Route Weather Resilience and Climate Change Adaptation Plans

London North West

Contents

Purpose of this document

This document sets out a Weather Resilience and Climate Change Adaptation (WRCCA) plan for LNW 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

The railway network, over the last few years, has been significantly affected by severe weather conditions such as wind, snow, rainfall, lightning, and high and low temperatures. These extremes can lead to asset system failure, degraded operation and ultimately, delays to our train services. During periods of drought we suffer soil desiccation and embankment earthwork deterioration, high temperatures increase the risk of track buckling and high winds can result in vegetation or foreign object incursion on to the infrastructure.

To address the weather resilience challenges on LNW Route, we are committed to identifying new and innovative ways of improving our infrastructure resilience during periods of severe weather conditions.

It is difficult to predict the changes in future weather events with any certainty, but it is probable that infrastructure reliability will be tested by climate change and more severe weather events. Projections indicate that in the LNW Route these events will be driven by increases in average and maximum daily temperature and changes in rainfall patterns, with drier summers and wetter winters. All these will challenge the infrastructure and require us to identify, plan and implement more activity that prevents this causing delay to trains.

We will address weather resilience and climate change by working more effectively through continuing to improve how we engage with all stakeholders involved in this challenge, including the Environment Agency and lineside neighbours.

LNW Route is experiencing significant investment over the next five-year control period (Control Period 5); we will spend over £6 billion enhancing, renewing, maintaining and operating the infrastructure. This level of investment reflects the growth in the demand for rail travel and the economic significance of the railway in the LNW Route connecting the Midlands and North West regions to the capital. So it is important for the network as a whole that we make these improvements – and in this document we outline how we will go about that challenge.

James Dean
Director, LNW Route Asset Management, September 2014

Executive summary

Weather events can cause significant disruption to the operation of train services and damage to rail infrastructure. A move to a warmer climate and a variance in the pattern of precipitation across the year, generally projected by the UK Climate Change Projections (UKCP09), could result in changes in the frequency and intensity of severe 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.

LNW 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, LNW Route has determined whether previous investments have mitigated weather impact risks, if actions planned during Control Period 5 (CP5) (2014 to 2019) are addressing these vulnerabilities, and where additional actions could further enhance weather and climate change resilience.

An analysis of Schedule 8 performance costs (the compensation payments to train and freight operators for network disruption) during the period 2006/07 to 2013/14 clearly shows wind, flooding and snow-related events have had the most significant impact on the Route. Vegetation incursion on the overhead line equipment and track as a result of high wind speeds has been the most significant factor on the LNW Route.

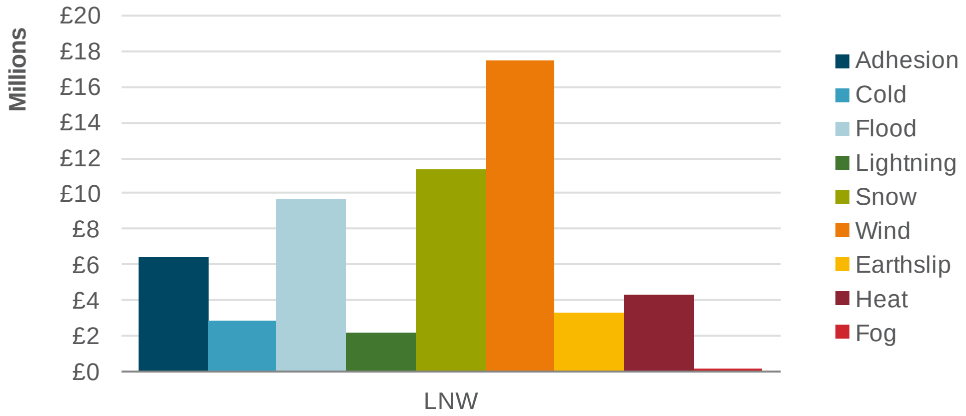


Figure 1 LNW Route weather attributed Schedule 8 costs 2006/07-2013/14

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

- improve the knowledge of weather impacts on LNW Route through identification of root causes and trends to support the identification of cost effective resilience measures
- improve operational responses and associated mitigation actions to severe weather events
- increase the understanding of potential climate change impacts on LNW Route
- develop and manage a LNW Route Climate Change Adaptation Plan to inform current and future control period investment plans and workbanks
- include climate change adaptation in Route Requirements Documents for any type of development work, be it renewal or enhancement
- support national and local initiatives aiming to deliver weather resilience improvements
- engage with key stakeholders to communicate the LNW Route strategy, planned programme of work and identified climate change adaptation actions, including the Environment Agency and lineside neighbours
- seek innovative technologies to support climate change resilience
- improve real-time weather monitoring ability on LNW Route.

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

- establish regular liaison meetings with the Environment Agency and local authorities to reduce flood risk through joint schemes
- engage with wider industry, including train operating companies to minimise delay impacts
- develop a more detailed drainage asset register to improve asset knowledge
- identification and assessment of earthworks (natural or man-made cuttings, embankments and slopes) which are located on adjacent land (Outside Party Earthworks) to deliver a susceptibility rating for land adjacent to LNW Route
- progress an enhanced vegetation management scheme to reduce the risk of disruption and increase operational safety in high wind speed conditions
- undertake trials of structure waterproofing solutions to reduce the risk of icicle formation in structures
- increase weather monitoring capability in order to predict flooding and earthwork failures at high-risk locations.

LNW 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 severe storm events demonstrated much of the network is resilient. However, asset failures such as the Dawlish sea wall, Cambrian sea defences, Botley landslip, and the widespread tree fall following the St. Jude storm, reveal the vulnerability of the rail network and the impact these weaknesses in resilience can have on train services and resources. The earthwork failure at St Bees in Cumbria in 2012 highlighted the susceptibility of earthworks following a period of intense rainfall.

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.

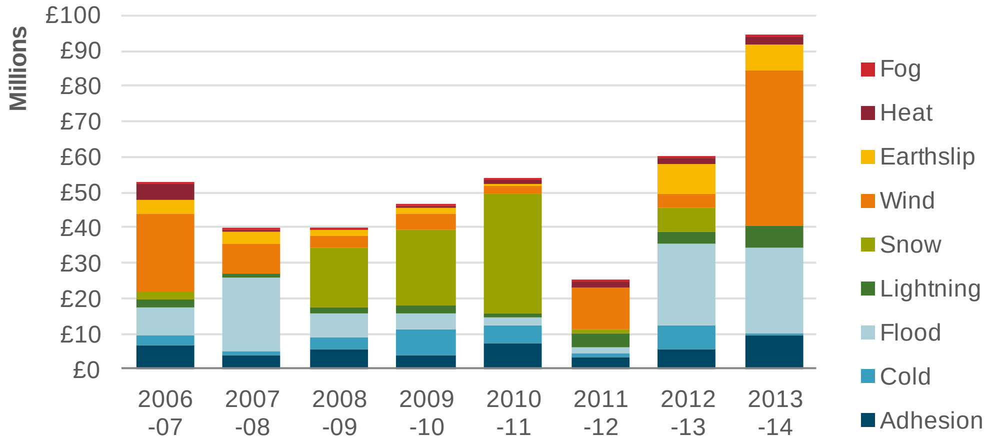


Figure 2 Whole network weather attributed Schedule 8 delay costs, 2006/07 to 2013/14

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

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

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].

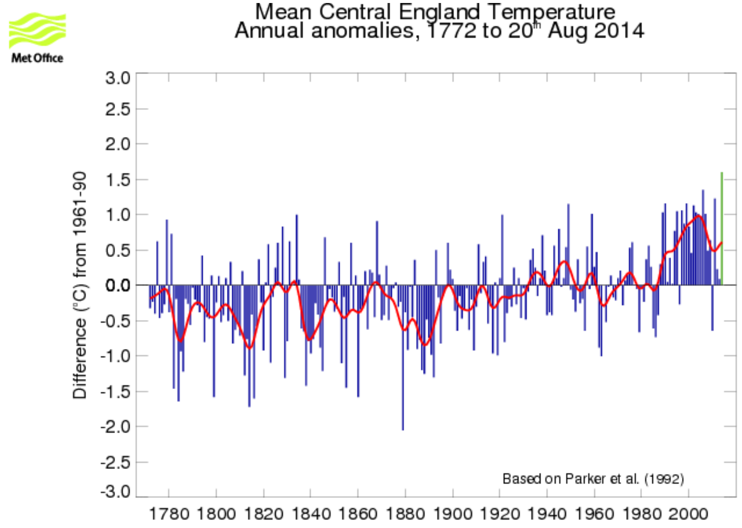


Figure 3 Mean Central England temperature record

[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.

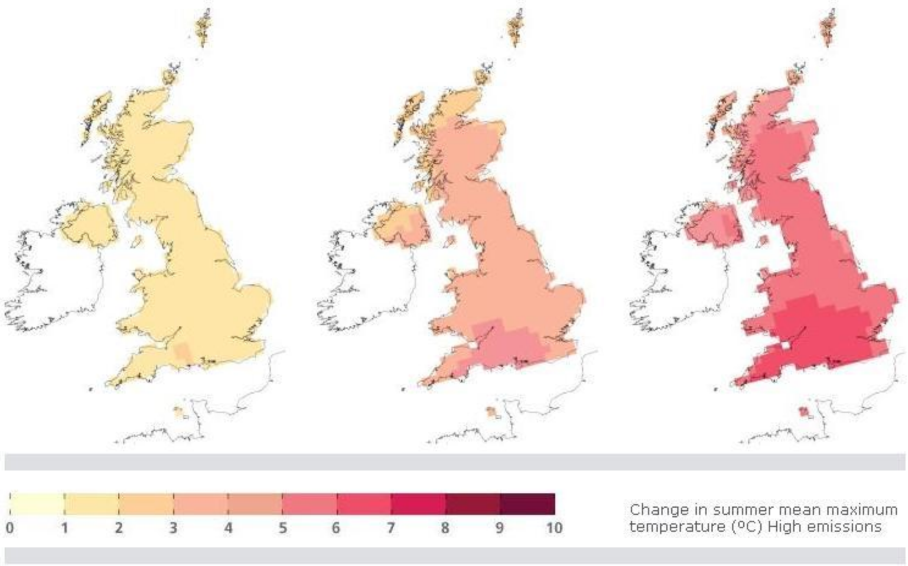


Figure 4 Change in summer mean maximum temperature (left 2020s, middle 2050s, right 2080s)[2]

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 WRCCA plan uses the projections to support the prioritisation of weather resilience actions.

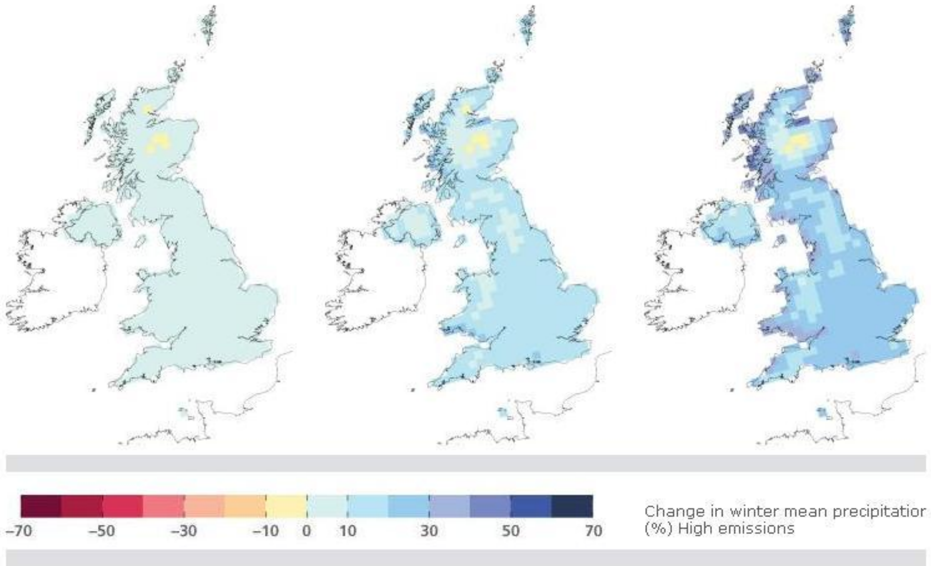


Figure 5 Change in winter mean precipitation (left 2020s, middle 2050s, right 2080s)[2]

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 LNW Route WRCCA plan.

[2]© UK Climate Projections, 2009

Figure 6 Weather resilience and climate change adaptation framework

Network Rail WRCCA actions will include a range of measures:

- 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 LNW Route vulnerability and impact assessments, and details of the WRCCA actions; both completed and planned in CP5, and potential additional actions, that aim to increase weather and climate change resilience.

Figure 7 Flooding at Castle Bromwich junction in the West Midlands

LNW 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 Flooding at Bescot sidings in the West Midlands

LNW Route Strategy

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

- improve the knowledge of weather impacts on LNW Route through identification of root causes and trends to support the identification of cost effective resilience measures
- improve operational responses and associated mitigation actions to severe weather events
- increase the understanding of potential climate change impacts on LNW Route
- develop and manage a LNW Route WRCCA plan to inform current and future control period investment plans and workbanks
- include climate change adaptation in Route Requirements Documents for any type of development work, be it renewal or enhancement
- support national and local initiatives aiming to deliver weather resilience improvements
- engage with key stakeholders to communicate the LNW Route strategy, planned programme of work and identified climate change adaptation actions, including the Environment Agency and lineside neighbours
- seek innovative technologies to support climate change resilience
- improve real-time weather monitoring ability on LNW Route.

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

LNW Route vulnerability assessment

This section provides the details of the general vulnerability of the rail network in Great Britain and LNW 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.

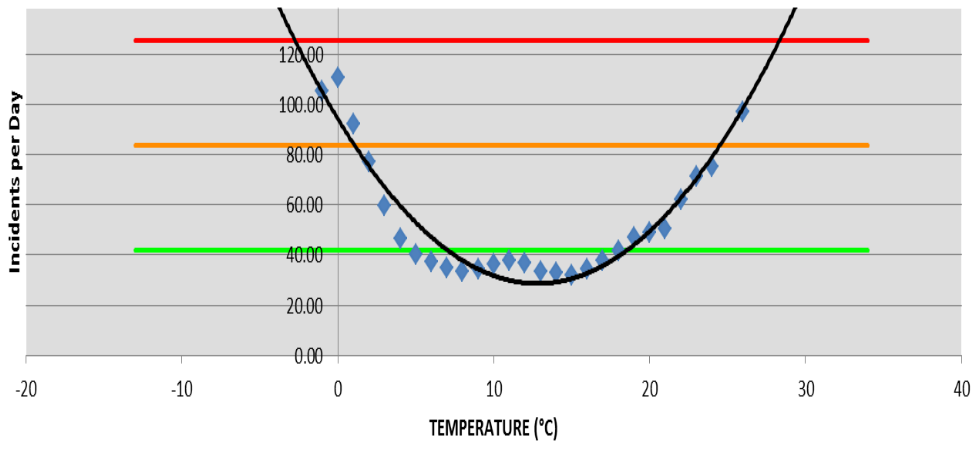


Figure 9 Example of asset failure and weather analysis

Managing operational response to weather vulnerability

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

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

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

Network Rail seeks continuous improvement of weather-based decision support tools, including flood, temperature, wind speed and rainfall alerts. A trial aiming to significantly improve real-time weather monitoring has installed approximately 100 weather stations on the Scotland rail network, Figure 10. The pilot study is currently being evaluated to support a potential wider roll-out of this level of weather service.

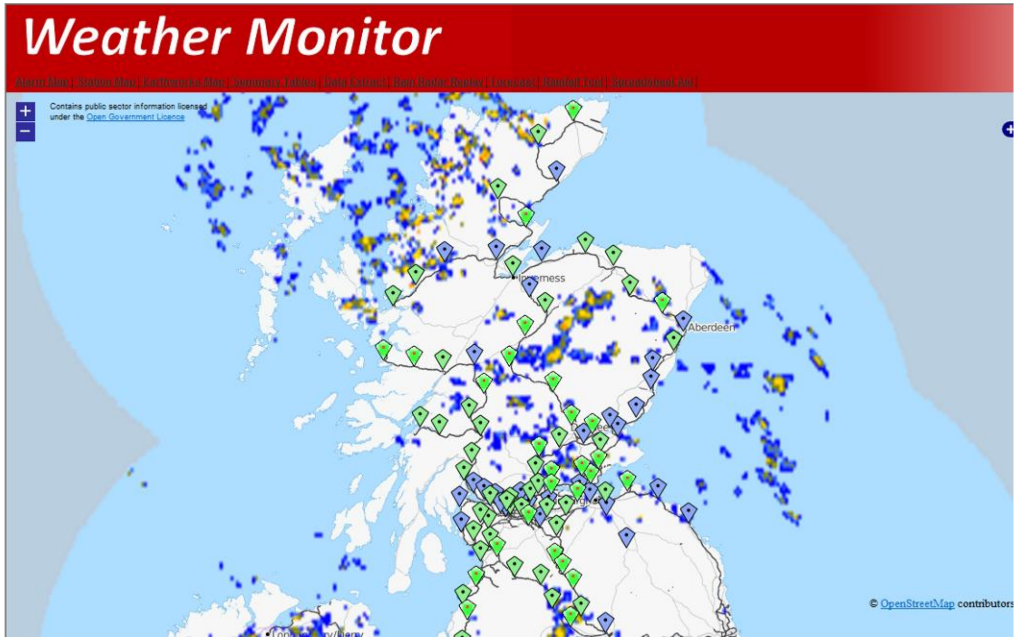


Figure 10 Scotland Route real-time weather monitor

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

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

Improving our network wide resilience

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

The WRCC programme is founded on a bow tie risk assessment 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.

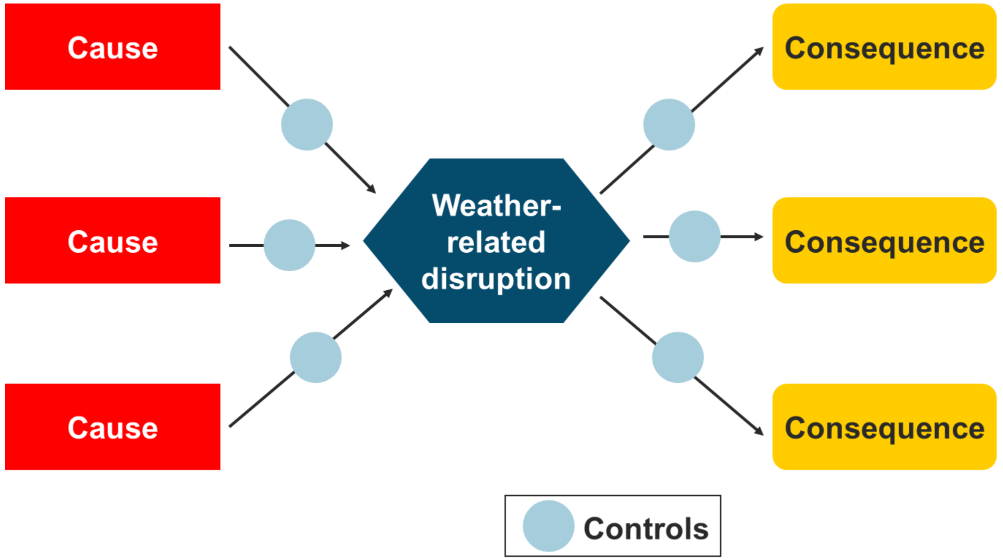


Figure 11 Bow tie risk assessment

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.

WWRCC Sub-Programmes

1 Infrastructure Resilience

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

2 Cross-industry Resilience

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

3 Earthworks Integrity

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

4 National Weather Event Response

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

5 Climate Change Adaptation

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

6 Information Exploitation

22. Delivering supplementary information
23. Delivering Weather Resilience Intelligence

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

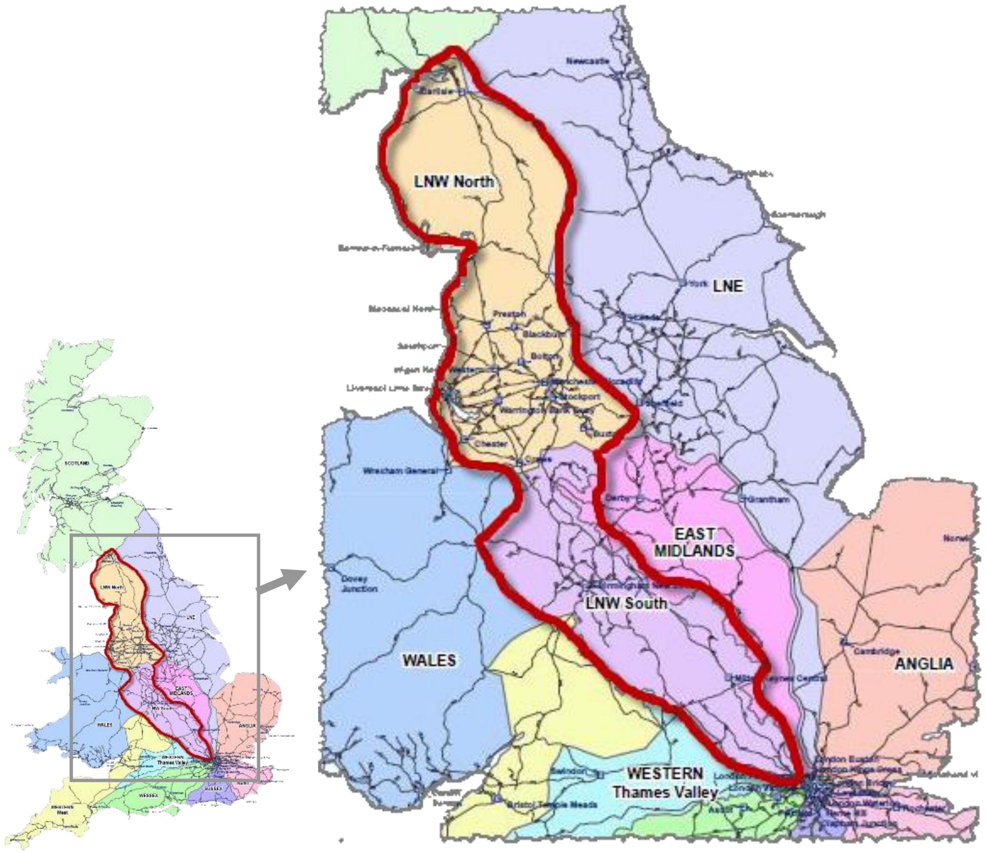
The WRCC programme is currently supporting the delivery of:

- 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

LNW Route extends from London to the Scottish border and from the Pennines to the West coast of Lancashire and Cumbria. It includes a very diverse range of rail track classification, topography and geology from very high tonnage on 125mph multiple track electrified railway to single track freight or passenger rural routes, and from low-lying and level coastal plains to steep mountainous terrain.

The very diverse range of topography, from typically low lying and gently undulating land in the south to the higher ground of the Peak District, Pennines and Cumbria in the central and northern areas significantly influence the weather conditions experienced. The nature of the topography, its height and steepness, is linked to the geology of the areas, and this plays an important role in determining the way in which the weather ultimately impacts the railway assets.



For the most part, clay geologies dominate the southern and central Midlands, providing a gently undulating and low lying topography which is bounded to the south by the chalk uplands of the Chilterns and to the west by the higher ground of the Welsh Borders. The impermeable ground and shallow gradients also encourage standing water, and flood waters can remain in place for prolonged periods of time as a consequence, rendering the railway earthworks assets vulnerable to softening and weakening of the clays and, as a consequence, an increased number of relatively slow moving failures in embankments and cuttings.

Some distance from the sea, this low-lying area can, at times, trap stable high-pressure ‘continental’ air which has the potential to bring prolonged periods of very high temperatures in the summer and very low temperatures in the winter. High summer temperatures encourage impacts such as desiccation shrinkage of clay geologies as trees extract moisture from the ground.

Further north, the lower-lying geology of the Cheshire Plain is different to that in the south, and is less susceptible to the earthworks failure mechanisms seen there. However, this area is more open to the influences of the warm moist south westerly maritime air streams and these travel in across Liverpool towards the higher, steeper, topographies of the Peak District, south Pennines and in the north, the southern boundary of the Cumbrian uplands. As these warm air masses are channelled and forced higher, they cool, forming cloud and increased precipitation.

The greater rainfall experienced in this area falls generally on steeper slopes over higher ground and can lead to ‘Flash’ flooding which has much higher energy and can quickly become very destructive to railway assets and other property.

During the winter this precipitation falls on the higher ground as snow, but the continued influence of warm air from the sea means that quite large swings in temperature can occur. This is problematic if sudden warming follows several days of cold, leading to a greater risk of ice accumulation and ice fall in tunnels, Figure 13.

The maritime air and prevailing south westerly winds also impact the very exposed Cumbrian Coast Line, in particular where it runs along the coastal sections from Arnside to Maryport. In many locations the railway forms the first line of coastal defence and is therefore vulnerable to wave action in high winds and in particular at times of high tide. The same ‘lifting’ of the warm moist air occurs as the weather systems reach Cumbria, so heavy rainfall is also common here and the railway can end up being impacted by high river levels and high intensity surface water run-off.

In the furthest north eastern part of the route, the catchments of the Caldew and Eden run through an area of generally low lying and gentle topography, but in contrast with the southern parts of LNW route, the geology is the product of glaciation, and the very variable geologies are susceptible to slope failure as a consequence of the very high rainfalls experienced in the foothills of the Pennines. The catchments of the two rivers are also susceptible to flooding, with severe impacts on the city of Carlisle.

Figure 13 Ice formation emanating from tunnel shaft in Birkett tunnel on Settle to Carlisle railway line

Future climate change vulnerability

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

The UK Climate Change Projections (UKCP09) provides regional climate change projections across 13 administrative regions in Great Britain, Figure 14. LNW Route spans across several of these regions, however, a large majority of the Route falls within North West England and West Midlands regions. Projections for these are considered to be representative of the future climate changes within the Route.

Figure 14 UKCP09 administrative regions

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

Mean daily maximum temperature change

Mean daily maximum temperatures for both North West England and West Midlands administrative regions are projected to increase throughout the year, with greater increases expected in the summer months.

In North West England, the average maximum daily temperature in July is expected to increase by over 2.4°C, reaching 20.8°C by the 2050s, and by over 4°C, reaching 22.4°C by the 2080s. Average maximum daily temperature in January is expected to increase by 1.9°C, reaching 7.5°C by the 2050s, and by 2.8°C, reaching 8.4°C by the 2080s, Figure 15.

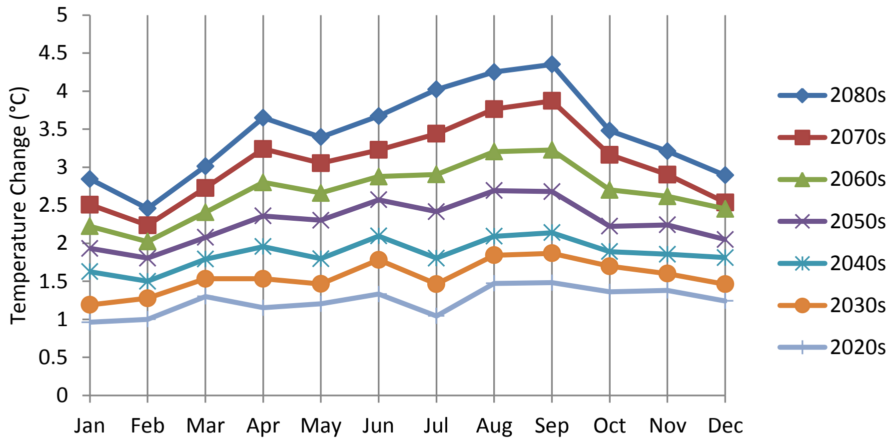


Figure 15 North West England, mean maximum temperature change (50th percentile)

The average maximum daily temperature in the West Midlands in July is expected to increase by 3°C, reaching 23.4°C by the 2050s, and by over 5°C, reaching 25.4°C by the 2080s. Average maximum daily temperature in January is expected to increase by 2°C, reaching 8.1°C by the 2050s, and by 3°C, reaching 9.1°C by the 2080s, Figure 16.

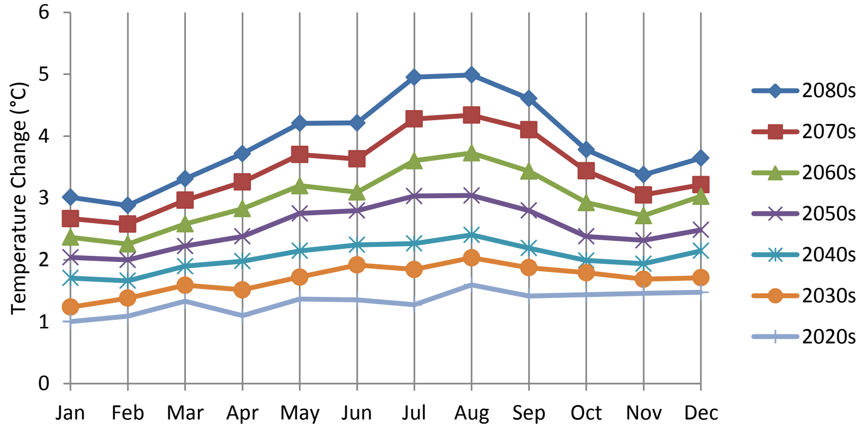


Figure 16 West Midlands, mean maximum temperature change (50th percentile)

Mean daily minimum temperature change

The mean daily minimum temperatures for both North West England and West Midlands administrative regions are also projected to increase throughout the year.

In North West England the average minimum daily temperature in July is projected to increase by 2.5°C, reaching 13.5°C by 2050s, and by 4°C reaching 15°C by the 2080s. Average minimum daily temperature in January is projected to increase by 2.4°C, reaching 3.1°C by 2050s, and by 3.5°C, reaching 4.2°C by 2080s, Figure 17.

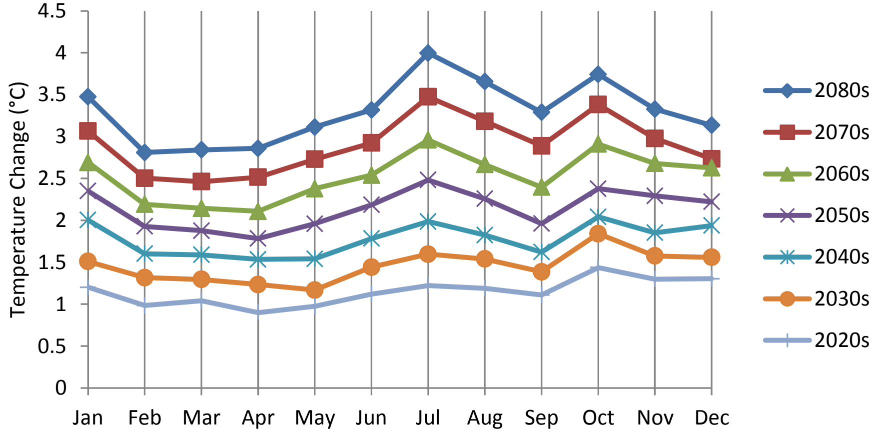


Figure 17 North West England, mean minimum temperature change (50th percentile)

In the West Midlands, the average minimum daily temperature in July is projected to increase by 2.6°C, reaching 13.8°C by 2050s, and by 4.2°C reaching 15.4°C by the 2080s. Average minimum daily temperature in January is projected to increase by 2.7°C, reaching 3.5°C by 2050s, and by 3.9°C, reaching 4.8°C by 2080s, Figure 18.

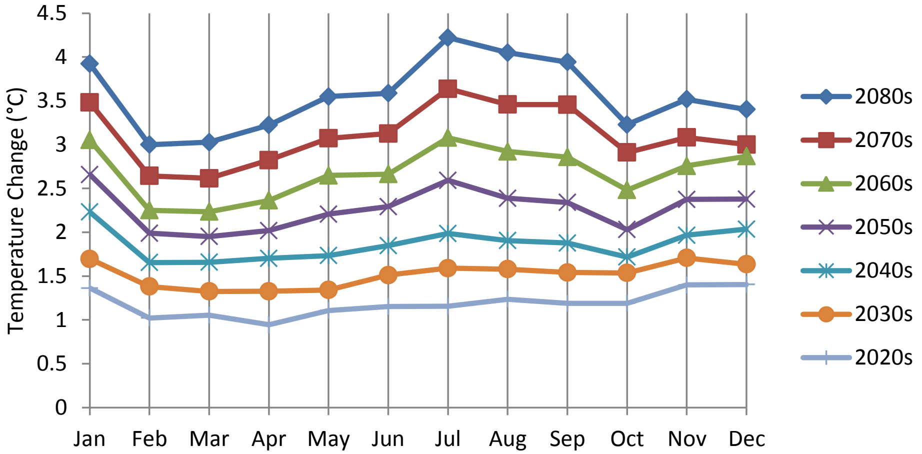


Figure 18 West Midlands, mean minimum temperature change (50th percentile)

Mean daily precipitation

Projections for mean daily precipitation for both North West England and West Midlands 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.

In North West England, the increase in daily precipitation in February is projected to be 13 per cent, reaching 3.4mm per day by the 2050s, and 26 per cent, reaching 3.8mm per day by the 2080s. The mean daily precipitation in August is projected to decrease by 21 per cent by the 2050s, to 2.4mm per day, and by 34 per cent, to 2mm per day by the 2080s, Figure 19.

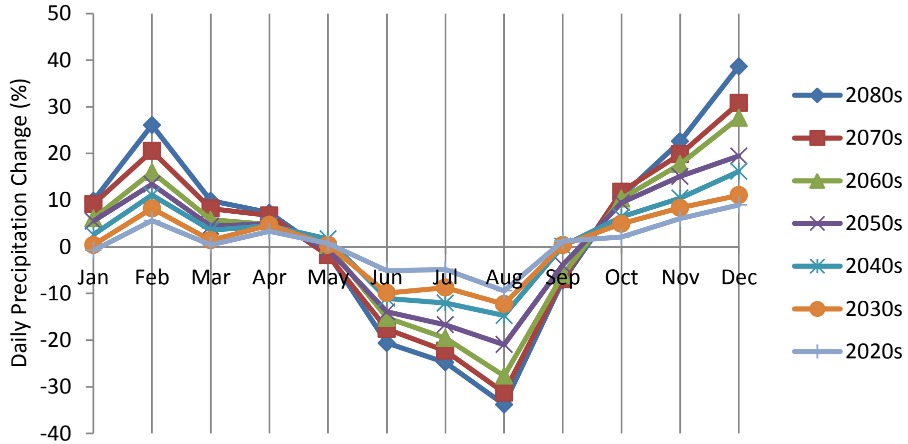


Figure 19 North West England, mean daily precipitation change (50th percentile)

In the West Midlands, the mean daily precipitation is projected to increase by 17 per cent, reaching 2.1mm per day by the 2050s, and by 31 per cent, reaching 2.4mm per day by the 2080s. Mean daily precipitation in August is projected to decrease by 25 per cent by the 2050s, to 1.5mm per day, and by 40 per cent, to 1.2mm per day by the 2080s, Figure 20.

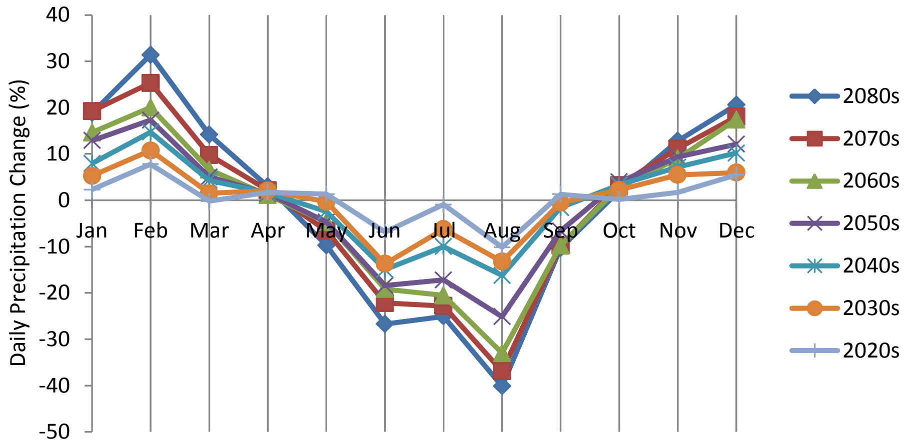


Figure 20 West Midlands, mean daily precipitation change (50th percentile)

Sea level rise

Sea level rise for LNW Route coastal and estuarine assets can be represented by the projections for the Cumbrian coast, near Flimby. For the high emissions scenario, the projections for the 50th percentile for 2050 is 0.197m and 0.45m by the end of century (the rise is unlikely to be higher than 0.34m and 0.773m respectively), Figure 21.

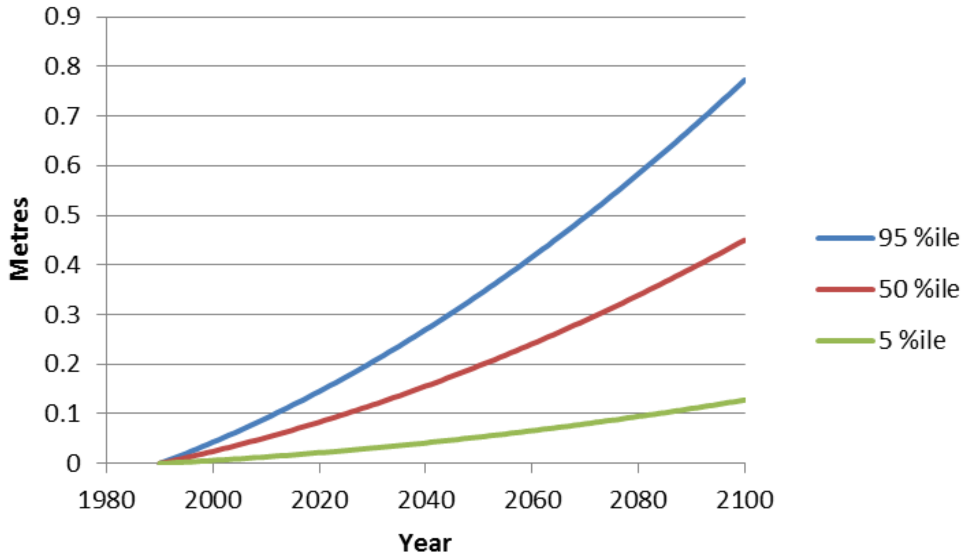


Figure 21 UKCP09 sea level rise projections for Flimby area

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

LNW Route impact assessment

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

Performance impacts

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

Schedule 8 costs, for the past eight financial years for the two areas LNW North and LNW South have been analysed, Figure 22, to provide an assessment of weather impacts,

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

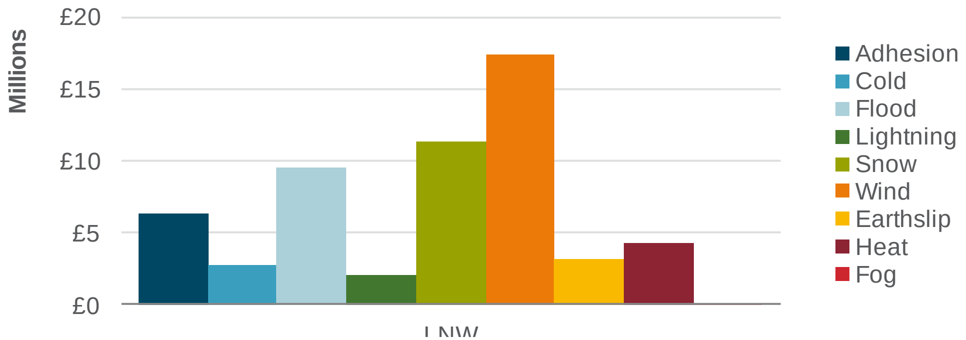


Figure 22 LNW Route weather attributed Schedule 8 costs 2006/07 to 2013/14

The analysis clearly shows that wind has been the most significant weather attributed performance impact for the Route, with Schedule 8 costs over £17m during the period 2006/07 to 2013/14. High wind speeds can result in vegetation and foreign object incursion on the overhead line equipment and track so blanket speed restrictions are applied when the specified wind speed threshold is exceeded.

Climate modelling cannot provide strong projections for future changes to wind speeds, though, increased storms are generally projected and may increase the risk of wind-related incidents on the Route.

Snow-related delays have been significant but are projected to decrease in the future. However, severe cold-related events are projected to continue to occur and actions to ensure resilience to cold-related weather impacts should continue to be factored in future seasonal preparedness and investment decisions.

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 presents increased risk to LNW Route over the coming decades.

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

Table 1 Prioritisation of weather-related impacts on LNW Route

Weather-related impact	Schedule 8 costs[1]	Projected future impacts	Prioritisation
Wind	£2.2m	Wind changes difficult to project, however, generally projected to increase	High
Flooding	£1.2m	Up to17% increase in February mean daily precipitation[2]	High
Snow	£1.75m	Up to 2.6°C increase in January mean daily minimum temperature[2]	Medium
Adhesion	£0.8m	Complex relationship between adhesion issues and future climate change.	Medium
Heat	£0.5m	Up to 3°C increase in July mean daily maximum temperature[2]	Medium
Earthslips	£0.4m	Up to17% increase in February mean daily precipitation[2]	Medium
Cold	£0.4m	Up to 2.6°C increase in January mean daily minimum temperature[2]	Low
Sea level rise	Not recorded	0.2m increase in sea level rise[3]	Low
Lightning	£0.3m	Storm changes difficult to project, however, generally projected to increase	Low
Fog	£3k	Complex relationship, however, research suggests fog events may decrease	Low

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

It is also worth noting the Schedule 8 cost per delay minute in CP5 (2014-2019) will be on average 60 per cent higher, hence further reinforcing the importance of effective WRCCA actions.

Identification of higher risk locations

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

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

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

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

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

Figure 23 Scour failure on the West Coast Mainline at the River Eden Viaduct

Wind impact assessment

The METEX data analysis revealed that LNW Route experienced 65,000 delay minutes on average per year due to wind. The cost in terms of Schedule 8 payments has been an average of £2.2m per year.

The analysis highlighted two consistently recurring themes of blanket speed restrictions and vegetation/foreign object incursion.

The Network Rail company standard NR/L3/OCS/043 – National Control Instruction, mandates that blanket speed restrictions are imposed when specific wind gust speeds are triggered. The trigger table for actions required is shown below:

Wind Speed	Action	Element
Forecast of gusts up to 59mph	No action	**Wind 1**
Forecast of gusts from 60mph to 69mph (not sustained)	Be aware of the possibility of 'Wind 3' being reached	**Wind 2**
Forecast of frequent gusts from 60 to 69mph (sustained over 4 hours+)	50 mph speed restriction for all trains in the affected Weather Forecast Area	**Wind 3**
Forecast gusts 70mph or over	50 mph speed restriction for all trains in the affected Weather Forecast Area	**Wind 3**
Forecast gusts 90mph or over	All services suspended in the affected Weather Forecast Area	**Wind 3**

While the number of incidents where a blanket speed restriction was imposed is just over 7 per cent of the total incidents coded to wind as the cause, these incidents accounted for over 20 per cent of the Schedule 8 costs.

The imposition of the blanket speed restriction is to reduce the likelihood and/or consequence of a train striking obstructions blown on to the line. There is currently no requirement to impose a speed restriction for the protection of the overhead line equipment on LNW following work carried out in May 2012 at North Rode Viaduct. Overhead line equipment design anomalies were identified at this location which resulted in asset vulnerability during high wind speeds. The work corrected the design issues at this location and no problems were encountered during the high winds which occurred in the winter of 2013/14.

Vegetation
Over 70 per cent of wind caused incidents contained in the METEX data-related to trees on the line or overhead line equipment and accounted for the highest proportion of the Schedule 8 costs.

The Network Rail vegetation management standard NR/L2/TRK/5201 mandates that a five metre clearance of all woody vegetation from the running rail is required along with a 3.5 metre clearance from the overhead line equipment. The standard also mandates that hazardous trees are identified and removed. There is no mandatory requirement to remove healthy trees which have the potential to fall on the overhead line equipment or track. LNW Route are progressing a business case for application of an enhanced vegetation management scheme which goes beyond the requirements of the current standard. The enhanced vegetation management scheme will work progressively through the LNW route track mileage over a five year programme, clearing the lineside back to a vegetation profile compliant with the Route specification. This will further address the risk of tree incursion on the overhead line equipment or track and enhance the asset resilience to the resultant effects of high wind speeds.

Significant lineside improvement works were funded in the final two years of CP4 in the West Coast South and Birmingham areas. A £10m lineside improvement scheme was delivered between Euston and Rugby and part of this project reduced the risk from vegetation incursion. Approximately 500,000 linear metres of vegetation clearance has been completed at a cost of £3.5m, this work was predominantly undertaken on the routes around Birmingham.

Figure 24 Fallen tree on the Chilterns line at Gerrards Cross

Removing trees that are tall enough to breach the boundary will reduce the liability risk of injury or damage to a third party. LNW Route has a potential liability from trees on Network Rail owned land that can breach the boundary and cause damage or injury; further investment will be investigated to establish the best value for risk mitigation.

Figure 25 Examples of trees breaching the boundary fence falling on third-party land

Further to the funding sought above, LNW Route is also proposing additional funding to deal with trees on third-party land that have the ability to impact the rail infrastructure. Undertaking this work will involve additional challenges as permission from the third party to access the land and remove the tree will be required.

It should also be noted that large scale removal of trees can be a sensitive issue which will require collaboration with our lineside neighbours as some trees are protected and also form a visual screen to train services.

Foreign objects
Approximately 15 per cent of the incidents caused by wind were caused by foreign objects on the infrastructure and accounted for over seven per cent of the Schedule 8 costs. LNW Route has experienced many different objects being blown on to the line, including trampolines and sheds but plastic sheeting and bags are the most common, Figure 26. Practicable action to reduce the risk of foreign object incursion on the infrastructure during high winds is difficult to manage, therefore, the operational risk is mitigated by the imposition of speed restrictions when wind thresholds are breached.

Figure 26 Removal of plastic sheeting from overhead line equipment on LNW Route

Stations

Station roofs and canopies which were considered at risk during high wind speeds have had renewal work undertaken in CP4 with others planned in CP5.

At Marylebone, a £5m renewal scheme was delivered which consisted of covering, glazing and rainwater goods including installation of a safe maintenance access system. The new roof is designed to withstand a 1 in 100 year weather event and effectively drains rain water away from the platform and track; this roof is no longer vulnerable to high winds, Figure 27.

Crewe station roof was at risk due to asset age and condition. This is currently being addressed with significant interventions well underway. The roof to Crewe station and train sheds is being renewed and is approximately 50 per cent complete, with completion planned by the end of 2014; this scheme will remove the wind-related risk at this location.

At Manchester Victoria, the roof is at risk due to asset age and condition which is currently being addressed with significant interventions well underway. The roof at Manchester Victoria is undergoing renewal as part of the station redevelopment which is a multi-party funded scheme.

Figure 27 New station roof at Marylebone

Flooding impact assessment

LNW Route METEX data analysis reveals that there were 423 incidents over £1000 Schedule 8 costs that were coded to 'Flooding' in the eight-year period. 34 of these incidents accounted for 50 per cent of the total Schedule 8 costs. The average annual Schedule 8 cost due to flooding is £1.2m.

The chart below shows the distribution of the incidents over the eight-year period:

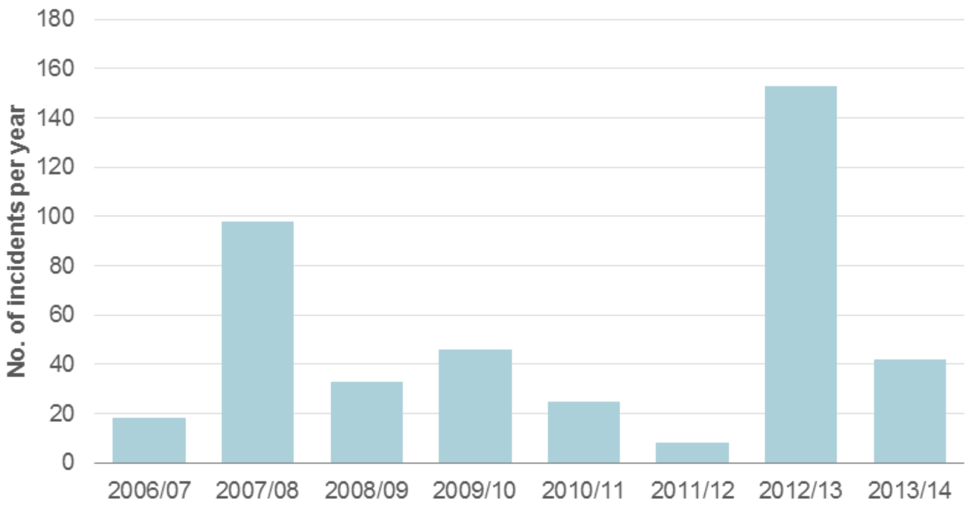


Figure 28 Number of flood Schedule 8 incidents in LNW Route

The winter of 2012/13 witnessed sudden and intense rainfall events over a prolonged period of time and resulted in many incidents of flash flooding and flood-related failures or damages on LNW Route. There were a wide range of factors for the cause of flooding and its impact on the railway but mainly it was due to the poor, aged and under-capacity railway drainage system, intensity of the rainfall and its location, the size, ground profile and steepness of the catchment the rain falls on, how much sediment is moved by the water and the vulnerability of the railway asset within the floodplain and flood path.

The METEX analysis revealed that in approximately 45 per cent of the flooding incidents, poor drainage condition was cited as a contributory factor. The drainage system also suffers from being overwhelmed during periods of heavy rainfall over a wide catchment area with run off from third-party land adding to the issues.

Nearly 20 per cent of the flooding incidents which cost over £1000 in Schedule 8 were located in just four per cent of the total Stannox locations (sections of rail track). Flooding is an extremely localised impact and the asset policy has the ability to drive resilience through the inclusion of climate change factors, such as our Drainage and Structures Design Standards.

Of the 55 flooding incidents analysed during the METEX data review, 42 of these have had mitigation action taken in CP3 or CP4, with 48 of the sites having further works funded and planned in CP5. One incident at Caldew Junction has had no mitigation action and no planned action in CP5 and will require further evaluation.

The climate change projections indicate a 13 per cent increase in winter rainfall by the 2050s (high emissions, 50th percentile). This will be a challenge for drainage assets as demonstrated by the winter of 2012.

Several major schemes have been developed to improve drainage system and flood defence work especially at critical and repeatedly known flooding locations along the Route. Examples include drainage improvements to third-party and cross track culvert drains at Shap in 2011 and creation of an attenuation pond to manage flood risk at Fenny Compton in 2013, **Figure 29**.

Figure 29 Flooding at Fenny Compton prior to the improvement works carried out in 2013

Additionally, other approaches were taken by commissioning schemes such as jetting and cleaning existing drainage, repairing, refurbishing and renewing part or full extent of a drainage system to improve its functionality and to install brand new drainage systems at locations where there weren't any in the past.

To reduce and better manage the impact of flooding, measures have been taken to have a strategy that is consistent with the Environment Agency's and other regulatory requirements where periodic and constant engagement with relevant stakeholders are held.

For LNW Route, Network Rail are involved in regular dialogues with strategic liaison working groups that include the Environment Agency, water companies – United Utilities, Severn Trent Water, Thames Water and Anglian Water, local authorities, Highways Agency, Canal & River Trust and any flood-affected local groups or communities.

These working groups aim to identify and communicate any issues of flooding, and draw up measures and plans to mitigate the problems. The objectives are to reduce the impact of flooding and the damage it causes, raise awareness and engage all responsible stakeholders including the wider communities, provide effective and sustained response in resolving issues of flooding, and prioritise the delivery or joint delivery of works to increase resilience to flood risks.

Figure 30 Material deposited on track during flooding at Walsden in July 2013

Figure 31 Flooding at Winterbutlee tunnel at Walsden in July 2013 when severe thunderstorms with heavy rainfall caused a third-party upstream culvert burst near Walsden Station resulting in water flowing directly on to the track

In order to successfully manage drainage going forward, LNW Route has created a dedicated Route Asset Manager (RAM) for Drainage and Off-track (D&OT) responsible for all drainage elements (Track, Geo-Technical and Structural). LNW Route is unique in Network Rail in having a Route Asset Manager assigned to Drainage and Off-Track, a role designed primarily to provide unified focus for drainage management across all disciplines. The RAM (D&OT) function 'owns' all drainage assets, and is responsible for:

- ensuring that a drainage asset register recording drainage asset location, type and condition is maintained
- establishing the extent and capacity of drainage systems and any interdependencies with other asset types
- monitoring delivery of drainage maintenance volumes
- establishing and maintaining a drainage refurbishment and renewal workbank
- provision of drainage expertise to Maintenance and other RAM teams
- establishing consistency in design standards and in the application of best practise for renewals, refurbishment and maintenance activities
- ensuring policy compliance in drainage activities
- monitoring and achieving regulatory measures for the control period for drainage asset condition and function.

LNW Route has produced a Drainage Management Plan which is a high level document intended to inform LNW Route executive, senior managers and other external stakeholders as to the shape and direction of drainage management from CP5 onwards.

The Route Drainage Management Plan provides an outline of the approach to be adopted on LNW Route for all aspects of drainage management including:

- accountabilities and responsibilities
- establishment and maintenance of an asset register
- inspection and survey
- delivery of maintenance, refurbishment and renewal
- route, national and regulatory reporting.

It is a Network Rail Tier 1 document which provides guidance on general principles applicable to drainage management on the Route. Geographically aligned Local Drainage Management Plans are being prepared for each track maintenance engineer area. These Local Drainage Management Plans are due for completion in September 2014.

The drainage workbank for CP5 has been created using the latest data from the national drainage survey – undertaken in CP4. This has allowed the Route to create robust plans to target renewals and refurbishment. The drainage plan is designed to slowly ramp up towards the final year of CP5 and continue on an even trajectory throughout CP6.

Snow and Cold impact assessment

LNW Route METEX data analysis reveals that there were 1135 incidents over £1000 Schedule 8 costs that were coded to 'Snow' or 'Cold' in the eight-year period. The average Schedule 8 costs have been £1.75m per year.

However, as would be expected from this type of weather event the spread of incidents is far from even. There are three years that stand out in the eight year period analysed; 2009, 2010 and 2012, Figure 32. In the winter of 2013, there was zero snow incidents recorded on the LNW infrastructure.

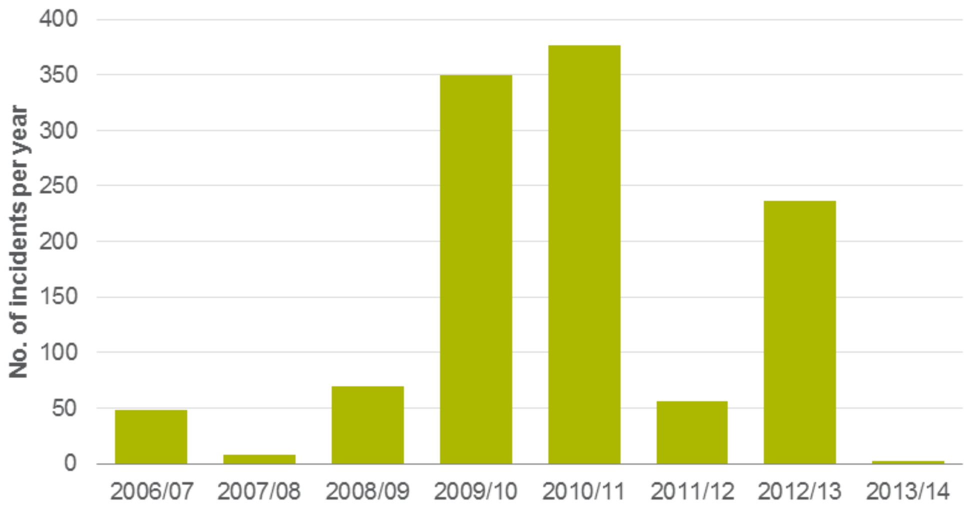


Figure 32 Number of snow and cold Schedule 8 incidents in LNW Route

The largest incidents in terms of delays due to snow were due to the implementation of Key Route Strategy. The basic principle upon which the Key Route Strategy is founded is to maintain all affected routes for main line running and not move them until conditions improve. In the event of weather conditions deteriorating to an extent where the Maintenance and Operations teams declare that their resources cannot cope with maintaining the full network, the Emergency Weather Action Team process is invoked and any decisions with regard to the implementation of the Key Route Strategy will be made at this time.

When the Key Route Strategy is implemented, operational restrictions come into force such as limiting the movement of points to the minimum level possible and the intention is to keep a train service running albeit at a reduced level. One incident of implementing Key Route Strategy in the winter of 2012 recorded delay minutes of over 18,000 and incurred Schedule 8 costs of over £800k.

The most significant incidents in terms of delay minutes incurred and Schedule 8 costs recorded due to cold-related to icicles in tunnels interacting with the overhead line equipment, Figure 33. In the worst incidents, this has resulted in a dewirement and significant disruption. When severe cold weather is forecast, additional bespoke icicle patrols are instigated as a risk control measure in known areas prone to icicle formation.

The only known proven solution for this failure mode is to re-line the tunnel, however, this course of action has a significant associated cost. Based on previous schemes, it is estimated that it would cost c. £10m per 100 metres to re-line a tunnel structure with an associated blockade required to undertake the work. We have found no case for lining tunnels and trials of alternatives have been undertaken and are still underway in LNW Route of more cost effective solutions.

In late CP3 and into CP4, LNW Route had undertaken trials of injection waterproofing systems to try and prevent water entry and therefore icicle formation in cold weather. These trials had very limited and isolated success; they effectively just moved water penetration to other locations on the structure so none were considered a solution to icicle formation.

LNW Route are currently attempting to trial a coating material called ‘Nansulate’, which has properties that prevent ice formation; unfortunately in the winter of 2013/2014 the conditions to perform comprehensive testing did not materialise so its effectiveness and cost associated with re-coating timescales are largely unknown.

Figure 33 Icicle formation in a tunnel impacting gauge clearance and overhead line equipment

High-risk sites for icicle formation in tunnel shafts are included in the CP5 Business Plan. However, incremental improvement will require further funding to install shaft cowells and undertake accelerated shaft lining renewal to reduce water penetration.

Incidents of ice affecting point operating and detection equipment have been recorded but often these events are sporadic and no patterns emerged in the data with respect to location, Figure 34. Numerous mitigation measures have been instigated to increase the resilience of points in cold weather and periods of snow.

These mitigation measures include the fitment of snow and ice covers to protect detection and drive equipment from the severe weather, the fitment of weather strips and associated sealant to point machine lids and application of anti-icing and dry Teflon film to components sensitive to the build up of ice and snow. Heat retainers can be fitted to point heating equipment to increase the effectiveness of the system.

Figure 34 Snow inside point operating equipment

Adhesion impact assessment

Based on data from September 2006 to March 2014, there were 38,512 adhesion-related incidents on LNW route, totalling 421,031 in delay minutes and costing £6,410,184 in Schedule 8 payments.

Adhesion affects the network in two ways:

Firstly, trains suffer from poor adhesion governed primarily by the local climate: weather conditions, temperature, humidity and dew point. A combination of these factors creates what is commonly known as 'Wet Rail Syndrome'; a film of water that forms a barrier between the railhead and wheel interface causing the train to aquaplane.

Secondly, there is the problem of leaf contamination. During autumn leaves fall directly on to the tracks; either blown on, or pulled into the train's slipstream, and then rolled on to the rails. These leaves, compressed by a force of 12-40 tonnes per square inch, can form an organic layer over the railhead which, when damp, has similar properties to PTFE or Teflon. In such conditions, this layer causes problems when a train attempts to brake for or pull away from a station or stopping signal. The contaminant may act as an insulator between wheel and rail causing problems with train detection systems. This issue can arise in wet or dry conditions.

Figure 35 Example of railhead contamination which can cause adhesion issues

Each year, operations teams set out a programme of mitigation measures to deal with the impact of poor adhesion during the autumn period. High-risk sites are identified and a list is published each year for monitoring and treatment. Network Rail has a fleet of six treatment trains on LNW Route that use a combination of water jets and adhesion modifier gel to remove contamination from the railhead and improve adhesion between wheel and rail. These trains run throughout autumn and, in addition, most passenger trains are fitted with sanders. Traction gel applicators (TGAs) are deployed at the worst locations which apply sandite gel as trains pass. Leaf fall teams are also able to deploy local railhead treatment at pre-designated sites or as a rapid response.

Rail head treatment acts to remove existing contamination, however, the primary mitigation is tree and vegetation removal. In CP4 all hazardous trees from a national lineside survey were removed or actioned providing a leaf fall benefit. In CP5 an enhanced vegetation management scheme is aimed preventing fallen trees from impacting the running lines and also assisting with leaf fall mitigation. Other mitigation measures such as autumn timetables can also benefit very busy routes by allowing extra time during the months when conditions are poor and it is hoped that improved forecasting techniques will enabled even more targeted treatment of the railhead.

Poor adhesion is a particular issue on the Cross City Route in the West Midlands and this is reflected in the Four Oaks to Aston and Birmingham New St to Kings Norton trust sections, with both appearing in the top 20 locations for adhesion-related delay. Both sections are identified as high-risk locations with TGAs being installed at Four Oaks, Erdington, Bournville and Selly Oak since 2011, with an additional TGA installed at Five Ways in 2012. Vegetation clearance has been completed between Birmingham New St to Five Ways, University to Northfield and Aston to Four Oaks. Further clearances are planned in CP5 to remove vegetation to meet the five metre clearance criteria.

Further methods of treatment are being developed in a trial to install adhesion laying equipment on London Midland class 323 units. The system will deploy traction gel at pre-programmed locations or on demand using GPS and will operate in addition to the existing sanders already installed on trains. Alternative timetables for autumn are also being investigated such as a skip-stop contra-peak service during the AM and PM peaks which would not require changes to unit or driver diagrams.

On LNW North, Totley Tunnel East to Earles Sidings Signal Box on the Hope Valley Line is the second biggest location for adhesion-related delay on LNW route and a number of mitigation measures are in place. Edale to Hathersage is identified as a high-risk location and has TGAs installed at Bamford and Hathersage. During CP5, Hope to Totley is the on the priority vegetation list with plans to reinstate a six metre clearance.

Lancaster to Preston also features in the top 10 locations for adhesion-related delay. In addition to the four TGAs that are installed at Lancaster, a number of locations are on the high priority list for vegetation removal during the first year of CP5 with a six metre clearance to be re-established.

Figure 36 Leaf fall on a Spital station platform

Heat impact assessment

LNW Route METEX data analysis reveals the average annual Schedule 8 costs for delays in the METEX Heat category was £0.5m per year.

Track

All of the METEX data in the 'Heat' category-related to track Temporary Speed Restrictions due to the Critical Rail Temperature being reached. The onset of hot weather brings with it the risk of track buckling, Figure 37; this will not be solely due to high temperatures but also because of at least one other defect in the track condition. Ideally all such defects should be eliminated before the hot weather season starts; if not, then the appropriate precautions must be taken to safeguard traffic.

Rails expand as they warm up; they also absorb heat and in the bright summer sun can reach temperatures far in excess of air temperatures. If the correct precautions are not taken, both Continuous Welded Rail (CWR) and jointed track can buckle as a result of the expansion. As a buckle normally occurs while a train is passing over the site there is a risk of derailment.

Figure 37 Track buckle at Waddeson near Aylesbury on LNW Route

In order to prevent buckles, CWR is kept at a 'Stress Free Temperature' (SFT) of between 21°C and 27°C; it is only above this temperature that the rail goes into compression and begins to generate potential buckling forces. The track system is designed to be safe in normal summer temperatures with rail sleepers and ballast restraining these forces.

If the design air temperature is likely to be exceeded or if there are known problems with either the Stress Free Temperature or an element of the track system (such as the ballast shoulder) it will be necessary to reduce the speed of trains over the site, so as to reduce the buckling forces and protect traffic. These restrictions of speed are known as Critical Rail Temperature (CRT) speed restrictions.

Jointed track is laid with gaps between each rail, which close up as the rail expands. If these gaps are not wide enough, they will close up at too low a temperature, putting the rail into compression, consequently increasing the risk of a buckle. Once a gap has closed, the rail must cool and contract to its original point before remedial work can be completed.

Switch and Crossing (S&C) work and the plain line immediately adjacent to S&C is at the highest risk of buckling and preparation work in these locations is the most critical. S&C with timber bearers are at greatest risk.

In the event of high temperatures, staff can be deployed to carry out watchman duties when the CRT threshold is reached for CRT(W). The watchman must remain on site watching the track every time a train passes over the location. The watchman must have a temperature gauge to take regular readings of the rail temperature. The watchman can be responsible for more than one site as long as the sites are near to each other.

An Insulated Rail Joint is located between two separate pieces of rail that are joined together mechanically, but are electronically insulated from each other in order to prevent a signalling system failure. Between the two joining ends there is a gap with a piece of plastic called a 'T' piece inside. The passage of trains can lead to the rail ends burring over the 'T' piece. If this occurs at any time in the year, it will cause a failure in the signalling system. During summer there is an increased risk of this happening as the rail expands and compresses the 'T' piece, forcing the two ends to make contact. An Insulated Rail Joint failure locks the signalling system and could lead to train service disruption.

All Insulated Rail Joints on LNW Route are identified with a unique serial number and inspected at least annually and, where possible, just before the onset of hot weather as a precaution. LNW Route are, where practicable, specifying and installing Axle Counter train detection systems in renewal and enhancement projects which removes the need for Insulated Rail Joints and hence increases the system resilience in periods of hot weather.

During the summer of 2013, LNW Route received correspondence from the managing director of a Train Operating Company which expressed gratitude for the high level of preparedness and subsequent resilience of the railway to the high temperatures experienced.

The climate projections suggest warmer drier summers in the future with possible mean maximum temperature changes of around +2^{o}C by 2050s (high emissions, 50th percentile), which would mean that the number of days where the Critical Rail Temperature is reached could increase. It is possible that the track standards will need be modified in the future to reassess the Stress Free Temperature values applied and sleeper/ballast configurations. However, application of the current standard should provide adequate resilience to higher temperatures expected in the UK.

Capital investment in the track asset has been targeted at removing assets that perform poorly in hot weather and as a result of rapid temperature fluctuations such as cold nights and hot days. An example of this on LNW Route is the removal of Switch Diamonds which are notoriously susceptible to temperature issues. Norton Bridge switch diamonds will be removed by the Stafford Alliance project in 2016 along with the remodelling of Galton Junction in the same year which will remove another set of Switch Diamonds.

Earthworks

Hotter summers are also expected to be drier, this is a risk for embankments constructed of moisture sensitive clays that shrink as they dry and expand when they are wetted. Generally on LNW the problem with desiccation on clay embankments is on the southern part of the Route. An up-to-date desiccation register highlights those embankments at risk from this issue and the risk is controlled by good vegetation management.

Lineside equipment

During periods of hot weather, relay rooms, equipment rooms, location cabinets and signalling centres can be at risk of overheating. If this occurs the signalling and telecommunication equipment may fail. This risk can be increased if additional Signalling and Telecommunications (S&T) equipment is added to location cabinets over time, putting extra strain on any existing cooling systems. To combat the build-up of heat at these locations on LNW Route, air conditioning and extractor fans have been fitted to keep the location and equipment cool along with the fitment of solar powered forced air ventilation and 'hoods' that shield the equipment housing case from direct sunlight.

Lineside fires

During drier summers the frequency and severity of lineside fires can be expected to increase. A lineside fire can seriously damage signalling equipment, lineside property and severely disrupt train services and of course be of risk to life for persons attending. Areas that are grassy with dry or dead vegetation and where there is a build-up of dry or easily flammable litter are key hotspots.

Lineside fires instigated on Network Rail land can be mitigated by managing the lineside environment to be largely free of combustible materials. A programme of 'tidy railway' is being progressed on LNW Route to remove discarded and waste material from the lineside.

Figure 38 A lineside fire on LNW Route

The enhanced de-vegetation programme that is being progressed on LNW Route to achieve the five metre clearance will reduce the risk from vegetation catching fire. The proposal to clear all trees taller than the distance from track and boundary would also reduce the risk further.

Earthslip impact assessment

LNW Route METEX data analysis reveals that there were 103 incidents with over £1000 Schedule 8 costs that were coded to ‘earthslip’ in the eight-year period. One third of these incidents resulted in over 1000 delay minutes being recorded. The total cost in Schedule 8 payments was £3.2m and 50 per cent of this cost was attributed to eight of the incidents. The average Schedule 8 cost per year due to earthslips is £400,000.

Analysis of the METEX top 20 revealed that 14 of these were identified as being the result of weather. Of these 14 incidents, over half identified third-party land run off as a contributory factor in the failure; this usually results in the railway drainage system being inundated by the water from third-party land. All of the sites have had mitigation action undertaken in CP3 or CP4 and 50 per cent of the sites have further work funded and planned in CP5.

The chart below shows the distribution of the incidents over the eight-year period. The surge in the number of incidents in 2012 was largely due to the very wet summer. The number of severe rainfall events experienced in June and July caused a disproportionate number of failures, especially in Lancashire and Cumbria.

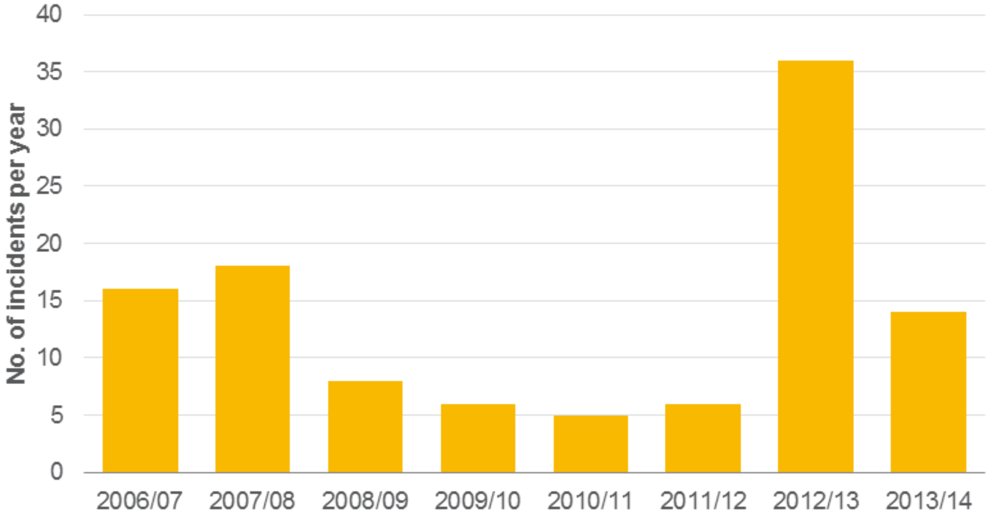


Figure 39 Number of earthslip Schedule 8 incidents in LNW Route

The climate change projections suggest that LNW route will experience more severe weather in the future with wetter winters and drier summers. In general, although total annual rainfall may not change significantly it is likely that individual rainfall events will produce more concentrated periods of rain.

This leads to two different types of event occurring. In the summer months, localised ‘storm cell’ events can cause flash flooding of small parts of the network when upwards of 60mm of rain can fall within an hour. In winter, changes to the jet stream have caused an unusually high number of low fronts to move over the UK, causing the saturation of areas such that earthworks fail and flooding occurs during rainfall events that would usually pass without incident. Both of these events are also accelerating the weathering of the natural materials that form the earthwork, meaning that estimated deterioration rates based on past data may now be inaccurate. This has implications for future modelling of earthwork condition scores and overall funding from the Office of Rail Regulation (ORR).

Nationally, Network Rail has undertaken an exercise to identify earthworks that are ‘at risk’ from severe weather events. Currently, LNW Route has approximately 360 sites that all need remediation in some form during CP5. The algorithm that gives us these sites is re-run annually against the earthwork database of known sites.

In order to ensure this process is as robust as possible, LNW Route is undertaking a 'Blue 5 Chain Length' exercise to positively visit every '5 Chain Length' on the network to confirm if an earthwork is present. This will give LNW Route a complete asset register that has compliant Earthwork Exams by March 2015. With these new sites and estimating the deterioration rate of the existing asset base somewhere between 150 and 200 new sites may well appear every control period on this list.

Intense rain and flooding can cause the failure of geotechnical assets via a number of mechanisms. A typical example of this is washout failure which occurred at Aigburth, Liverpool in 2010, Figure 40. The washout failure was due to the saturation of the cutting face caused by surface water not being intercepted by adequate drainage. Another example is an earthflow failure which occurred at St Bees in August 2012, Figure 41. This particular example was due to saturation of the cutting face due to susceptible granular geologies allowing groundwater to move through the earthwork which caused the derailment of a train.

In all cases, good water management is required and a co-ordinated drainage investment strategy to look at the drainage system as a whole is required to ensure that by solving one problem another is not created. More information on the drainage management strategy can be found in the flooding section of this document.

Figure 40 Washout failure at Aigburth in 2010

Figure 41 Earthflow failure at St Bees in August 2012

The drier summer months will have an impact on soil desiccation; generally on LNW Route the issue is on the southern part of the Route which has a high proportion of clay embankments. These are at risk due to shrinkage and/or differential movement of clay caused by the seasonal cyclic removal and replenishment of water from the soil. Soil desiccation issues typically manifest in track quality deterioration and are detected through track quality monitoring or rough-ride reports from drivers.

Traditionally, for railways built on clay embankments that were subject to these seasonal movements, Temporary Speed Restrictions were imposed or regular re-ballasting or tamping carried out to maintain consistent rail level and alignment. More permanent 'hard' remedial solutions (such as the construction of pile walls to support the slope) were used but now 'softer' approaches including improved surface drainage, vegetation/tree management and longer-term monitoring of infrastructure performance are playing a more prominent role.

LNW Route has an up-to-date desiccation register to highlight those embankments at risk from this issue, which can then be controlled by good vegetation management.

Dissolution features are natural features such as cavities, sinkholes and caves caused by the dissolution of soluble rocks such as limestone, chalk, dolomite and gypsum by carbonic acid. The acid is formed as rain passes through the atmosphere picking up carbon dioxide, which then dissolves into the water. Once the rain reaches the ground, it may pass through groundcover which provides much more carbon dioxide to form a weak carbonic acid solution that dissolves calcium carbonate, which is the main component of these rock types.

The recent elevated groundwater levels caused by the weather events of the winter of 2013/14 has resulted in an increase in solution features in chalk in the southern part of the Route as well as issues with gypsum dissolution on the Settle to Carlisle line which is ongoing.

Further issues with limestone ‘karst’ landscapes will also become apparent as increased rainfall and higher groundwater levels combine, increasing the rate of erosion of these materials. Further work will be needed to quantify these issues before we can begin to estimate any realistic costs, but the current ongoing issue at Kirkby Thore on the Settle to Carlisle line with gypsum dissolution may result in costs of over £1m.

Increased weathering of weak chalk/coal measures rock slopes is a difficult subject to quantify as this may only become more apparent in the longer term but these are a particular asset group that may prove more susceptible to accelerated deterioration rates over and above what would be expected. The slopes can be affected by both increased rainfall intensity and temperature variations which will speed up the natural weathering processes of weak rock material.

The only way that this can be countered would be an increase in proactive interventions and remedial works activity. Localised measures for dealing with smaller failures would include the installation of shotcrete and passive and active netting systems. Larger-scale works may involve the reprofiling of the entire face.

Increased rainfall and temperature variations may lead to accelerated weathering of softer rock slopes, an example of this was at Birkett on the SAC line in 2009, Figure 42.

Figure 42 Accelerated weathering of softer rock slopes at Birkett in 2009

Long-term saturation risk to railway embankments on flood plains or adjacent to rivers was emphasised by the recent derailment on Barrow upon Soar. The cause of the embankment failure was due to an increase in pore water pressure due to the toe of the slope having been under water for a number of weeks. Locating similar vulnerable sites on flood plains can be done using the Network Rail Earthworks Examinations Database in conjunction with the JBA Flooding Database.

Other risks from water ‘ponding’ at the toe include scour of the embankment from the standing water being whipped in waves by the wind. Analysis would need to be undertaken to identify any such embankments, followed by an increase in remedial works activity including drainage improvements and the replacement of slope materials vulnerable to such process will be required. An example of this risk was the River Wrye Viaduct in June 2012, Figure 43. The Embankment base was saturated for a number of days.

Figure 43 River Wrye Viaduct in June 2012

The number of events where either drainage or landslide material from upper slopes, and in some cases slopes outside the Network Rail boundary, have resulted in derailments or caused damage to railway infrastructure has led to a specific project on LNW Route.

As the source slopes of many of these incidents have not been routinely assessed by Network Rail and its predecessors, LNW Route decided to review their procedures against the NR Management of Earthworks (NR/L2/CIV/086) and Examination of Earthworks (NR/L3/CIV/065) standards.

LNW Route has decided to investigate the options for identification and assessment of earthworks (natural or man-made cuttings, embankments and slopes) which are located on adjacent land (Outside Party Earthworks). This project is scheduled to deliver a susceptibility rating for land adjacent to LNW Route to affect the operational railway by the end of 2014.

The potential for washout failure caused by water flowing over the crest of cuttings as a result of a build up of surface water due to inadequate drainage provision is illustrated in the following image on the Cumbrian Coast Line, Figure 44.

Figure 44 Build up of surface water at the crest of a cutting on the Cumbrian Coast Line in August 2012

LNW Route has a Risk Mitigation Process for Earthworks in Adverse and Extreme Rainfall which describes the short-term control measures that are implemented at a number of the earthwork locations assessed as presenting the highest risk during times of severe weather.

Currently LNW Route uses the Met Office National Severe Weather Warning Service as the trigger for implementation of this procedure. This service is recognised outside the railway industry and is widely used by public and emergency responders, providing a warning of severe or hazardous weather which has the potential to cause danger to life or widespread disruption. Further weather information is provided by Network Rail’s contracted weather forecasters, Meteo Group, to assist with assessment of the weather patterns.

LNW Route has recently installed 16 weather stations on Crewe-Chester, Crewe-Carlisle and Crewe-Manchester routes. These weather stations transmit rainfall, temperature and wind speed data to a website that can be accessed by Control via the mobile phone network. Some also have a sensor embedded in a short length of rail which provides rail temperature data.

Sea level rise impact assessment

LNW Route manages a large section of coastal railway, the Cumbrian Coast Line (CBC) and a short section of the West Coast Main Line (CGJ7) at Hest Bank near Carnforth. There are over 50 sites on LNW Route with sea defences and the vast majority of these are on the Cumbrian Coast Line.

LNW Route has undertaken works to coastal assets throughout CP3 and CP4 using Minor Works and Capital funding streams. These included repairs to damaged concrete and scour pockets in 2011 and resilience improvement works were carried out at Nethertown, Bransty and Parton between 2010 to 2013 to provide or improve the toe of sea defences.

The LNW Route team responsible for managing the sea defences have drafted a rolling programme for maintaining and upgrading sea defences throughout CP5, commencing with those assets considered to be most vulnerable. The following coastal and estuarine defence assets will receive investment in the next two years:

2014-2015

- Kents Bank Pitching
- Levens Viaduct and Approaches
- Walls Bridge Embankment
- Ravenglass Viaduct and Approaches
- River Mite Pitching
- Bransty – Parton Sea Walls
- Parton – Harrington Sea Walls No. 1
- Siddick Sea Wall.

2015-2016

- Lidge Gate wall
- River Esk Pitching
- Sellafield Pitching
- Parton – Harrington Sea Walls No.2
- Parton – Harrington Sea Walls No.3
- Parton – Harrington Sea Walls No.5
- Flimby South Sea Defence
- Flimby Pitching.

The current CP5 plans have been generated based on maintaining existing coastal defence asset capability; however our development of Frontage Management Plans will include potential impacts from sea level rise and identification of appropriate actions to mitigate.

To improve resilience we may require larger and more extensive interventions on existing coastal defence assets to improve their capability and performance and the introduction of new ‘hard’ defences where currently only ‘natural’ defences exist.

Figure 45 Reinstated sea defence at Siddick sea wall following storm damage in January 2014

Lightning impact assessment

LNW Route METEX data analysis reveals that there were 86 incidents over £1,000 Schedule 8 costs that were coded to lightning in the eight-year period. The average Schedule 8 cost is £0.25m per year.

The analysis of historical lightning strike data revealed that Blea Moor is the only location in the Route that has received multiple lightning strikes over the eight-year period. On average this site receives one lightning strike per year at an average annual Schedule 8 cost of £3,728.

There is not much that can be done to prevent a lightning strike but mitigation measures such as the fitment of surge arresting equipment can minimise the damage caused. Delivery units have undertaken fitment of lightning protection units in addition to the lightning transient suppressors or 'varistors' which were fitted to all DC track circuits. Routine replacement of the surge arrestors can be undertaken in areas prone to lightning damage, but usually this is not a cost effective solution.

On days when thunderstorms are active in the Route, the Route Control is advised to obtain detailed information from the Meteo Group duty forecaster or from the dedicated Seasons Management Team (SMT) weather website in order to monitor lightning activity and update warnings to areas as necessary.

Figure 46 Example of lightning activity monitoring on LNW Route

Fog impact assessment

LNW Route METEX data analysis reveals that there were six incidents over £1,000 Schedule 8 costs that were coded to Fog in the eight-year period. The average Schedule 8 cost is £3,000 per year.

The majority of fog delays are related to inability to read semaphore signals; installation of new modern signalling systems provides resilience to this weather impact.

Only four rail sections were highlighted by the METEX data and the analysis of these sites revealed they have been resignalled in CP4 with the one remaining site scheduled for resignalling in CP5.

LNW 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 LNW Route actions planned in CP5, Table 2, beyond Business as Usual (BAU), and potential additional actions, Table 3, 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	LNW Route will ensure clear requirements for climatic conditions and resilience levels are specified in Route Requirements Documents	Ongoing
Risk to staff from severe weather conditions	Staff trained to use and supplied with appropriate equipment, e.g. life vests for flooding events, seasonal PPE, offices and depots temperature controlled	Ongoing
Met Office and Meteo Group real-time weather monitoring locations are remote from the railway	Engage with the Weather Resilience and Climate Change board to determine the strategy for further weather station installation	May 2015
Flooding		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of flood resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Level of engagement with flood risk management authorities may not support effective discussions	The RAM (Drainage and Off Track) team is leading an initiative to establish regular liaison meetings with regional Environmental Agency, local flood authorities and other bodies. The first of these meetings is planned in the North West for September 2014, with the intention of having a full programme of meetings established for 2015	March 2015
Successful policy implementation cannot occur without a reliable asset register.	LNW Route is committed to developing a more detailed drainage asset register. In CP5 Year 1 (2014/15), LNW Route will undertake validation surveys to establish the quality of drainage data in the asset register, ensure integration of other asset data sets where relevant, review data quality and establish further independent surveys and standardise drainage layout sketches to facilitate drainage inspections across the Route	April 2015
Earthworks		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of earthwork resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Robust earthwork asset knowledge	Complete 'Blue 5 Chain Length' exercise to positively visit every '5 Chain Length' on the network to confirm if an earthwork is present	March 2015
Damage to railway infrastructure from upper slopes landslide material and in some cases slopes outside the Network Rail boundary	Investigate the options for identification and assessment of earthworks (natural or man-made cuttings, embankments and slopes) which are located on adjacent land (Outside Party Earthworks) to deliver a susceptibility rating for land adjacent to LNW Route to affect the operational railway	April 2015
Coastal and estuarine		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of sea level rise resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing

Vulnerability	Action to be taken	By when
Operational response to severe tidal events	Develop and formalise process for operational response to severe tidal events	October 2015
Long-term Asset Management Plan for sea defences	Develop ‘Frontage Management Plans’ for coastal, estuarine and river defence assets in association with key stakeholders (other sea defence authorities) to produce long-term Asset Management Plan for sustainable management of Sea Defences. The Frontage Management Plans will include an assessment of all assets at risk from future seal level rise	October 2016
Wind		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of wind resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Risk of trees on the OLE and/or track	Complete enhanced vegetation management scheme to reduce the risk of disruption and improve safety	March 2019
Risk to third-party property from trees on Network Rail owned land	Remove ‘taller than distance’ from boundary trees through application of the enhanced vegetation management scheme	March 2019
High temperatures		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of temperature resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Track hot weather preparation	Continue to ensure that all required hot weather mitigation preparation work is completed before the onset of high temperatures	Ongoing
Cold and snow		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of low temperatures and snow resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Icicle formation in structures	Review results of Nansulate trials after winter of 2014/15 to determine if this solution is effective and should be adopted route-wide.	April 2015
Failure of points during snow conditions	Implement Key Route Strategy to minimise the use of points during severe snow conditions.	Ongoing

Vulnerability	Action to be taken	By when
Resilience of points in periods of severe cold temperatures or snow	Fitment of mitigation measures such as covers and heat retainers where required on critical assets	November 2014
Adhesion		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of adhesion resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Vegetation management at poor adhesion sites	Complete enhanced vegetation management scheme to reduce the risk of disruption from leaves on the line causing adhesion issues	March 2019
Application of adhesion modifier	Trial adhesion laying equipment trains. The system will deploy traction gel at pre-programmed locations or on demand using GPS and will operate in addition to the existing sanders already installed on trains	March 2016
Lightning		
Climatic conditions and specific weather-related risks are not clearly communicated to asset renewal and enhancement processes	LNW Route will ensure assessments of lightning resilience measures against climate change projections are specified in Route Requirements Documents	Ongoing
Reaction to lightning strikes	Utilise lightning alert and monitoring systems to assist with identification of failed assets and reduce impact on performance	Ongoing

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	
Drainage workbank	Review of drainage renewal enhancement to deliver increased drainage workbank
Effects of flash floods	Culvert cleaning, jetting, CCTV inspection and relining on primary and main secondary routes and flood plain locations to improve culvert capacity and alleviate flooding risk
Ulverston area flooding	The Environment Agency is proposing to install a new culvert through the railway embankment as part of a larger flood relief scheme. The Environment Agency is exploring possibilities of a contribution from LNW Route and ultimately for LNW Route to take on ownership of the new culvert. The proposed scheme will mitigate potential flood damage to the Network Rail railway embankment as the amount of out of bank flood water that spills out uncontrollably towards the embankment is minimised as it is kept in channel and flows are directed downstream and away from the railway embankment. Other benefits of this scheme include removal of a pre-school nursery from the natural flood plain, environmental enhancements and habitat creation
Flooding due to Environment Agency turning off pumping stations (Alt-Crossens project)	Form a cooperative or pay the Environment Agency to maintain the pumps (or not use pumping stations and protect with flood defence long term)
Flooding from the catchment area; overflow from River Cherwell	Continuation of the Environment Agency work within railway land to include renewal and refurbishment of track and off-track drainage
Collapse of River Tame engineered channel wall at Bromford	Develop a holistic solution for Bromford with the Environment Agency to repair the collapsing wall as part of the Bromford estate flood resilient scheme. The Environment Agency are seeking joint funding with LNW Route to facilitate a holistic solution
Excessive inflow from Dwr Cymru-owned Combined Sewer Overflow entering the often-silted and undersized track drainage	Collaborate with Dwr Cymru to potentially construct another storage tank on top of the cutting and away from the railway to reduce and limit the amount of flow entering track drainage at Christleton Tunnel

Vulnerability	Action to be evaluated
Management of Scour risk following flooding event can result in the line being shut for long periods	Undertake robust scour mitigation works to allow specific flood actions to be established at site
Drainage at level crossings	Improvements to drainage over and above the existing at 80 public highway level crossings
Earthworks	
Real time monitoring of earthworks	Engage with the national team to investigate Remote Condition Monitoring solutions for earthworks
Dissolution of chalk, gypsum, limestone and other soluble rocks	Issues with gypsum dissolution on the Settle to Carlisle line and in particular at Kirkby Thore is ongoing and an increase in solution features in chalk in the southern part of the Route has been reported by the BGS. Further issues with limestone 'karst' landscapes will also become an issue. Analysis will be undertaken to quantify these issues
Increased rainfall intensity and temperature variations will speed up the natural weathering processes of weak rock material.	More analysis is required in the longer term in the Lancashire and Yorkshire areas in the north of LNW Route and areas around the Chilterns and West Midlands in the southern part of the Route, as these are a particular asset group that may prove more susceptible to accelerated deterioration rates over and above what would be expected. Increased rainfall intensity and temperature variations will speed up the natural weathering processes of weak rock material. An increase in remedial works activity including shotcrete and active netting will be investigated
Soil Desiccation	Sections on the southern part of the Route that have a high number of clay embankments and are susceptible to soil desiccation issues and require enhanced vegetation management plans to control the issue
Wind	
Risk of trees on the OLE and/or track	Review of enhanced removal of all 'taller than distance' from track trees
Risk to third-party property from trees on Network Rail owned land	Review of enhanced removal of all 'taller than distance' from boundary trees
Imposition of blanket speed restriction during high wind speeds	Review of the requirement to impose a blanket speed restriction during periods of high wind speeds post completion of LNW enhanced vegetation management scheme
Cold and snow	

Vulnerability	Action to be evaluated
Ice formation in wet tunnel shafts	Install tunnel shaft cowells and undertake accelerated shaft lining renewal to reduce water penetration. High-risk sites are already included in CP5 business plan but incremental improvement will require further funding
	Consider the benefits of producing a LNW Route Tunnel Asset Management Strategy to develop and align CP5 plans
Coastal and estuarine	
Combined fluvial and tidal events	Improve the resilience of bridge assets at Arnside, Derwent, Duddon and crucially where the West Coast Mainline crosses the River Caldew at Carlisle to scour and bridge deck hydraulic loading effects
Current CP5 plans are based on maintaining existing coastal defence asset capability and don't provide for enhanced asset capability required to maintain asset performance against rising sea levels	To improve resilience will require larger and more extensive interventions on existing coastal defence assets at Flimby and Hest Bank to improve their capability and performance and the introduction of new 'hard' defences where currently only 'natural' defences exist
Lightning	
Signalling system lightning vulnerability	Birmingham New Street Proofhouse junction interlocking is going to be recontrolled and not resignalled as part of the Birmingham New Street resignalling scheme. Given the importance of Proofhouse interlocking to operations in the Birmingham New Street area, fitment of lightning protection systems would increase the system resilience
	Historical lightning strike data reveals Blea Moor is a particularly vulnerable location to lightning sites. Routine replacement of the surge arrestors would reduce the risk of asset failure

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.

LNW Route management and review

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

In terms of flood management, various water management groups exist across the Route which includes participation by the Environment Agency, Severn Trent Water, United Utilities, Thames Water, Anglian Water, Canal & River trust and local authorities. These groups convene to provide an interface for all stakeholders where flood mitigation studies are shared and schemes are developed to provide maximum benefit for the overall water management in the catchment area.

A six monthly LNW Route review of seasonal preparedness plans will continue to ensure that all preparatory work has been completed.

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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