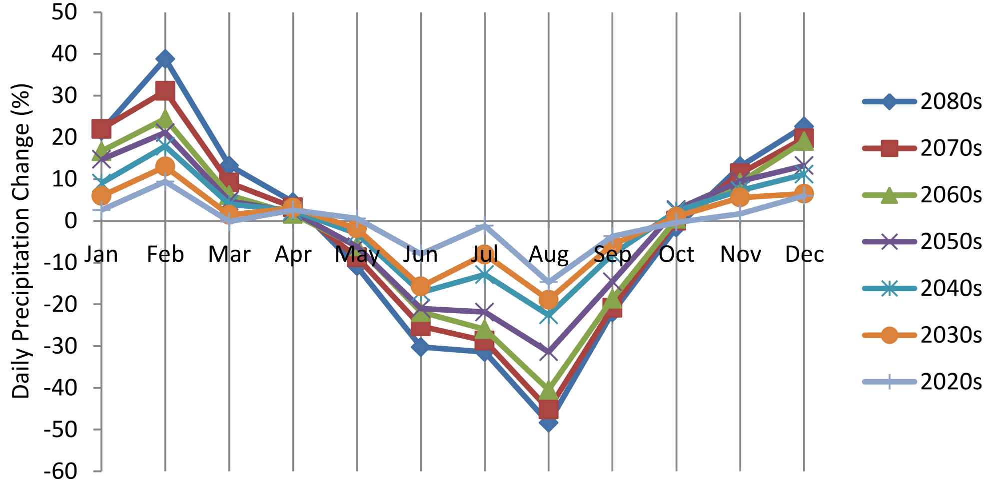


Figure 23 South East England, mean daily precipitation change (50th percentile)

In South East England the mean daily precipitation is projected to increase by 25 per cent, reaching 2.3mm per day by the 2050s, and by 42 per cent, reaching 2.6mm per day by the 2080s. Mean daily precipitation in August is projected to decrease by 20 per cent by the 2050s, to 1.4mm per day, and by 32 per cent, to 1.2mm per day by the 2080s, Figure 23.

Sea level rise

Sea level rise for Western Route coastal and estuarine assets can be represented by the projections for the Dawlish coast line, relative to 1990 level. For the high emissions scenario, the projections for the 50th percentile for 2050s is 0.269m and 0.584m increase by the end of century (the rise is unlikely to be higher than 0.413m and 0.907m respectively), Figure 24.

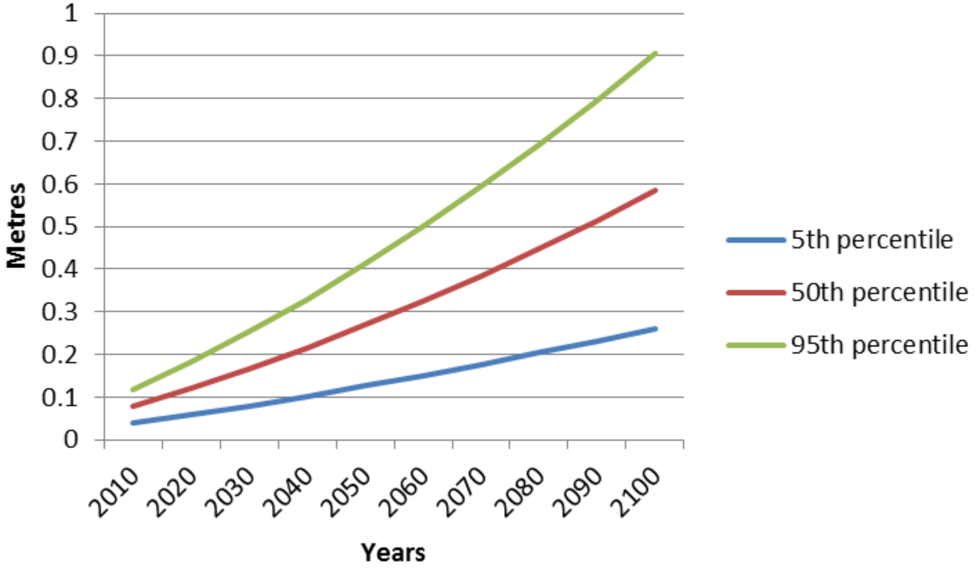


Figure 24 UKCP09 sea level rise projections for Dawlish area

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

Western Route impact assessment

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

Performance impacts

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

Schedule 8 costs for the past eight financial years for Western Route have been analysed to provide an assessment of weather impacts, Figure 25.

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

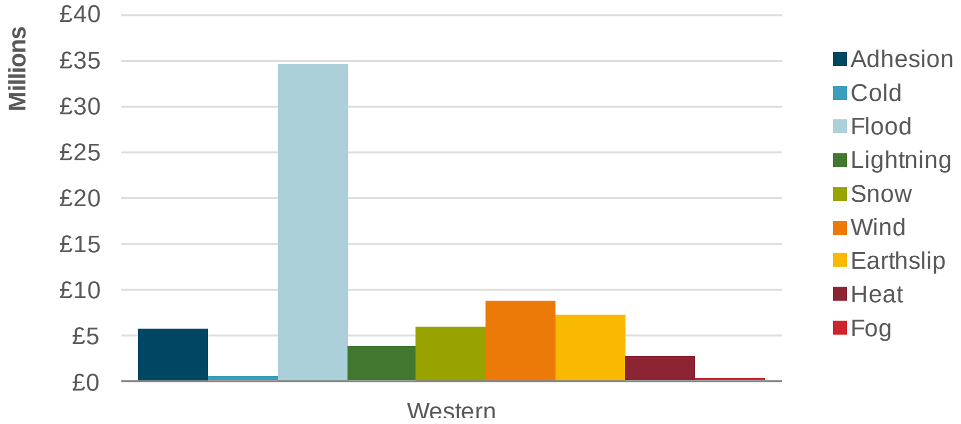


Figure 25 Western Route weather attributed Schedule 8 costs 2006/07-2013/14

The analysis clearly shows that flooding has been the most significant weather impact for Western Route, with total Schedule 8 costs over £34 million during the period 2006/07-2013/14.

The impacts of changes in winter and summer precipitation on flooding patterns are complex, however, it is expected that flooding events will increase in frequency and intensity and present increased risk to Western Route over the coming decades.

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

Table 1 Prioritisation of weather-related impacts on Western Route

Weather-related impact	Schedule 8 costs[1]	Projected future impacts for South West and South East England	Prioritisation
Flooding	£4.3m	21-25 per cent increase in February mean daily precipitation[2]	High
Earthslips	£0.9m	21-25 per cent increase in February mean daily precipitation[2]	High
Heat	£0.3m	>3°C increase in July mean daily maximum temperature[2]	Medium
Sea level rise	Not recorded	0.27m increase in sea level rise[3]	Medium
Wind	£1.1m	Wind changes difficult to project however generally projected to increase	High
Snow	£0.7m	2.7°C increase in January mean daily minimum temperature[2]	Low
Cold	£0.1m	2.7°C increase in January mean daily minimum temperature[2]	Low
Adhesion	£0.7m	Complex relationship between adhesion issues and future climate change.	Medium
Lightning	£0.5m	Storm changes difficult to project however generally projected to increase	Low
Fog	£10k	Complex relationship, however research suggests fog events may decrease	Low

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

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

Identification of higher risk locations

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

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

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

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

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

Flooding impact assessment

The Western Route is highly vulnerable to flooding, as shown in the two recent wet winters of 2012/13 and 2013/14, as well as 2007.

Flooding in 2012/13

2012 saw the wettest April to December on record[4] and the wettest January to November since 1960. The ground was saturated with a soil moisture deficit of zero. Rainfall for both November and December was above the long-term average for the months, with 167 per cent and 189 per cent for the South West region.

Rainfall came in intense events on 3 November and from 19 to 25 November (70 per cent of the month's rain fell in these 7 days), and again from 19 to 22 December.

The result of these intense rainfall events, combined with saturated ground and already high river flows, was widespread flooding across the South West. The Environment Agency reported both river flows and groundwater levels as exceptionally high for both November and December.

From mid November 2012 to early January 2013 Western Route experienced:

- over 80 reported incidents of flooding
- over 30 reported landslips
- one scour incident
- one electrical isolation.

The worst day was 21 November 2012, when 31 incidents were recorded. On 22 December 2012, 23 were recorded.

Comparison of rainfall across the Western Route area and the number of flooding and landslip incidents reported, Figure 26, shows a strong correlation. Climate change may impact with more frequent intense rainfall events similar to those in November and December 2012. This demonstrates the need to invest in flood resilience for the railway.

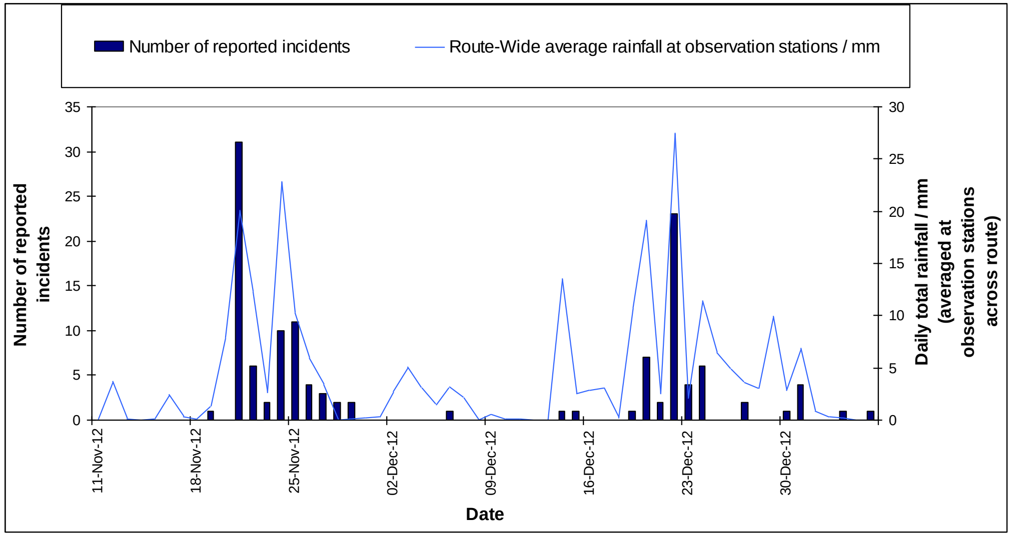


Figure 26 Daily flooding and landslip incidents reported compared with rainfall, Periods 9-10 2012/13

[4] Environment Agency Monthly Water Situation Report, South West, November 2012 and December 2012

Western Route undertook a study in 2013 to identify and prioritise locations vulnerable to flooding, Figure 27. Following a government announcement in February 2014, the major sites identified by the 2013 report are now funded in part or full for resolution in CP5 with a total of £31m. These sites are indicated by an asterisk (*) in the tables below.

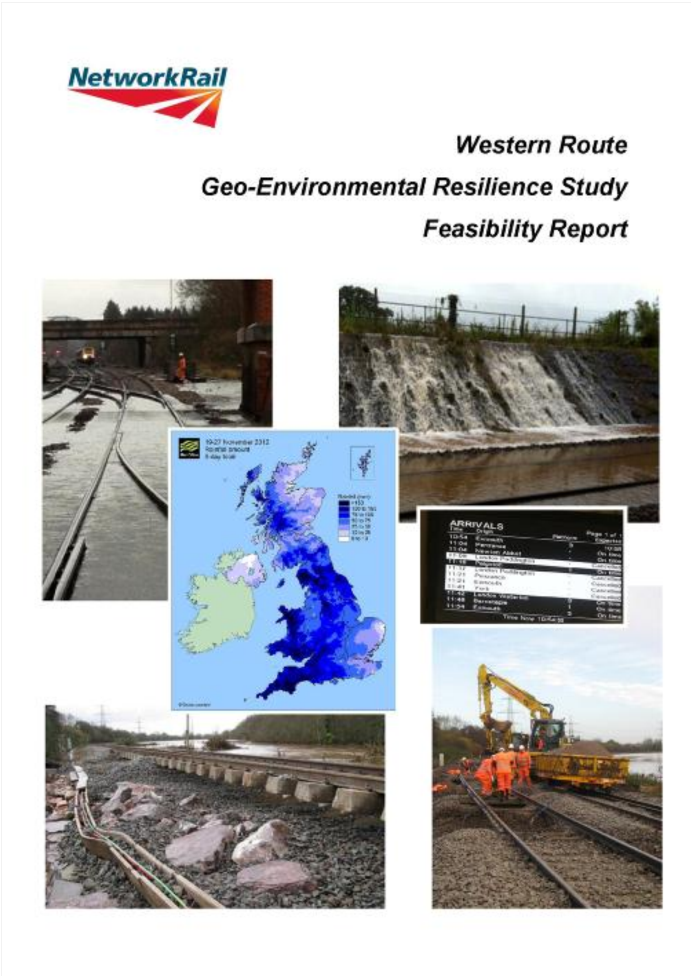


Figure 27 The Western Route Geo-Environmental Resilience Study, published April 2013

Flooding in 2013/14

The first five months of 2014 saw 140 per cent of the long-term average rainfall, and the nine months from October 2013 (beginning of the 'water year' for records) to June 2014 saw 160 per cent of the long-term average. An Environment Agency report states "this makes 2014 the wettest calendar year and wettest water year on record so far for the South West of England."[5]

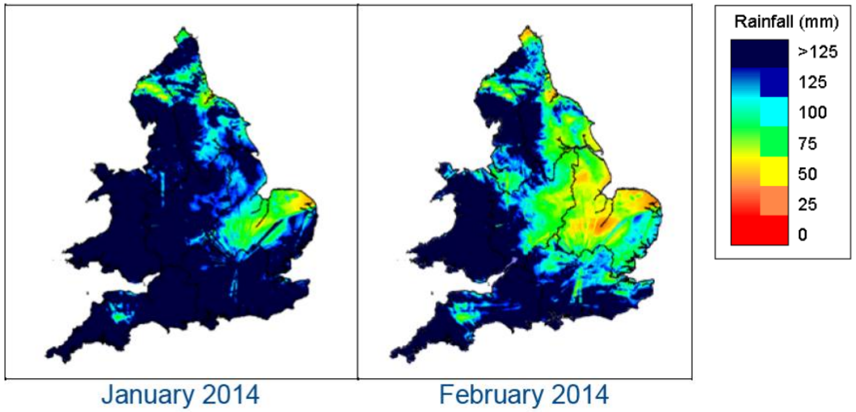


Figure 28 Rainfall in 2014 (Environment Agency[5])

Following the 2013/14 winter, further sites have since been identified and remedial works to these are currently being defined. Western Route is now reviewing the events of Winter 2013-14 and will update this study by the end of 2014.

Forecasting and monitoring

The severe groundwater flooding events in the Thames Valley and extended flooding of the Somerset Levels, both in early 2014, show how difficult it is to predict not only the location but also the duration of flooding events. This is of great concern to an industry that relies on real-time data and where constant updates are provided to both passenger and freight customers.

The Route is engaging with the Met Office to increase and improve the Route's rainfall forecasting capability. This live data will facilitate safe management of assets against both flooding and earthwork failures.

[5] Environment Agency Monthly Water Situation Report, South West, June 2014

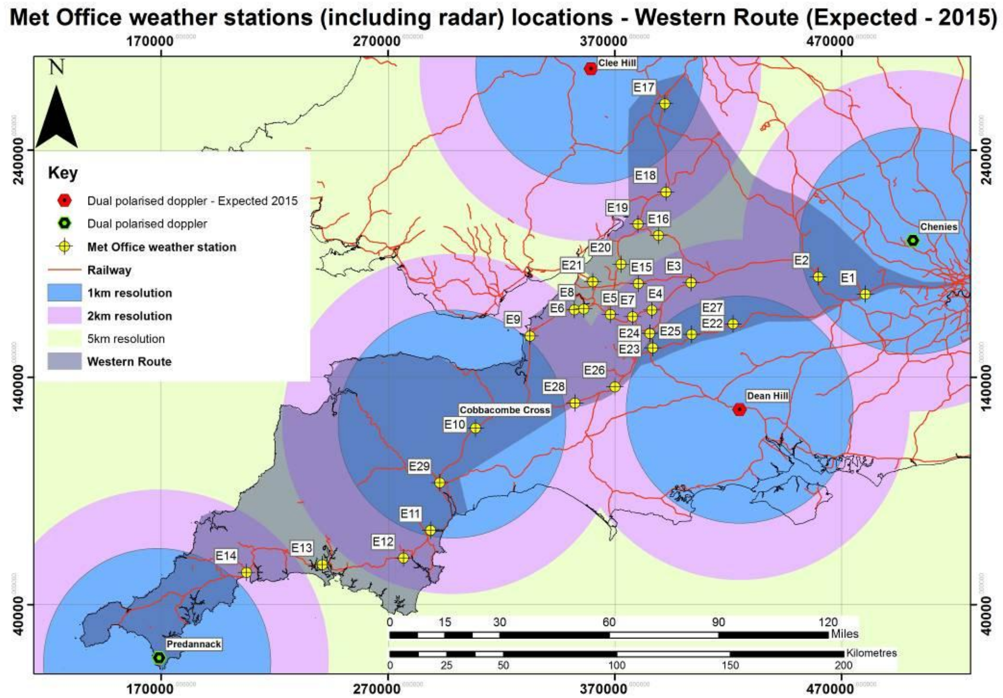


Figure 29 Met Office weather station locations by the end of 2015[6]. (compare with Figure 10, showing existing radar)

By the end of 2015, the Route will have at least 2km radar resolution coverage over 85 per cent of assets, as shown in Figure 8. Three existing radar stations already use dual polarised Doppler radar (Cobbacombe Cross, Predannack and Chenies) and the remaining two (Clee Hill and Dean Hill) will be upgraded by 2015[7].

[6] Geotechnical Remote Condition Monitoring Strategy for Western Route. Rees, Richard (2014). Unpublished MSc Thesis.
[7] 2015 locations based on http://www.metoffice.gov.uk/water/radarimprovements/timescales

Categorising flood events

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 ‘bankfull’ 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
- 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).

Figure 30 Surface water flooding cascades on to the track at Flax Bourton, Bristol

Figure 31 Groundwater flooding at White Waltham, Maidenhead in 2014

On Western Route, at present, the following cuttings are known to be vulnerable:

Location	SRS	Pluvial (rainwater/ direct run-off)	Groundwater	2013-14	2012-13	Other repeats 2006 to 2014	Intervention plan (* indicates 2013 resilience study)	Intervention date
White Waltham (near Maidenhead)	J.02	–	✓	✓	–	–	Increased monitoring Signalling renewal	2014 2015
Chipping Sodbury	J.04	✓	✓	✓	✓	Many	* Increased monitoring * In development	2014 2016
Flax Bourton	K.01	✓	–	-	✓	-	* Drainage upgrade	2015
Whiteball Cutting	K.01	✓	–	-	✓	2012 2008 2007	* Enhanced and renewed drainage	Complete
Lyng/Curry Road (Athelney-Cogload)	J.06	✓	–	✓	✓	–	* Crest drain	2014
Patchway Up Tunnel	J.04	✓	–	–	✓	2007	* Drainage upgrade with electrification	2016
Newnham Tunnel	L.02	✓	–	✓	✓	Many	Boundary drainage renewal	2014

Chipping Sodbury, between Bristol Parkway and Swindon, is Western Route's most frequently flooded cutting, Figure 32, Since the railway was routed here at the end of the 1800s, a combination of groundwater and surface water floods the line in most winters. As a result of successive projects, flooding is now largely confined to the West Cutting rather than the Tunnel. Following the announcement of funding for Western Route Flood Resilience works, a larger scheme is under development to further reduce the duration and frequency of flooding on this key route between South Wales and London.

Figure 32 Chipping Sodbury cutting flooded in 2012

Effective flood and drainage management in cuttings may include source control management and storage beyond the railway boundary.

Drainage systems: pluvial flooding

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 on a case-by-case basis when flooding occurs or damage/defects are found during inspection, and the relevant Drainage Management Plan is updated.

River valleys or flood plains: fluvial flooding

In addition, a number of lines across the Route follow river valleys, these often being level, and therefore cost-effective, route for railway construction.

Principal vulnerable lines and locations include:

Location	SRS	River(s)	2013-14	2012-13	Other repeats 2006 to 2014 and historic	Intervention plan (* indicates 2013 resilience study)	Intervention date
Cowley Bridge Junction and Staffords Bridge	K.01	Exe	–	✓	–	* Major works to be defined with Environment Agency	2016
Hinksey	M.11	Thames Isis	✓	✓	2007 2003	* Track lifting prior to electrification	2015
Hele & Bradninch	K.01	Culm	✓	✓	Annual	* Track lifting across level crossing	2016
Cullompton	K.01	Culm			Yes	To be defined	CP6+
Barnstaple Branch	K.08	Exe Yeo Creedy	✓	✓	Annual	Gabion protection to repeat washout locations, or alternative	New proposal
Over Viaduct	L.02	Severn	✓	–	–	Modifications to bridge deck	New proposal

Bridge structures which are vulnerable to scour, uplift or impact from flowing debris are tracked separately through an existing bridge scour programme.

The damage to Cowley Bridge Junction, just north of Exeter St. Davids, in late 2012 was highly disruptive and widely publicised, Figure 33 and Figure 34. Works at Cowley Bridge Junction could include flood plain management; discussions with the Environment Agency are ongoing to define the best solution for the railway and the City of Exeter.

Although the railway did not flood at Cowley Bridge Junction in Winter 2013/14, levels in the Exe and flood plain did rise significantly and the railway came close to flooding before Christmas. Following the 2012 flooding this location was closely monitored by the Environment Agency and Network Rail teams (using the river gauge at Trews Weir on the River Exe) and will remain so.

Figure 33 Water floods on to the track from the River Exe flood plain at Cowley Bridge Junction, Exeter

Figure 34 Water pours from the railway back into the river channel on the downstream side of the railway at Cowley Bridge Junction, Exeter

At Hinksey, the most frequent fluvial flood site on a critical freight and passenger route, the track floods from predictable and managed use of the flood plain to protect Oxford and surrounding villages, Figure 35.

Western Route is presently developing a design to lift the track through this area. As part of the design process the Route will demonstrate that there are no adverse effects on third parties.

Figure 35 Trains run at significantly reduced speed with low-lying flood water through Hinksey

Figure 36 As well as reduced speeds, points cannot be used, reducing operational flexibility

Western Route understands that new route sections will become vulnerable to fluvial flooding as a changing climate affects rainfall and run-off patterns. The Route will review the latest flood risk projections for rivers, sea and surface water provided by the Environment Agency against an updated rail network elevation model by the end of 2015 to identify future risks.

However, it is notable that the main line in the Thames Valley (East of Oxford/Didcot) is largely on embankments and viaducts, and is separated from the River Thames.

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.

Location	SRS	Estuary	2013-14	2012-13	Other repeats 2006 to 2014 and historic	Intervention plan	Intervention date
Fordgate-Cogload	K.01	Somerset Levels – former estuary	✓		–	Flood plain study to review economic options	Unknown
Athelney-Cogload	J.06		✓	✓	–	Scour defences to embankment	New proposal
Looe Branch	K.10	Looe	✓	✓	Seasonal (spring tides)	Management plan to inspect and reopen line after flooding	
						Gabion protection to repeat washout locations	New proposal

Figure 37 Flooding on the Looe Branch in 2012

Repeated seasonal flooding on the Looe branch is subject to a local management plan to inspect, repair and reopen the line after flooding, Figure 37.

Flooding on the Somerset Levels was extensive and, as reported in press coverage during the event, long-lasting with the duration hard to predict.

The railway line flooded for the first time ever at Bridgwater, Figure 38. The two-track line from Bristol to Taunton was submerged for a month, with damage to signalling further disrupting services for a second month.

With climate change bringing sea level rises and more intense rainfall events, we expect that this event will reoccur.

Western Route is collaborating with the Environment Agency and Somerset County Council proposals to improve the resilience of the Somerset Levels as a whole but at present has no plans to alter the track alignment in this area.

Figure 38 Somerset Levels flooding, 2014

Coastal railway: storm surge

In February 2014 major storms damaged the railway at Dawlish and Penzance, Figure 39. The Met Office reports this as a significant and unusual event:

> "…the later storms from early to mid-February were much more severe [than the earlier two storms in late January]. Overall, the period from mid-December 2013 to mid-February 2014 saw at least 12 major winter storms, and, when considered overall, this was the stormiest period of weather the UK has experienced for at least 20 years."[8]

As well as the widely reported failure at Dawlish, the February storms inundated the track at Penzance and severely damaged signalling equipment, leaving debris strewn across the track.

Figure 39 Signalling cables and equipment strewn across the track at Penzance after February 2014 storms

On the 4-5 February storm the Met Office reported:

> "This storm was more severe than the previous two, particularly across south Wales and south-west England where winds gusted at 60 to 70 kt widely around exposed coastlines. St Mary's Airport (Isles of Scilly) recorded a gust of 80 kt (92 mph) and Berry Head (Devon) 79 kt (91 mph). This storm damaged the South West main line railway at Dawlish."

The risk of adverse impact of the storm on the railway line at Dawlish was successfully predicted by a bespoke weather forecasting system which takes into account tidal variation, storm surge, wind, swell, and wave height. Conditions for the storm period of 4-5 February were rated as exceptional (note black bar in Figure 40) leading to the closure of both lines in advance of the sea wall failure.

For the first 165 years since the line through Dawlish and Teignmouth opened in the 1840s, there have been approximately 52 days of full suspended service. In 2014 there were 58.

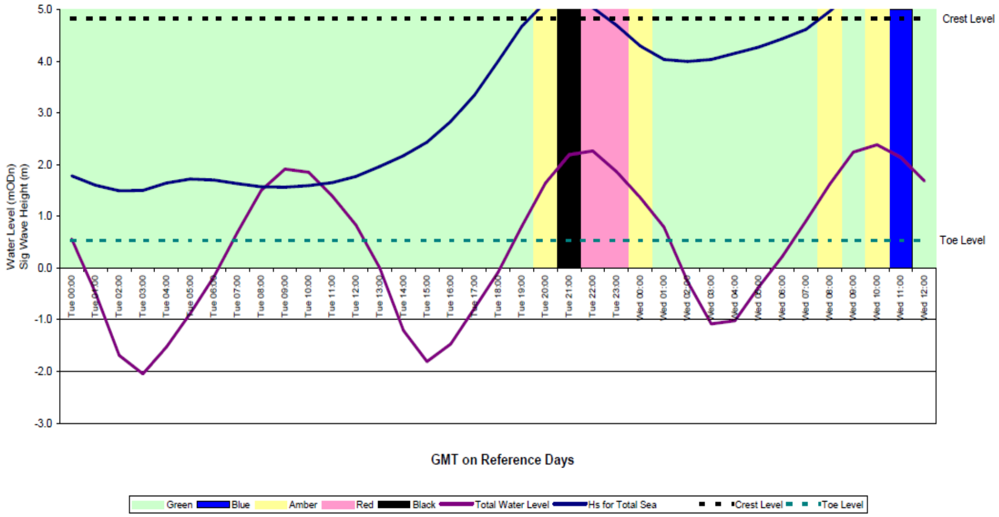


Figure 40 Weather forecasting system for Dawlish sea wall, Tuesday 4th February 2014

8 Met Office, "Winter storms, January to February 2014" at http://www.metoffice.gov.uk/climate/uk/interesting/2014-janwind

Figure 41 Suspended track and suspended train service at Dawlish following February storms

Proposals for increasing the resilience of the coastal railway at Dawlish are under development following the publication of the West of Exeter Route Resilience Study[9], and will be available in 2015.

The areas of Dawlish and Penzance will be further vulnerable when sea level rise (due to climate change) is taken into account; this is discussed in further detail in the following section.

Sea level rise impact assessment

Western Route has recently had an increase in high profile coastal flooding events as described in this document. There are mitigations in place to reduce the impact of these incidents, however, with sea levels due to rise between 0.269m by 2050s and 0.584m by the end of century, relative to 1990 level (based on Dawlish Area, see Figure 24) water inundation will become more prevalent within coastal sections of the Route.

Western Route has 245 miles of coastal boundary, which accounts for 41 per cent of the Route boundary miles. With sea level rise, there are lines that are inherently more vulnerable to more flooding, coastal erosion and loss of the railway, Figure 42.

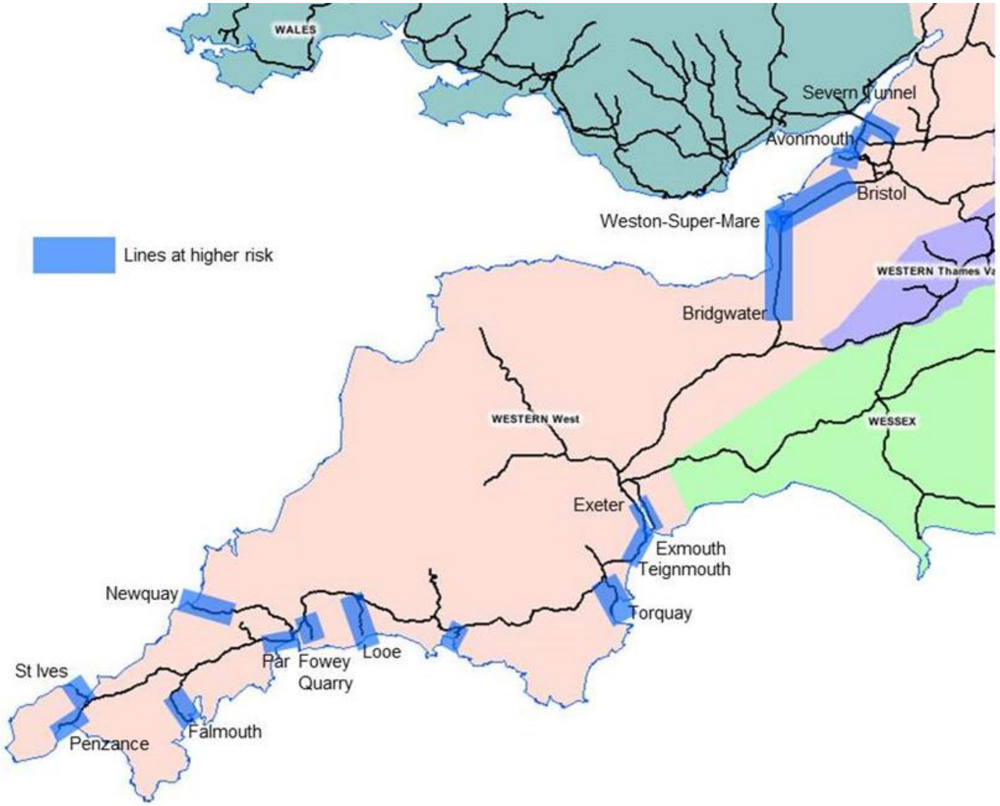


Figure 42 Western lines at higher risk to sea level rise

[9] West of Exeter Route Resilience Study, Network Rail, published 15 July 2014
http://www.networkrail.co.uk/publications/west-of-exeter-route-resilience-study/

As shown on the Route map, there are 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)
- Severn Tunnel approach (from Bristol to Wales Route).
- Torquay
- St Ives (Lelant)
- Falmouth
- Fowey Docks
- Looe
- Newquay
- Clifton Down – Avonmouth
- Exmouth Branch (Lympstone on East Exe Estuary)
- Bere Ferrers (Gunnislake Branch).

In recognition of the potential risks that sea level rise will bring to connectivity West of Exeter, proposals are under development to improve resilience at Powderham Banks, Dawlish and Teignmouth. These proposals 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 and will be published in 2015.

In addition to this work, the asset management plans for Coastal, Estuarine and River Defences (CERD) to be produced during Control Period 5 will outline Route-wide vulnerabilities at all other coastal, estuarine and major river locations and set up an option development process where required.

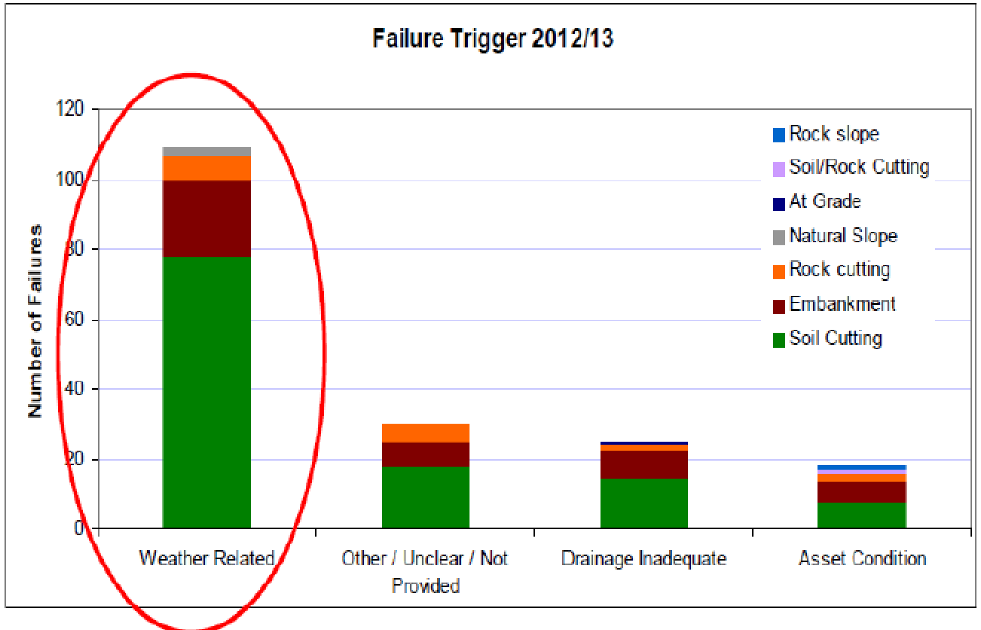
Earthslip impact assessment

There are long Route sections known to be vulnerable to adverse weather, and where earthslips or proactive safety measures have restricted the running of trains.

The vulnerability of earthwork assets to adverse weather events can be linked to the type of underlying geological material cut through or used as 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.150 years since construction has left certain slopes susceptible to intense and/or sustained rainfall.

The rock and soil cuttings at Teignmouth, Chipping Sodbury, Badminton and Langport and the embankment slopes at Westerleigh and Hullavington have all experienced failures in recent years for which the primary trigger was an adverse weather event.

Earthwork failures are often triggered by water, Figure 43. This can be by direct rainfall and saturation of the earthwork, a failure of a drainage system at the crest or toe of the earthwork, third party inflows, or groundwater level changes.



Source: CIV028

Figure 43 Earthwork failures (national) by trigger

A nationwide analysis of earthwork failures in 2012/13 (a year of significant rainfall and flooding in Western Route) shows that the majority of failures were triggered by weather. This is particularly true for embankments and soil cuttings; highest proportion of failures triggered by weather.

Adverse weather earthworks sites

A significant increase in soil cutting and embankment failures over the winters of 2012/13 and 2013/14 (shown by failure mode in Figure 44 and Figure 45) can be attributed closely to the severity of the adverse weather events experienced over the same period.

As a consequence of this strong relationship, Western Route actively monitors Met Office rainfall data at a number of locations where poor condition earthworks are known to be at risk of failure due to heavy rainfall. This has enabled the Route to monitor, manage and implement appropriate safety restrictions at the known vulnerable sites.

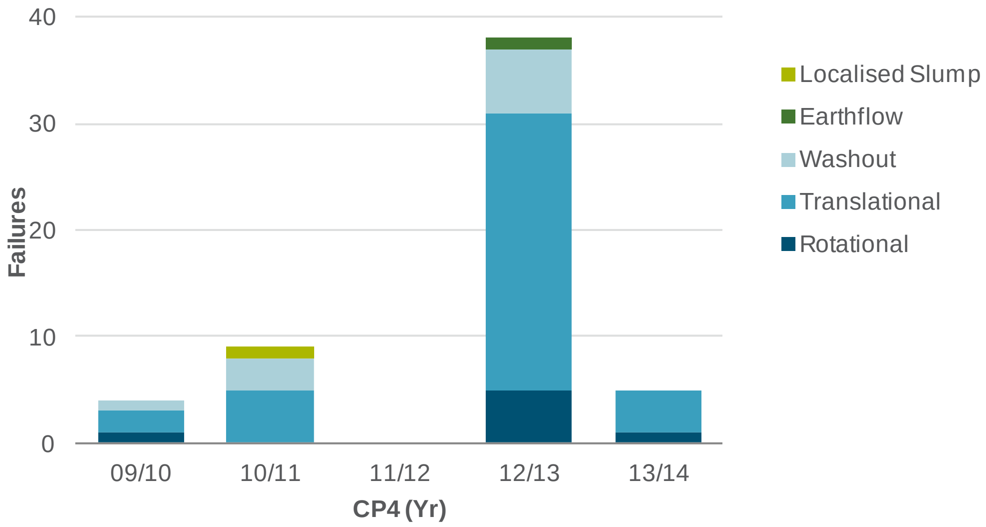


Figure 44 CP4 soil cutting failures on Western Route by failure type

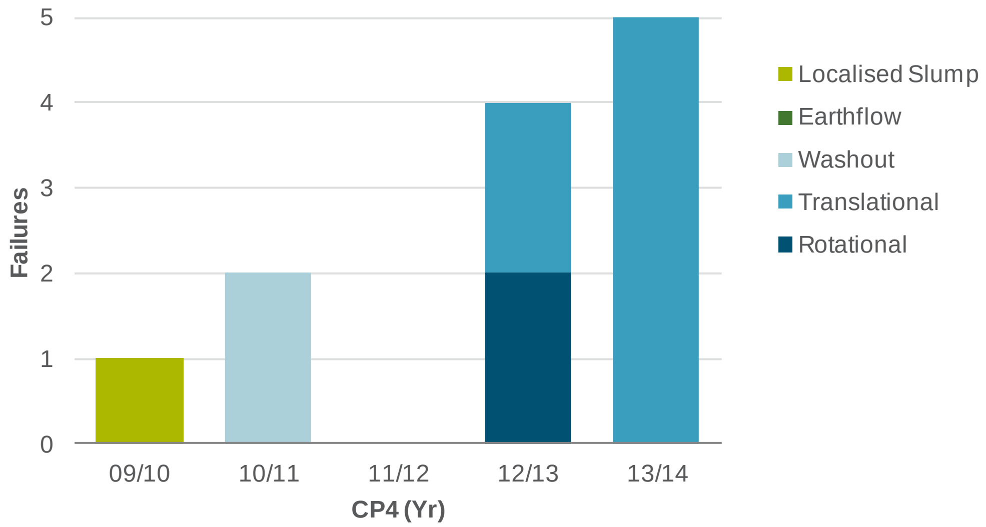


Figure 45 CP4 embankment failures on Western Route by failure type

Sites mitigated in CP3/CP4

In the past 10 years we have reduced the risk of earthworks failure due to adverse weather at:

Site	SRS	Asset type	Intervention complete	Details
Kemble Tunnel	J.10	Cutting	✓	Earthwork renewal, new drainage
Wootton Bassett	J.04	Cutting	✓	Regrade, partial renewal
Langport	J.06	Cutting	✓	Remediated, new counterfort drains
Chipping Sodbury West	J.04	Cutting	✓	Regrade, shear trenches, drainage
Uphill Junction to Brent Knoll	K.01	Cutting	✓	Soil nailing, drainage
Blackboy Tunnel	K.06	Cutting	✓	Soil nailing and netting, drainage
Whiteball South and North	K.01	Cutting	✓	Drainage, partial regrade

This is in addition to the earthworks renewal programme which, in targeting the poor condition earthworks, further reduces the risk of earthworks failure due to adverse weather.

At each of the sites pictured below there was an earthwork failure triggered by adverse weather. Usually all failure locations are fixed under 'emergency works'. At these sites, following the emergency works, a greater length of earthwork was renewed to include similar adjacent assets.

Figure 46 Landslip at Langport cutting (November 2012)

Figure 47 Remediated Langport cutting with counterfort drains (June 2013)

Figure 48 Slip failure at Chipping Sodbury West (2012)

Figure 49 Remediation works at Chipping Sodbury, ongoing (2013)

Remote Condition Monitoring

Western Route has commissioned a strategy for Remote Condition Monitoring (RCM), principally of earthworks and structures over watercourses, for CP5. This will reference the existing Met Office weather stations across the Route, as discussed in the flooding assessment and Figure 29).

The aims of the RCM strategy are:

- provide a risk mitigation tool allowing for line speed to be maintained and to allow for remediation to be planned in advance
- to manage safety and performance risks posed by earthwork failures between identification and renewal
- improve staff safety – by eliminating as much as possible manual monitoring and the use of watchmen
- to replace as far as practicable the current process of 'Very High Risk' sites during periods of adverse weather
- to be a reusable, mobile, self-reliant, robust, 'off the shelf' and cost effective system.

The strategy will be finalised in 2014 with rollout to follow throughout 2015-2017.

Current CP5 earthworks renewal plans

By 2017 (the end of Year 3 of Control Period 5), we will reduce the risk of earthworks failure due to adverse weather at:

Site	SRS	Asset type
Pewsey	J.06	Cutting
Wootton Bassett	J.04	Cutting
Westerleigh Junction	J.04	Embankment
Standish/Stonehouse	J.14	Cutting
Box Tunnel to Corsham	K.15	Cutting
Oldfield Park	K.15	Cutting
Badminton	J.04	Cutting
Saltash	K.03	Cutting
Cattybrook	J.04	Cutting
Castle Cary	J.06	Embankment
Somerton	J.06	Cutting
St. James	K.06	Cutting
Saltford Tunnel	K.15	Cutting
Parsons Tunnel	K.02	Cutting
Bincombe Wood	J.04	Cutting

Wind impact assessment

Western Route is vulnerable to the impact of wind, although as a proportion of the Route-affecting weather categories, it is smaller than the national proportion. Wind contributed 13 per cent of the Route delay costs in 2006/07-2013/14. Nationally, wind contributed 24 per cent in the same time period.

The West Country in particular has significant exposed coastline with 'fetch' from the Atlantic Sea, and the topography of the Route influences the impact of wind. The Route has numerous cuttings that can either protect the track from high winds or can align with the direction of wind creating a 'wind tunnel' effect. Large sections of the railway between Swindon to Bristol are in flat areas, increasing the exposure to wind.

Future projections for wind speeds in are difficult to establish, but it is expected that wind conditions will increase across the UK and it is probable that the South West will continue to 'bear the brunt' of the conditions.

Overhead lines

The Great Western Electrification Project is installing Series 1 overhead line equipment (OLE) between Paddington and Bristol, and to Oxford and Newbury. This is to be completed by December 2016.

The new OLE has been specified to withstand the expected wind loading, including climate change effects. Analysis has been undertaken in 2014 to understand the effects of wind in all directions on both the catenary wires and the structural elements.

However, the major risk to overhead line from wind is not the primary impact of wind loading, but the secondary effect of vegetation incursion as discussed below.

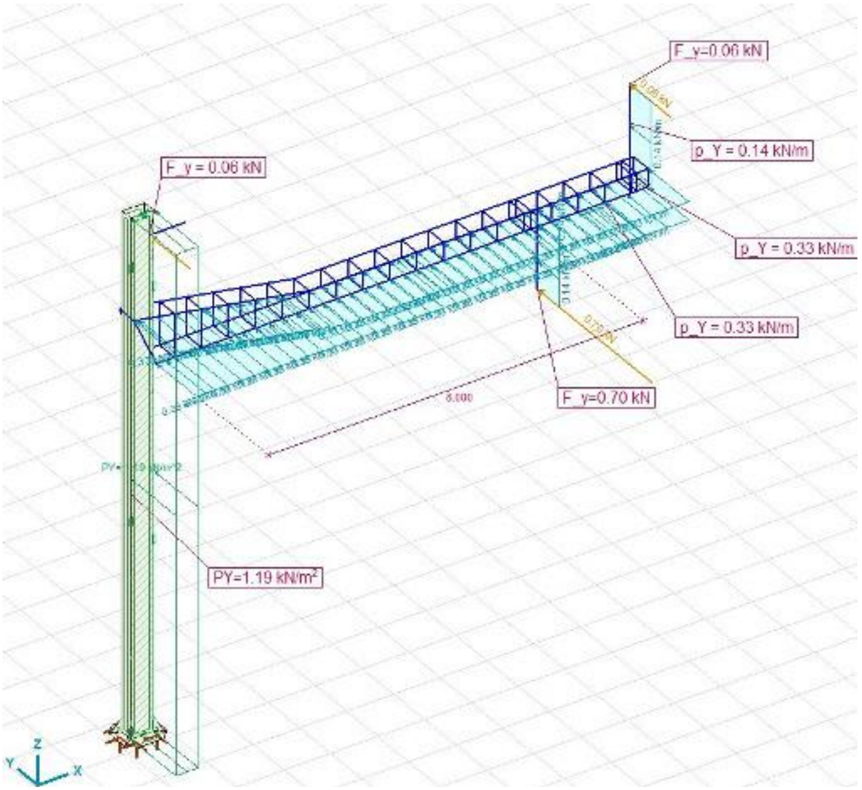


Figure 50 Structural analysis and assessment of overhead line supports for Series 1 overhead line equipment – wind loading applied to a Twin Track Cantilever (TTC)

Vegetation
A large proportion of the current issues associated with wind for the Route are trees on the lines. Presently, the risks are managed through regular inspection of vulnerable trees and removal of trees when there is an incursion on or near the track.

With electrification progressing along the Route, wind and trees on the line could have a significantly larger impact on performance. Also, the new IEP bi-mode rolling stock have pantographs that are exposed and susceptible to damage from overhanging or detached parts of vegetation, including where bi-mode trains operate on non-electrified Routes.

Figure 51 Tree incursion affecting track and OLE

The Route is spending more than £5m in Autumn 2014 on lineside vegetation including reducing crown size, with similar investment on a robust vegetation clearance programme on all lines and branches over the next five years. This will reduce the incidents associated with OLE and rolling stock defects in the short term. However, in order to maintain these reduced levels of vegetation risk, sustained operational expenditure will be required.

Seawater spray
The South West coast can be significantly impacted by spray caused by wind over the sea. For the Western Route, this is primarily the Dawlish Sea Wall. Spray can affect signalling and train fleet reliability; special operation arrangements are invoked when this risk is identified. Re-signalling along the Dawlish Sea Wall will reduce the infrastructure-related impact of spray.

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 forceful sea spray, modern rolling stock fleet must itself become more resilient to these conditions in order to operate without restriction.

Adhesion impact assessment
Western Route has a substantial proportion of adhesion incidents, accounting for 12 per cent of the Route costs over the past eight years. This is similar to the national situation in which adhesion accounts for 11 per cent of the national total costs.

The Route incidents are not all associated with leaf fall – the adhesion category also includes driver error, driver caution and station overruns. The high-risk sites are primarily in the West Country, which typically has lower linespeeds and more varied topography. The Thames Valley is largely flat and therefore adhesion issues are focused on accelerating and decelerating at stations.

With climate change, there is likely to be more frequent, more severe wind events. An increase in the associated leaf fall may cause more adhesion issues.

Vegetation
As part of the national action plan for lineside management, the Route is engaging with the LIDAR survey and modelling during 2014. This will provide detailed information of the number of trees and critical dimensions of these trees, for example the crown size. The results from this survey, available in Spring 2015, will be used by the Route to target the areas at which the railway appears to be vulnerable.

The Route’s policy on vegetation management, both from the LIDAR survey and on a case-by-case basis, is to reduce the crown size, not to remove the tree completely. The Route has reduced its high-risk sites from 55 to 33, which will continue to be managed through the autumn.

With climate change, adhesion incidents may become more numerous and more frequent. A regular survey of lineside trees will be undertaken. This includes liaising with third parties, councils and lineside neighbours regarding the management of trees that may incur on Network Rail land.

Rolling stock
Notwithstanding the Network Rail funded mitigations of vegetation management, railhead treatment trains and static sanding equipment, it is vital that rolling stock operating on Western Route is able to deal with low adhesion conditions most effectively.

Four new rolling stock fleets will be introduced on to the Route's infrastructure as part of the Route upgrade programmes in CP5, including a fleet of Intercity Express Programme (IEP) trains. In order to maximise the efficiency of these upgrades and reduce reliance on Autumn timetables, all new rolling stock should be equipped with sanding equipment for both power and brake application, and with wheelslip and wheelslide protection.

Figure 52 Leaves on the line cause problems with signalling, braking and acceleration

Treatments
In addition to proactively mitigating the risk of leaf fall, adhesion is managed through daily treatment of known problem areas throughout the autumn period, typically early October to late November/early December (dependent on actual seasonal conditions).

A fleet of Rail Head Treatment Trains (RHTT) are utilised across the Route, Figure 53, although they primarily circuit Cornwall & Devon, the Cotswolds area, Swindon & Basingstoke and there is a shared train between Western and Wales. These apply adhesion modifier gel and high-pressure water to increase adhesion. Traction Gel Applicators are also used throughout the Route to increase traction.

The locations for treatment are reviewed annually based on low adhesion areas and known risk sites. This review process will continue as weather patterns and the timing/duration of autumn change.

Figure 53 Rail Head Treatment Train in action

Snow and cold impact assessment

Western Route generally experiences less cold weather and lying snow than other areas of the country. The map, Figure 54, shows the snow lying on the ground in December 2010, which was highlighted in the train delay data from 2006/07-2013/14 as an extreme year for the Route in terms of delays due to snow. However, the Route experienced less snow than the rest of the country.

With climate change, South West England is predicted to experience less snow and cold overall and a general increase in daily winter temperatures of 3.9^{o}C by 2080 (high emissions, 50th percentile). However natural variability, the complexity of the UK weather system and the impact of the Arctic ice melt 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.

Points assets

One of the Route's primary weaknesses against cold weather is the failure of points. Over the past eight years, points failures have accounted for 37 per cent of incidents in cold and snowy weather. 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 less frequent, more severe cold and snow events, it is imperative that points are reliable in order 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:

- to reduce the number of incidents associated with frozen POE, the Route is increasing the number of POE that have internal heating.
- snow compacted into point end will continue to be 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. To further improve reliability and to check that the points heating is physically attached to the rail, train-borne monitoring will be used.

Currently during snowfall or freezing events, a Key Route Strategy (KRS) is implemented to reduce the movements of points and minimise 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 regardless of the KRS to maintain performance. The Route is planning to specify these robust minimum design features for all new and renewed points, although support is required from the wider industry.

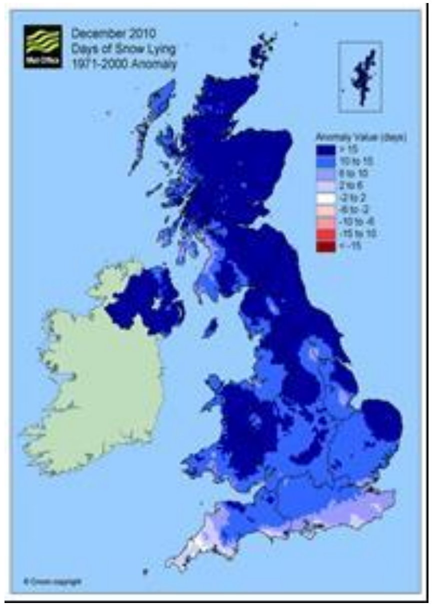


Figure 54 Lying snow, December 2010

Figure 55 Working points heating

Signalling assets

One of the Route's major signalling weaknesses against cold weather is manual signalling and points rodding. This equipment is prone to freezing which can cause long delays. There are three areas in the Route that still work from manual signalling: the Greenford line, the Worcester area and the Penzance area.

There is resignalling work planned for Penzance and Greenford in CP5 and the Worcester area in CP6, which will address the unreliable signalling due to freezing.

Electrification and plant assets

The Route will have overhead line equipment (OLE) from Paddington to Bristol, Oxford and Newbury from 2016. This imports an additional risk of icicles in cold weather. Currently, the route has 12 miles of OLE which present no performance-affecting icicles. Frequent train services reduce the opportunity for icicles to form on the OLE itself.

With large scale OLE along the route in the future, a maintenance 'Ice Maiden' locomotive is a possible mitigation that is being investigated. This train physically clears ice from the overhead line before service start up.

Structures assets
There have been incidents in the past eight years of icicles in tunnels and on bridges that have caused delays, primarily because they pose a danger of damage to train fleets. These have been inspected and removed on a case-by-case basis. Incidents are infrequent and no one structure is particularly vulnerable; therefore proactive resilience is currently difficult to target.

With an increase in winter temperature, icicles are unlikely to increase in regularity. However, extreme cold events are predicted and so wet tunnels and structures, such as Chipping Sodbury Tunnel and Sapperton Tunnel, may present concerns. Chipping Sodbury and other mainline structures also poses a risk of short-circuiting the OLE, or damaging external roof mounted equipment such as pantographs.

It is therefore suggested that a programme of ice management or removal could be undertaken where there is an overlap between cold weather conditions, wet structures and electrified lines.

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

Heat impact assessment

South West and South East England are both due to experience an increase in temperature throughout the year due to climate change. During the winter months, it is predicted that the South East average daily maximum temperature will increase by more than 3^{o}C by 2080 (high emissions, 50th percentile). This is unlikely to significantly affect the management of heat during these months. During the summer months, it is predicted that the average daily maximum temperature will increase by 5.1^{o}C by 2080.

There are several assets that are vulnerable to the effects of heat. There are proactive measures in place currently to reduce the impact of heat on the railway system, and consideration has been given to the opportunities available to mitigate an increase in impact as temperature increases.

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

Timber bearers – One of the Route weaknesses are the switches and crossings that are supported by timber bearers. The Route has a strategic renewal programme which has replaced significant areas of timber bearers with concrete. This has reduced the vulnerability to heat in these areas. The renewal programme on primary routes is due to be completed by the end of CP5 and therefore these assets should not pose a performance threat as temperature rises with climate change.

Critical Rail Temperature – Another of the Route's concerns as temperature rises is the probable increase in the number of sites that reach Critical Rail Temperature (CRT) and require a speed restriction. Over the past eight years, this has caused the most delay with regards to heat effects and it is forecast that delay and financial implications are likely to increase with climate change.

As this is a known approaching issue, the Route is reviewing and introducing several different solutions:

- different technologies are being used for tactical solutions
  - for example, strengthening plates have been installed at sites of tight curvature, glued ballast is used on some embankments and some sites are being considered for renewal
- painting the rail white
  - this increases the amount of heat radiation reflected and lowers the rail temperature by a few degrees
  - however, this has implications for the performance of the Plain Line Pattern Recognition (PLPR) monitoring train, which will need to be further investigated if painting is to become widespread across the Route
- remote condition monitoring (RCM)
  - this would give real-time accurate data to reduce the duration of any speed restriction.

These solutions, together with the mitigating speed restrictions dictated by company standards, will continue to significantly reduce the risk of a buckled rail.

Points – Currently, in conjunction with the 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 points 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.

Figure 56 Colnbrook, Thames Valley – track buckle

Figure 57 Signalling temperature control 'Top Hat'

Signalling assets
Electrical equipment in lineside buildings can be severely affected by high temperatures. Currently the Relocatable Equipment Buildings (REBs) are air conditioned and are able to maintain constant temperature conditions.

With an increase in temperature and more heat-generating technology in lineside REBs, it is likely that the air conditioning requirements will increase. Remote condition monitoring is currently installed and operated, and will be extended to more critical sites during CP5. Air conditioning is to be a more valued asset within the Route, as it is noted that it is critical to the performance of the signalling assets.

Lineside location cabinets are also susceptible to failures due to overheating. To reduce the failure frequency, ‘top hats’ are being attached to the cabinets which will reduce direct sunlight and heat on the cabinet (Figure 54).

Electrification and plant assets
Currently, E&P assets are not largely affected by high ambient temperatures. Some batteries and equipment in lineside buildings can have a reduced life span if they are kept at high temperatures for a long period of time. However, this is not significant across the life span of the asset.

With climate change projections showing ambient temperature rises, air cooling units in lineside buildings will become more important. There are already air cooling units in many lineside buildings and new units will be installed on a merit basis, in conjunction with the signalling programme.

Western Route is installing OLE along large sections of the Route in CP5, increasing track miles of OLE by 900 per cent. OLE is vulnerable to the effects of heat as the wire expands and sags, potentially causing loss of contact with the pantograph or a dewirement. The OLE is designed for air temperatures of 40°C. The projected heat extremes using UKCP09 weather generator fall within the design parameters for the OLE contact system.

Lightning impact assessment
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. This is primarily due to the granite-based geology and extremely high soil resistivity.

Climate change projections are not available for lightning strikes, however it is understood storm events are likely to increase in intensity and frequency. Lightning is potentially increasing with climate change, however, it remains unpredictable.

Cornwall signalling equipment is currently mechanical and is not as badly affected as other signalling systems would be. However, any lightning strike on signalling equipment causes widespread damage as the equipment is required to be interconnected. Cornwall is currently under review for accelerated re-signalling in CP5 which provides an opportunity to upgrade the lightning protection (which is usually achieved with specialist fuses) to significantly reduce the impact of lightning strikes on the equipment and train performance.

Lightning can also cause problems in rural areas across the whole Route. The track is exposed on an embankment and the rail is conductive to the lightning which can damage track circuit equipment. Depending on the equipment, this can take varying amounts of time to recover.

Lightning can strike both Network Rail and third-party lineside vegetation which can result in trees and vegetation incursion on track. This is rare and unpredictable and hence cannot be practically proactively mitigated.

Fog impact assessment
The Route suffers from very little fog accounting for 0.14 per cent of the Route delay costs and 0.12 per cent of the Route delay minutes.

The train delay data from 2006/07-2013/14 shows that there are two areas that were severely affected by fog. The Cotswold Line (Oxford – Moreton-in-Marsh – Pershore – Worcester) vulnerability this has been largely eliminated by signalling upgrades in CP4 included in the redoubling enhancement works.

The Worcester area is still 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.

Western Route WRCCA actions

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

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

Table 2 Planned actions in CP5

Vulnerability	Action to be taken	By when
All Impacts		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	Include clear requirements for climatic conditions and resilience levels in Route Requirements Documents	December 2014
Risk to staff from extreme weather conditions	Staff trained to use and supplied with appropriate equipment, e.g. lifevests for flooding events, seasonal PPE	Continually reviewed
Weather Information		
The provision of only cyclical forecasts (e.g. daily general forecast) limits the prediction of weather impacts on vulnerable assets.	Use real-time Met Office weather data to confirm actual weather conditions and assess asset vulnerability	Completed August 2014
Flooding		
Safety risk to staff responding to flooding sites and assessing the condition of the railway	Provision of water safety equipment (lifejackets, lifesaving rings) at repeat flood sites which require staff attendance	End October 2014
	Staff who respond to flooding and assess flood risk to receive Water Awareness Training	End 2014
Level of engagement with flood risk management authorities is not supporting effective discussions	Strengthen relationship with the Environment Agency through setting up of a Local Liaison Group on flood risk management to share information and resolve issues	Completed March 2014: Steering group and working group set up
	Engage with Local flood resilience forums	March 2015
	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
Major repeat flood sites: Chipping Sodbury Flax Bourton Lyng/Curry Road Patchway Up Tunnel Cowley Bridge Junction Hinksey Hele & Bradninch	Deliver the major projects identified in the 2013 Flood Resilience Study and funded in February 2014	Three-year programme with staged completion 2014, 2015, 2016
New flood sites: White Waltham (Maidenhead)	Review new flood sites and prioritise them for design development and remedial works	End 2014
	Install Remote Condition Monitoring	End 2014
Railway lines adjacent to rivers exposed to future flood risk by climate change	Review latest flood risk projections against updated rail network elevation model	End 2015
Coastal and estuarine		
Somerset Levels is at risk of major repeat flooding and further vulnerable to Climate Change	Support regional resilience proposals developed by Somerset County Council and the Environment Agency	Ongoing
Exeter St Davids to Newton Abbot is vulnerable to waves, storm surge and cliff instability. This will worsen with climate change.	Develop and publish proposals for increasing the resilience of the coastal railway at Dawlish	End 2015
Other Route sections (including those noted on p26) are at increased risk of flooding following sea level rise due to climate change.	Develop individual Asset Management Plans for Coastal, Estuarine and River Defences (CERD) which detail vulnerable coastal assets and their management plan for inspection, maintenance, renewal and upgrade	March 2019 (End CP5)

Vulnerability	Action to be taken	By when
Earthworks		
There are a number of high-risk earthworks which presently require proactive safety management in heavy rainfall.	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
	Remediate the highest risk earthworks as planned within the renewals workbank	March 2017
Failure precursors at earthwork sites are not directly monitored.	Install Remote Condition Monitoring on select high-risk earthworks	Start Autumn 2014 End 2017
There are residual risk sites which require remediation.	Prioritise and include adverse weather sites in the Civils Adjustment Mechanism submission, for remediation in Years 3-5 CP5	Funding submission ongoing, to be complete end March 2015
Wind		
Detailed tree asset knowledge (location, size) is limited.	Review and catalogue the results of the national LIDAR survey	End Q1 2015
On electrified Routes, 'tree on line' incidents will cause greater disruption than non-electrified routes. The Great Western Main Line will be electrified in 2016.	Undertake Autumn 2014 tree clearance programme (£5m)	End 2014
	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	Series 1 Reference Design signed off June 2014
	Vegetation clearance ongoing within Great Western Electrification Programme	Staged completion 2014-2018
Adhesion		
Continued vegetation growth increases the volume of leaf fall and worsens adhesion.	Undertake Autumn 2014 tree clearance programme (£5m) – *as noted in Wind*	End 2014
Adhesion issues continue to cause a large number of delay minutes	Improved management of adhesion and development of Autumn Timetables	Ongoing; Annual plan by May with September readiness

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

Table 3 Potential additional WRCCA actions requiring further evaluation

Vulnerability	Action to be evaluated
Flooding	
Staff are required to respond in person to flood warnings on structures.	Install Remote Condition Monitoring on the most frequently monitored bridge structures in the 'flood plan' to reduce requirement for staff response.
Coastal and estuarine	
Penzance station, and in particular signalling equipment, is vulnerable to storms	Combined with Cornwall Signalling Renewal, relocate signalling equipment into storm resilient cases and buildings
Exeter St Davids to Newton Abbot is vulnerable to waves, storm surge and cliff instability. This will worsen with climate change.	Following the development of proposals by End 2015 (see Table 2), 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)
Earthworks	
Residual risk sites which require remediation.	Remediate additional earthworks at adverse weather sites
Wind	
On electrified Routes, 'tree on line' incidents will cause greater disruption than non-electrified Routes. The Great Western Main Line will be electrified in 2016.	Maintain new reduced levels of vegetation (following clearance during 2014 and the Electrification Programme)
Cold and Snow	
Overhead line: icicles can form, affecting performance of the first trains each day	On extreme snow/cold days, consider running a maintenance train ahead of the first passenger trains to clear icicles, or other mitigation
	Inspect and monitor wet structures/tunnels for icicle growth
Only a limited number of points operating equipment (POE) have internal heating	Increase the number of points operating equipment with internal heating as part of the renewals process
System failure occurs when points heating strips become detached, but this is not detected by Remote Condition Monitoring (which monitors the electrical properties of the points heating)	Use train borne monitoring where possible. Review inspection frequencies during Winter preparation

Vulnerability	Action to be evaluated
High temperatures	
Speed restrictions are imposed earlier than required as actual site conditions are not known. Remote Condition Monitoring is not widespread.	Install Remote Condition Monitoring of rail temperature on some of the high-risk, highest delay impact locations
Lightning	
Cornwall is particularly vulnerable to lightning strikes due to its geology.	Include lightning risk in business case for the proposed accelerated Cornwall Signalling Renewal and install lightning protection measures in the new signalling system

Further opportunities for increasing rail system resilience

In developing this plan, Western Route has identified actions that could be taken to improve the weather and climate change resilience of train fleet, thus improving the overall resilience of the railway system. These actions will be proposed through the Joint Seasons Management Group.

- fleet restrictions override default 'Rule Book' instructions with regard to floodwater depth, operating speeds and line closure level. A consistent approach is required to simplify operational arrangements during flooding and meet the expectations of the passenger
- current rolling stock is not resilient to exceptional weather conditions, in particular sea spray, poor rail adhesion and heavy frost/snow. Retrofitting of some fleets may be required. These conditions should also inform the design criteria for new rolling stock.

Management and review

Corporate management and review

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

Key actions being taken within corporate functions include:

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

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

Western Route management and review

The Western Route is already committed to managing and reviewing the implementation of weather-related resilience actions and has several forums in which risks are identified and tracked.

The principal forums are:

- Route Infrastructure Reliability Group (Periodic)
- Quarterly Asset Stewardship Review with each Maintenance Delivery Unit (Quarterly)
- Seasonal delivery meeting with TOCs, FOCs and other stakeholders (Periodic)
- Review of Flooding Resilience Actions (Periodic)
- Joint Performance Improvement Plan (Periodic)

Actions from Route reports and the above forums are tracked regularly to measure the effectiveness of the resilience actions.

Review of Route WRCCA plan actions

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

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

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

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

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