Network Rail Asset Management

Weather Resilience and Climate Change Adaptation Plan

Contents

1. Chief Engineer Statement

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May 2021

As a passenger and customer focussed business, it is our responsibility to deliver railway assets that enable the efficient running of a safe and punctual railway that is capable of operating in a wide range of demanding adverse and extreme weather conditions.

The cost to Network Rail from weather related events over the past 15 years has been at least £3bn in delays and cancellations, insurance claims and autumn preparation. The reduction in our performance caused by such weather events has a negative impact on our passenger and freight customers and inhibits our ability to deliver on the governments' targets. The impact of extreme weather can vary significantly year-by-year; delays and cancellations cost £50-100m per year.

The number and intensity of extreme weather events has put increasing demands on the safety and performance of the network. Despite the impact on passenger numbers from the COVID-19 pandemic, we must continue to focus on the effect climate change will have on the railway, with adverse and extreme weather events becoming more frequent and intense. This will result in greater damage and disruption, making it harder to retain resilience at current levels of investment.

This report provides an overview and summary of the detailed climate change risk assessment, gap analysis and action plans that have been developed as part of our review of assets and which are intended to inform our asset policies.

It brings together our current knowledge of the vulnerability of our assets to weather impacts into a single document to support future research, analysis and action planning. It is our first attempt at undertaking an assessment at this level of detail and our intention is to review and update as our understanding of our assets improves and as the impact of climate change becomes clearer.

The Technical Authority (TA) organisation is focussed on embedding management of weather and climate change risk within Network Rail. This is through a programme of activities including:

- Understanding and managing climate change risks to assets,
- Consideration in long term strategic planning,
- Updates to asset policies, specifications, designs and maintenance standards, and
- Carrying out research and analysis.

The actions identified from this activity then consider the changes required to these in order to improve, maintain and control weather and climate change risk and resilience now and into the future. These actions will be further developed through CP6 to support route and region asset management investment strategies from CP7 and beyond.

2. Executive Summary

Network Rail manages, maintains and develops the assets which make up the United Kingdom's railway network. This includes tracks, signalling, electrification, bridges, tunnels, level crossings, vegetation, stations and many other assets.

Every day, millions of people depend on our railway to get to work and school, to see family and friends and for leisure. In addition, rail freight and many linked businesses depend on us to transport everyday essentials, like fuel and food. The long-term impacts of the Coronavirus pandemic are still emerging and being understood, with the effect on passenger numbers and future funding for our railway representing some potential challenges. Whilst this affects the context in which the strategy is presented, it makes climate change adaptation no less important and our infrastructure will need to be resilient against adverse and extreme weather in the future.

The increased frequency and severity of extreme weather events affecting the railway has already put more demands on delivering safe, reliable and punctual rail services. The rising temperatures, changing rainfall patterns and more extreme weather events which climate change will bring, for example high wind speeds, will continue to make these impacts even more profound. This will affect passengers and freight services and for Network Rail, its sub-systems covering, Track, Rolling Stock, Buildings, Structures, Signalling and Electrification, Earthworks, Drainage and others. While it would be unrealistic to expect that we can eliminate every obstacle the weather may throw at us, we need to anticipate and prepare to deal with disruption by establishing improved standards and systems to deliver resilience both now and in the future.

This paper provides an overview of Network Rail's asset vulnerabilities to the current weather and to projected future climate changes over a timeframe of 30 to 60 years. A summary of current and recommended activities to address any identified gaps is also set out, with expected timescales for delivery, where available.

Climate Change Projections Guidance produced by Network Rail[1] was used to undertake the asset risk assessment applying the latest climate change projections available. Risk evaluation identified vulnerabilities across each of Network Rail's assets with temperature, rainfall, wind and flooding being the most likely causes of significant disruption, and an understanding that local topography can have a significant impact on how these weather events affect a particular asset.

The climate change impact on each asset was assessed against current mitigations and asset designs to determine where gaps may exist that require further investigation or adaptation to be put in place to provide additional resilience to changing weather conditions. These identify dependencies between different assets to provide a broader understanding of the challenges we face with the future climate, and the actions required to address any system vulnerabilities.

The aim of this report is to outline Network Rail's asset vulnerabilities to climate change and the investment in adaptation or responsiveness to prepare for future weather adversity to help the railway cope better when things go wrong. Developed through collaboration with each of Network Rail's asset functions, in depth knowledge of our assets has fed into the evaluation of weather and climate change impacts and actions have been defined to improve resilience in the medium to long term.

The findings from the risk assessment and learning from the activities in the action plan will also be used to inform work being under taken by our Technical Authority to be able to value climate impacts and justify the level of funding required to achieve appropriate resilience.

The general remit of this report establishes:

- A baseline position for current asset risks to weather,
- The effect from climate change projections on assets over a 30 to 60-year time frame,
- The gaps in asset resilience or resistance to climate change and actions to address these gaps, including Network Rail, external collaboration and European research, and
- An action plan for steps required to enhance the resilience of the railway or justify where improved response and faster rectification can be applied.

[1] Network Rail climate change projection guidance note (NR/GN/ESD/23) **https://safety.networkrail.co.uk/wp-content/uploads/2019/09/Climate-change-projections-Guidance-Note.pdf**
[2] Due to the timing of this analysis it has been based on UKCP09 projections data. Future iterations will use UKCP18 or the latest data available at the time. The overarching findings are not expected to change significantly

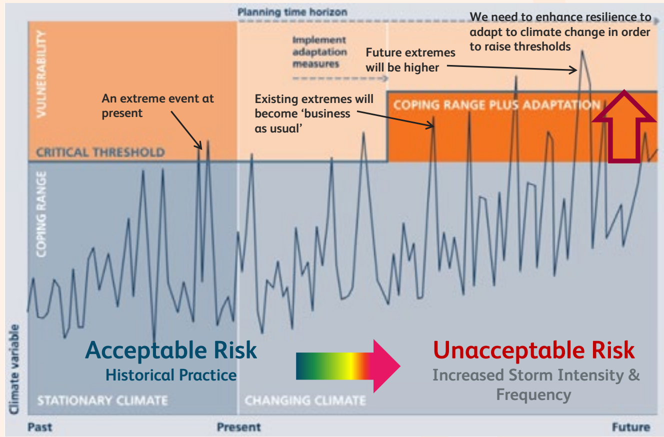
3. Introduction

3.1 Adverse weather linked to climate change is accelerating deterioration of our assets

Climate change is often viewed as a future problem. However, it is already causing more frequent and more severe extreme weather events and we are experiencing its impacts. The weather over the past few years is part of a clear trend of an increased frequency of extreme drier periods followed by prolonged and extreme wet weather. Very hot summers such as 2018 are “30 times more likely than would be expected from natural factors alone”.[3] “Extreme regional rainfall such as Storm Desmond in 2015 has a return period of about five years (20 % chance in any given year) and is at present roughly 60 % more likely due to human-caused climate change.”[4]

These factors increase deterioration of our earthworks and put pressure on drainage systems, increasing the likelihood of critical coping thresholds being exceeded, prompting increased levels of intervention (as illustrated in Figure 3-1).

Adverse weather can also impact other assets, with accelerated scour increasing risk at bridges over rivers for example. Some assets can be replaced more quickly/easily with current technology (e.g. track/signalling), but others, such as earthworks, cannot be future-proofed quickly. These assets require progressively rising investment accompanied by transformational change in how we manage the network and deploy technology. ‘Good’ management of climate change risk involves improved on the ground resilience which will come at significant cost and will take many years to achieve. These risks need to be balanced against economic pressures and safety impacts to determine the most appropriate mitigations to implement.



Source: Adapted from Willows, R.I. and Connell, R.K. (Eds) (2003) Climate adaptation: Risk, uncertainty and decision-making, UKCIP Technical Report, UKCIP, Oxford.[5]

Figure 3-1 Coping thresholds and the need to manage unacceptable risk.

[3] Madge G (2019) Study examines drivers of 218 UK summer heatwave. **https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/drivers-for-2018-uk-summer-heatwave** viewed 26 August 2020
[4] World Weather Attribution (2017) **https://www.worldweatherattribution.org/uk-storm-desmond-revisited-december-2017/** viewed on 26 August 2020
[5] UK Climate Impacts Programme (2003) Climate adaptation: Risk, uncertainty and decision-making. **https://www.ukcip.org.uk/wp-content/PDFs/UKCIP-Risk-framework.pdf** viewed on 26 August 2020

3. Introduction

3.1 Adverse weather linked to climate change is accelerating deterioration of our assets

Our challenges are shared by other operators of historical infrastructure[6]. Our re-surveys are suggesting accelerated deterioration and the Environment Agency (EA) has estimated that their assets have seen this increase to be between 30 % and 60 %[7]. These findings are consistent with the changes we forecast for Control Period 7 (CP7: 2024-2029) but have arisen much sooner than we thought.

The threat of extreme weather also increases the influence of broader 'catchment-wide' impacts. The complex nature of drainage systems that transfer water from multiple private owners can concentrate risks at or near the railway (for example Figure 3-2). Past inspection processes have not always been able to pick up vulnerabilities associated with these diffuse sources, or how others are changing these. We work with other infrastructure operators to share experiences and learning to help validate our own judgements and work together to better understand deterioration, performance and forecasting improvements. We will need to focus more on these interdependencies to redress risks from the changing climate.

Figure 3-2 Interdependencies: the Union canal embankment collapse washed away the railway between Edinburgh and Glasgow (12 August 2020)

[6] Examples include Environment Agency (EA), Scottish Environmental Protection Agency (SEPA), Canal & Rivers Trust (C&RT), Scottish Canals, Natural Resources Wales and utility companies.
[7] Jim Barlow, Deputy Director for Asset Performance & Engineering at the Environment Agency in discussion with Tim Kersley on 17 August 2020.

3. Introduction

3.2 Railway assets and the impact of weather

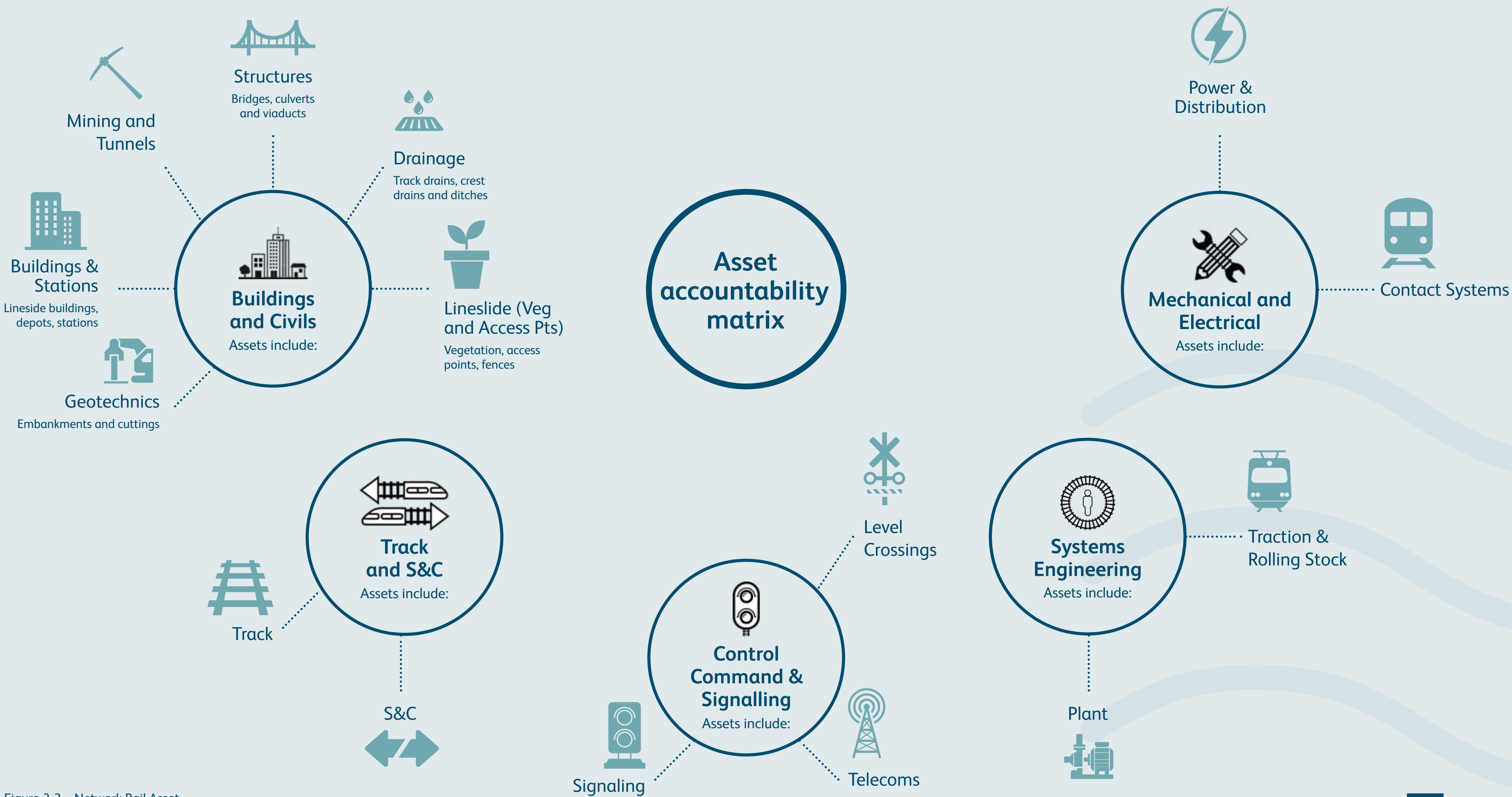


Figure 3-3 – Network Rail Asset Accountability Matrix

3. Introduction

3.2 Railway assets and the impact of weather

We group our assets into five overarching categories with a varying number of assets of a similar nature (Figure 3.3 refers). This report discusses vulnerabilities, risks and actions in line with the categories that are outlined below alongside an indication of the types of weather events that cause the most impact.

Buildings and Civils

Buildings and Civils assets are worst affected by heavy rainfall, flooding and periods of high temperatures. Failure rates for these assets rise when rainfall increases or is persistent for a period of time. There is a direct correlation between rainfall and flooding events which also affects Buildings and Civils assets.

Mechanical and Electrical

Mechanical and Electrical assets include overhead line equipment (OLE), conductor rails, power and distribution systems. High temperatures, cold (snow and ice), high wind speeds and flooding have the biggest impact on these asset.

3. Introduction

3.2 Railway assets and the impact of weather

Systems Engineering

Systems assets made up of Engineering Trains, wagons, Road Rail vehicles and small plant (e.g. generators, pumps).

Systems assets are less vulnerable than other asset classes, but they can be impacted by all weather parameters with high temperatures and the rate of temperature change having the biggest impacts. With control of these asset types predominantly managed by people, there is a close relationship with human factors and extreme weather that tends to arise before assets themselves begin to fail from the effects of weather.

Track and S&C

Track and S&C consist of rails, sleepers, ballast and Points Operating Equipment (POE) to mechanically move rails to switch trains from one track to another. Track and S&C assets are vulnerable to high temperatures, heavy rain/flooding and large temperature variations. Low temperatures also affect rail and S&C (including POE) with rail breaks and S&C failures.

Control Command & Signalling

Control and Command systems include signalling (mechanical and electronic), level crossings and communication systems (for signalling systems and train control systems). These assets suffer adversely from heavy rainfall/flooding, extreme heat and large temperature variations. High temperatures and low relative humidity also have a close correlation to increased failure rates of signalling assets. At very low temperatures Level Crossing equipment may also be affected.

3. Introduction

3.3 Systemic impacts on our assets

Our assets act as a system with interdependencies between asset types during adverse and extreme weather conditions that may react differently under future climate conditions.

Earthworks depend on good drainage during convective rainfall events or as a result of localised flooding. This enables water flows through appropriate drainage systems to minimise water level build up in the soil or against embankments and in cuttings that could otherwise lead to increased asset degradation and or rapid failures such as landslips, washouts and erosion.

Ice, snow, heavy rainfall, lightning, heatwaves and high winds can all lead to asset degradation or system failure. For example, periods of drought can lead to embankment deterioration, and high temperatures increase the risk of track buckling, both of which may result in the requirement to impose temporary speed restrictions or closure of railway lines in the event of failure.

Figure 3-4 illustrates some of the linkages and dependencies between different assets which highlight how external factors such as weather on one asset could have a knock-on effect on others.

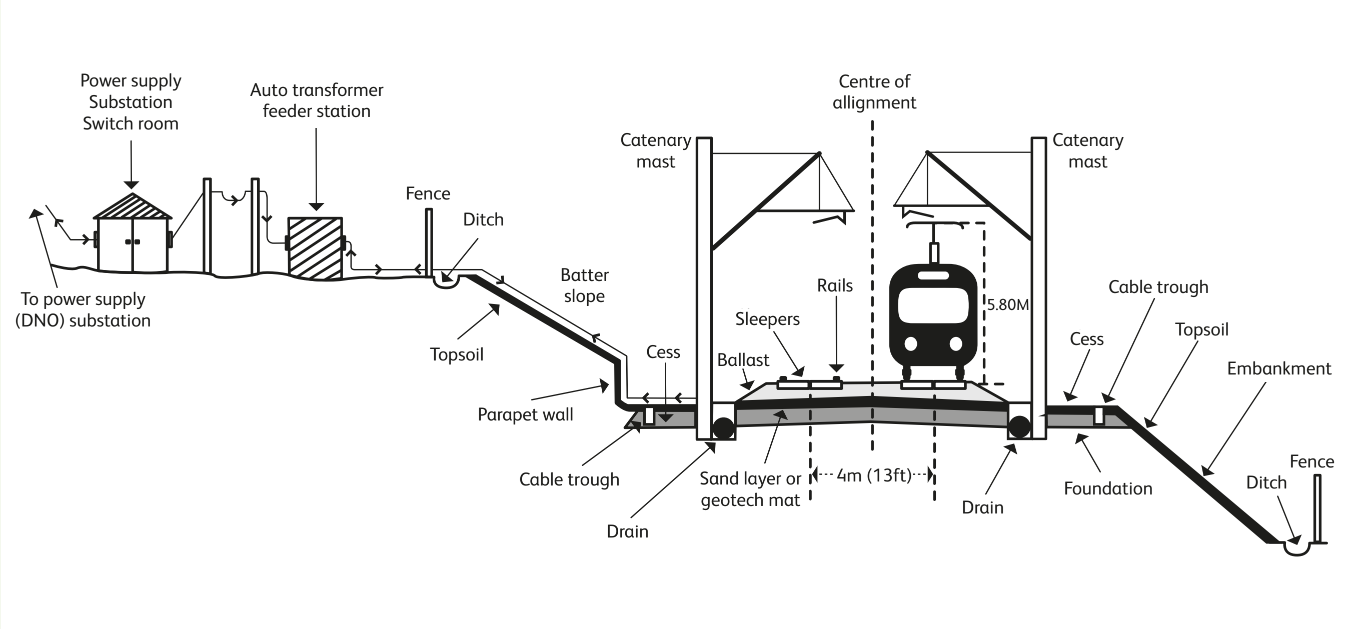


Figure 3-4 Illustration of interdependencies between different asset systems

3. Introduction

3.4 Purpose of this report

This report provides an overview and summary of the detailed climate change risk assessment, gap analysis and action plans that have been developed as part of our review of assets.

It brings together our current knowledge of the vulnerability of our assets to weather impacts into a single document to support future research, analysis and action planning. It is our first attempt at undertaking an assessment at this level of detail and our intention is to review and update as our understanding of our assets improves and as the impact of climate change becomes clearer.

We are exploring a number of options to improve both the resilience of the infrastructure (by changes to design or installation specifications) and its ability to mitigate the impact on service disruption during periods of degraded infrastructure operation.

A primary aim of this work is to identify opportunities to make a step change in the resilience of the network and to discuss the affordability of these options with funders. These provisions are represented in the appropriate policy for each asset. In addition, we are reviewing whether large-scale environmental testing (measurement of the performance of equipment under specified environmental conditions) of switches & crossings, points, signalling systems, overhead lines and train carriages should be adopted to demonstrate correct operation in the required environmental conditions. This will enable identification and modification of those components that fail environmental testing and support innovative design in pursuit of a more resilient railway system.

The information provided in this report and the appendices will feed into the following:

- UK Climate Change Risk Assessment (third report due 2021),
- Network Rail's 2021 Adaptation Report to Defra under the Climate Change Act,
- Update and development of policies, standards, specifications and procedures in advance of our next investment period (2024 – 2029),
- Improved knowledge of asset inventory and condition,
- Research and development on mapping weather and climate change vulnerability and criticality as well as more resilient asset and component designs,
- Regional analysis on asset vulnerability and planning for investment in CP7, and
- Development of extreme weather plans to ensure actions and trigger levels are fit for purpose.

4. Weather and climate change impacts on the railway

4.1 Historic weather impacts on the railway

Over the last 15 years weather has cost Network Rail at least £3bn in delays and cancellations, insurance claims and autumn preparation alone. Weather-related delays account for almost £1billion of this and performance measured by the Public Performance Measure (PPM) on 'adverse' weather days has been 2-4 % lower than on 'normal' weather days as illustrated in Figure 4-1.

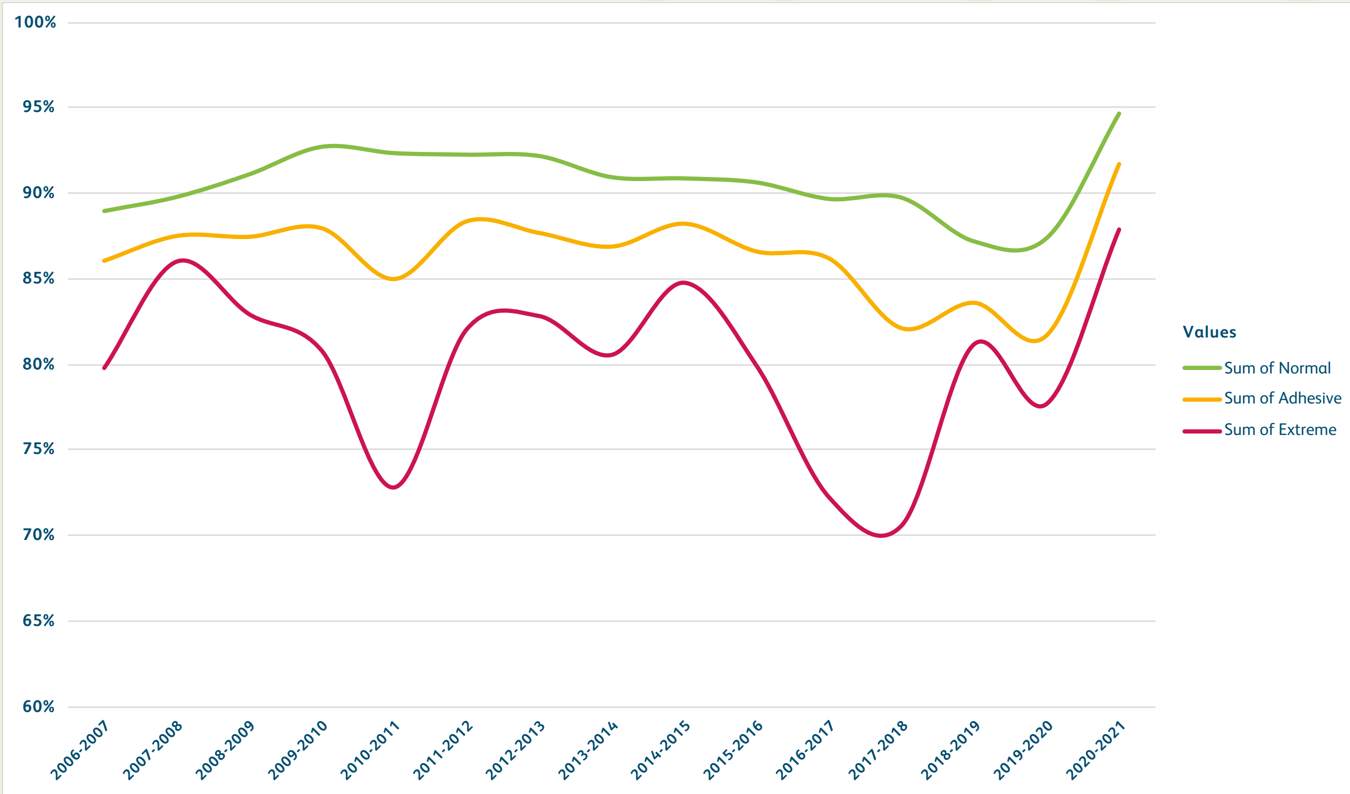


Figure 4-1 Performance on weather affected days (2006/07 – 2020/21)

4. Weather and climate change impacts on the railway

4.1 Historic weather impacts on the railway

Between 2006 and 2020, weather related incidents caused over 320,000 delay events resulting in around 26 million delay minutes and over £1 billion of Schedule 8 compensation payments (see Figure 5 2). Since 2013 and 2014 Schedule 4 cancellations attributed to weather have exceed a further £169m (although the actual cost is likely to be much higher as not all incidents have been correctly attributed to weather).

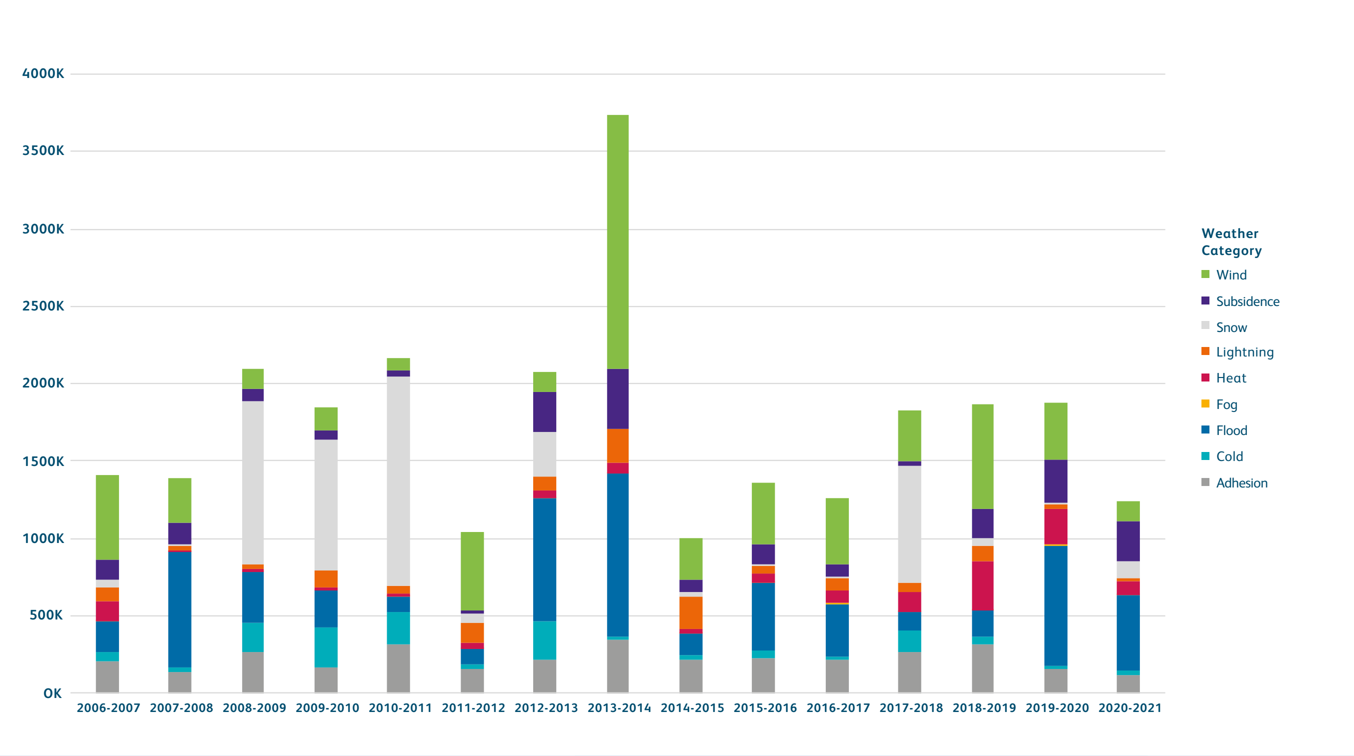


Figure 4-2 Delay minutes data April 2006 to March 2021

4. Weather and climate change impacts on the railway

4.1 Historic weather impacts on the railway

The annual cost of delays and cancellations averages between £50-100m and the inclusion of missed targets, repairs and socio-economic costs raises this to an estimated £200-300m per year. On extreme days the average delay minutes (approximately 6500 mins) are much higher than on normal days (2500 mins) with adverse days on average reaching 3500 minutes. There is also a clear impact of seasons on PPM and on average there is a 1.5 % drop in summer, 3.5 % in winter and 5 % drop in autumn (see Figure 4-4).

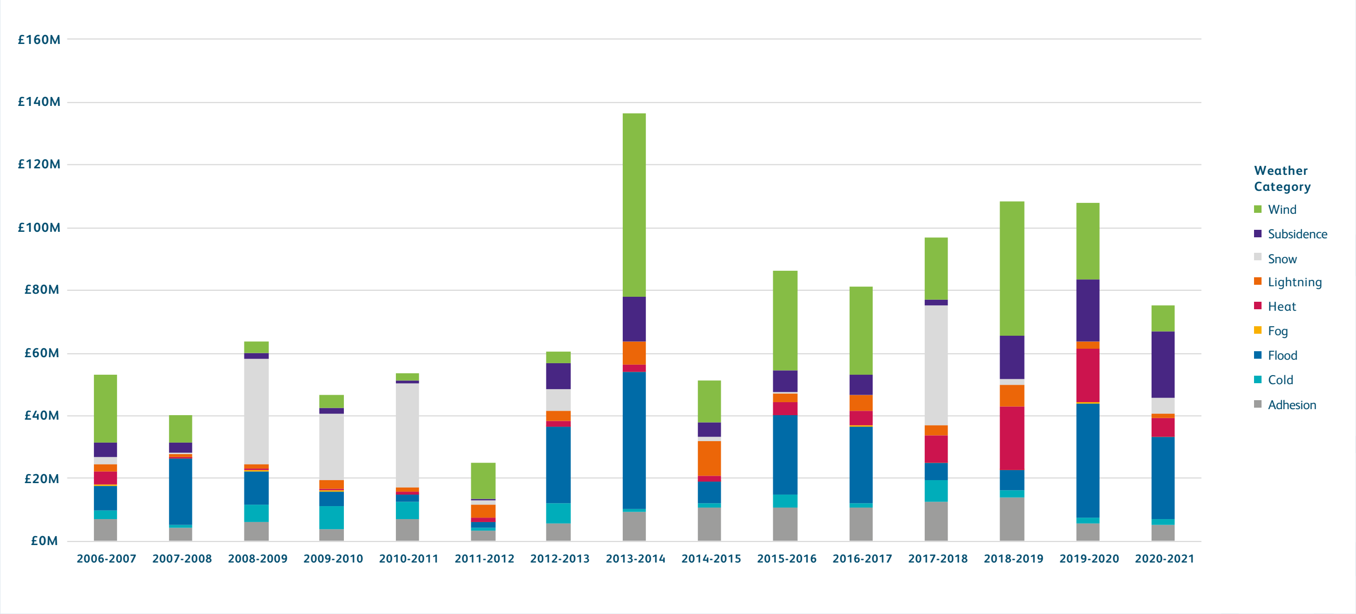


Figure 4-3 Schedule 8 delay cost data April 2006 to March 2021

4. Weather and climate change impacts on the railway

4.1 Historic weather impacts on the railway

Whilst the Figure on the right describes the average impacts of weather, it should be noted that instances of extreme weather can vary significantly year-on-year and that other factors such as asset condition, asset location, asset function, topography and asset criticality all have a bearing on the impacts that we experience. Evidence from weather attribution studies is now showing that recent years have seen increases in the frequency and intensity of extreme weather events. Our own asset and performance monitoring and analysis is indicating that we are seeing this through increases in delays on adverse and extreme weather days in recent years.

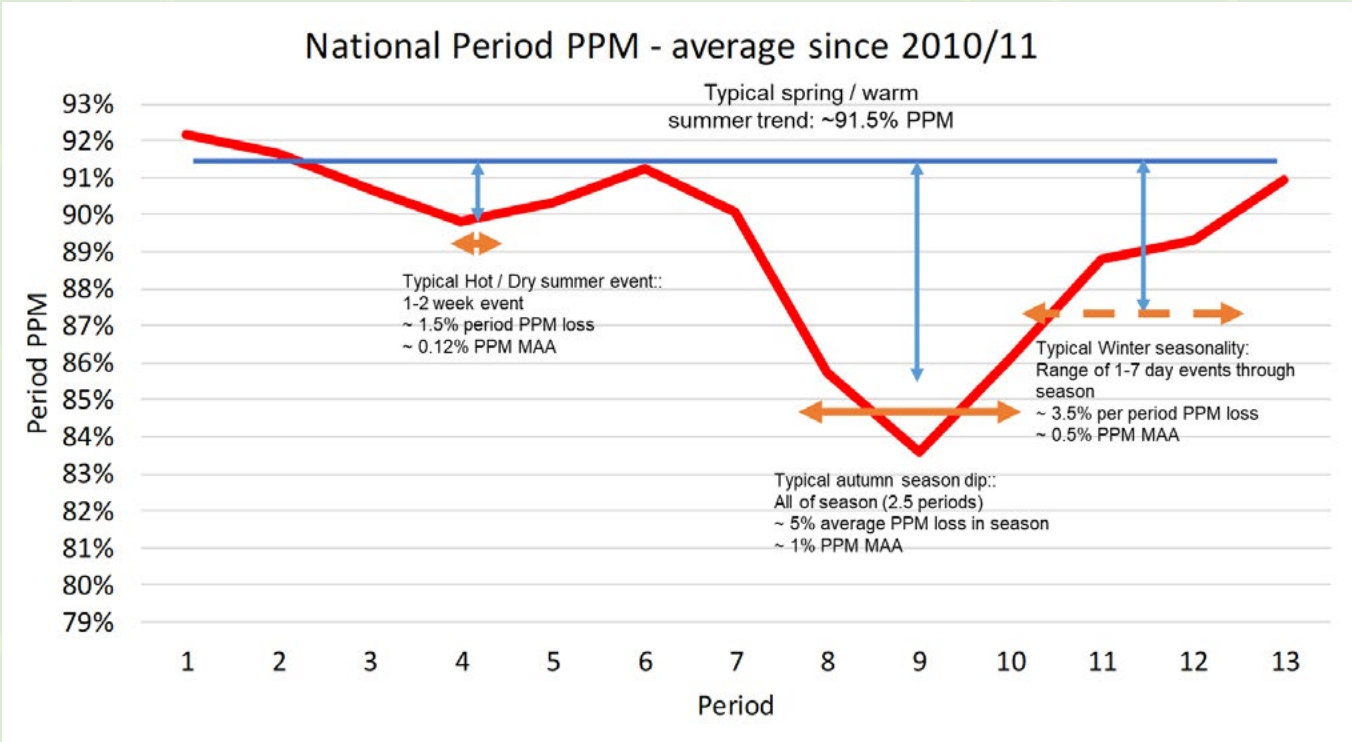


Figure 4-4 Performance (PPM) by period showing influence of seasons

4. Weather and climate change impacts on the railway

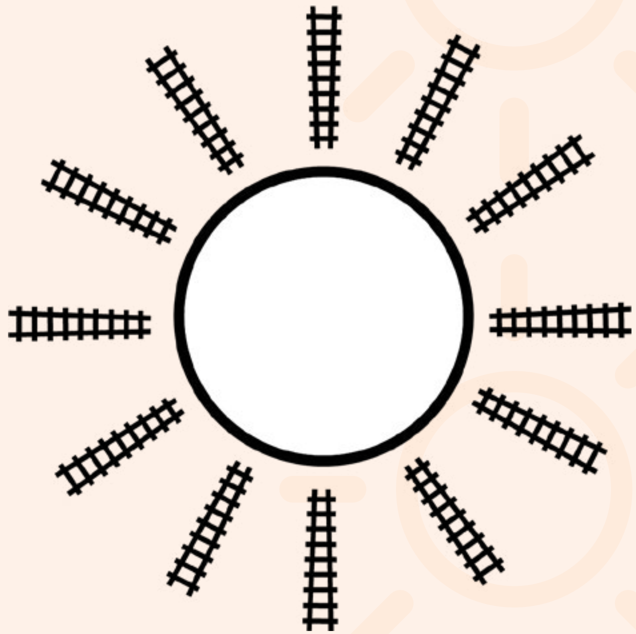
Some recent weather impacts on the railway include:

Heatwaves

The exceptionally hot summer in 2018 impacted train performance significantly with the prolonged heatwave causing a 40-50 % increase in asset failure rates on hot days compared with normal – this was particularly pronounced for early hot days (April-June) with an 80 % increase in asset failures compared to normal days. There was a 4.2 % reduction in PPM due to asset failures and heat speeds with heat-related disruption payments of £35-40 million between April and August 2018. The subsequent dry autumn resulted in earthworks desiccation, track degradation and increased lineside fires bringing this total to around £50m. These figures exclude impacts to train operator's fleet equipment.

Thursday 25 July 2019 was the hottest UK day on record (at 38.7°C in Cambridge). Extreme Weather Action Teams were deployed with heat speed restrictions and cancellations in force across the network to manage the risk of track buckles. The network suffered from over 121,000 delay minutes costing £9.8m (in Schedule 8 compensation alone) from 24 – 26 July with services struggling to get back to normal the following day after problems with sagging and failed overhead lines being pulled down by passing trains, brought the east and west coast mainlines to a halt.

In 2020, assets suffered again in the hot weather from issues such as signalling failures, heat speeds and overhead line failures. We experienced a much-reduced performance and cost impact compared with the previous hot years (less than twice the usual summer impact) due to the effect of reduced services from the COVID19 pandemic. Although there was a proportional increase in the number of hot days that occurred in summer 2020 compared to 2019, the absolute level of failures was lower with improvements in some areas following preparation work prior to summer. OLE failures saw a sharp improvement in the number compared to summer 2019 as, despite the increase in the number of hot days in summer 2020 (above 30-35 degrees), temperatures didn't rise to July 2019 record levels.



4. Weather and climate change impacts on the railway

Some recent weather impacts on the railway include:

Heavy rainfall

The tragic derailment at Carmont in Scotland in August 2020 has brought the devastating effects of climate change to the fore. Although Britain has one of the best safety records among European railways, and we generally manage extreme weather well, a fatal derailment in August 2020 has had a profound impact on the GB rail sector and further accelerated the work we are doing to keep our network resilient.

That morning there had been thunderstorms with associated heavy rain across northeast Scotland - records indicate that more than 50 mm of rain fell in the Carmont area between 05:00 and 09:00. Coming on top of what had already been one of the wettest Augusts ever recorded, the heavy rainfall from convection storms disrupted railways and other transport links over a wide area.

There were landslips on several major roads, and a canal breach at Polmont caused significant damage to our Edinburgh - Glasgow main line.

At Carmont, water flowing from higher land beside the railway washed stones out of a drainage channel onto the track after the previous train had passed, some 2½ hours before. The Network Rail owned drains had been installed in 2010 and were last inspected in May 2020, with no defects recorded - although further investigations will examine the accuracy of those records. The earthworks had been inspected in June and scored as having a low to medium likelihood of failure. The rapid failure of cutting slopes is difficult to predict, particularly when failures are triggered by intensive local rainfall. And such localised weather events can also be difficult for meteorologists to forecast accurately with a high level of confidence.

Immediately after the incident, we mobilised our engineers, specialist contractors and our aerial surveying team to inspect earthworks with similar features. We conducted an intensive audit of our assets across the country and we reported in detail the state of resilience of the entire network. And pledging to learn lessons from the tragedy we also commissioned two separate taskforces led by independent specialists.

One review, led by Lord Robert Mair, is looking to see how we can improve the management of our massive earthworks' portfolio, looking at past incidents, the latest technologies and innovations, and best practice from across the globe. The other is a weather action task force, spearheaded by Dame Julia Slingo, former chief scientist at the Met Office and a world-renowned expert in climatology. This aims to help us better understand the risk of rainfall to our infrastructure, drawing on the latest scientific developments in monitoring, real-time observations and forecasting. The outputs and recommendations from both taskforces will guide our work and help us make improvements to our asset management and operational preparedness.

4. Weather and climate change impacts on the railway

4.2 Climate trends in the UK

Climate change is projected to alter the timing of the seasons and the frequency, intensity and pattern of weather events such as storms and heatwaves. With the exception of cold weather events (snowfall, frost etc.), which will show a general decrease, climate change will increase the impact of weather on the railway.

Whilst there will be regional differences and local issues such as topography will cause variations across UK the general trends that we will see over the next 30 – 60 years are:

- Spring will move earlier, summer will lengthen, and autumn will move later in the year,
- Day and night temperatures will increase as will the diurnal temperature range in all seasons,
- Total rainfall will decrease in summer and increase in winter – overall rainfall total will show little change,
- Drought and heatwave frequency, severity and duration will increase,
- Summer and winter storm frequency and intensity will increase,
- Whilst snowfall will decrease, current winter low temperatures and snow fall severities will still be possible. Should a more intense winter storm coincide with low temperatures it is possible that greater than current snow fall may be possible,
- Wind speeds and humidity may show increases,
- Trends in fog days vary with decreases in summer, but with winter showing reductions in the South and East changing to increases and the North and West,
- Projections for lightning show mixed trends, and
- Sea level will rise significantly across the whole UK coast with rises higher in the south and lower in the north as the topography continues to adjust after the end of the last ice age.

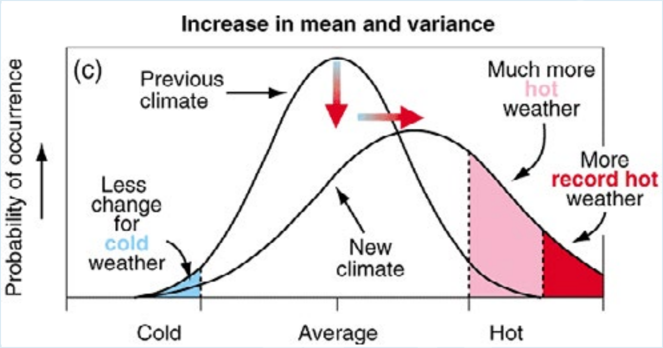


Figure 4-5 Climate change impacts on average and extreme temperatures.

Figure 4-5 illustrates how the changes in climate will impact average and extreme temperatures. Very hot summers in Europe historically occur at a frequency of 1:1000 but climate change has already increased this frequency to 1:5 and heatwaves are 30 times more likely. The UK summer mean maximum temperature is projected to increase by an average of 3.2°C by 2050 and 4.6°C by 2070[8] with the daily maximum temperature reaching into the 40s. In 2050 it is projected that the peak temperatures could be up to 44.4°C in the South East, 37.3°C in Western Scotland and 40.5°C in Wales[9].

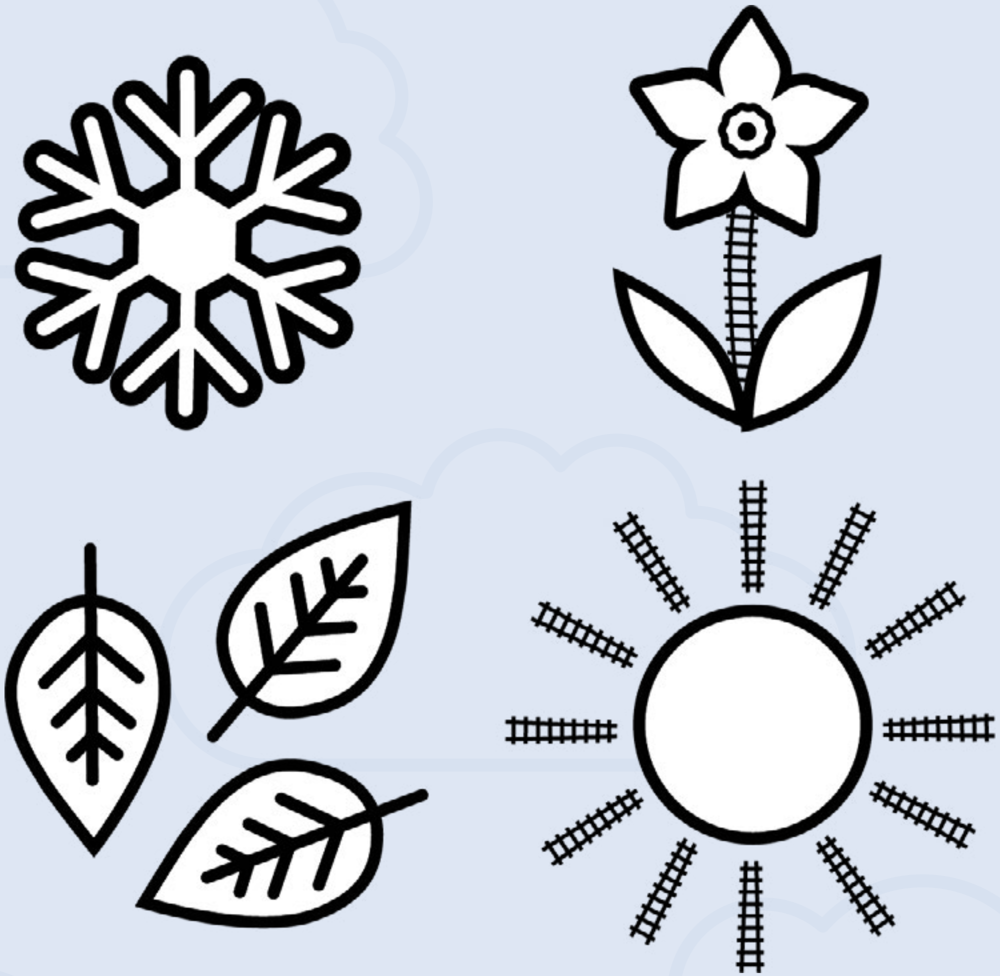
[8] UKCP18 RCP6.0 90th percentile
[9] Calculated using the MetOffice UK monthly country extreme temperatures and the UKCP18 RCP8.5 90th percentile

4. Weather and climate change impacts on the railway

4.2 Climate trends in the UK

Climate change is already causing more frequent and more severe extreme weather events and we are experiencing its impacts. The weather over the past two years is part of a clear trend of an increased frequency of extreme drier periods followed by prolonged and extreme wet weather. Very hot summers such as 2018 are “30 times more likely than would be expected from natural factors alone”.[10] “Extreme regional rainfall such as Storm Desmond in 2015 has a return period of about five years (20 % chance in any given year) and is at present roughly 60 % more likely due to human-caused climate change.”[11]

Network Rail Climate Change Projections Guidance Note (NR/GN/ESD/23) presents two climate scenarios selected from government UK Climate Change Programme (UKCP) modelling outputs as the most appropriate for adapting the railway. At the time of the assessment, NR/GN/ESD/23 was based on UKCP09 data and regulator guidance derived from it, including quantitative data from the Environment Agency, the Scottish Environment Protection Agency and Natural Resources Wales. It has since been updated to reflect UKCP18 data sets where available. Further detail on climate change and the UKCP09 and UKCP18 data sets used to generate the Network Rail guidance can be found on the UK Climate Projections web site UKCP18[12].



[10] Madge G (2019) Study examines drivers of 218 UK summer heatwave. **https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/drivers-for-2018-uk-summer-heatwave** viewed 26 August 2020
[11] World Weather Attribution (2017) **https://www.worldweatherattribution.org/uk-storm-desmond-revisited-december-2017/** viewed on 26 August 2020
[12] UK Climate Projections 2018 **http://ukclimateprojections.metoffice.gov.uk** Met Office Hadley Centre

5. Weather and climate risk and vulnerability assessment

5.1 Methodology for asset vulnerability and risk assessment

Each Asset function introduced in Section 3.2 undertook a risk assessment of current weather impacts on its assets and the projected changes in climate. This was broken down to the most critical components of the asset class (as defined in Network Rail's Asset Accountability) that can cause significant disruption on the rail network when they fail. The type of weather experienced can result in accelerated degradation of components or complete failure of the asset resulting in service disruption for up to a day whilst faults are rectified.

The assessment of current weather risk was based on existing failure evidence and engineering expertise within the asset functions, involving route consultation where appropriate to verify the effect and impact of weather. The assessment of the future risks used the Network Rail Climate Change Projections Guidance Note (NR/GN/ESD/23) and links impacts to the risks identified in the UK governments' Third Climate Change Risk Assessment (CCRA3). The CCRA is completed every 5 years and summarises the key climate risks facing the UK as the basis for informing government adaptation and the 5 yearly National Adaptation Plan.

The assessments used weather variables as the primary event with the secondary effect resulting in an adverse impact on assets which can lead to failure. Figure 5-2 illustrates types of and linkages between primary and secondary events.

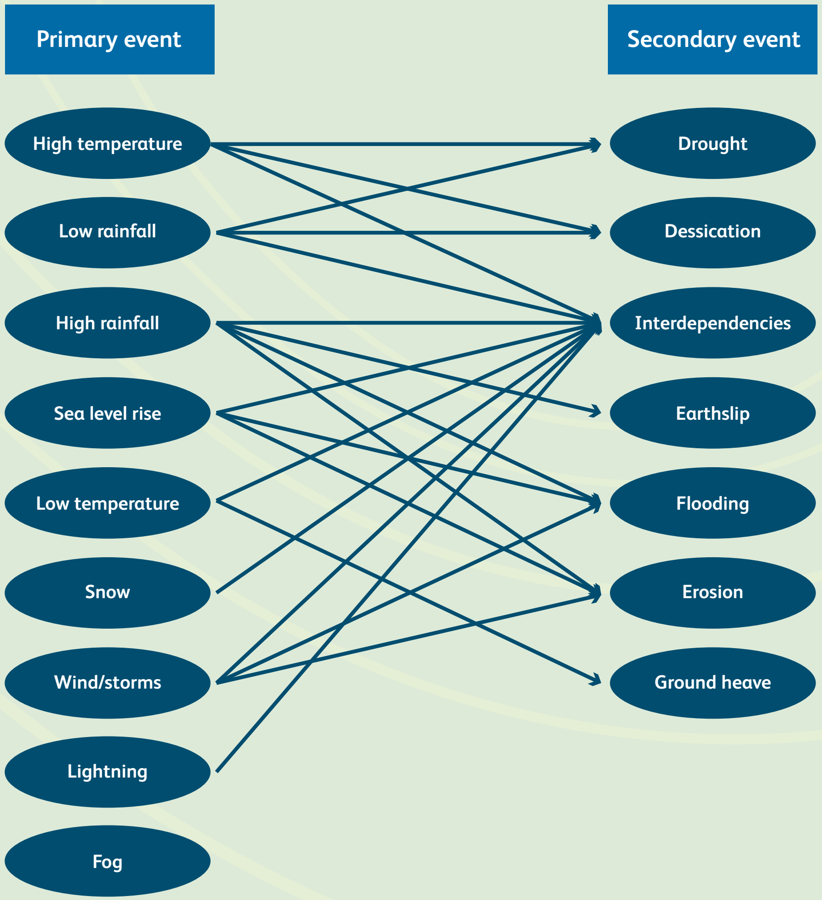


Figure 5-2 Examples of primary and secondary events

5. Weather and climate risk and vulnerability assessment

5.1 Methodology for asset vulnerability and risk assessment

The Cabinet Office infrastructure resilience definitions (Figure 5-3) and the six aspects of resilience outlined in the National Infrastructure Commission Resilience Report from May 2020 **(https://nic.org.uk/app/uploads/Anticipate-React-Recover-28-May-2020.pdf)** were used to guide this process. These were used in conjunction with the risk assessment matrix in Table 1 Future Climate Risk Assessment Matrix - aligned with Network Rail's Corporate Risk Assessment Matrix (CRAM) to generate current and future risk scores, taking account of the impact of current weather parameters and their effects on Network Rail Assets. Assessments were carried out for 2019, the 2050s and the 2080s.

The scores from the risk assessments were generated based on existing controls and designs, assuming that no new adaptation was applied. The purpose of this evaluation was to determine the gaps in current asset designs, standards and controls that would result in significant disruption to the network as a result adverse and extreme weather. The effect of some asset failures due to adverse or extreme weather could result in safety related incidents. The assessment also considers this where it applies. The risk assessments were then used to derive action plans to address any gaps identified.

The template used for the risk assessment is based on guidance provided by Defra for the third round of adaptation reporting under the Climate Change Act (2008) and this work will form a core element of Network Rail's third Adaptation Report which will be submitted later in 2021.

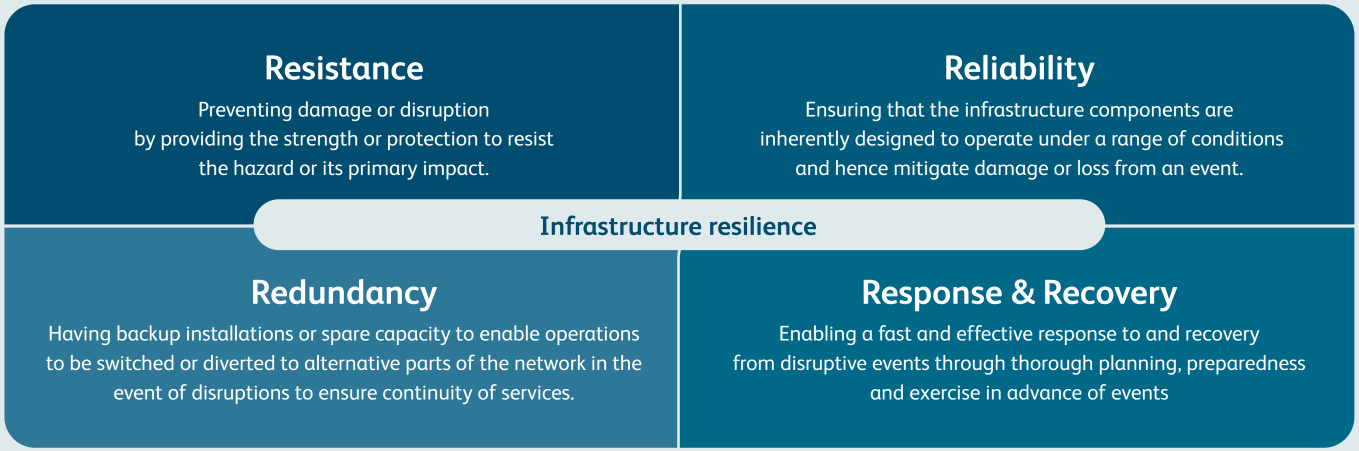


Figure 5-3 UK Cabinet Office definition of Infrastructure Resilience

Figure 5-4 NIC Resilience Study: Six aspects of infrastructure resilience

Table 1: Future Climate Risk Assessment Matrix - aligned with Network Rail's Corporate Risk Assessment Matrix (CRAM)

Impact

Impact area	1-Minimal	2-Minor	3-Moderate	4-Major	5-Catastrophic
Safety / Environment	Minor safety event with the potential to cause up to 20 minor injuries or a single major injury and with environmental incidents that can be addressed using existing control measures.	Significant safety event with the potential of a single major injury to five major injuries with adverse environmental impact within a control period that can be mitigated using existing control measures.	Significant safety event with the potential of between five major injuries and two fatalities, with significant environmental impact that results in Regulatory intervention and it exceeds existing control measures.	Catastrophic safety event with the potential of between two and ten fatalities, with major environmental impact resulting in Regulatory fines and current control measures are not suitable.	Catastrophic safety event with the potential of over 10 fatalities, with catastrophic long term environmental damage.
Performance	Planned disruption for up to a day on any one route.	Unplanned disruption for up to a day on any one route.	Unplanned disruption (for up to a week) on any one route or multiple routes.	Unplanned disruption for over a week on multiple routes.	Prolonged and unplanned severe disruption to key routes resulting in adverse media attention and protests/lobbying resulting in a review of Network licence condition.
Finance	Costs to resolve issue - up to £2m per annum.	Costs to resolve issue - £2m to £25m per annum.	Costs to resolve issue - £25m to £75m per annum.	Costs to resolve issue - £75m to £250m per annum.	Costs to resolve issue in excess of £250m per annum.
	1-Highly Unlikely	2-Unlikely	3-Possible	4-Likely	5-Almost Certain
Likelihood criteria	No known event or if known extremely rare.	Low likelihood the risk will occur and current mitigations provide effective risk control.	Medium likelihood with risks resolved using current controls. Further control improvements underway or actively being developed to mitigate.	High likelihood the risk will occur with current controls ineffective leaving problem unresolved for a long period. No effective mitigations currently identified and control weakness known and unmanaged.	Very high likelihood the risk will occur and there are no effective controls or mitigations to prevent the event.

Impact

Likelihood

Horizons: 2050-2080	Minimal	Minor	Moderate	Major	Catastrophic
Almost certain	5 / Moderate	10 / Major	15 / Major	20 / Severe	25 / Severe
Likely	4 / Moderate	8 / Moderate	12 / Major	16 / Major	20 / Severe
Possible	3 / Minor	6 / Moderate	9 / Moderate	12 / Major	15 / Major
Unlikely	2 / Minor	4 / Moderate	6 / Moderate	8 / Moderate	10 / Major
Highly unlikely	1 / Minor	2 / Minor	3 / Minor	4 / Moderate	5 / Moderate

5. Weather and climate risk and vulnerability assessment

5.2 Current operational weather management approach

From an operational perspective, our standards, developed with our meteorologists, establish plans that identify assets vulnerable to current weather, identify trigger thresholds for action and recommended mitigations such as speed restrictions. We have a small team of weather specialists supported by our external specialist weather forecast provider to support the operational railway with forecasts and incorporate engineering standards to help improve our operational response to weather impacts on the railway. The current weather forecast management approach uses an extreme weather action teleconference (EWAT) process to advise our routes of forthcoming extreme weather such as heavy rainfall and thunderstorms and analyse historical weather events and delays, so that actions can be taken to manage train services.

When action is triggered, EWATs bring together route control, maintenance, operations, and train and freight operators to amend timetables. Our weather forecasting service provides a five-day outlook of weather conditions at a national and local level to provide alerts of adverse or extreme events. These forecasts are updated daily and communicated to control centres and to our extreme weather action teams.

We also use mobile applications, geospatial mapping and remote monitoring to support faster and more accurate site data collection, which we will deploy during our inspections. These technology solutions are used by some of our maintenance and engineering teams to better understand the behaviour of our assets in adverse and extreme weather, such as increased water level, before they affect the safe passage of trains. These applications are used by some assets such as earthworks and drainage, with decision support tools and risk models developed as part of our whole life cost models for tactical and annual plan decision making. Additional work is required to enhance these tools with climate change weather projections and costs to provide more meaningful outputs to support strategic decision making.

5. Weather and climate risk and vulnerability assessment

5.3 Overview of risk and vulnerability assessment

Asset functions and disciplines carried out individual risk assessments which are summarised below and presented in detail in Appendix 1 to this report. The process took into account the fact that our assets act in concert as a system.

Each assessment therefore identifies risk where there are interdependencies between assets in the generation of risk, the transference of risk, the impacts suffered or the mitigation of the risk.

The interdependencies between the different asset sensitivities to a variety of weather types and climate variables was assessed as part of the asset risk evaluation; for example, earthworks dependence on good drainage during convective rainfall events or as a result of localised flooding. This enables water flows through appropriate drainage systems to minimise water level build up in the soil or against embankments and in cuttings that could otherwise lead to increased asset degradation and or rapid failures such as the incident at Wallers Ash in 2020 shown in Figure 5-5.

Ice, snow, heavy rainfall, lightning, heatwaves and high winds can all lead to asset system failure or degraded operation. For example, periods of drought can lead to embankment deterioration, and high temperatures increase the risk of track buckling: both impacts may result in the requirement to impose temporary speed restrictions.

A summary of the asset risk assessments showed that within the current weather context, 4 % of risks scored as major, almost half as moderate (49 %) and 47 % as minor. With climate change the profile of the risks changes with around 1 % scoring severe and the number of major risks increasing to 11 % by 2080 as illustrated in Figure 5-6.

A gap analysis of existing asset vulnerabilities to weather events and current action plans identified to address these risks is outlined in Section 8.

We are exploring a number of options to improve both the resilience of the infrastructure (by changes to design or installation specifications) and its ability to mitigate the impact on service disruption during periods of degraded infrastructure operation and these are set out in the action plan in Section 10.

Figure 5-5 Failed Earthwork at Wallers Ash, Wessex August 2020

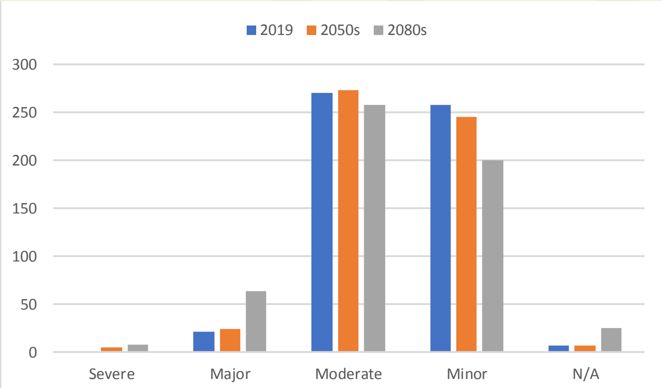


Figure 5-6 Asset Risk Assessment score summary

5. Weather and climate risk and vulnerability assessment

5.4 Hot weather (heat waves, daily maximum temperature change)

Over the past two decades the railway has experienced some of the highest recorded temperatures in the UK causing many train delays from speed restrictions, track buckles (see Figure 5-7), electrical equipment failures or overhead lines sagging. In general at the start of summer when hot weather begins, signalling failures account for around 50 % of all failures; electrical assets (e.g. OLE) for 20 % of failures with Track and S&C for around 25 % of all failures. Earthworks are also badly affected by long periods of hot and dry weather, causing embankment shrinkage that weakens these assets and, in some cases, results in reduced speeds on some lines from track settlement. Heat waves are projected to increase which will result in assets vulnerable to hot weather being adversely affected without adaptation. The table below provides an overview of the impact on Network Rail's assets and the consequences of heat related failures.

Figure 5-7 Track buckle

Table 2: Impact and consequences of heat related failures on Network Rail's assets

Affected Asset	Effect of heat	Consequences
Vegetation	Prolonged growing seasons with healthy vegetation growth. Risks generally likely to increase but with a moderate effect on rail services; however, some areas could be more severely impact depending on congestion within these areas. Increased lineside fires from dry vegetation. The occurrence of fires is likely to increase due to the drier and hotter weather.	Extensive growth can lead to signals being obstructed, reduced sighting distance and damage to trains. Lineside fires can cause extensive damage to lineside equipment, buildings and other track side furniture which will slow down or stop services and could lead to a period of reduced train services until repairs are completed.
Geotechnical/ Earthworks	Soil shrink especially in areas with clay soils as a result of hot, dry weather. Earthwork failures present some of the highest risks on the network and are likely to worsen with increasing and lengthening periods of long and hot dry weather in future. Earthworks failures also have a direct impact on other assets including: • Track, • Tunnels, • Culverts and retaining wall structures, • Signals, • Buildings, and • Overhead line equipment structures.	Heat waves can cause embankments and cuttings to dry and shrink which can affect their stability and lead to poor track quality. This causes passengers to experience discomfort (bumpiness) when travelling on trains leading to speed restrictions or in some cases line blockages until the track or embankment are repaired. Earthwork failures can also have a direct impact on other assets resulting in significant train delays or line closures, such as: • Change in loading to the tunnel linings leading to more defects or damage e.g. brick arch collapse), • Culverts and retaining walls can shift due to a change in loading making these assets weak or prone to damage and failure, • Signal posts or structures subsiding or failing due to loss of footings, • Buildings supported on embankments or within cuttings become undermined or damaged from earthworks/cutting failure, and • OLE structures become undermined or "lean" to one side resulting in the OLE wires being misaligned.

Affected Asset	Effect of heat	Consequences
Buildings	High temperatures can cause electrical and mechanical components within station or lineside equipment buildings to overheat due to poor ventilation or lack of cooling. Risks within buildings are generally controlled against weather depending on the criticality of equipment or people within these buildings. However, buildings can be indirectly affected by failure of other assets such as unstable cuttings or earthworks, power failures causing air conditioning systems to overheat or lineside fires.	Electrical or mechanical equipment failures cause station buildings or depot accommodation to become uninhabitable or lineside equipment such as signals, S&C, track circuits, or OLE and power systems to fail and disrupt services.
Structures	Thermal expansion of components in bridges (especially swing bridges).	Swing bridge failure due to component expansion prevents these structures from raising or closing thereby preventing the passage of rail or river traffic. This can cause severe congestion on some parts of the network and result in pushing more traffic onto local highways causing traffic jams.
Power & Distribution systems	Heat waves or high daily temperatures can affect electrical equipment and degrade batteries for control systems resulting in early life failures. There can also be an adverse cumulative effect on power and signalling, power cables, cable routes, switchgear, power supply systems and air conditioning systems.	Power supply systems are generally designed within the current temperature ranges that are experienced in the UK. These assets are generally resilient to hot weather, however there may be some secondary effects such as air conditioning system failure which would affect electrical and signalling equipment that these systems feed, resulting in failure of signals, track circuits and points equipment and subsequent delays or stopping of train services whilst repairs are carried out.
Signalling	Extreme hot weather affects legacy signalling systems such as interlocking components, modules, evaluators, transmitters and other components that make up track circuits, axle counters, equipment location housings and other signalling equipment.	These failures tend to result in trains coming to a halt or slowing down as a result of overheating of electronics or electrical components that are usually sited in lineside location cases. Failures are usually rectified in a few hours to a day and cause severe delays whilst response teams attend to fix.
Level Crossings	Equipment located in lineside location cabinets overheats and causes electrical components to fail or degrade reducing asset life.	The equipment failures such as treadles and modules associated with level crossings will result in level crossing barriers failing to raise or drop, which is a safety and performance risk at level crossings for pedestrians and road vehicle users. These failures also affect the passage of trains disrupting passengers.

Affected Asset	Effect of heat	Consequences
Track and S&C	Tracks can buckle when air temperatures rise and reach extreme levels. Track is particularly vulnerable to buckling in legacy jointed track designs or in old legacy S&C layouts that are constructed on wooden sleepers/bearers. Expansion of rails can also result in track circuit failures and points failures.	Track buckling can have serious safety consequences with the potential for multiple fatalities on passenger services which might derail as a result. In many cases mitigation in the form of speed restrictions is applied as the air temperature rises above 30°C resulting delays to passenger and freight services. Track circuit failures can cause delays to trains when the rails expand due to insulating material between two lengths of rail coming into contact and causing a short circuit. Points failures will generally cause disruption to services because the signalling system will only allow services to operate at a significantly reduced level to maintain a safe distance between trains.
Contact systems - OLE	During heat waves when air temperatures exceed 38°C wires are more likely to sag and balance weights, that maintain tension in OLE, expand beyond design limits. This especially affects legacy OLE designs with fixed tension wires or balance weights that require manual maintenance. In some cases where defects exist in OLE their poor condition is less resilient to hot weather and these assets are susceptible to failure lower than 38°C.	Sagging wires prevent trains from operating on an affected line. In cases where the wires sag as a train approaches at normal line speed, the wire will be damaged and become disconnected from the overhead structure causing significant damage to OLE and also to trains creating significant disruption. These failures can take at least a day to repair and reinstate normal train services.
Traction & Rolling Stock	Mobile plant and rail vehicles may be severely affected by excessive heat related to electrical or hydraulic failure for diesel traction motors.	Diesel engine failure or hydraulic failure from overheating which is likely to occur more frequently resulting in rail vehicle failure and blocking the line. This would adversely affect passenger and freight services resulting in delays that could last hours.

5. Weather and climate risk and vulnerability assessment

5.5 Heavy rain, high average seasonal rainfall and flooding, and increased risk of overtopping from sea/river

Heavy or persistent rainfall has a negative impact on primary assets such as earthworks and cuttings and a host of other assets that are dependent on earthworks or cuttings. Heavy rain can lead to surface water flooding and prolonged periods of rain to groundwater flooding. The majority of assets are outside and exposed to the weather making them vulnerable when adverse and extreme weather occurs.

Overtopping of water from the sea or rivers can also result in localised surface water flooding on adjacent railways and lead to floating debris that can cause damage to other assets or block existing drainage. In some cases where water levels rise above the top of the rail, train services will be stopped to protect the safety of passengers and freight goods until the water level subsides.

An example of the extensive damage from stormy weather causing heavy rainfall and flooding occurred on the Conwy Valley line in 2019. Ballast and track were washed away by water flows from a nearby river with track drainage and culverts unable to cope with the volume of water. Extensive resilience measures including six miles of track, embankments, nine culverts (large drains beneath the track) was carried out as part of reinstatement works to protect against future events. Six additional culverts were installed in the space which the embankment used to fill to help dissipate the water rising against the embankment and protect the embankment and the track infrastructure from water pressure and reduce the impact from flooding.

Flooding of the railway can be the result of external factors outside the control of Network Rail, e.g. runoff from farmland or failure of assets managed by others. Network Rail's assets have been mapped against the Environment Agency, Natural Resources Wales and Scottish Environmental Protection Agency flood maps to determine the extent to which the railway is at risk from flooding. Over 40 % of track is at high (1:30) or medium (1:100) flood risk and a further 33 % at low risk (1:1000). These figures exclude any amplification due to climate change.

Figure 5-8 Impact of flooding from Storm Gareth (2019) on Conwy Valley line in Wales and subsequent repairs

5.5 Heavy rain, high average seasonal rainfall and flooding, and increased risk of overtopping from sea/river

Flooding also has a significant impact on assets such as Earthworks and Track. Saturated ground from persistent and heavy rain can result in high ground water levels that could cause flooding and lead to unstable or failed earthworks and erosion from flowing flood water can cause severe disruption and closure of some lines. There may be a range of solutions at each location and exploring options will enable a longer-term strategy to be developed by looking at the wider system.

Analysis of the past flooding incidents on our network has shown that roughly 50 % of the flood-related Schedule 8 cost occurred within the known top 20 risk locations, often with multiple incidents occurring in the same location. This suggests that a small number of priority interventions targeted at these sites could make a real difference to safety and performance.

Fixing the problems can be extremely expensive and difficult (e.g. track flooding along coastlines, rivers or canals). Alternative solutions could be to increase the resilience of associated infrastructure such as raising signalling equipment, so the most vulnerable assets are protected and recovery time is reduced when incidents do occur, or to work with neighbouring stakeholders like farmers, National Highways and the Environment Agency to look for more holistic and cost-efficient solutions.

In the longer term, when the risk of flooding becomes unacceptably high due to climate change, other options may need to be considered such as raising track, improving drainage capacity, reinforcing defences or relocating the railway. Understanding options to manage risk over the life of the asset allows us to implement different options over the course of the century as and when the business case stacks up.

Figure 5-9 Flooded tracks at Corby in Northamptonshire, following heavy rainfall and river overflow

Table 3: Impact and consequences of heavy rainfall/flooding on Network Rail's assets

Affected Asset	Effect of heavy rainfall/flooding	Consequences
Geotechnical (Embankments/ cuttings)	Prolonged periods of wet weather increase pore water pressure and reduce effective stress within clay slopes. This reduces the factor of safety and increases the likelihood of asset failure causing landslides. Short duration of extreme rainfall that can lead to rapid washout failures in granular slopes.	Earthworks failures generally affect other assets due to the interdependencies between geotechnical assets and other asset classes that are supported by earthworks or cuttings. Wet weather can lead to erosion of embankments and cuttings and block lines for weeks until debris is cleared and the track reinstated.
Drainage	Heavy rain can result in the design capacity of a drainage system being compromised and causing flooding. In some cases, drainage systems can be reliant on the integrity of earthworks to continue to perform their intended purpose.	Failure of drainage systems can result in flooding that has a negative impact on other assets including track, signalling, electrification and can cause these assets to become overwhelmed or partially blocked by water or debris delaying passenger and freight services. Pumps can be used as a mitigation to transfer water away from the railway to reduce the risk of it flooding, however in particularly extreme events pumps can also be overwhelmed.
Structures	Culverts, bridges and retaining walls are subjected to scour/erosion by high river levels following heavy rainfall which can undermine a weak structure. These are usually related to defects or weaknesses in earthworks assets.	Undermined structures will result in trains moving at severely reduced speeds or a total block of the line until repairs are completed and it is safe to operate train services.
Tunnels	Following heavy rainfall where drainage is overwhelmed or there is water ingress from a nearby water course, tunnels can become flooded and flowing water can cause scour/erosion.	Scour in tunnels could result in speed restrictions being imposed with significant repairs required to repair any damage causing disruption for weeks.
Vegetation	Heavy rain or localised flooding can cause washout of root anchorage weakening trees until they fall and/or cause slope failure.	Damage to trees from heavy rainfall can be associated with embankment or cutting failure or drainage system failure. Trees falling onto the track can damage trains and cause injury to railway staff or passengers, lineside neighbours or equipment and buildings. Trains can strike trees and derail as a result and lead to severe delays and cancellations.
Boundaries	Flooding in the vicinity of boundaries (walls, fences, hedges) can cause waterlogging and undermine footings supporting these assets.	Breaches of boundary measures will enable animals or trespassers to access the railway. Unauthorised access can result in trains being stopped or speed restrictions being imposed. In some cases where animals are involved, they can derail or disable a train resulting in passengers being stranded for hours.

Affected Asset	Effect of heavy rainfall/flooding	Consequences
Power & Distribution	Heavy rain and flooding affects electrical control rooms and power supply systems, due to water breaching existing barriers and short-circuiting electrical supplies. Power supplies and control buildings are indirectly affected by other assets such as earthworks and drainage that fail or become overwhelmed. Building design can also have an indirect effect on power supplies that are housed within them.	Heavy rainfall or flooding events can result in significant infrastructure damage requiring lengthy repairs and will cause disruption to services for days. These are, however, not regularly affected by heavy rain unless they are supported by another asset that is vulnerable to heavy rain or flooding such as earthworks.
Traction & Rolling Stock	Mobile plant and rail vehicles are generally dependent on other assets, such as earthworks and track, as the line on which these assets operate could be affected by weak earthworks that have either failed or had their condition worsened.	Failure of other assets can lead to a derailment of T&RS assets causing injury and serious damage to existing fleet used on the network.
Signalling	Heavy rain or flooding affects signalling systems due to water ingress caused when the local area floods or rivers breach their banks from rising water levels. They can also be affected by erosion of earthworks that causes ground movements and signalling equipment could be damaged.	Damaged signalling equipment will cause significant disruption to services and repairs can generally take weeks to rectify the issue, particularly where there is a reliance on other asset classes that are most likely to have been the primary cause of signalling equipment failure.
Track	Where heavy rainfall or flooding occurs this can lead to water levels exceeding rail head levels, as a result of drainage failure or being overwhelmed by excessive flowing or standing water.	Speed restrictions or line blockages will need to be imposed until water levels subside. Rail will also become rusty over time reducing its serviceable life and if not replaced will result in rail breaks due to weakening of the rail structure.

5. Weather and climate risk and vulnerability assessment

5.6 Sea level rise

Storm surges, rough seas and high tides can cause significant damage to coastal defences and localised or potentially extensive flooding. Sea level rise is, due to climate change, compounding this risk, although isostatic rebound[13] continuing from the end of the last ice age means that the effect will be greater on southern coasts than the coasts in Scotland and the North of England.

Although the mechanism, frequency and extent of the damage is different to that of the various other flooding types, the resulting damage and impacts can be very similar. Sea water flooding can overwhelm drainage systems designed to manage water build up by moving water away from our assets to downstream outfalls leading to flooding of and damage to other assets such as earthworks, track, signalling and electrification equipment.

This can cause significant disruption to train services. Sea level rise can result in accelerated degradation to assets such as build-up of scour and damage to rails or electrical components that will cause early life failures. Climate change is likely to increase the frequency of coastal storms and floods such as the one seen on the Dawlish coast in 2014 in South West of England.
This section of line has minor disruptions throughout the year especially during stormy or windy weather and with land at this location sinking by approximately 1mm each year in addition to sea level rise, major line closures are projected to become more frequent with climate change.

The table on the next page provides an overview of the impact on Network Rail's assets and the consequences of sea/river level rise.

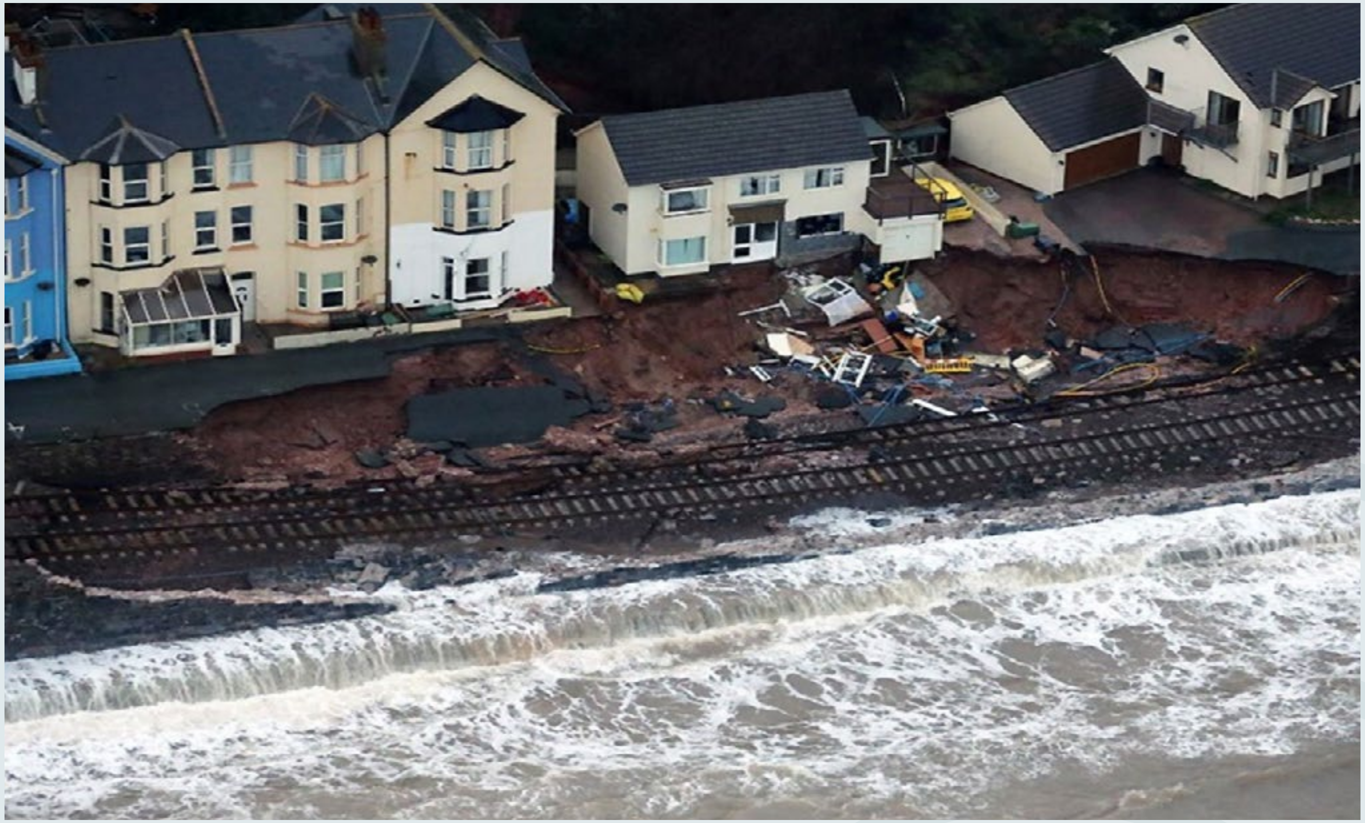


Figure 5-10 Damaged sea wall and tracks at Dawlish (2014)

[13] 1 – isostatic rebound is the uplift of land masses that are depressed by the huge weight of melting ice sheets causing land closer to glaciers in the north pole to rise and land in the south to sink.

Table 4: Impact and consequences of sea/river level rise on Network Rail's assets

Affected Asset	Effect of sea/river level rise	Consequences
Geotechnical (embankments)	Damage to embankments from overtopping of the sea will increase erosion of defences and lead to increased pore water pressure and reduce the effective stress on earthwork slopes. This increases the likelihood of landslides or rapid washout on granular slopes.	Earthworks failures can also affect other assets due to the dependencies on geotechnical assets from other asset classes that are supported by them. Overtopping of water can lead to erosion of embankments that are generally more costly and a bigger threat to service disruption than cuttings. They also take longer to repair.
Geotechnical (cuttings)	Damage to cuttings from overtopping of the sea will also cause erosion and reduce the effective strength of cuttings increasing the threat of washout onto railway tracks.	Cutting failures affect railway tracks when they fail. They can also damage other assets such as signalling equipment, trees, and parapet on structures. Excessive water on top of cuttings can lead to overloading of cutting slopes, however unlike embankments, cuttings can usually be rectified quicker and at lower cost.
Drainage	Flooding from sea level rise can result in the design capacity of a drainage system being exceeded. Pumps can be used as a mitigation to transfer water away from the railway to reduce damage to assets from water surges. In some cases, drainage systems are reliant on the integrity of earthworks to continue to perform their intended purpose.	Overwhelmed drainage systems can result in flood damage that has a negative impact on other assets including track, signalling, electrification and can cause these assets to fail or become blocked delaying passenger and freight services.
Structures	Culverts, bridges and retaining walls can become submerged by water flow and loading from water and debris can cause structures to collapse, weaken from damage or partially foul gauge for trains to pass safely. Storms and high tides can damage coastal and estuarine defences.	Failed or weakened structures will stop trains or result in speed restrictions for weeks until repairs are completed. This can be costly and is very disruptive to train services. Damage to coastal infrastructure can close likes for weeks if not months causing significant disruption to services.
Boundaries	Water surges in the vicinity of boundaries (walls, fences, hedges) can cause significant damage from undermined footings supporting these assets.	Breaches of boundary measures will enable animals or trespassers to access the railway. Unauthorised access can result in trains being stopped or speed restrictions being imposed. In some cases where animals are involved, they can derail or disable a train resulting in passengers being stranded for hours.

Affected Asset	Effect of sea/river level rise	Consequences
Vegetation	Sea level rise can cause washout of root anchorage due to localised flooding or sea spray weakening trees until they fall.	Damage to trees from coastal flooding can be associated with embankment or cutting failure or drainage system failure. Trees falling onto the track can damage trains and cause injury to railway staff or passengers, lineside neighbours or equipment and buildings. Trains can strike trees and derail as a result and lead to severe delays and cancellations.
Power & Distribution	Coastal flooding can significantly affect equipment in electrical control rooms as well as cables and power supply systems, due to water exceeding existing barriers and as a result of inadequate or poor drainage systems. Cable routes and power supply points can also be undermined and affect earthing resistance from erosion of earthworks.	Water surges can cause flooding of power supply systems and cables/cable routes short-circuiting electrical supplies, causing significant disruption requiring costly repairs and resulting in train delays for days.
Traction & Rolling Stock	Rail vehicles are generally dependent on other assets, such as earthworks, structural barriers and drainage either on running lines or at stabling points. Water surges from sea level rise can affect rail vehicles resulting in electrical, mechanical and engine systems being damaged or some components degrading from water ingress. Sea water spray can cause poor visibility for drivers and salt water can degrade components within rolling stock due to water ingress.	Significant damage to rail vehicles resulting in delay to rail services and proving costly to repair. For example the typical cost of replacement of a passenger train carriage is in excess of £1million.
Signalling	Coastal flooding can affect signalling systems from ground mounted signals, signalling cables and lineside location cabinets due to water ingress. They can also be affected by erosion of earthworks that causes ground movements and signalling equipment could be damaged.	Damaged signalling equipment will cause significant disruption to services and repairs can generally take weeks to rectify the issue. This is due to a reliance on other asset classes that are most likely to have been the primary cause of signalling equipment failure.
Level crossings	Sea level rise can cause rushing water to damage location cabinets and level crossing barriers on coastal areas from water ingress that damages electrical and electronic components.	Equipment damage to electrical and electronic components (modules) associated with level crossings will result in level crossing barriers failing to raise or drop, which is a safety and performance risk and will impact pedestrians and road vehicle users. These failures also affect the passage of trains disrupting passengers.
Track	Coastal flooding can cause track to corrode or result in trains being stopped or speed restrictions imposed where water exceeds the top of the rail (rail head). The rail foot or steel sleepers are prone to corrosion where sea water frequently breaches or falls onto the track.	Persistent water surges and flooding of track can result in accelerated degradation of rails, sleepers and ballast displacement that can cause rail breaks or poor track quality which can affect passenger and freight services with drivers reporting rough rides. Overtopping of sea water can also damage track from washouts.

5. Weather and climate risk and vulnerability assessment

5.7 High winds

High winds and wind gusts can have an adverse effect on some assets on the railway such as vegetation, buildings, plant, overhead line equipment and power supplies. Wind gusts usually occur on exposed parts of the network and on coastlines. High winds can result in reduced train services as speed restrictions are imposed to minimise damage to train pantographs from flying debris or risk of striking fallen trees or branches. Flying debris or falling trees can also damage overhead lines, severing connections or in some cases knock down masts or signals. Engineers are unable to work at height during high winds, this affects their ability to repair any damage or defects such as to OLE or structures.

The table on the next page provides an overview of the impact high winds can have on Network Rail assets.

Figure 5-11 Damage to trees and OLE

Table 5: Impact and consequences of high winds on Network Rail's assets

Affected Asset	Effect of high winds	Consequences
Vegetation	High winds can result in trees, vegetation or branches becoming dislodged or damaged and blocking or partially obscuring railway infrastructure (track, OLE etc). Debris from vegetation and trees can also be blown into passing trains causing damage or injury to passengers and train crew.	Damage to vehicles striking trees can be quite extensive and also cause trains to derail. There is also the risk of harm to passengers or train crew and also to railway staff working on the track.
Power & Distribution	High winds can cause excessive wind loading on lighting structures, signage and at principal supply points that are exposed to the elements and flying debris.	Damage can block lines or cause severe disruption to services where power supplies are affected and unable to supply power to other assets such as signals or overhead line wires. This will prevent the movement of trains and could take a day or two to undertake costly repairs.
Plant	On track equipment (Plant) such as cranes or excavators are at risk of toppling over from high winds and work is generally curtailed or stopped when severe winds are forecast.	Damage to Plant and also to passing trains, lineside assets or external properties and also injury to people could result from Plant failure. Mitigations are normally put in place to prevent this occurrence but the disruption to work activity could result in significant costs to rebook possessions and resources in order to carry out planned works.
Traction & Rolling Stock	High winds can result in flying objects (e.g. trampolines) striking rail vehicles causing damage, derailment and disabling them. Flying debris can also damage track or overhead lines that could close lines or disable electric trains.	Damage from flying objects can also cause harm to people on trains either those operating the rail vehicle or travelling on it. Speed restrictions are imposed when high winds are forecast to minimise damage or risk of trains become disabled or damaged from asset failures.
Buildings	Wind gusts and high wind speeds can cause damage to roofing and building fabric and also result in flying debris from buildings that can block lines or result in trains striking these objects.	The impact of damage to buildings can be extensive and costly and could cause harm to passengers, the public and railway staff at stations, by the roadside or on the track. Damaged buildings can affect other services such as signalling or power supply systems contained within buildings, subsequently causing disruption to train services.
Level crossings	Level crossing barriers are subjected to damage and failure during high winds, especially in exposed areas of the network.	Damage to level crossing barriers will result in disruption to services and although repairs can normally be carried out in a few hours, or resources deployed to protect trains and road users/pedestrians, disruption to passenger and freight services which have to operate at reduced speeds can last a whole day.

Affected Asset	Effect of high winds	Consequences
Signalling	Signal posts (especially ageing assets) are difficult to access during high winds and are also at risk of being damaged by high winds, flying objects or subject to component degradation from excessive wind speeds. Track circuits can also be affected during autumn leaf fall season where high winds cause heavy leaf fall from trees to occur forming an insulating layer on the rails to prevent detection of trains.	Failure of these assets can result in wrong side failures due to drivers being unable to see the signal aspect and potentially proceeding through a red signal. This could result in collision or derailment which would cause harm and also significant disruption to train services. Track circuit failures can create a false detection of trains leading to trains passing signals at danger or not stopping at stations. In severe cases this could lead to a train collision if track circuits do not detect trains correctly due to the insulating layer of leaves.
Contact systems - OLE	High wind speeds and gusts can cause OLE wires to swing around and become misaligned to make contact with the pantographs that help to power trains on many parts of our network. Flying objects and vegetation can also land on/damage infrastructure.	High winds cause significant disruption to services through blocked lines and speed restrictions slowing trains to prevent damage to equipment and trains.

5. Weather and climate risk and vulnerability assessment

5.8 Heavy snow/ice

Heavy snow causes significant disruption to railways, adversely affecting most of our assets including, Track and S&C, signalling systems, buildings, power supply systems, rail vehicles, OLE, structures and tunnels. The effects of freezing weather and heavy snow leads to increased snow loading on assets making them vulnerable to failure. Signals, icicles in tunnels and on bridges and OLE damage from icicles are all affected by severe snow falls. Tracks can be blocked by heavy snow and ice and conductor rails are unable to provide power to trains, disabling trains when this occurs. Trees can also snap due to snow loading branches and fall on the tracks, potentially damaging overhead lines or trains that may strike the fallen debris.

Frost can also cause damage to tunnels, structures and rock slopes reducing asset life and result in debris falling onto the track. Melting snow is also of particular concern where drainage systems are not capable of withstanding excessive water flows. The secondary effect of overwhelmed drainage and high groundwater levels could lead to flooding or earthwork instability.

Whilst snowfall is projected to decrease as a result of climate change, current winter low temperatures and snow fall severities will still be possible. Should a more intense winter storm coincide with low temperatures it is possible that greater than current snow fall may be possible.

With Britain not experiencing a lot of snowfall in comparison to other European countries, providing equipment such as snow ploughs on all rolling stock is expensive and unnecessary for the amount of snow. However, we have a fleet of snow ploughs available across the network that are used when and where they are needed. Time to get these trains deployed to clear snow means services are usually delayed.

The table on the next page provides an overview of the affected assets from heavy snow and ice build-up.

Figure 5-12 Icicles in tunnel

Table 6: Impact and consequences of heavy snow/ice on Network Rail's assets

Affected Asset	Effect of heavy snow/ice	Consequences
Tunnels	Ice formation within tunnel shafts.	Ice build-up in gaps within tunnel brickwork could cause structural damage resulting in brick debris falling onto tracks. This could lead to risk to both operational trains and the workforce. Damage to trains can disable them causing disruption and stranding passengers.
Structures	Deterioration of asset condition due to ice exposing weaknesses in concrete structures encased in brickwork (e.g. bridges). Swing bridges may be prevented from opening or damaged from ice build-up.	Ice and snow loading could result in brickwork becoming displaced and falling onto the track partially obscuring or blocking the track. These failures can derail or cause damage to trains and injury to passengers and train crew. Failure of swing bridges can also result in significant disruption to services on a line of route.
Boundaries	Boundary fences can be affected by snow loading that can result in damage and failure.	Failure of boundary measures exposes the railway to animal incursion and trespass and vandalism. Unauthorised access can lead to delays while trespassers are removed or derailments/damage to trains from striking animals or objects on the line. Where these incidents occur, trains are either stopped or speed restrictions imposed as a precaution until repairs have been completed.
Power & Distribution	Lighting structures and power supplies for trains stabled in stations, train depots or sidings (also known as shore power supplies) are subject to damage from snow loading or excess water from snow build-up or thawing.	Snow build-up or thawing water creates a low resistance path between exposed terminals that physically prevent the use of shore supplies for trains. Loss of shore supplies will prevent trains from moving, disrupting timetabled services. Damage to lighting structures that could fail, risks injury to people on walking routes, platforms or at stations and depots and it also risks lighting falling onto tracks and being struck by trains.
OLE and conductor rail	Snow loading on OLE can cause it to sag or icicles to form causing damage to train pantographs and potentially pulling wires down. Conductor rails (3^{rd} rail) are affected by snow and ice which prevents them from powering up trains.	Failed OLE wires will cause significant disruption to services and can result in lines blocked for more than a day. Ice on the 3^{rd} rail is at risk of stranding trains and passengers. This can result in passengers being stranded for hours and potentially disembarking trains without permission which happened at Lewisham and in Hampshire during the 'Beast from the East' in 2018.

Affected Asset	Effect of heavy snow/ice	Consequences
Plant	Snow and ice can cause hydraulic bufferstops and mechanical moving parts of swing bridges to seize as temperatures drop or snow causes obstruction.	The effect of these asset failures can cause delays and disruption to services with platforms signed out of use or bridges unable to open or close to allow rail or river traffic to operate.
Traction & Rolling Stock	Dynamic braking on rail vehicles can fill with snow powder ingress into the brake equipment causing poor braking performance.	This can lead to signals passed at danger (SPAD) with the risk of collision with other trains or derailment causing significant damage or serious harm to passengers, public and train crew.
S&C	Point heaters for switches and crossings can become overwhelmed by heavy snow preventing these assets from operating with points unable to swing to move trains from one line to another.	These failures can cause significant delays to train services resulting in stranded passengers and stopping trains for hours. There is also a knock-on effect on trains held stranded in remote areas with heavy snow as trains could breakdown leaving passengers with no power or heating in rural locations.
Signalling	Signals can be obscured by snow build-up preventing drivers from seeing the correct signal aspect being displayed.	This is a SPAD risk and could lead to collision or delays.
Level crossings	Road traffic lights, warning signals and barrier booms can be obscured or obstructed by snow causing poor visibility of CCTV and obstacle detection equipment at level crossings.	Obscured signals and signs or obstructed barriers caused by snow could lead to delays to services and road traffic crossing at level crossings. Passengers could be stranded and disrupted for hours until these faults are cleared.

5. Weather and climate risk and vulnerability assessment

5.9 Lightning

Lightning strikes can damage assets on the railway including trees that may fall on the track, signalling, overhead lines and power supply systems damaged or disrupted from electrical failures. Bridges and buildings can also be affected by lightning where conductors are not robust.

Whilst modelling for lightning frequency under climate change scenarios is of low confidence the greater frequency of summer and winter storms may lead to increases. The table below provides an overview of the assets affected by lightning strikes.

Table 7: Impact and consequences of lightning on Network Rail's assets

Affected Asset	Effect of lightning	Consequences
Power & Distribution	High voltage and low voltage power systems, mains power supply and functional supply points, switchgear and lighting can all be damaged by lightning strikes as they act as conductors.	Damage to electrical equipment from lightning strikes can disrupt power supply to trains, signals and other systems resulting in severe delays and stranded passenger services. Whilst many of these systems have protection systems or fuses to minimise or prevent damage, these can be weakened or damaged.
Signalling	Lightning strikes can damage interlocking systems resulting in component failure. Signals and European Traffic Control Systems (ETCS) can also be affected by lightning strikes especially on LED type signals and lineside equipment housings.	Damage to interlocking or LED signals usually result in disruption to train services for up to a whole day whilst replacement components are sourced. The cost of protecting these systems currently outweighs the likelihood of damage.

5. Weather and climate risk and vulnerability assessment

5.10 Storms

Storms are a combination of high wind gusts, lightning and rainfall, and the effect of these can be more pronounced on coastlines where storm surges and heavy seas can cause additional damage. Earthworks, trees, drainage systems, buildings and structures are damaged by storms, as are signalling, plant and electrification assets.

Where these assets are located near coastlines the impact could be more pronounced. For example, during storm Ciara in 2020, strong winds, intense rainfall and flooding across Wales caused damage to the Cambrian line with the embankment and ballast washed away and debris brought onto the track by flood water. Repairs took approximately two months before the line was eventually reopened for services.

As storms are a combination of different weather events, the effects tend to mirror the causes highlighted above, however the consequences can be more severe with combination effects creating greater impacts and repairs sometimes taking months to complete causing significant disruption and sometimes cutting off communities – such as when the line at Dawlish collapsed into the sea in 2014 cutting off South West England for eight weeks. With climate change the frequency of storms is projected to rise leading to an increase in damage and disruption. Table 8 on the next page provides an overview of the assets affected by storms; it should be read in conjunction with the impact tables above.

Figure 5-13 Storm damage on the Cambrian line

Table 8: Impact and consequences of storms on Network Rail's assets

Affected Asset	Effect of storms	Consequences
Structures	Structures located at coastal and river areas are worst affected by storms with large waves causing damage and in some cases erosion or complete washout.	The effect of erosion or damage to assets can block railway lines for months requiring extensive and costly repairs to reinstate traffic on affected lines.
Boundaries	High winds and heavy rain can cause damage and loss of effective boundary measures.	The impact of these failures could mean that animals and trespassers may easily access the railway causing disruption to services and potentially fall foul of open lines.
Vegetation	Trees can foul or block a line due to stormy weather blowing them down.	Fallen trees can derail or damage trains stranding passengers for hours and result in significant disruption for the whole day.
Power & Distribution	Power and distribution systems, including floodlights, signage and power supply points can be indirectly affected by damage to structures.	Damaged assets can result in disrupted power supplies, lighting, and other track side equipment.
Plant	Road rail vehicles and mobile plant are able to operate in stormy weather, however there is a risk to operators from flying debris and objects.	Damage to plant can cause harm to operators and prevent repairs to other assets where it becomes unsafe to use these vehicles during stormy weather. Delays to planned or emergency works may arise from damage or as a result of risks associated with storms.
Level crossings	Storms can cause damage to level crossing booms preventing them from operating and stopping or slowing down trains.	Damaged level crossing barriers disrupt services and delay trains for many hours. In addition they can disrupt road traffic over the level crossing adding to traffic congestion on the highway.
Signalling	Track circuits can fail as a result of storms that cause leaves to fall from trees and form an insulating layer on the rails to prevent detection of trains.	Track circuit failures from storms can result in SPADs, collisions or disruption to services from speed restrictions or trains failing to stop at a booked station. This usually occurs in the autumn period.
Track and S&C	Storms that are a combination of high wind gusts and heavy rainfall can result in flooding of tracks due to drainage unable to cope or rivers/sea breaching banks.	Flooded track generally causes significant delays to trains by imposing speed restrictions or stopping trains and stranding passengers for hours.

6. Benchmarking against other infrastructure managers

In order to better understand the synergies between our assets and other railways and industries, Network Rail asset functions have been working collaboratively on several fronts to share learning and identify innovative opportunities and better value to deliver asset resilience as efficiently as possible.

The collaborative work we are engaged in includes:

- Working with European railways as part of the Shift2Rail research and development programme (including SNCF – France; DeutcheBahn – Germany; Trafikverket – Sweden; SBB – Switzerland; and many other European railways),
- Partnering with UK Research and Innovation Network (UKRRIN) Universities,
- Partnering with UIC (International Union of Railways) in support of the Adaptation of railway infrastructure to climate change project,
- R&D collaboration with ProRail including the execution of demonstrators on track, Intelligent Infrastructure, Advanced data analytics, earthworks and drainage management, sustainable traction energy, European Railway Traffic Management System (ERTMS) and Automatic Train Operation (ATO),
- Collaboration with UK asset owning organisations such as National Highways, Transport for London, Environment Agency and learning how these asset owners manage their asset risks to better understand deterioration, performance and forecast improvements,
- Partnering with Energy Innovation Centre on power supply developments and innovation, and
- Membership of the Manufacturing Technology Centre to develop new improved manufacturing techniques for railway products and unlock frailties with current manufacturing methods. Through our association in the (UIC) with Europe, Canada and Australia, we have compared how other countries manage high temperatures and Network Rail is seen as one of the most effective at managing and minimising the occurrence of track buckles with interest from Dutch and Belgian Railways who have previously interviewed members of Network Rail Engineering team to understand what controls and mitigation we adopt. We have also identified different practices across other parts of the world where in some cases rails are restressed during summer and winter to manage large temperature variations (minimum and maximum). However, this approach is very costly to adopt.

6. Benchmarking against other infrastructure managers

We will continue to work with other agencies, such as the Civil Aviation Authority, Transport for London and other infrastructure bodies in Scotland and Wales specifically to compare approaches to the issues we face including the impact from neighbouring landowners so that we have a better understanding of the effect on the railway system from catchment level consideration of water flow towards the railway.

In 2020, following the tragic derailment of a passenger train near Carmont in Scotland, we commissioned two independent task forces to investigate how weather forecasting and earthworks risks can be managed more effectively. The findings from the task force reports sets out how we will use the expert advice to continue to develop earthworks and weather risk management.

An example of the collaborative engagement is demonstrated through the Geotechnical Asset Owners Forum of which Network Rail is a founding member along with National Highways and London Underground. This forum includes regular engagement with all major asset owners in the UK. It meets quarterly and routinely engages with newer members of the forum such as the Environment Agency, Transport for Scotland, Welsh Assembly and the Canal & Rivers Trust. The Geotechnical Asset Owners Forum is a highly regarded group bringing together the collective thinking power of all asset owners in the UK to share best practice and collaborate on research initiatives within the wider geotechnical industry.

We are seeking to improve our asset management capabilities in all asset areas and identify opportunities and key contacts in other organisations to progress benchmarking activities. It is also worth noting that Network Rail appears to be leading in many areas already including:

- Asset inventory, in terms of coverage of the network and the granularity of recorded detail,
- Examination specifications and systems using GIS,
- Whole life cost modelling at strategic and tactical levels, and
- Climate change adaptation planning.

7. Gap analysis of current asset management

7.1 Gap analysis of current asset management

Following the risk evaluation by each asset, an assessment of the risks against current asset knowledge, standards and controls was undertaken to determine where the effect of climate change was not properly understood or was likely to be intolerable.

Additionally, the independent investigation undertaken by Lord Robert Mair into earthworks risk management (following the Carmont derailment) identified gaps in our asset management with the impact of climate change required to be better understood and managed.

The gaps identified were focussed on current risks scored between moderate to severe and also those risks with a likelihood of increasing due to projected climate change. This ensured a risk-based approach to tackling asset risks associated with climate change in order that these vulnerabilities could be adequately controlled or mitigated.

The following sections provide an overview of the asset functions gaps from the risk assessments undertaken, with a detailed breakdown included in Appendices to this report.

Gaps were identified within each asset function with several key themes:

- Asset Policy not acknowledging or aligned to climate projections,
- Critical asset standards and specification not adequately defining projected resilience thresholds,
- Asset condition knowledge gaps and limitations in asset sensitivities to a variety of weather types and climate variables (e.g. impact of heavy rainfall associated with drainage failure),
- Inadequate asset inventory and prediction of asset failure,
- Extreme weather plans associated with weather resilience not fit for purpose,
- Interdependencies between different assets and/or caused by external factors not addressed, and
- Inadequate geographical asset vulnerability profiles.

7. Gap analysis of current asset management

7.2 Asset Policies

Our asset management policy defines the key principles and requirements which apply to all our assets and sets out our overall approach for delivering a safe, sustainable and efficient railway. Our current asset policies take account of existing weather impacts and define requirements for remediation which adequately address current adverse weather. In a few cases some functions (e.g. drainage and earthworks) refer to Environment Agency (EA) projections in their policies and design standards (e.g. 1 in 200 year resilience to river flooding). A Regulatory measure is used to monitor the average earthwork condition score within each region (known as M33).

Informed by asset condition data and integrated into whole life cost modelling the M33 measure enables the average condition score to be monitored. Integration into whole life costing (WLC) models also allows for future volume projections to sustain the condition score to be determined.

This advice allows for conscious decisions to be made in strategic planning with regards to the activity levels in earthworks.

Many of Network Rail's asset have not kept up with changes in EA policy and Network Rail's climate projections guidance (NR/GN/EDS/23) derived from UKCP18[14].

Whilst uncertainty comes with modelling there is no current allowance for climate change in the WLC models. Objective assessments of sustainable investment to manage weather resilience in a changing climate should recognise the metrics we have today and build on these.

Those assets with a long-life cycle are likely to remain in place with no planned refurbishment or renewals such as earthworks and drainage. Investment in some assets such as earthworks, over the last two control periods allow for the average condition of the national portfolio to degrade, which goes against the wider challenge of making the railway more resilient. However, we recognise that one component of resilience is the ability to respond and recover quickly from disruptive events. Future investments will require a continuation of this approach to make the earthwork portfolio more resistant to the impact of the changing climate.

For assets with shorter lifespans, such as level crossing barrier packs or POE, it is likely that they may be able to cope with the climate changes in their 10 – 20 year lives. However, we still need to verify this and to identify changes that may be needed in their design and operation specifications as the climate changes over the longer term.

[14] Climate Change Projections Guidance Note **https://safety.networkrail.co.uk/wp-content/uploads/2019/09/Climate-change-projections-Guidance-Note.pdf**

7. Gap analysis of current asset management

7.2 Asset Policies

Asset policies for CP7 have been consulted with regions and the Technical Authority, with the overall policy requirements focussed on providing a framework by which regions will develop their strategies.

The policies are still being developed to improve decision making on asset lifecycles adopting agreed value frameworks, business requirements and covering cost, risk and benefits to allow trade-offs between assets to support delivery of services to meet passenger and freight needs. Policies will also need to be aligned with Network Rail's strategic intentions. For climate change impact, we will define resilience requirements against a specified range of weather conditions, taking account of emerging knowledge of climate change.

This will provide clarity on what changes are needed to current assets in response to climate change based on asset lifecycle and resistance to adverse and extreme weather for the future.

Our asset policies will be developed and completed by September 2021 to assist our regions with producing their asset strategies.

We will align our asset management interventions to the principles defined in our asset policies for all operational assets, and set out the major requirements and decision making criteria for the work we do to deliver the required network and route outputs for the funding available.

An overview of the main gaps in our asset policies against climate change include:

- Incomplete understanding across the entire railway estate of how catchment wide hydrology or multi agency management plans interacts with railway drainage, earthworks and flood defence schemes. Modern drainage and earthworks are designed with environmental impacts, and consequent raised water levels considered, but need to be assessed against climate change guidance,
- Insufficient understanding or modelling of the adverse effect water logging or flooding will have on assets; for example, tree mortality rates in different species,
- Whole life cost models do not account for climate change impacts on asset degradation,
- Inadequate asset condition inspections for degradation as a result of adverse and extreme weather to ascertain the critical thresholds for the most crucial assets and determine potential resilience measures,
- Assets, systems and networks do not consider the long-term social, environmental and weather impacts of climate change and how to improve the way these are managed through inspection, maintenance and renewals of existing and new assets, and
- Technological solutions to support fact-based decision-making, to detect and provide early warning of risk levels, do not provide adequate protection against the effects of climate change.

Our asset policies and strategies for CP7 will take into account the level of investment available to make the railway more resilient, however we recognise that resilience can also be achieved through our ability to respond and recovery quickly from disruptive events. Our policy will go hand in hand with investing further in our asset portfolio of risks from climate change to offer the most effective controls that offer the greatest safety, environment, performance and cost efficient benefits.

7. Gap analysis of current asset management

7.3 Asset Standards

Standards are a set of documents produced to define the way the UK railway works. They give us a consistent, safe and coherent set of requirements across the whole company.

The majority of asset standards and specifications were produced between 1990s and 2000s and have been continually updated and in the main provide sufficient controls against existing weather patterns and events either by design or by implementing operational controls as part of weather response plans.

For instance, OLE and Track standards identify deficiencies to hot weather based on asset type and condition with control such as reducing speed restrictions applied to mitigate against catastrophic and disruptive failure. These controls reduce the current forces applied on these assets, but they do not address their increasing vulnerability to failure under future weather conditions.

For some asset classes such as drainage for example, the picture for the control of current risks is more variable. Where designs are known and understood for a catchment, the mitigations and controls for current risks are clearly covered by standards, but given the inherent variability of drainage asset designs and a lack of historic design information, it is difficult to assure that standards always fully align with the intervention measures provided against current weather patterns.

With the new assets, construction and installations due over the next five to ten years, and beyond it is essential that asset standards are updated to deal with not just any gaps around current weather patterns, but also projected future weather conditions.

This will improve resilience to the anticipated changes in the severity and increasing frequency of rainfall and hot and dry weather against a backdrop of maintenance, refurbishment and response to asset failures.

Competence and skills gaps have also been identified and standard controls and mitigations need to be covered in training material to improve asset installation, maintenance and to implement suitable risk controls.

The current gaps in standards and design specifications include:

- Lack of asset design information especially on legacy asset designs,
- Inadequate factor for safety built into sustainable drainage systems (SuDS) due to historic designs not developed to accommodate the effects of climate change, and
- Insufficient understanding of OLE design thresholds for higher temperatures (>42°C) and the conditions that determine these limits. Current techniques for maintenance intervention may not be adequate to control OLE failures, due to access constraints which will restrict these interventions leaving more defects on the infrastructure, resulting in more disruption as temperatures rise.

7. Gap analysis of current asset management

7.4 Asset condition knowledge associated with weather types and patterns

Asset condition is a fundamental aspect of understanding the hazards associated with the asset based on weather and environmental factors. In some cases, for example sustainable drainage systems may have been designed with a factor of safety that addresses climate change challenges, but there are likely residual risks remaining because of poor asset condition knowledge, lack of maintenance and impact of third party land drainage systems. In these situations we may not be aware of the inadequacies that may exist in the drainage system and these vulnerabilities may only become evident during adverse or extreme rainfall. Earthworks assets are also complex, and many were built over 150 years ago and details of some as-built design and construction are limited.

Improved asset knowledge and design thresholds will also help with analysing and determining failure modes, which is difficult to apply due to gaps in asset condition data.

Third party landowner, facilities or local authority asset controls and condition is also an important feature that needs to be better understood to help better manage water flow both now and in the future with climate change.

Improved forecasting is also a factor for consideration as it helps to identify at risk locations, such as areas that may be at risk of lightning strikes or where flooding may occur. Identification of these locations will provide visibility of asset vulnerability.

Flooding and other changes in weather patterns may also affect the growth rates, range and disease vulnerability of some types of vegetation more than others, but understanding on this is currently low.

Research work to better understand the current relationship between weather and the response of different types of trees or vegetation will need to be undertaken to determine what combination of weather patterns stimulates growth rates or disease so that appropriate maintenance plans can be put in place to mitigate tree hazards on the network.

Work is already being commissioned by the Weather Resilience and Climate Change Adaptation Team to identify the current knowledge base on the impacts that climate change may have.

The behaviour of assets based on hot and dry weather, wind speeds, heavy rainfall, storms, ice and snow and sea level rise needs to be analysed and better understood to assist with asset management strategies.

7. Gap analysis of current asset management

7.4 Asset condition knowledge associated with weather types and patterns

Examples of the current gaps include:

- A lack of information on soil, tunnel and drainage asset conditions overlaid to provide a detailed understanding of the system vulnerabilities for assets that have a dependency on each other,
- Incomplete understanding of vegetation and tree growth rates and increases in tree species diseases causing more trees to obscure or foul the line. This would enable a broader understanding of what maintenance regime to apply to control vegetation growth and encroachment,
- Insufficient understanding or modelling of the adverse effect water logging or flooding will have on tree mortality rates in different species,
- A more expansive understanding of legacy OLE assets with no available adjustment and interface with crossovers and overlaps,
- Measurement of signalling systems behaviour associated with existing weather is not well recorded due to complexity of systems and an inability to associated root cause of component failures,
- Ageing signal posts and associated equipment have no detailed inspections or condition-based assessment to determine remaining life of these assets,
- Inadequate condition-based modelling tools to support decision making and improve ability to predict and prevent failures during heat waves and cold spells,
- Lack of understanding of thermal stress on electrical components to determine remaining life of POE assets, and
- Inability to predict POE and associated electrical component failures based on hot weather, cold weather and rainfall levels to determine the triggers that contribute to weather related failures to enable early intervention.

7. Gap analysis of current asset management

7.5 Inadequate asset inventory and predicting asset failure

The gap analysis highlights some areas where further asset condition inventory is needed to better understand how different asset types or compositions behave with different weather patterns or events.

Poor asset condition data and an inaccurate inventory of asset design and composition makes it difficult to predict failure modes for some of our assets. Asset data and designs are an important factor for managing assets and assessing whether they are deficient to deal with adverse or severe weather events.

Asset inventories need to be fully populated to aid provision of suitable risk matrices to provide risk controls or plan mitigation to address climate change threats.

Some of the asset inventory deficiencies that exist include:

- Lack of complete inventory of drainage assets and their design meaning that it can be difficult to predict whether the asset will cope with extreme rain or whether it is at risk of failing and in some cases, these vulnerabilities are only identified when the asset fails, and flooding occurs,
- Detailed understanding on the effectiveness of imposing speed restrictions to minimise derailment risks from buckling track,
- Lack of available asset information for legacy systems to determine the triggers that may lead to track buckling during heat waves,
- Lack of understanding of thermal stress on electrical components to determine remaining life of electrical components for signalling and POE assets, and
- Inability to predict POE and associated electrical component failures based on hot, cold weather and precipitation levels to determine the triggers that contribute to weather related failures to enable early intervention.

7. Gap analysis of current asset management

7.6 Extreme weather plans

Network Rail uses adverse/extreme weather plans to mitigate risks to vulnerable assets from weather events[15]. These plans combine details of asset vulnerabilities to weather types with operational actions to help the application of suitable controls such as imposing speed restrictions where heavy rain or high winds are forecast. These weather plans include mandatory actions, local actions that can be applied through risk assessment and guidance on good practice actions that can be applied.

Whilst these plans require routes and regions to identify high-risk assets or locations, they do not contain all assets that may pose a risk due to a lack of information on asset vulnerability to different types of weather.

Localised risks from adjacent landowners or external asset managers (such as drainage authorities) are also not fully understood and in situations where there are vulnerabilities to adverse or extreme weather, their impact on the railway is not known and no plans have been put in place to mitigate against these. Climate change will have a significant effect on such locations.

There is also a lack of consistency applied by routes due to a lack of understanding or the methodology used to identify at-risk sites for inclusion and exclusion in Adverse/ Extreme Weather Plans.

Without this there is a risk that sites which are of highest risk, or low frequency/high consequence, will not be consistently captured and monitored across the business.

Whilst the weather plans manage risk to the best of our current ability, there are a range of issues where further research would enable better forecasting and more targeted alerts and operational controls (e.g. temporary speed restrictions on more localised areas).

[15] Reference to Network Rail Operational Weather plans - **NR/L2/OPS/021** (includes asset management during extreme weather).

7. Gap analysis of current asset management

7.6 Extreme weather plans

Some of these include:

- Lack of understanding of weaknesses in track assets aligned with vulnerabilities in other assets namely, drainage and earthworks to heavy rain, flooding and long periods of dry weather,
- Lack of capability and tools to predict future flood locations without comprehensive hydrological data,
- Incomplete understanding of vegetation and tree growth rates and increases in tree species diseases causing more trees to obscure or foul the line. This would enable a broader understanding of what maintenance regime to apply to control vegetation growth and encroachment. This lack of knowledge and information means that tree hazards are unlikely to be flagged leaving the infrastructure exposed to accidents, disruption and delays,
- Rainfall patterns that are relevant to identifying triggers for earthworks failures and the form of failure from antecedent or cumulative rainfall and rainfall intensity are not consistently understood,
- Legacy signalling systems such as solid-state interlocking (SSI), are prone to failures on hotter days, however there is little understanding of the triggers that result in component failure to enable proactive interventions,
- Inadequate lightning protection on exposed sections of the network leaves these exposed to failure and damage from lightning strikes. Plans to implement these protection measures everywhere are likely to be very costly with limited business benefit for less busy sections of the rail network,
- Some electrical equipment in lineside location housings are not protected against dripping water due to legacy housings still in use that are not up to modern standards, and
- Combined effect of rainfall and wind/storms during autumn in addition to leaf fall causes track circuits to fail and loss of train detection which causes disruption to services and introduces safety risks. The extent this combined effect can have on failure of track circuits and where these occur is not completely known resulting in failures at locations that have not been identified as a risk.

7. Gap analysis of current asset management

7.7 Interdependencies between different assets and caused by external factors

Assets managed by Network Rail generally have a level of dependency on each other, for example earthworks and drainage failures are likely to impact other assets such as track, signalling equipment and OLE. In order to manage our assets, it is essential to understand the hazards caused by the different weather types on other asset disciplines and how these are controlled and managed either by design or through mitigations applied.

In addition to the internal system dependencies we also need to consider that our assets operate within the wider UK 'system' and that this brings its own set of dependencies. The resilience of other sectors such as power suppliers can have a material effect on our operations, and we can be depended on by others, for example the ability to move freight to and from ports by rail. A summary of our external weather-related interdependencies is shown in Figure 6-1. They are grouped by the type of relationship – dependent on us, us dependent on them and, mutual dependency – with the thickness of the arrow showing the relative importance.

While this assessment goes some way to identifying the internal systemic risks (Section 3.3) it does not address them, or the external ones, at this time. A more detailed analysis will help to determine if mitigation on one of our assets will resolve all issues relating other internal assets and/or the assets of other organisations, or whether additional mitigation will be required by other assets be they ours or those of an external organisation.

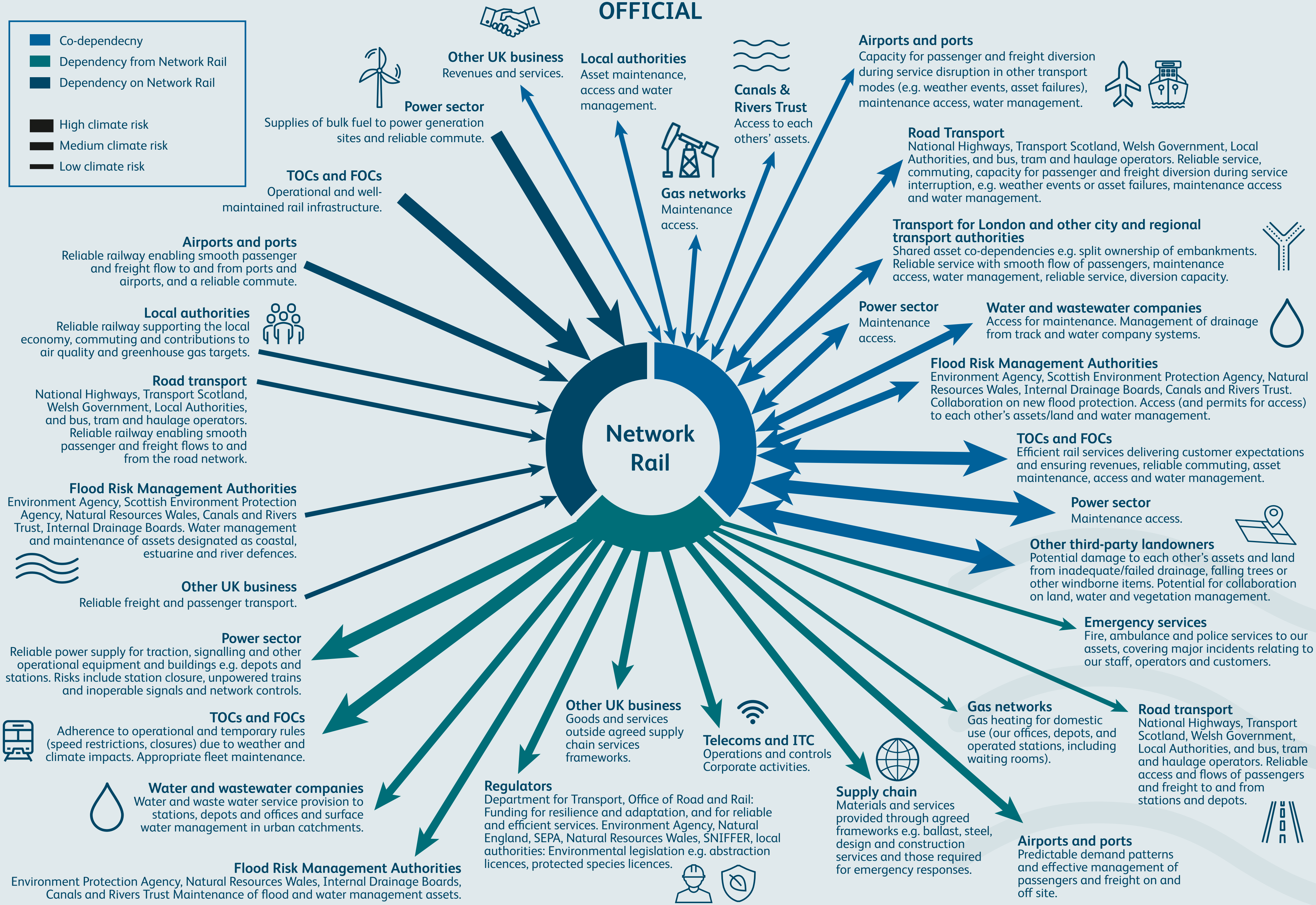


Figure 6-1 Our external interdependencies

7. Gap analysis of current asset management

7.7 Interdependencies between different assets and caused by external factors

External factors including third party landowners, services providers, flood catchment areas, etc, can have a negative effect on Network Rail assets. For instance, surface water run-off from neighbouring land can wash away embankments and trees from neighbouring properties could fall onto the railway during high winds or cause wheel slip during autumn when the leaves from trees fall onto the track.

The current lack of a systems analysis approach to assess the effect from other asset failures exposes a vulnerability which may not have suitable controls to mitigate against serious accident or significant disruption.

Identified gaps include:

- Incomplete understanding across the entire railway estate of how catchment wide hydrology or multi agency management plans interacts with railway drainage, earthworks and flood defence schemes. Although our more modern drainage and earthworks are designed with environmental impacts, isostatic rebound, and consequent raised water levels considered, there is an incomplete understanding across our estate of our asset designs and how catchment wide hydrology or multi agency management plans interacts with railway drainage, earthworks and flood defence schemes,
- A lack of information on soil, tunnel and drainage asset conditions overlaid to provide a detailed understanding of the system vulnerabilities for assets that have a dependency on each other,
- Extent of defect growth with water table rise from increased intensity and frequency of storm and winter rainfall causing water ingress within tunnels, on earthworks and to drainage channels, could reach unmanageable levels resulting in simultaneous failures on multiple lines, and
- Broaden understanding of weaknesses in track assets aligned with vulnerabilities in other assets namely, drainage and earthworks to heavy rain, flooding and long periods of dry weather.

7. Gap analysis of current asset management

7.8 Inadequate geographical asset vulnerability profiles

The gaps in asset knowledge make it difficult to identify and address local geographical risks due to the effect of different weather conditions across the country. Accurate designs, asset condition data and suitable failure modes and asset behaviours to different weather types would help to provide a geospatial mapping of asset risks and also a combination of different assets and their dependencies and weaknesses to adverse and severe weather. Availability of such information will aid development and confidence in decision support tools that could be used to derive asset management strategies based on local weather factors, passenger and freight demands, consider life cycle cost and determine the most effective barrier against adverse and extreme weather caused by climate change.

Regions have details of assets that are vulnerable to flooding, weak embankments, vulnerable track, etc, which enables them to implement operational controls to mitigate the risk of failure or degradation. In many cases speed restrictions are imposed to manage the risk to passengers and freight services. But this has an adverse impact on railway punctuality and delays passengers.

A common consequence tool developed by Network Rail provides a method of estimating the potential safety consequences (such as injuries or fatalities) arising from a train derailment. This provides a location-based consequence rating and has the ability to compare different assets in terms of overall safety criticality. But the tool does not consider the effect of weather on different asset designs or compositions.

Work has already commenced with specifying a vulnerability and criticality mapping tool that would help regions to identify asset weaknesses to help with prioritising actions to improve asset resilience to adverse and extreme weather.

8. Asset management weather and climate change resilience policy

Network Rail's Technical Authority is responsible for our assets and accountable for developing asset policies, standards, technical strategies, sharing best practice, defining staff competency and assessment, and conducting company-wide engineering & safety assurance.

Regions own their Technical and Asset Strategies and manage application of Technical & Safety policies. Regional safety and engineering teams are empowered to make local decisions, challenge and support the Working with the regions' safety and engineering capability. The Technical Authority is required to take a holistic approach to the development of policies and standards, balancing safety, train performance, finance and deliverability.

Policy development for CP7 will consider the effect climate change will have on our assets and assess whether the gaps identified from the asset risk assessments need to be addressed now or for future control periods. This will be dependent on the life cycle of the specific asset class.

The Technical Authority will review asset policies and strategies to make sure that they address risks from climate change and provide suitable and easy to understand guidance to regions and routes in order for them to determine sufficient controls as part of refurbishment, renewal and enhancement schemes in CP7. Technical Authority develop good practice and innovation and act as an intelligent client for the delivery of services.

In order to deliver these policies, we will apply an asset management system approach that will form part of a wider integrated management system. These are enshrined within the core principles to provide a safe, sustainable and resilient railway. To do this, decision-making processes will need provide a safe and consistent way of working to ensure that all infrastructure is managed in a safe manner and within critical limits. The critical limits must also consider the effect of weather now and in the future to improve the asset management system in a way that strikes appropriate balance between stakeholder expectations regarding system reliability, risk and cost.

All critical risks will be assessed and interventions will be aligned to the principles defined in asset policies for operational assets to set out the requirements for decision-making to identify the work we need to deliver to achieve the required network and route outputs for the funding available. This will also include defining resilience requirements as a specified range of weather conditions, taking account of climate change guidance.

Technologies and tools will be developed and used to support fact-based whole life cycle decisions on maintaining, renewing and enhancing the infrastructure and improving our capability for predicting and preventing failures. Whole life cost models will be enhanced with climate change included for all different weather types that affect Network Rail's assets.

The policies do not currently overlap between different assets despite dependencies (e.g. drainage and earthworks have dependencies, but their asset policies are produced in isolation of each other). This creates a vacuum for managing asset risks from adverse or severe weather and does not help to produce standards and designs that would otherwise address these risks.

Although our assets meet or in some cases are over and above Euronorms (European standards), as part of our adaptation plans, these will need to be further developed based on climate projections and updated to reflect future weather challenges.

As we approach CP7, regions will own their strategy and plans with focus on bottom-up workbanks using models to assist them.

These will be derived using asset risk assessments, to support decision making and assurance as part of their planning activities for the next control period.

9. Action plans – Weather and climate resilience

We recognise the challenges that the changing climate will bring to the management of our infrastructure. However, it is important to note that it is not economically viable to strengthen all sub-standard infrastructure within the next 30 years, nor is it technically or economically possible to eliminate all risks from the furthest extremes of the weather scale e.g. 1:1000 year storms. It is therefore inevitable that we will continue to experience some asset failures during extreme weather. We will target our highest risks and through continuous improvement and continue to evolve our application of technology and refine our operational procedures to respond quickly to manage the safety impact of asset failures to protect our passengers and freight.

Many actions have been identified to address the risks and gaps summarised in this report and detailed in the Appendix. This section provides an overview of the headline actions which are required from an overarching asset management perspective or which are applicable to many of the asset functions. Several of the actions are cross discipline and have some interdependencies on other assets or external agencies/third parties, but offer the opportunity for shared learning. Our whole life cycle modelling requires updating with several data layers to factor the impact of extreme weather on asset degradation on individual assets and also across asset classes. Developing these models with climate change projections in mind will enable prediction of future impact from weather on Network Rail's assets.

Key activities to be delivered by asset functions include:

- Updating asset policies for CP7 to factor in climate change impacts, including the development of WLC models
- Identifying and updating critical standards to take account of the asset/component vulnerabilities identified in this study,
- Updating asset/component specifications to strengthen designs and improve resilience to climate change in line with Network Rail Climate Change Projections guidance (NR/GN/EDS/23),
- Systems review of interdependencies and impacts between different asset classes,
- Water management to mitigate accelerated degradation of assets and compound effect on other assets through resilience management such as rapid response and time to fix failed assets minimising the length of disruptive events,
- Development of decision support tools,
- Research, development and innovation to determine impacts and solutions to improve asset resilience to climate change, and
- Recommendations from the Weather Action (Dame Julia Slingo report) and Earthwork (Lord Robert Mair report) taskforces.

Asset owners have been assigned to the action plans produced with target dates to assure that activities are being managed and delivered in a timely manner.

Each asset function will be required to provide updates to their respective discipline officer from the Office of Rail and Road (ORR) to demonstrate that actions are being managed.

The table on the next page provides a summary of some of the key actions plans across all asset functions in response to Network Rail's climate change projections guidance (NR/GN/EDS/23).

Table 10: Overview of headline actions

Action type	Owner	Implementation timetable	Action plans and future scope
Monitoring and management review	Chief engineer	5 yearly review (mid control period) with interim review at the start of control period.	The analysis outlined in this report will be reviewed every five years to reflect updates to climate change projections and to enable updates to standards in advance of future control periods. Review of each asset function's progress with climate risk management plans to be tracked and updated in individual asset function Enterprise Risk Registers (ERRs).
Enterprise Risk Registers	All Asset Functions	31/12/2021	Review of each asset functions progress with climate risk management plans to be tracked and updated in individual asset function ERRs.
Climate risk assessment and action plans	Telecoms	30/06/2022	Complete weather and climate change risk assessment and develop action plans to address any significant gaps identified.
Whole life cycle models	Head of asset management strategy	31/03/2025	Development of whole life cycle models to incorporate weather and climate change into asset sustainability models to measure degradation.
Asset Policies for CP7	All Asset Functions	31/12/2021	Update policy to reflect approach to managing climate change risks in line with Network Rail Climate Change Projections guidance (NR/GN/EDS/23) and through justification and prioritisation of available funding. This includes review of interdependencies between asset functions.
Standards	All Asset Functions	01/12/2021	Identify critical standards which require update in order to incorporate climate change as appropriate in line with Network Rail Climate Change Projections guidance (NR/GN/EDS/23).
Asset Specifications	All Asset Functions	31/12/2023	Review and update materials, component and asset specifications to improve resilience to climate change projections, where assessed appropriate with asset whole life cost. This includes review and update of design standards relating to the design and maintenance of drainage systems.

Action type	Owner	Implementation timetable	Action plans and future scope
Asset inventory and condition monitoring	Structures, Geotechnical, Drainage, Tunnels and Mining	31/03/2024 (Drainage) 01/12/2025 (other assets)	Evaluation and improvement of asset knowledge, inventory and condition to enable determination of effects to control against different weather events, e.g. flood defence requirements. Condition assessments and remote monitoring techniques will also need to include interaction with other surrounding assets.
Water management	Drainage, Geotechnical, Track, Structures, Power Distribution	01/12/2024	Review and update existing drainage and water management strategy which includes consideration of catchment-based impacts for the management of current and future precipitation and water flows to incorporate climate change in line with the Network Rail Climate Change Projections guidance (NR/GN/EDS/23). The review to include flood mitigation measures in low-lying and at-risk areas which account for current and projected flood levels and the effects on all assets identified as a risk.
Impacts from asset function interdependency from multi-discipline systems and third-party risk assessment reviews	Drainage, Geotechnical, Track, Structures, Power Distribution, Signalling	Various: from 01/04/2024 to 01/07/2026	Review of the effect of adverse and extreme weather on assets and compound effect on adjacent or dependant asset classes to develop revised specifications and common strategies for management of heat, rainfall, river flows, sea level rise and catchment-based impacts from third parties.
Impacts from River flows and Sea level rise	Structures	01/12/2025	Review and update scour standards and remedial actions to align with projected increases from climate change from sea level rise and river flows alongside catchment-based assessments.
	Drainage	01/06/2022	Review outfalls and robustness of these in catchment areas to account for rises in river or sea levels.

Action type	Owner	Implementation timetable	Action plans and future scope
Research, Development and Innovation	OLE	30/12/2021	Determination of robust OLE designs and conversion of legacy systems to build in more resilience.
	Track	01/12/2022	Track lateral support and behaviour of Continuously Welded Rail within different track designs and features, determination of revised Stress-Free Temperature (SFT) and non-destructive testing/measurement of rail stress.
	Tunnels & Mining	2024	Development of automated/remote inspection techniques and icicle prevention/ automated removal techniques to improve the quality, efficiency, repeatability and reproducibility of asset inspections and evaluations.
	Geotechnical	01/12/2025	Determination of the behaviour and effects of Soil moisture and pore water pressure on tunnel portals, drainage and earthworks.
	Drainage	01/07/2024	Measurement and Identification of the effects of different ground settlements on piped drainage systems.
Recommended actions from Weather Action Taskforce	Geotechnical, Drainage	2022	Review of Weather Action Taskforce (Dame Julia Slingo report) recommendations and work with other asset functions to develop actions to improve current weather and future climate operational risk management.
Recommended actions from Earthworks management Taskforce	Geotechnical, Drainage	2023	Review and develop actions from Earthworks Management Taskforce (Lord Robert Mair report) and work with other asset functions to improve current weather and future climate risk management.

10. Management and review

Network Rail is committed to ensuring that we will appropriately govern and assure implementation of our strategies and plans. This plan forms a key milestone on the climate change adaptation roadmap in our Environmental Sustainability Strategy. It is owned by the chief engineer and the Office of Rail and Road (ORR - Network Rail's regulator) will monitor progress in implementation during CP6 and beyond.

Successful implementation of weather resilience and climate change adaptation plans across the whole of Network Rail requires a long-term commitment to the regular review and management of the process at all l evels of the business. This will ensure the timely delivery of the technical and cultural changes necessary to develop cost-effective climate change adaptation strategies and actions which will avoid unacceptable increases in safety risk, system unreliability or the compromising of downstream risk mitigation strategies.

The following high-level management, review and reporting will be undertaken:

- Asset functions will provide updates on implementation of these climate change action plans to the chief engineer and the Technical Authority Environment and Sustainability Team twice a year,
- An overarching summary of progress will be reported to the Executive Leadership Team's Sustainable Growth Strategy Committee twice a year,
- ORR will track progress through Quarterly Liaison Meetings with the chief engineer, asset professional heads and the chief environment and sustainability officer,
- Asset climate change action plans form a key control in managing Network Rail's enterprise risk for weather and climate change which is managed through Technical Authority and Board Business Assurance Committees,
- The Technical Authority Environment and Sustainability Team will use the information in this report to inform the next National Climate Change Risk Assessment being compiled by the Climate Change Committee and as part of its Adaptation Report under the Climate Change Act which is due to be submitted to Defra by 2021, and
- The climate change risk assessment will be revised every five years and action plans updated accordingly

Network Rail is also engaging with the wider rail industry and other international railways to review weather resilience and climate change activities to identify opportunities for collaboration to facilitate effective increase in rail system resilience.

11. Definitions and abbreviations

Asset functions	Refers to engineering disciplines within Network Rail that is accountable for Infrastructure with a distinct value that make up the operational railway.
Adaptation	Climate change adaptation is action taken to improve the resilience of assets, networks and systems to future weather conditions, avoiding, minimising or mitigating the impact of more severe or frequent adverse and extreme weather events and gradual or erratic changes in weather patterns due to climate change.
Adverse weather	Weather conditions that are challenging for operating the railway, such as snow, ice, heavy fog, floods, rain and excess heat, and which increase risks to infrastructure, services and rail users.
Adaptation Reporting Power (ARP)	The Adaptation Reporting Power (ARP) of the UK Climate Change Act (2008) allows the Secretary of State to ask key organisations to report on their risks from climate change and the steps they are taking to prepare for them. This is done every 5 years.
Asset lifecycle	A series of stages involved in the management of an asset throughout its life.
Bufferstops	A device usually fitted on the end of a terminus station to prevent railway vehicles from going past the end of a physical section of track.
Catchment	A catchment is an area of land drained by a defined drainage system (manmade or natural).
Climate	Defined as average weather over a longer time period (ranging from months to many years). The classic period for averaging these variables is 30 years, as defined by the World Meteorological Organisation. For the definition of weather see below.
Climate Change	A change in global or regional climate patterns, attributed to changes in levels of atmospheric greenhouse gases.
Climate Projection	Modelled response of the climate system to a scenario of future greenhouse gas emissions (or of greenhouse gas concentration levels). For example, the UKCP18 RCP2.5 scenario assumes rapid decarbonisation of the world economy and a rapid shift to renewable energy.

Climate Scenario	A projection of future greenhouse gas emissions used by analysts to assess future vulnerability to climate change using future population levels, economic activity, the structure of governance, social values, and patterns of technological change. Economic and energy modelling can be used to analyse and quantify the effects of such drivers.
Coastal Flooding	Is where high tides and/or storm surges raise the sea level and/or wave height above that of the natural coastline or defences causing over topping.
Committee on Climate Change (CCC)	An independent, statutory body established under the Climate Change Act 2008. Their purpose is to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of climate change.
Control Period (CP)	CP6 – control period 6 2019-2024 CP7 – control period 7 2024-2029
Convective rainfall	This type of rainfall commonly occurs in summer months for the UK and is the result of intense and usually localised storms.
Critical asset standards	Standards associated with asset that have a high consequence if they fail.
Diurnal temperature range	The difference between the lowest and highest temperatures in a 24 hour period.
Delay minutes	Disruption to passenger trains, calculated in minutes, against the agreed timetable.
Environment Agency (EA)	Environment Agency- English environmental regulator.
Extreme Weather	Weather conditions which are so severe that consideration has to be given as to the level of service which can be safely operated. Extreme weather includes intense rainfall, repeated freezing and thawing, prolonged hot weather.
GIS	Geographical Information System – Digital mapping.
Heat wave	A heat wave occurs when a location records a period three or more consecutive days with daily maximum temperatures meeting or exceeding a heatwave temperature threshold. The threshold varies by UK county.

Isostatic Rebound	Also called continental rebound, post-glacial rebound or isostatic adjustment, this is the rise of land masses that were depressed by the huge weight of ice sheets during the last ice age e.g. Scotland. In the UK this off sets a degree of the sea level rise in the north of the UK and increases the impacts in the South of the country as it sinks.
Level crossing booms	Barriers and gates fitted at level crossings to clearly indicate to vehicles and pedestrians that the crossing is closed.
Mitigation	As this report is concerned with the adaptation of Network Rail's assets to the impacts of weather and climate change 'mitigation' does not refer to the reduction of greenhouse gasses in the context of this report. It refers to actions taken to reduce the vulnerability of assets to weather events and the subsequent reduction in the nature, frequency and scale of their impacts.
Overtopping	Occurs when excess water creates waves that exceed the height of a structure designed to retain it.
Pantograph	An apparatus which is mounted on the roof of electric trains to collect power through an overhead wire.
Point heaters	Heating element fitted to switch blades to prevent ice forming or snow build up.
RCP	Representative Concentration Pathways are the current IPCC climate projection scenarios There are four: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These scenarios have been used in the UKCP18 climate projections.
Resilience	The ability of assets, networks and systems to anticipate, absorb, adapt to and rapidly recover from disruptive events. This includes the adaptive capacity gained from understanding current and future risks to our assets.
River Flooding	Also known as fluvial flooding. Caused by the migration of snowmelt or rainfall into watercourses raising their flows to the point where they exceed the channel capacity and overtop the banks and/or flood defences into the flood plain.
Schedule 4	Compensation agreement paid to train operators for the impact of planned service disruption to cover fare revenue losses or costs (such as running replacement buses for passengers).
Schedule 8	Compensation agreement paid to train operators for the impact of unplanned service disruption to cover refunds to passengers and other resultant costs such as diversions or emergency replacement buses.

Scour	Erosion of soil surrounding a bridge foundation.
Shore supplies	Shore supplies are provided at railway stations, depots, and stabling sidings as a facility to pre-heat, air condition and provide lighting and general power to rolling stock.
Stress Free Temperature	Temperature range at which a rail is not in tension or compression.
Storm Surge	An increase in sea level under storm conditions, beyond the normal tidal maximum, due to low atmospheric pressure and gale force winds forcing water towards the coastline.
Surface Water Flooding	Also known as pluvial, rainfall or flash flooding. The result of rapid snowmelt or intense or prolonged rain falling onto land and accumulating at low points in the topography.
Switchgear	Electrical components such as switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.
Track side furniture	Equipment including signs. Mechanical equipment, components that are fitted to the railway to operate it safely and punctually.
Trigger level	A concentration or exceedance which sets off a specific response that exceeds design limits.
(T&RS)	Traction and Rolling Stock.
UK Climate Change Risk Assessment (CCRA)	The UK CCRA is completed every 5 years and summarises the key climate risks facing the UK as the basis for informing government adaptation and the 5 yearly National Adaptation Plan. The iteration for 2021 is CCRA3.
UKCP09	National climate projections for the UK produced in 2009.
UKCP18	National climate projections for the UK produced in 2018.
Value framework	The value delivered from spending to improve outcomes for passengers.

Vulnerability	In this context, the predisposition to being adversely affected by weather events or impacts.
Weather	The occurrence of weather variables such as temperature, precipitation and humidity, in the short term, as opposed to the long-term definition of climate. See above.
Washouts	The removal of material that is usually caused by constant or heavy rain.
Workbanks	A list of work activities associated with infrastructure defects or renewals.
Wrongside failure	A failure condition in a piece of railway equipment (usually signalling related) that results in an unsafe state.

Appendix 1

(i) – Risk assessments

(ii) – Gap analysis

(iii) – Action plan and monitoring

For further detail on these datasets please see the appropriate tab of the attached spreadsheet.