TRANSPORT FOR THE NORTH

Climate Change Vulnerability Assessment

Final Report

September 2025

Overview

Transport for the North's (TfN's) Climate Change Vulnerability Assessment aims to improve understanding of how risks such as extreme temperatures, flooding and ground instability could affect the North's heavy rail and major road transport infrastructure. TfN worked with specialist consultancy Accelar, to assess and map levels of vulnerability across the North. A summary of the key findings is presented below, ahead of the main report authored by our consultancy partners.

This work aligns with national adaptation policy under the Climate Change Act 2008 and responds to growing evidence that climate and weather impacts on infrastructure will intensify over the coming decades. This assessment supports TfN's role in assisting our constituent authorities with both local and pan-regional resilience planning and reflects the increasing importance of adaptation in future infrastructure policy and investment.

The assessment combines publicly available climate hazard datasets with GIS mapping and infrastructure usage data to evaluate the likelihood and severity of climate impacts across the North's transport networks. Four priority hazards (flooding, slope integrity, extreme weather including temperature, wind, and wildfire, and ground stability) were identified using UK Climate Projections, expert input, and stakeholder engagement, with the methodology shaped by feedback from TfN's constituent authorities as well as wider stakeholders including DfT, Network Rail, and National Highways.

Key Findings

Flooding

The flooding assessment found that while most of TfN's Major Road Network and rail corridors are at low risk, certain areas face significantly higher vulnerability. Around 21% of the road network, particularly near rivers and floodplains such as the A65 in Kendal and A650 east of Bradford, showed moderate or high flood risk. For rail, only 2% of the network was similarly exposed, with notable risks around Doncaster and Sheffield. These findings highlight that although widespread flooding risk is low, localised impacts could be severe.

Slope Integrity

The assessment found that most road sections across the TfN network have a low likelihood of slope or embankment failure, with only a few areas near Hull, Selby, and Norton showing elevated risk. The A139 near Norton was the only road section identified with major vulnerability. In contrast, 68% of the rail network was classified as highly susceptible due to unstable soils, though overall impact is generally low given the location of these sections. However, any disruption could have wider consequences across the rail system.

Extreme Weather

Most road and rail corridors across the North are exposed to at least one type of extreme weather, such as high or low temperatures, wildfires, or strong winds, with many areas facing multiple hazards in combination. Key area of risks are concentrated around urban centres like Manchester, Liverpool, Sheffield, Newcastle, and York, where overlapping hazards affecting busy parts of the transport network pose significant threats to both road and rail infrastructure.

Ground Stability

Ground stability risks across the North of England are generally low, with only a few isolated areas, such as parts of Middlesbrough and Doncaster, showing a probable likelihood of shrink-swell impacts. The A66 through Middlesbrough is the only road section rated as severe risk, due to high traffic volumes and significant exposure to unstable ground. The rail network shows a similar pattern, with most corridors assessed as low risk.

Transport for the North

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Version: Final Draft for Client Review

March 2025

accelar

1. Introduction

Transport infrastructure across the North of England is increasingly at risk from the impacts of climate change, such as flooding, extreme temperatures, and ground instability. To address these challenges, Transport for the North (TfN) has commissioned a Climate Change Vulnerability Assessment to better understand these risks and use this information to consider how the region might plan for long-term resilience. This report outlines the findings of that Climate Change Vulnerability Assessment, highlighting the areas that are most vulnerable to climate change.

With a growing focus on the impacts of climate change, new strategy and policy frameworks are emerging to support adaptation and resilience planning. In the UK, the Climate Change Act 2008 provides the legal foundation for managing climate risks. Under this framework, the UK Government is required to:

- Assess and report climate change risks by preparing an assessment of the risks of climate change to the UK and presenting it to Parliament every five years;
- Prepare a National Programme of Adaptation that sets out objectives, policies, and proposals for addressing these risks;
- Assess progress on implementing the National Programme of Adaptation.

The Climate Change Committee, an independent statutory body established under the Climate Change Act, is responsible for assessing the risks posed by climate change to the UK. In January 2017, the committee published the second Climate Change Risk Assessment (CCRA), which identified flooding as one of the most significant risks to the UK's infrastructure. The report projected that by the 2080s, the number of transport assets at risk from flooding could double under expected climate conditions.

The CCRA Summary for England highlights specific risks that have high future magnitude and where immediate action is required. Of particular relevance to transport infrastructure are:

- The risk of more frequent flooding and coastal erosion, which could damage key infrastructure services such as energy, transport, water, and information and communication technologies (ICT); and
- The impact of extreme temperatures, high winds, and lightning on the transport network, which could lead to disruptions and infrastructure damage.

Although there is no established blueprint for how sub-national transport bodies should address climate resilience, TfN, like other regional bodies, plays a crucial role in planning for resilience within the context of the UK's legal and policy framework. Transport for the North's Strategic Transport Plan (STP) recognises the growing importance of adaptation. It states, "as the effects of climate change on our transport system grow, we will need an increasing focus on resilience and adaptation, in relation to both planned infrastructure and existing networks."

1.1 Structure of the Report

Section 2 considers the Climate Change Profile for the North, offering an overview of the geographical and environmental factors that shape the region's vulnerability to climate change. This section explores how topography, soil types, and weather patterns contribute to risks such as flooding, slope instability, and ground movement. It is supported by a more detailed Climate Data, Geology and Environmental Trends assessment in **Appendix A**.

Section 3 contains the Assessment Process, which outlines the methodology used to conduct the vulnerability assessment. It describes the data collection and processing, the application of the risk-based framework, and the use of GIS mapping to identify risk areas across TfN's network. The assessment follows the framework set out in Accelar's Climate Resilience Risk assessment Tool (acra), a bespoke software-driven service that assesses the vulnerabilities and opportunities for planned and existing infrastructure in the context of a changing climate. By bringing together GIS mapping, projected climate information, and asset data, acra allows for both holistic oversight of entire infrastructure networks, and granular insights pinpointed to a local scale.

The Assessment Results in Section 4 present the key findings of the vulnerability analysis, highlighting specific risks such as flooding, extreme weather events, and ground instability, and showing which areas of the transport network are most vulnerable. The full assessment across each section of the TfN network is presented in **Appendix B**, and mapping supporting the findings is presented in **Appendix C.**

Section 5, Summary and Conclusions provide an overview of the main outcomes of the assessment and recommendations for next steps. These recommendations will guide TfN and its partners in incorporating climate resilience into future infrastructure planning and investment.

Accompanying the report is an Atlas Viewer[1], which provides an interactive tool for exploring the climate risks across TfN's transport network. The viewer allows users to visualise vulnerabilities in greater detail, helping stakeholders to prioritise resilience measures and allocate resources where they are most needed, this has been made available to key individuals within TfN.

1.2 Summary of Work Completed Informing this Report

The initial phase of this project was the development of a Scoping Report, produced in August 2024. The Scoping Report set out the key objectives and the methodology for the Climate Change Vulnerability Assessment. It defined the types of climate risks that would be assessed, focusing on critical issues such as flooding, slope instability, extreme weather events, and ground stability.

Flooding, including river, surface water, and coastal flooding, were identified as some of the most significant risks to transport infrastructure. The Scoping Report also highlighted the increased risk of slope and embankment instability due to higher rainfall and changing moisture levels in the soil. Other key risks included damage to transport systems from extreme weather, such as high winds and heatwaves, as well as ground stability issues, particularly in areas with clay soils or soluble rock formations.

During the Scoping stage stakeholders were contacted for feedback on the outline methodology and to ensure that any concurrent work they are carrying out does not provide a conflict. The report was provided for comment to the Department for Transport, National Highways, Network Rail and Energy Distributors. Responses provided from these stakeholders has been fed back into the assessment process as appropriate.

Following the Scoping Stage a workshop was held with TfN to take them through the findings and present potential areas for investigation. An output of the workshop was a **Metrics Briefing Note** which provided a detailed breakdown of the four main climate risk metrics that were selected for assessment. These metrics were:

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[1] Atlas is software developed by Ardent Management to manage data (within a GIS portal) and allow users to interact with the assessment findings.

- **Flooding:** This metric evaluates the risk of flooding—whether from rivers, surface water, groundwater or coastal sources—on transport infrastructure, including road and rail networks. The emphasis is on how projected changes in rainfall patterns and sea levels could increase the frequency and severity of flooding events, leading to disruptions and safety hazards.
- **Slope Stability**: This metric assesses the vulnerability of slopes and embankments to failure due to projected increases in rainfall and soil moisture variability. The focus is on predicting how these changes might increase landslide risks, affecting both road and rail networks, particularly in areas where these networks converge.
- **Extreme Weather**, this metric focuses on the impact of predicted extreme temperature events—both high and low—on transport infrastructure, including the risk of rail buckling, road surface damage, and the potential for wildfires. The metric also considers urban heat island effects, where higher temperatures in urban areas could exacerbate infrastructure stress, and the role of shading and tree coverage in mitigating these effects. and
- **Ground Stability**, this metric examines the risk of ground subsidence due to shrink-swell soils and soluble rock formations under future climate conditions. The focus is on areas within the TfN region known for these geological features, assessing how predicted changes in rainfall and temperature might exacerbate subsidence risks, leading to infrastructure damage and service interruptions.

For each metric, both likelihood and impact scores were calculated, allowing for a comprehensive assessment of each section of the major road and heavy rail network within the TfN area. The metrics are explained in further detail in Section **Error! Reference source not found.** of this report.

2. Climate Change Profile for the North

2.1 Introduction

The North of England, with its diverse landscapes and regional characteristics, faces a variety of climate-related risks. These risks are shaped by the region's geographical, geological, and environmental conditions, which in turn affect the transport infrastructure connecting its urban, rural, and coastal areas. This section summarises the current and projected climate conditions in the region, setting the context for the assessment. **Appendix A** provides a more detailed climate profile.

Transport for the North (TfN) covers a broad geographical area, encompassing North West England, North East England, and Yorkshire & the Humber (**Figure 2.1**). These areas, with their varied topography and land use, experience different climate impacts.

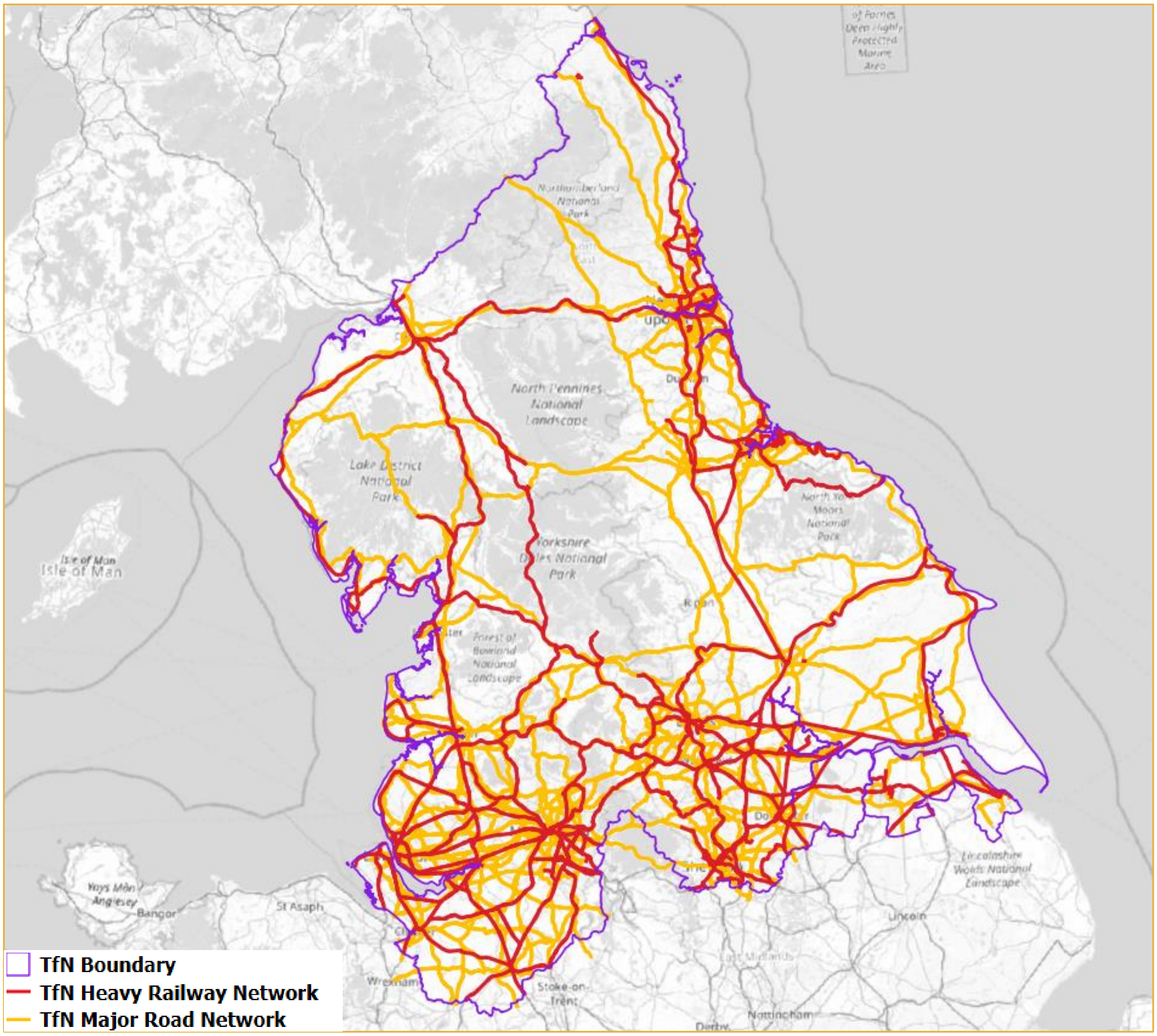

Figure 2.1 Transport for the North Region

The North of England experiences a temperate maritime climate, with significant variation across its regions. Local climate conditions are heavily influenced by the region's topography, proximity to the coast, and elevation.

Temperatures across the region are generally cooler than in southern parts of the UK, with average annual temperatures ranging from 8°C to 11°C, around 2°C lower than in the south. Winter temperatures are often cold, with frost and snowfall common in upland areas such as the Pennines and Lake District, while coastal regions tend to experience milder conditions. Under future climate projections (RCP 8.5), extreme temperatures in the North of England are expected to increase significantly, with summer heatwaves potentially reaching highs over 30°C. In winter, although milder conditions are projected overall, cold snaps may still bring temperatures near or below freezing.

Rainfall patterns are also heavily influenced by topography, with western upland areas, particularly the Lake District and Pennines, receiving some of the highest levels of rainfall in the UK. These areas can see annual totals exceeding 2,000 mm, while lowland areas to the east, such as the Vale of York, experience much lower levels of precipitation. This distribution makes upland transport routes particularly susceptible to flooding and landslides, although lowland routes also face increasing flood risks due to changing rainfall patterns.

In recent decades, the North of England has experienced significant changes in its climate, in line with broader national and global trends. The region has seen a rise in average temperatures, with the UK as a whole warming by around 1°C since the 1950s. Warmer summers have become more common, with heatwaves occurring more frequently, particularly in urban areas such as Manchester, Leeds, and Newcastle. At the same time, winters have become milder, with fewer frost days and less snow cover, particularly in lowland areas.

Rainfall patterns have also shifted, with an increase in the frequency and intensity of heavy rainfall events. These changes have led to more frequent flooding, especially in river valleys and low-lying urban areas. The floods caused by Storm Desmond in 2015, for example, resulted in widespread disruption to transport networks with the resultant infrastructure damage leading to an estimated £500 million in economic costs, with Cumbria being one of the hardest-hit areas. As recent as October 2024, the A1(M) between Newton Aycliffe and Bradbury was closed due to flooding causing major disruption for motorists on the main route between Newcastle, Durham, Darlington and the south[2].

Land stability is an ongoing issue with key routes like the A57 Snake Pass recently experiencing closures, with some landslip repairs estimated at up to £15 million[3]. The region's unique geology, combined with more extreme weather, is creating significant and ongoing challenges for infrastructure resilience, prompting the council to seek additional government funding to support sustainable repair efforts.

2.2 Geographical and Environmental Profile

Transport for the North's geographical remit covers a diverse area, ranging from the industrial heartlands of cities like Manchester, Leeds, and Newcastle, to the rural and coastal areas of Cumbria and the Humber. The varied topography of the region introduces different vulnerabilities to climate change, affecting the stability and reliability of the transport network.

The North West includes major metropolitan areas such as Greater Manchester and Liverpool, alongside rural areas across Lancashire, Cheshire, and Cumbria. The region's geography varies from

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[2] How flooding caused travel chaos as A1(M) and A68 closed | The Northern Echo

[3] Fears major landslip could shut A57 Snake Pass for good - BBC News

Derbyshire landslip repairs are 'huge cost burden' - BBC News urban areas to the uplands of the Lake District. The Lake District and Pennines experience some of the highest rainfall levels in the UK, increasing their susceptibility to flooding, landslides, and soil erosion.

In the North East, the industrial heritage of cities like Newcastle, Sunderland, and Teesside coexist with rural areas and the exposed coastline of Northumberland. This region's economy, historically centred on heavy industries, is now focused on advanced manufacturing and energy. The coastal areas, particularly around the Tees and Tyne rivers, are vulnerable to both coastal erosion and inland flooding, posing risks to critical transport links.

The Yorkshire & the Humber region encompasses a range of landscapes, from the Pennine hills to the lowlands of the Vale of York and the Humber estuary. The urban centres of Leeds, Sheffield, and Hull are crucial economic hubs, but they also lie in areas prone to river flooding, particularly from the Ouse and Humber rivers. Rural areas, such as those in the North York Moors, are exposed to soil erosion and landslides, whilst coastal regions face significant risks from sea level rise and storm events.

The environmental characteristics of the North influence the region's vulnerability to climate change. The diversity of soil types across the region also affects transport resilience.

2.3 Projected Climate Changes

Climate projections for the North of England indicate further significant changes, particularly under high-emission scenarios. These changes will have profound implications for the region's transport infrastructure, necessitating adaptation and resilience measures, **Figure 2.2** sets out the general trends for the north.

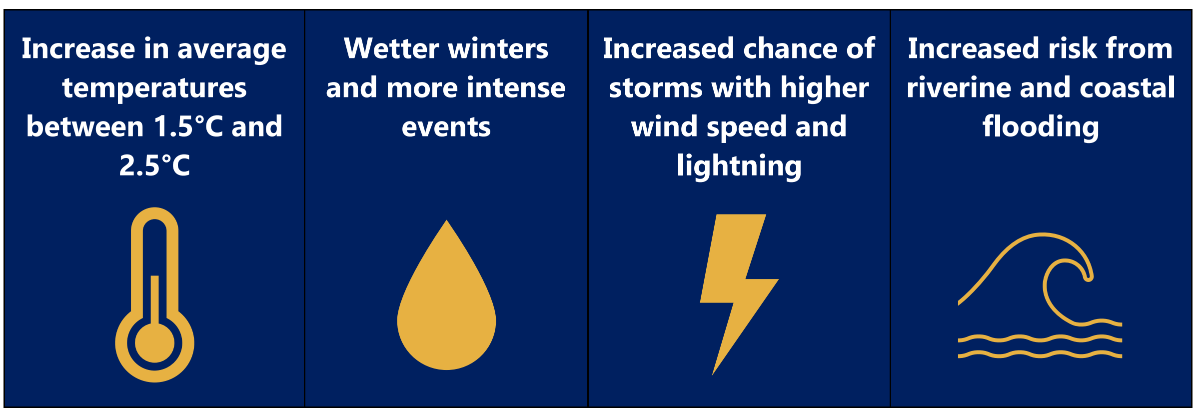

Figure 2.2 UKCP18 Climate Trends for the North of England

Temperature projections suggest that between 2040 and 2060[4], the North of England could experience an increase in average temperatures of between 1.5°C and 2.5°C under moderate-emission scenarios (against the baseline period of 1981-2000). The frequency and intensity of heatwaves are expected to increase, posing challenges to transport infrastructure, such as the risk of rail track buckling and road surface damage.

Precipitation patterns are also expected to change, with wetter winters and more intense rainfall events likely. This will exacerbate the risks of flooding, particularly in upland areas such as the Pennines and Lake District, as well as in low-lying areas like the Humber and Mersey estuaries. Coastal transport routes will face additional pressures from rising sea levels, with the potential for increased coastal erosion and storm surges threatening infrastructure stability.

[4] UK Climate Projections 2018 (UKCP18)

The combination of rising temperatures, changing rainfall patterns, and more frequent extreme weather events presents a growing challenge for transport systems across the TfN area.

Appendix A provides a more detailed profile of the area and provides supporting information about the UK Climate Projections 2018 (UKCP18), which has been used to inform the profile for the North. This assessment has used Representation Concentration Pathways (RCP), which are different greenhouse gas concentration scenarios used in climate modelling. The RCPs included are:

- **RCP 4.5**: A moderate scenario where emissions peak around 2040 and then decline.
- **RCP 8.5**: The highest baseline emissions scenario where emissions continue to rise throughout the twenty-first century.

Focusing on RCP 4.5 and RCP 8.5 in this report provides a balanced view of potential future climate impacts, covering both moderate and high-emissions pathways. RCP 4.5 represents a scenario with achievable mitigation efforts, offering insight into risks if emissions are reduced, while RCP 8.5 captures the "worst-case" risks should emissions continue to rise.

The RCP scenarios themselves—RCP 4.5 and RCP 8.5—are global emissions pathways and not specific to the North of England. However, in this report, these scenarios are applied to the North through UK-specific climate projections, such as those from UKCP18, which provide regional climate impacts based on these global scenarios. By using these projections, the report tailors the global RCP scenarios to forecast likely temperature and weather pattern changes specific to the North of England.

Figure 2.3 shows the maximum temperature trends under a moderate scenario with a clear trend of growing maximum temperatures across all seasons of the year (against the baseline period of 1981-2000).

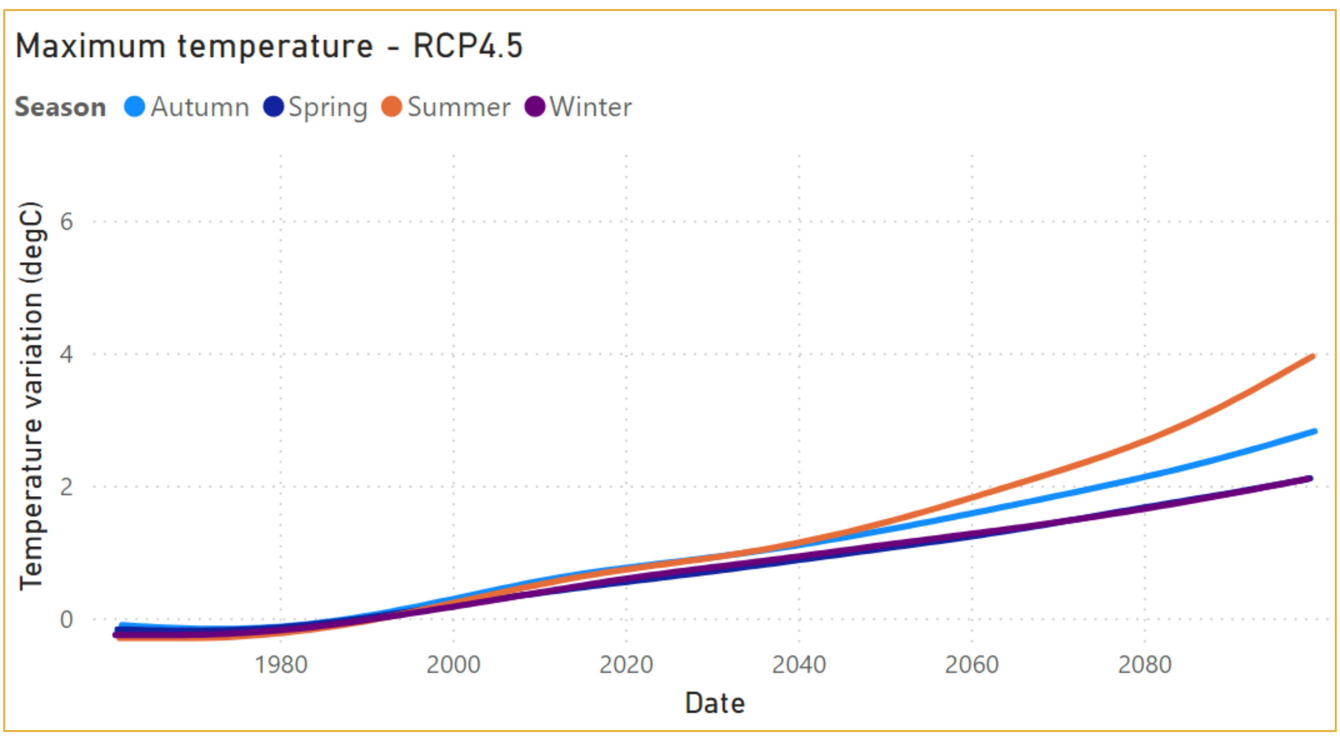

Figure 2.3 Maximum Temperature under RCP4.5 moderate scenario

Under the highest baseline scenario, **Figure 2.4** shows that the continued trend of increasing maximum temperatures across all seasons of the year, with a potential to exceed a temperature variation increase of over 6 degrees in summer by 2090 (against the baseline period of 1981-2000).

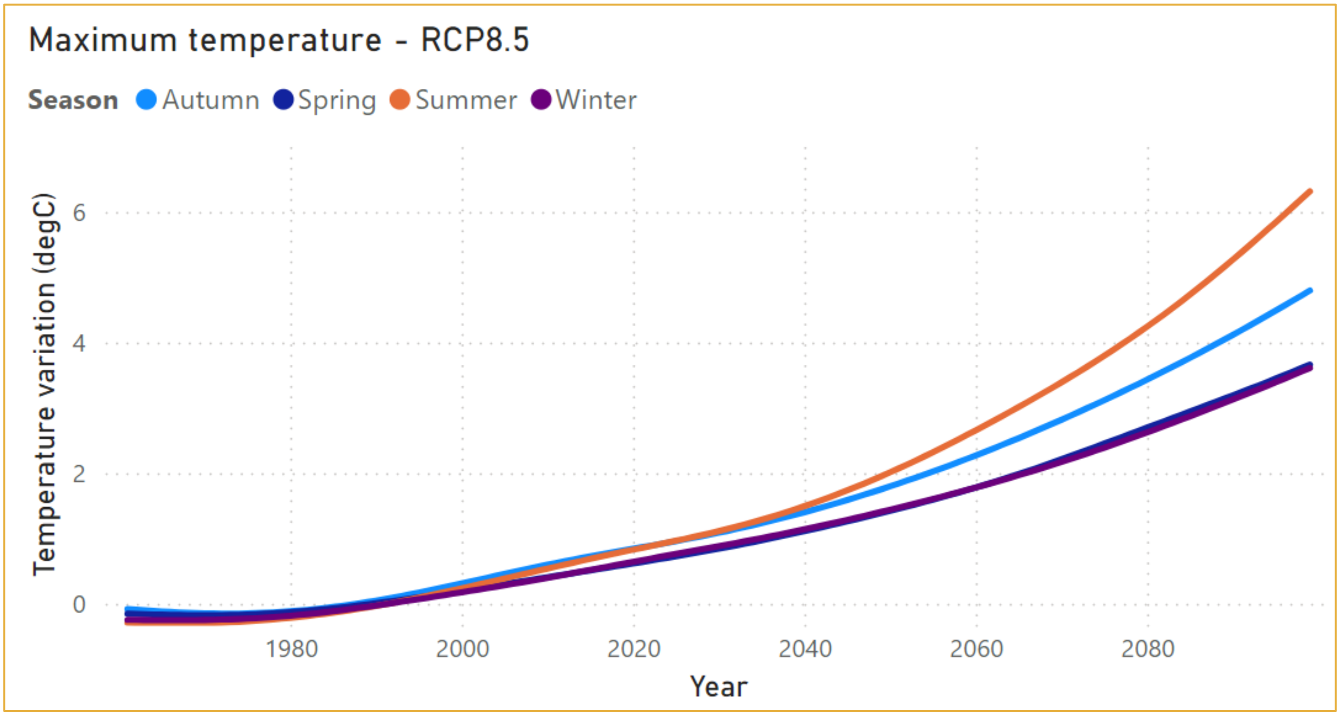

Figure 2.4 Maximum Temperature under RCP8.5 worst case scenario

In terms of precipitation, under the moderate scenario, the region is likely to be drier in summers and springs, but may experience increasingly wet autumn and winter seasons, as shown in **Figure 2.5**.

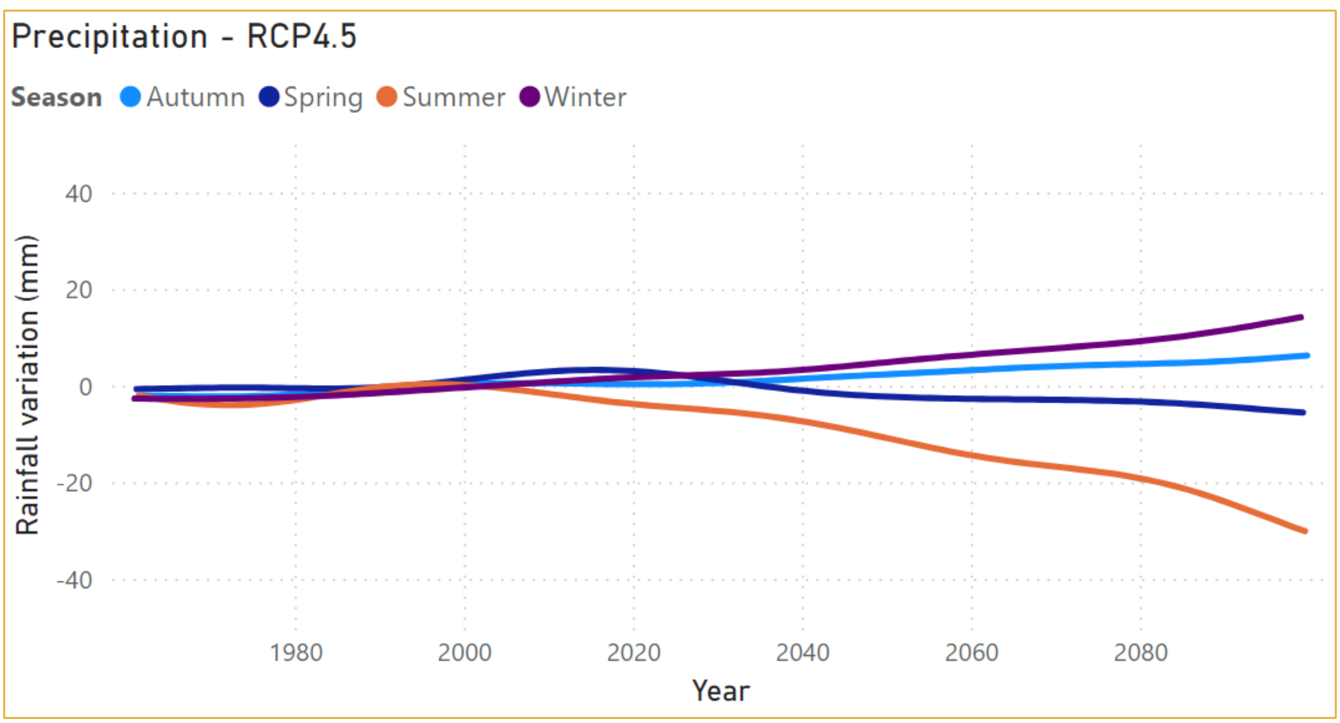

Figure 2.5 Maximum Rainfall under RCP4.5 moderate scenario

Under a worst case scenario, summers will become much drier, and overall the seasons will become much more varied in terms of precipitation levels, as shown in **Figure 2.6**.

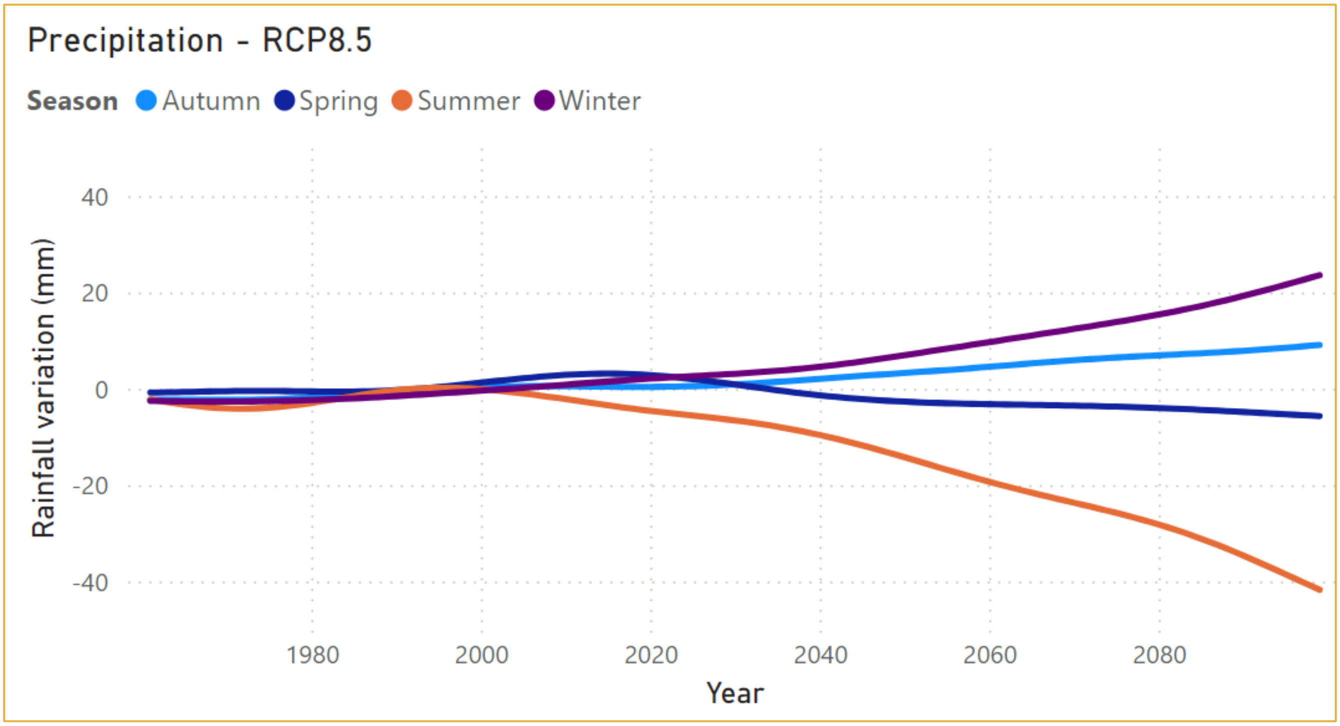

Figure 2.6 Maximum Rainfall under RCP8.5 worst case scenario

The trend under all scenarios will result in a change to the baseline in which infrastructure will operate. This mean that there will be ways in which infrastructure is affected, resulting in increasing vulnerability across networks, variation and new extremes under which they operate.

According to the UK Climate Projections 2018 (UKCP18), under the RCP4.5 scenario, the UK is projected to experience an increase in winter precipitation of approximately 10% to 20%[5] by the 2060s, relative to the 1981-2000 baseline. Under the RCP8.5 scenario, this increase is more pronounced, ranging from 20% to 30%. Conversely, summer precipitation is expected to decrease, with reductions of about 10% to 20% under RCP4.5 and 20% to 40% under RCP8.5 for the same period.

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[5] UK Met Office

3. The Assessment Process

This section outlines the methodology employed to conduct the assessment. During Scoping it was outlined that a high-level vulnerability analysis of road and rail infrastructure across the entire TfN area would be undertaken. The focus of the project is to provide a broad overview of climate vulnerability across the entire major road network and heavy rail network within the TfN area.

Based on the acra framework, a high-level assessment is considered the most appropriate for the scale of a project. This is shown in green in **Figure 3.1**. The high-level assessment provides outputs that allow for a quick and clear understanding of where the most and least vulnerable areas are located, and therefore the infrastructure vulnerability based on whether they are within these areas.

TfN or a local authority could also choose to apply a more detailed assessment along one of the identified most vulnerable sections to better understand the vulnerability, the pathway shown in orange in **Figure 3.1**. A full assessment is used to examine specific climate-related vulnerabilities at an asset level, useful for transport corridors requiring assessment at a granular level. It allows for precise vulnerabilities to be identified across a range of datasets and a broader range of impacts and subsequent metrics. This enables the identification of resilience opportunity areas; whereby targeted actions can be recommended based on the impact assessment outcomes.

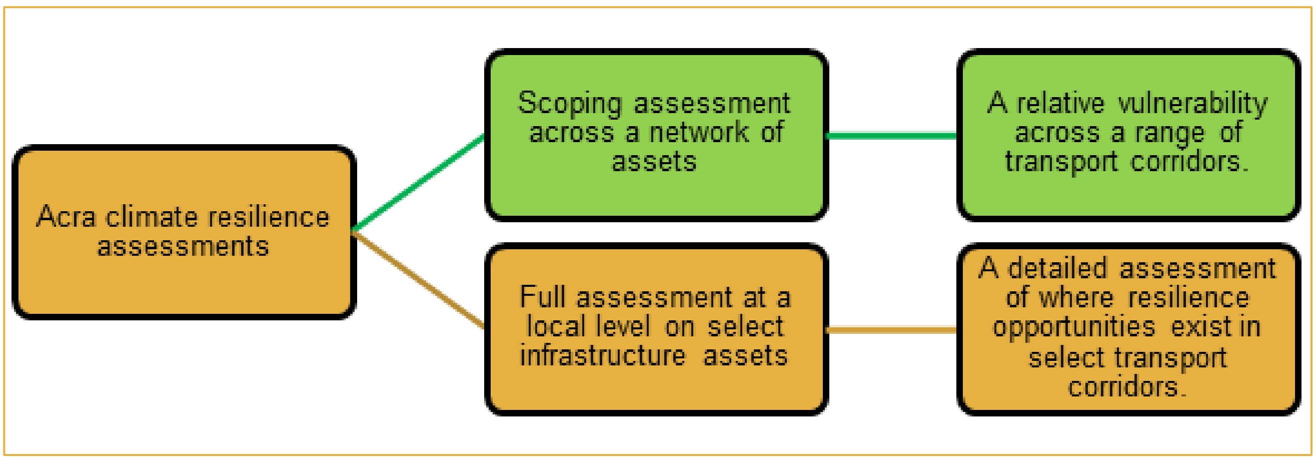

Figure 3.1: Breakdown of different types of resilience assessments, with the assessment pathway in green

A high-level assessment is used to look across a broader range of assets and locations and is designed to be used at a regional level to give a gauge on the resilience of different transport corridors. A full assessment is based on a more precise set of metrics, which will allow for relative vulnerability to be calculated.

Metrics have been defined for the high-level assessment based on data availability, and which climate parameters and subsequent impacts are a priority for the region. The outcomes from this high-level assessment provide some guidance as to which transport corridors require greater analysis.

3.1 TfN Climate Resilience Analysis Framework

To deliver the high-level assessment in a systematic and consistent manner, a framework was developed to ensure comprehensive consideration of all potential impacts, at a level of detail which is suitable for the spatial scale of the area being reviewed. This framework listed all known risks to transport networks, directly or indirectly, from climate-related sources. These were categorised based on the type of climate conditions that would cause such risks, as well as the type of infrastructure that may be impacted.

From this list, metrics that would allow quantification of the impacts were identified, along with datasets needed to produce the metric values.

3.1.1 Metric Selection and Design

Climate parameters that have a direct impact on TfN's transport network were identified using forecasting guidance including the UKCP18 projections. These parameters were discussed during a workshop in August 2024, with those having the most severe potential impact selected. The climate hazards caused by these parameters were identified, and then the measurements that could be used to quantify these risks were considered. **Figure 3.2** shows the hazards identified and their expected impact against the ability to find data that could support the modelling of the impact. Limitations such as data availability were included in the discussion, as an example there is more data available on high temperature compared to low temperature, which afforded a different 'ability to model' rating.

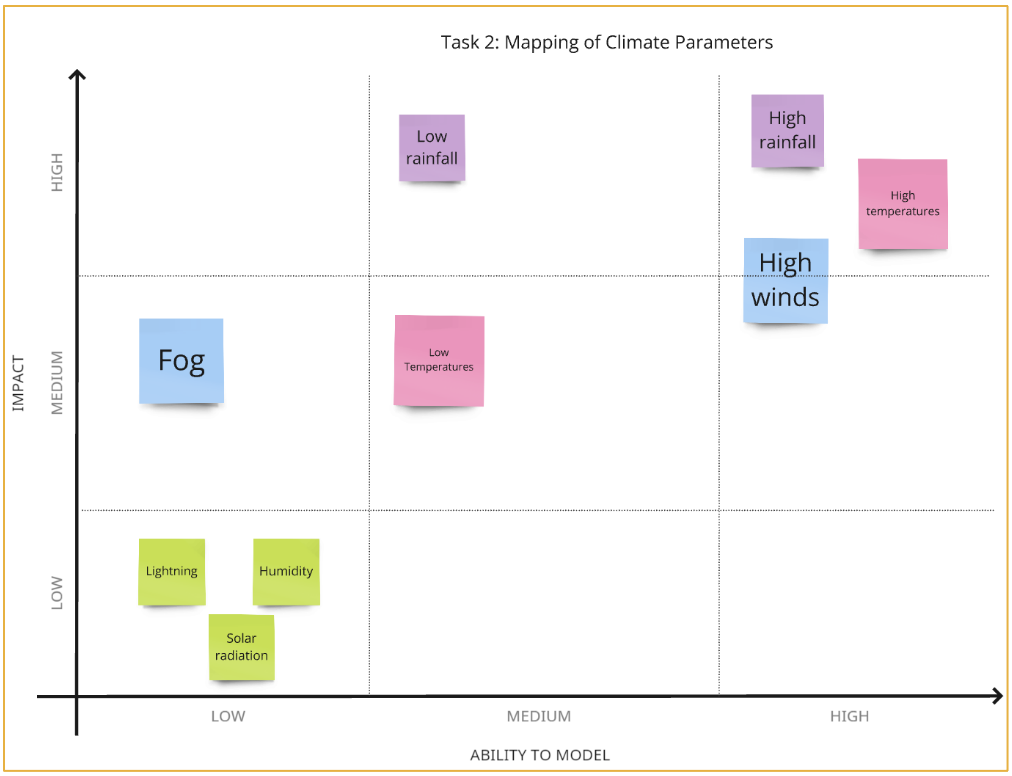

Figure 3.2: Climate parameter and impact review from the August workshop

Based on these discussions and previous scoping, four distinct metrics were developed, which have been utilised to cover different aspects of climate vulnerability. These were:

- Flooding,
- Slope integrity,
- Extreme weather conditions (including abnormal temperatures, wildfires, and high winds), and
- Ground stability.

These hazards have been chosen due to their significant impact on the integrity and functionality of transportation systems across the entire TfN area. All of these are critical to understanding the overall risk profile of the infrastructure network.

Following the identification of metrics, a review of all available climate resilience datasets was conducted to establish the quality of data available across a large range of sources. These were collated and reviewed in the data repository (**Appendix D**), and datasets that could potentially be used for quantitative analysis were shortlisted.

Each metric consisted of both a likelihood and an impact variable for the hazard being evaluated. A table summarising the metrics, their variables, and which datasets were used to quantify them is shown in **Table 3.1** with more detail provided within the 'Methodology' tab within **Appendix B**.

To determine the likelihood of risk to the network from each metric, the shortlisted spatial datasets were used to depict the areas most affected by the given hazard. In the case of extreme weather, with multiple datasets contributing to the analysis (maximum and minimum temperatures, wildfires, high winds, and storm damage), these were combined to give one layer for the likelihood of any form of extreme weather. The individual layers for the extreme weather metric were made available on the Atlas viewer.

Combining these with statistics around transport network usage was considered the most appropriate way to determine impact for slope integrity, extreme weather and ground stability.

Table 3.1: Variables used to evaluate the different metrics, and the datasets required.

	Flooding	Slope integrity	Extreme weather	Ground stability
Likelihood parameter	% of corridor at risk of flooding at 1 in 1000 level	% of corridor located on unstable soils	% of corridor at risk of extreme weather	% of corridor at risk of possible or probable shrink-swell
Datasets	• Risk of Flood from Rivers and Sea • Risk of Flood from Surface Water	• Soil material	• Maximum future temperatures • Minimum future temperatures • Risk of wildfires • Risk of high winds • Risk of storm damage	• BGS GeoClimate shrink-swell (for subsidence)
Impact parameter	Traffic flow within corridor	Traffic flow within corridor	Traffic flow within corridor	Traffic flow within corridor
Datasets	• Road traffic flows • Rail station usage data	• Road traffic flows • Rail station usage data	• Road traffic flows • Rail station usage data	• Road traffic flows • Rail station usage data

For road impact evaluation for slope integrity, extreme weather, and ground stability, the use of data on suggested alternative routes was considered. However, a major limiting factor for this dataset was the uncertainty around the closest available diversions being able to remain open under similar conditions. As such, it was decided that using the traffic flows would be a more consistent and reliable approach. However, this remains a potential area for further investigation at a more refined level, as set out in Section 5.1.

Once the metrics and data used to support the metrics was agreed, the framework assessment was updated with these inputs, along with the risk scoring profile. The metrics were devised to be applicable to both road and rail, with impact parameter data covering both types of infrastructure.

As set out in **Appendix B,** the framework also details how the risk is scored for each metric. The likelihood for each metric is the percentage of the area being assessed that falls within an area of significant risk from the given hazard, such as the percentage of a section that is located on unstable soils.

The datasets used to measure impact look to evaluate the expected severity of an occurrence in that corridor, for example the total number of vehicles travelling along the corridor that would be impacted.

Based on the datasets selected there is a varying future projection timescale. Generally, the datasets used were all only available for a single time period, which was 2060-2080, therefore, vulnerability should be expected within this time period.

3.2 GIS Viewer Atlas

The Atlas viewer was set up with the datasets identified in the data repository, including the infrastructure layers. With over 15,000 km of major road networks within the TfN boundary and 3,800 km of railway network, it is necessary to divide the network into discrete sections to allow for comprehensive analysis.

Road Analysis: It was decided to perform the assessment over sections up to 25km long, resulting in 795 sections across the TfN area. This section length was selected based on the availability of UKCP18 data at this level of granularity. This scale allows for a manageable evaluation of the entire area, dividing the region into hundreds rather than thousands of sections for analysis, whilst also being short enough to distinguish impact between adjacent sections. A 50m buffer either side of the road corridor is included in the analysis, to capture any impacts to adjacent features that may have knock-on effects for the network under evaluation. Each section is assessed independently to ensure that localised vulnerabilities are accurately identified and addressed.

Rail Analysis: Breakdown of the rail network into similar 25km lengths produced 193 sections. The same 50m buffer was applied either side of the corridors for inclusion of local impacts. Again, each section was assessed in isolation to avoid knock-on from upstream or downstream risks.

With the spatial extent and split of each section of infrastructure in place within the GIS viewer, layers were created to carry out the evaluation of the metrics within Atlas, following the risk-based assessment framework detailed in Section 3.1.

3.3 Framework Assessment Outputs and Analysis

Once the assessment was completed within Atlas, the metric scores produced for each corridor were analysed.

For standardisation purposes, the quantitative scores for each likelihood and impact variable were categorised into five bands. The upper and lower limits for each band are relative to data within the region, ensuring that the scoring was data-driven, locally sensitive, and objective (as far as practical at the TfN scale). A score for each band was assigned, ranging from 1 to 5, with 1 indicating the best possible score (least risk) and 5 representing the worst (highest risk). The definition of each band score for likelihood is shown in **Table 3.2**, with an example of banding for flooding. The respective definitions used for impacts are shown in **Table 3.3**. Details of the calculation and classification of each metric's likelihood and impact scores can be found in **Appendix B**.

Table 3.2: Definition of risk levels assigned to likelihood scores and example categorisation of flooding outputs

Score	Likelihood	Condition
5	Certain	75% - 100% of corridor at risk of flooding in a 1-in-1000-year scenario
4	Probable	50% - 75% of corridor at risk of flooding in a 1-in-1000-year scenario
3	Possible	30% - 50% of corridor at risk of flooding in a 1-in-1000-year scenario
2	Unlikely	10% - 30% of corridor at risk of flooding in a 1-in-1000-year scenario
1	Rare	0% - 10% of corridor at risk of flooding in a 1-in-1000-year scenario

Table 3.3: Definition of risk levels assigned to impact scores and example categorisation of flooding outputs

Score	Impact	Condition
5	Severe	Very high traffic flow / rail usage
4	Major	High traffic flow / rail usage
3	Moderate	Medium traffic flow / rail usage
2	Minor	Low traffic flow / rail usage
1	Negligible	Very low traffic flow / rail usage

To determine the overall score for each metric, the scores for the likelihood and impact variables are then multiplied together, giving a metric score between 1 and 25. The risk matrix is shown in **Table 3.4** below. This approach provides a nuanced understanding of both the probability and potential severity of climate-related events.

These metric scores are then allocated into Red, Amber, Green (RAG) categories. The conversion of numerical results into a RAG format required defining the maximum and minimum values that can be allocated to each colour. This distribution was adjusted based on the spread of metric scores across the region.

Table 3.4: Example Risk Score Matrix for a metric

		Impact				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Certain	5	10	15	20	25
	Probable	4	8	12	16	20
	Possible	3	6	9	12	15
	Unlikely	2	4	6	8	10
	Rare	1	2	3	4	5

Table 3.5: Associated RAG band colouring for a metric

Category	Description	Min score	Max score
Dark Red	Very high vulnerability forecasted	20	25
Red	High vulnerability forecasted	12	19
Amber	Moderate vulnerability forecasted	8	11
Pale Amber	Low vulnerability forecasted	4	7
Green	Minimal climate vulnerability forecasted	1	3

Dark Red is considered to have the highest vulnerability to climate change, and Green the lowest risk from climate change.

Application of these colours to the corresponding corridors in spatial visualisations can then help identify climate vulnerability hotspots, and opportunities for adaptation.

After quantification of each parameter, results are categorised into different bands via a universal scoring system. These scores are assigned based on the range of specific datasets for each 25km section, ensuring that the scoring is data-driven and objective. Details of the calculation and classification of each metric's likelihood and impact scores can be found in **Appendix B.**

Finally, the scores for each of the four metrics are aggregated to provide a total section vulnerability score out of 100. This cumulative score allows for a straightforward comparison of risk across different sections, highlighting areas that are potentially the most vulnerable to climate change. Supporting this output is the Atlas viewer where all the sections are colour coded with the RAG findings, and **Appendix B** provides mapping of the assessment.

3.4 Limitations

While this Climate Change Vulnerability Assessment seeks to provide a robust high-level framework for understanding the impacts of climate change on transport infrastructure across the North of England, there are some limitations to consider. These limitations highlight areas where future improvements can be made, and where additional data or analysis could enhance the assessment:

1. **High-Level Datasets**: Assessing the climate resilience across such a large and diverse transport network required the use of high-level datasets. The assessment focuses on key climate resilience parameters, being flood risk, slope stability, extreme weather, and ground stability. However, other climate-related parameters that could impact road and rail corridors, such as fog and other visibility-limiting conditions, were not fully explored due to data availability. Further inclusion of additional parameters in future assessments would strengthen the overall risk evaluation.
2. **Relationships Between Climate-Related Hazards and Infrastructure Impacts**: The methodology used allows for the identification of areas where climate-related hazards such as flooding and extreme weather events may coincide with infrastructure vulnerabilities. However, the direct relationship between these hazards and specific impacts on infrastructure, such as road traffic accidents or service interruptions, cannot be fully established with the available data. Influencing factors such as human error, mechanical failure, and infrastructure condition may also play a role, complicating the analysis of direct links.

3. **Accuracy of Geospatial Data**: The geospatial analysis and mapping were based on publicly available data layers for climate risks, including flood risk maps that cover the whole of England. These datasets, while comprehensive, may be less accurate than detailed, site-specific flood risk assessments that include topographic surveys and flow route analysis. Future assessments could benefit from incorporating more refined, area-specific data to provide greater precision in risk identification.
4. **Professional Judgement in Data Interpretation**: Elements of professional judgement were necessary throughout the assessment, particularly when interpreting data gaps or areas of uncertainty. While all assessments underwent quality assurance to reduce inaccuracies, the reliance on professional judgement could result in minor variances in the results. The methodology was applied consistently across the region to ensure comparability between sections, but future studies could automate additional aspects of the analysis to further enhance objectivity.
5. **Standardisation of Risk Metrics**: Due to the varying lengths and characteristics of transport corridors within the TfN area, a standardisation approach was adopted for the metrics. This involved calculating instances per kilometre for certain metrics. However, this method can obscure the severity of individual events. For example, a single critical flood incident along a long transport corridor may be diluted in the overall risk rating, potentially leading to lower prioritisation for mitigation efforts. Also, the potential impact from different sources – such as the possible disruption from a major storm being more substantial than an extreme heat event – may be obscured by giving each source an equal effect on the overall scoring. In such cases, more granular analysis of high-severity events could provide additional insights for targeted interventions.
6. **Data Gaps and Availability**: Some aspects of transport infrastructure vulnerability could not be fully evaluated due to data limitations. In some instances, desired data was not available or a decision was made that either due to timescale, cost and the basis that this assessment is a broad scoping exercise, rather than a detailed assessment, effort to obtain a dataset would not be proportionate to the activity. For instance, data on the usage of different rail corridors by passenger trains were not readily available, meaning approximations were required – in this case based on footfall at stations along each route. It was considered that this data was a suitable proxy for this scoping exercise. Freight train route usage data was also unavailable, so has been assumed proportional to passenger route usage. In future, more detailed applications it may be appropriate to review data collected. By acknowledging these limitations, this assessment serves as a foundation for future, more detailed analyses that could enhance TfN's understanding of climate resilience. Addressing these gaps in subsequent assessments will further strengthen the ability to plan for and mitigate the impacts of climate change on transport infrastructure.

4. Assessment Results

The following section presents the key findings from the assessment across the four metrics identified across the TfN network for both road and rail infrastructure. A summary is provided of the most vulnerable areas across the network for each metric, and an overall rating when the metrics are combined. **Appendix B** provides a detailed breakdown and scoring for each section and **Appendix C** provides mapping to illustrate the results.

4.1 Flooding

Metric: Flooding Risk and Impact on Transport Infrastructure
Description: This metric evaluates the risk of flooding—whether from rivers, surface water, groundwater or coastal sources—on transport infrastructure, including road and rail networks. The emphasis is on how projected changes in rainfall patterns and sea levels could increase the frequency and severity of flooding events, leading to disruptions and safety hazards.
Impact Consideration: As climate models predict more intense and frequent storms, the potential for widespread flooding increases, which could simultaneously disrupt multiple transport modes.
Data Sources used in the assessment: o **Risk of Flood from Rivers and Sea**: **Environment Agency.** Provides data on flood zones from river and sea sources, helping to plan infrastructure resilience. o **Susceptibility to Groundwater Flooding: British Geological Survey**, identifying areas prone to groundwater flooding based on geotechnical conditions. o **Flooding from Surface Water: Environment Agency**, updated as of August 2024, providing surface water flood risk data which is key for urban areas where surface drainage might be overwhelmed. o **TfN Road network traffic flows**. Provides insight into the demand for different road corridors, and therefore the number of users who would be affected by impacts to infrastructure operation. o **Rail network passenger demand**. Built from data around station entries and exits provided by the Office of Road and Rail (ORR) to understand the number of passengers who would be affected by impacts to infrastructure operation.

4.1.1 Road Vulnerability to Flooding

The assessment outputs relating to flooding showed that the majority of corridors have a low likelihood of being affected by this source of hazard. Areas with the highest probability of flooding were those closest to water sources, in particular coastal areas, rivers, and along floodplains. For example, the A65 in Kendall runs adjacent to the river Kent, therefore increasing its susceptibility to flooding.

From an impact perspective, the most severe disruptions would occur along route sections with the highest traffic demand. These include major transport routes such as the M1, M6 and M62, as well as more concentrated urban areas such as Manchester and Leeds. Corridors further to the north would be impacted less in relative terms due to reduced traffic flows.

The distribution of all road sections across the risk matrix can be seen in **Table 4.1**.

Table 4.1: Likelihood and impact scores for flooding for all road corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	63	77	45	19	6	210
2	78	160	168	106	33	545
3	1	8	20	4	-	33
4	1	1	3	-	-	5
5	-	-	1	1	-	2
Total	**143**	**246**	**237**	**130**	**39**	**795**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.2**.

Table 4.2: Flooding RAG bands for all road sections

RAG band	Corridors per band	% of Total
Green (Negligible climate vulnerability potential)	264	33%
Pale Amber (Minor climate vulnerability potential)	362	46%
Amber (Moderate climate vulnerability potential)	160	20%
Red (Major climate vulnerability potential)	8	1%
Dark Red (Severe climate vulnerability potential)	1	Less than 1%
Total	**795**	

These results suggest that the majority of the TfN road network is at direct risk from future flooding although, for most roads, it is 'rare' or 'unlikely'. This is mainly due to a low likelihood of flooding, with many sections spread across areas that are at sufficient distance from water sources, or across areas which are not susceptible to groundwater flooding. However, when flooding does occur, the impacts can be large. The results are shown in **Figure 4.1**.

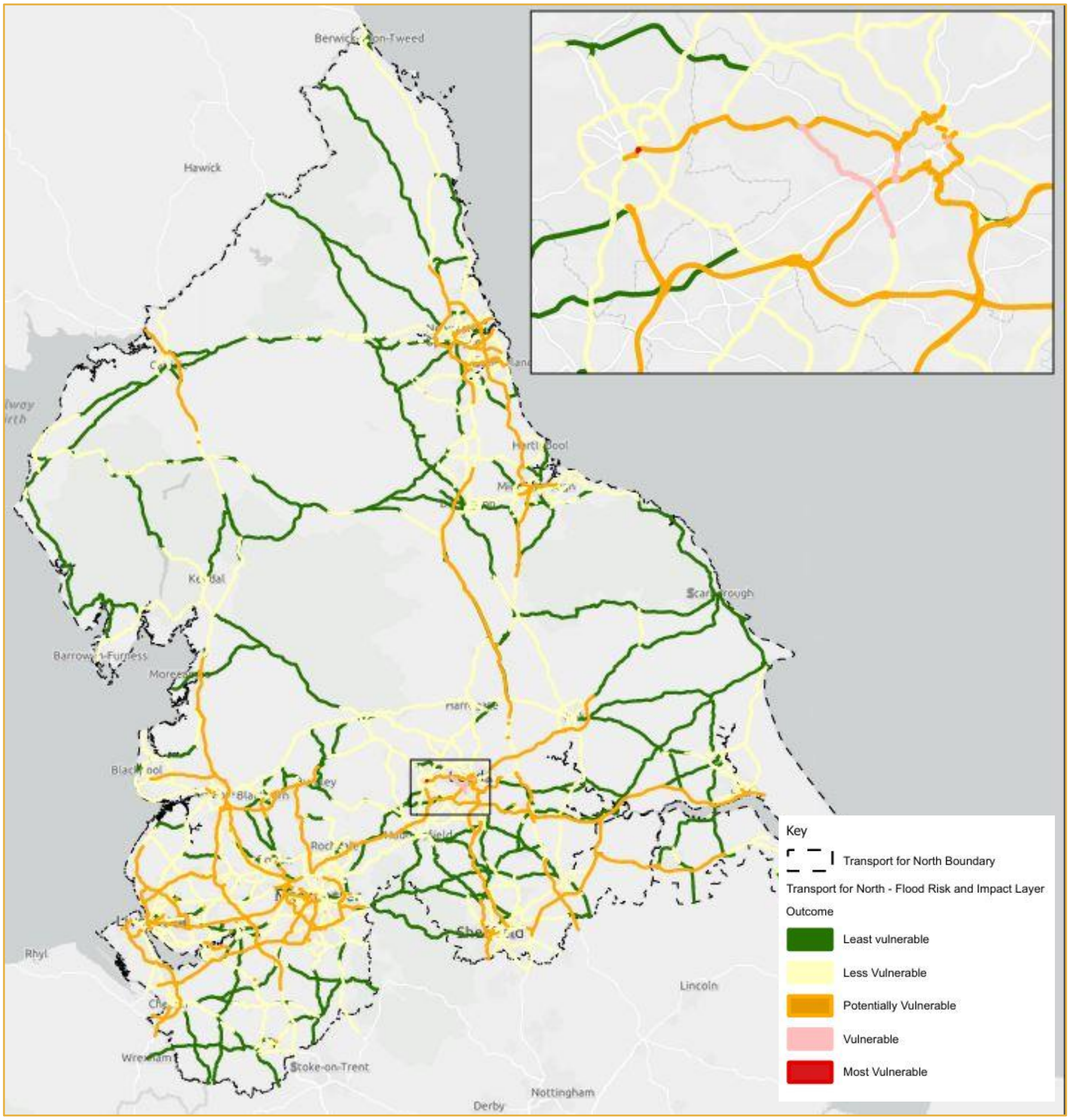

Figure 4.1: Road flooding Vulnerability

The metric has sought to identify those areas where flood risk will have the most significant impact to infrastructure. Approximately 21% of the entire network is at moderate or high risk of flooding (rated amber and above), which could result in prolonged disruption across these corridors. The section where the highest levels of vulnerability were identified, and placing in the highest RAG band, was East of Bradford (A650/Leeds Road).

4.1.2 Rail Vulnerability to Flooding

As with the road network, few rail corridors are in areas of high flooding likelihood. Areas that do show a higher likelihood of flooding are similar to road infrastructure findings, most notably around river floodplains including the Humber (affecting routes around Doncaster and Grimsby) and Ribble (affecting Preston).

The impact severity of flooding on rail is also skewed towards lower scores, with only three sections scoring 4 or 5 (major or severe impact respectively) being Carcroft to Dunscroft, West of Thorne and Warmsworth to Dunscroft (all in South Yorkshire). In terms of impact, the most populated areas are most likely to have higher scores, with train routes around cities like York, Sheffield and Leeds seeing the most demand.

The distribution of all rail sections across the risk matrix can be seen in **Table 4.3**.

Table 4.3: Likelihood and impact scores for flooding for all rail corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	21	4	4	-	-	26
2	104	48	8	2	1	163
3	2	2	-	-	-	4
4	-	-	-	-	-	-
5	-	-	-	-	-	-
Total	**127**	**54**	**9**	**2**	**1**	**193**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.4** and shown in **Figure 4.2**.

Table 4.4: Final flooding RAG bands for all rail sections

RAG band	Corridors per band	% of Total
Green (Negligible climate vulnerability potential)	132	68%
Pale Amber (Minor climate vulnerability potential)	58	30%
Amber (Moderate climate vulnerability potential)	3	2%
Red (Major climate vulnerability potential)	-	0%
Dark Red (Severe climate vulnerability potential)	-	0%
Total	**193**	

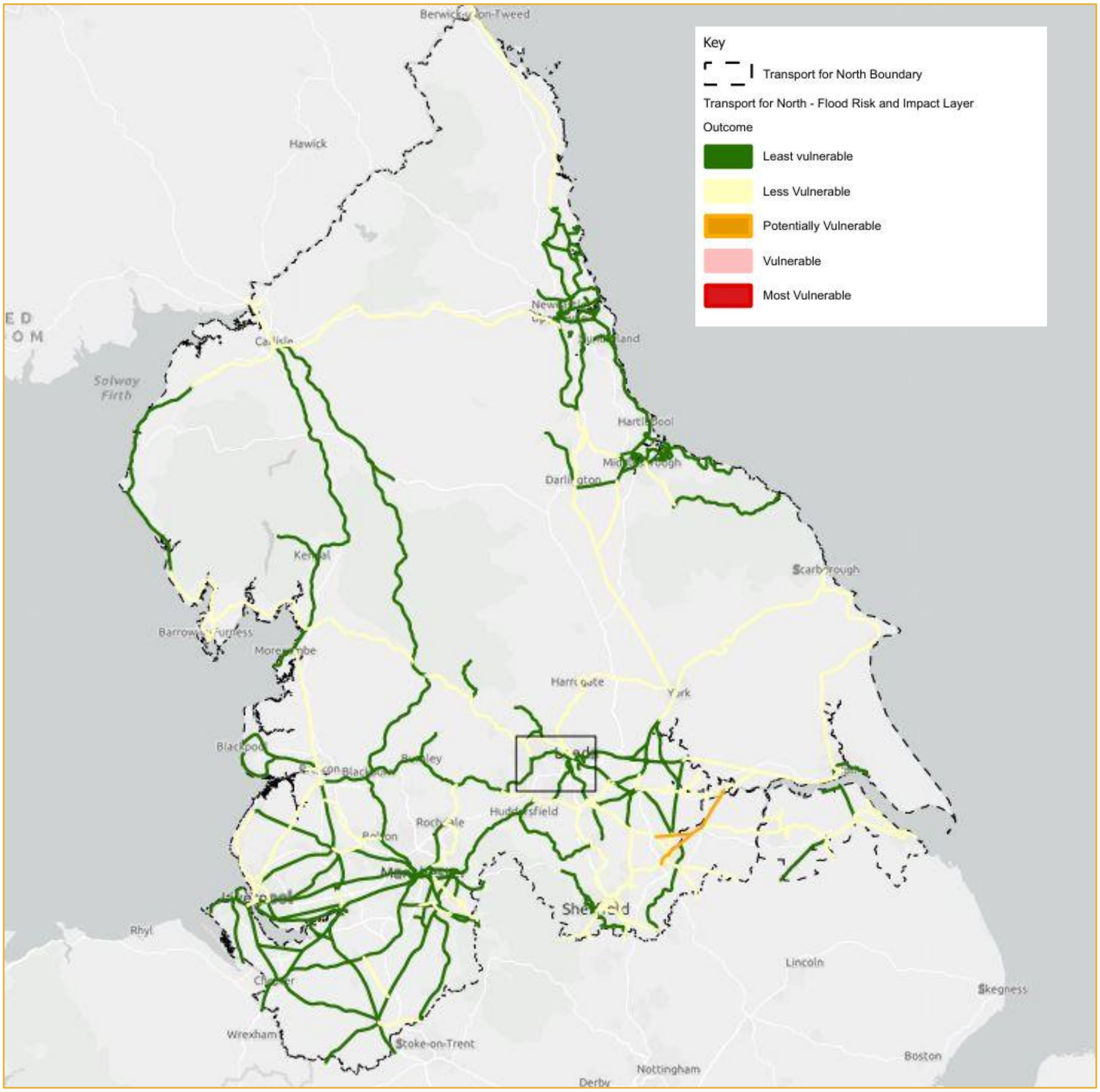

Figure 4.2: Rail flooding Vulnerability

The data suggests that the majority of the TfN rail network (98%) has minor to negligible climate change vulnerability to flooding. However, three route sections face moderate-level risks, which may want to be investigated further. These are all found in South Yorkshire, around Sheffield and Doncaster.

4.2 Slope integrity

Metric: Slope and Embankment Stability under Future Climate Conditions
Description: This metric assesses the vulnerability of slopes and embankments to failure due to projected increases in rainfall and soil moisture variability. The focus is on predicting how these changes might increase landslide risks, affecting both road and rail networks.
Impact Consideration: With heavier and more frequent rainfall expected, there is an increased risk of landslides and embankment failures, which could lead to major disruptions and safety risks.
Data Sources used in the assessment: o **BGS GeoClimate Shrink-Swell Data: British Geological Survey**. Assesses the impact of changes in soil moisture levels on embankment stability, particularly in areas prone to shrink-swell behaviour. o **TfN Road network traffic flows**. Provides insight into the demand for different road corridors, and therefore the number of users who would be affected by impacts to infrastructure operation. o **Rail network passenger demand**. Built from data around station entries and exits provided by the Office of Road and Rail (ORR) to understand the number of passengers who would be affected by impacts to infrastructure operation.

4.2.1 Road Vulnerability to Slope Integrity

When assessing the risk related to slope and embankment failure, soil composition and rainfall predictions were combined to approximate the likelihood of breakdown in each section. Against the metric criteria, it was determined that most sections had a low likelihood of slope and embankment failure. Only four sections across the entire TfN area resulted in possible, probable or certain levels of likelihood, two of these being approximately 10 miles west of Hull. The others are in Selby and Norton. The underlying data for this assessment can be seen in **Figure 4.3**.

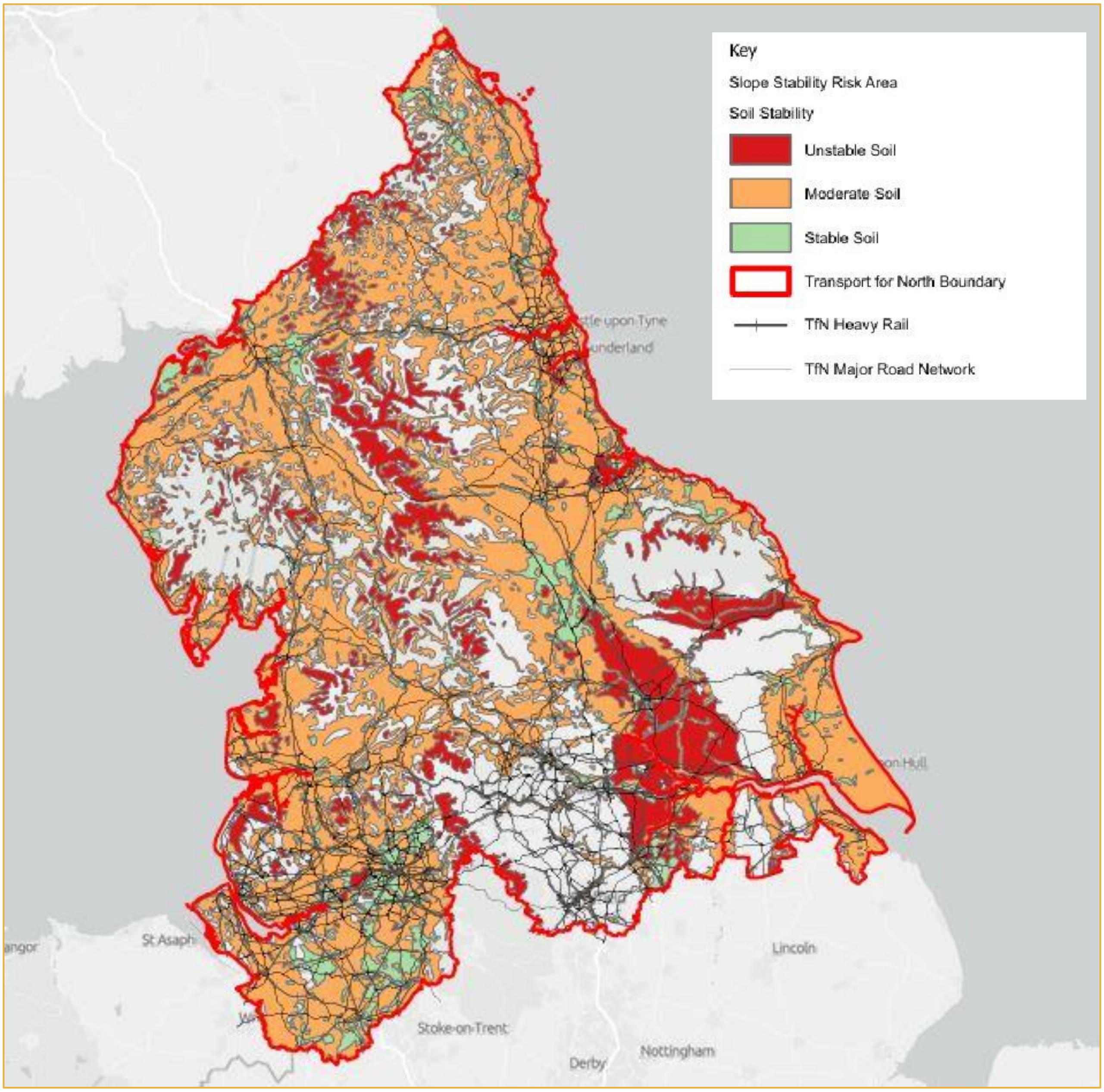

Figure 4.3: Slope failure risk areas across the TfN area

From an impact perspective, the most severe disruptions will be realised along route sections with the highest traffic demand. These include major transport routes such as the M1, M6 and M62, as well as more concentrated urban areas such as Manchester and Leeds. Corridors further to the north would be impacted less in relative terms due to reduced traffic flows.

The distribution of all road sections across the risk matrix can be seen in **Table 4.5**.

Table 4.5: Likelihood and impact scores for slope integrity issues for all road corridor sections.

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	1	5	7	19	11	43
2	19	104	192	274	159	748
3	1	-	-	-	-	1
4	-	1	-	-	-	1
5	-	1	1	-	-	2
Total	**21**	**111**	**200**	**293**	**170**	**795**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.6**.

Table 4.6: Final slope integrity RAG bands for all road sections

RAG band	Corridors per band	% of Total
Green (Negligible climate vulnerability potential)	33	4%
Pale Amber (Minor climate vulnerability potential)	326	41%
Amber (Moderate climate vulnerability potential)	435	55%
Red (Major climate vulnerability potential)	1	Less than 1%
Dark Red (Severe climate vulnerability potential)	0	0
Total	**795**	

There are very few sections at major or severe risk from poor slope integrity. However, significantly 55% of all sections across the TfN network have an amber rating, meaning they are at moderate risk. More detailed analysis, for example using detailed topography on those sections categorised as amber, would reveal a better understanding of incidents occurring. The only section that has been assessed as a major vulnerability risk is the A139 near Norton, in Stockton-on-Tees.

4.2.2 Rail Vulnerability to Slope Integrity

In contrast to the likelihood of slope integrity loss for the road network, the rail corridors across the TfN region are far more likely to face high probabilities of failure. This is due to higher coverage of moderate or unstable soils along the railway route section. As such, 68% of rail sections fall into the highest possible likelihood band.

In terms of impact, the most populated areas are most likely to have higher scores, with train routes around cities like York, Sheffield and Leeds seeing the most demand. An example of the RAG scoring for impact based on route demand around Manchester can be seen in **Figure 4.4**.

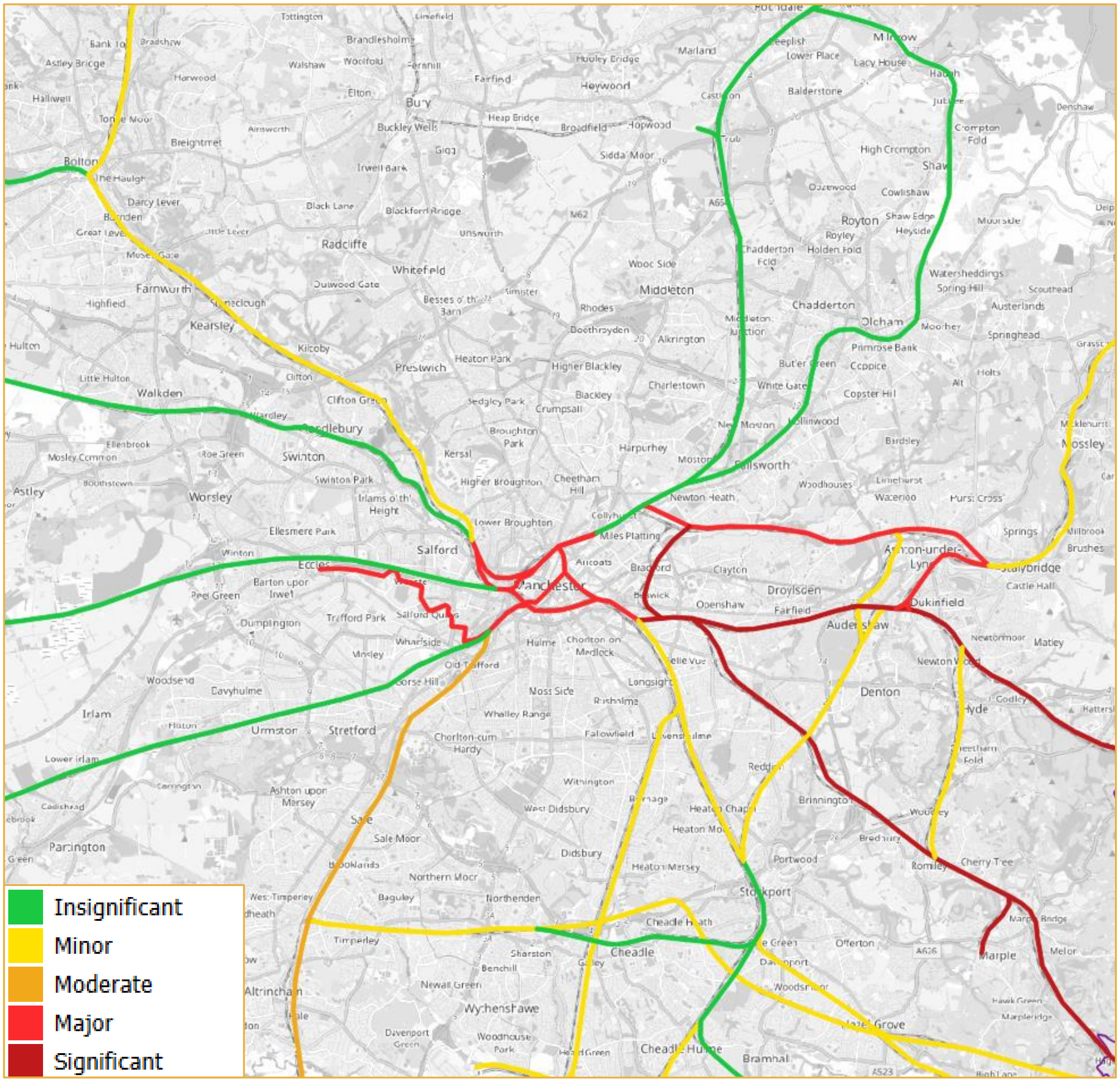

Figure 4.4: Slope failure impact for rail corridors in the Manchester area

Outside of the most urban areas, rail sections are at a lower risk of major impacts due to lower demand. As more rural areas cover the majority of the TfN region, the overall spread of impacts is skewed towards the lower end of the scale. The distribution of all rail sections across the risk matrix can be seen in **Table 4.7.**

Table 4.7: Likelihood and impact scores for flooding for all rail corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	6	6	-	-	1	13
2	2	2	-	-	2	6
3	6	10	-	-	4	20
4	12	8	-	-	2	22
5	52	43	2	3	32	132
Total	**78**	**69**	**2**	**3**	**41**	**193**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.8.**

Table 4.8: Final Slope Integrity RAG bands for all rail sections

RAG band	Corridors per band	% Total
Green (Negligible climate vulnerability potential)	20	10%
Pale Amber (Minor climate vulnerability potential)	77	40%
Amber (Moderate climate vulnerability potential)	53	27%
Red (Major climate vulnerability potential)	6	3%
Dark Red (Severe climate vulnerability potential)	37	19%
Total	**193**	

The areas of the network, with the most concentrated lines at severe risk (i.e. dark red) from poor slope integrity are lines from Newcastle, both to Sunderland and further north towards Berwick-upon-Tweed. Other sections at severe risk are around central and eastern Manchester; north and west of Selby; lines north from York; and the line into Liverpool from Prescot.

4.3 Extreme weather

Metric: Infrastructure Resilience to Extreme Temperature Events, Storms and Wildfires
Description: This metric focuses on the impact of predicted extreme temperature events – both high and low – on transport infrastructure, including the risk of rail buckling, road surface damage, and the potential for wildfires. The impact of storms or high winds is also analysed.
Impact Consideration: ○ **High Temperatures:** As global temperatures rise, extreme heat events are expected to become more frequent, potentially leading to infrastructure failures, such as rail buckling and road surface degradation, causing widespread service disruptions. ○ **Low Temperatures:** Acute cold events, including frost and ice, can damage road surfaces, cause rail disruptions including from rail fractures, and lead to safety hazards like black ice, increasing the risk of accidents. ○ **Wildfire Risk:** Increasing temperatures and prolonged dry spells could heighten the risk of wildfires, particularly in rural, moorland and forested areas, threatening transport routes and safety. ○ **High Winds**: Strong wind events can cause significant damage to overhead power lines, road infrastructure (e.g., overturned vehicles, fallen trees), and rail services. Winds also exacerbate wildfire risks by spreading flames and embers, leading to more widespread damage to both natural environments and transport infrastructure.
Data Sources used in the assessment: ○ **National Trust Future Average Minimum Daily Temperature.** Used to establish areas which are at high risk of effects associated with extreme cold, such as freeze-thaw deterioration and icy surfaces. ○ **National Trust Future Average Maximum Daily Temperature.** Used to establish areas which are at high risk of effects associated with extreme heat, such as drought, material deformation, and fires. ○ **National Trust Future High Winds.** Used to establish areas which are at high risk of effects associated with high winds, such as infrastructure damage and tree fall. ○ **National Trust Future Storm Damage.** Used to establish areas which are at high risk of damage to network infrastructure from storms. ○ **National Trust Future Wildfires.** Used to establish areas which are at high risk of wildfires which may damage assets or put passengers at risk.

- **TfN Road network traffic flows**. Provides insight into the demand for different road corridors, and therefore the number of users who would be affected by impacts to infrastructure operation.
- **Rail network passenger demand**. Built from data around station entries and exits provided by the Office of Road and Rail (ORR) to understand the number of passengers who would be affected by impacts to infrastructure operation.

4.3.1 Extreme Weather: Road Vulnerability to Climate Change

To assess various forms of extreme weather events, the likelihood of extreme temperatures (high or low), wildfires, and high winds (including storm damage) were aggregated. Across the entirety of the North, most sections can expect significant frequency of at least one form of these weather events in the future. Many sections fell within risk areas for multiple forms of weather, especially in combinations of extremely high temperatures and wildfires, e.g. near Doncaster, or very low temperatures and high winds/storms, as seen across the North Pennines and Yorkshire Dales. The spread of the different datasets can be seen in **Figure 4.5,** layered in the order shown in the key.

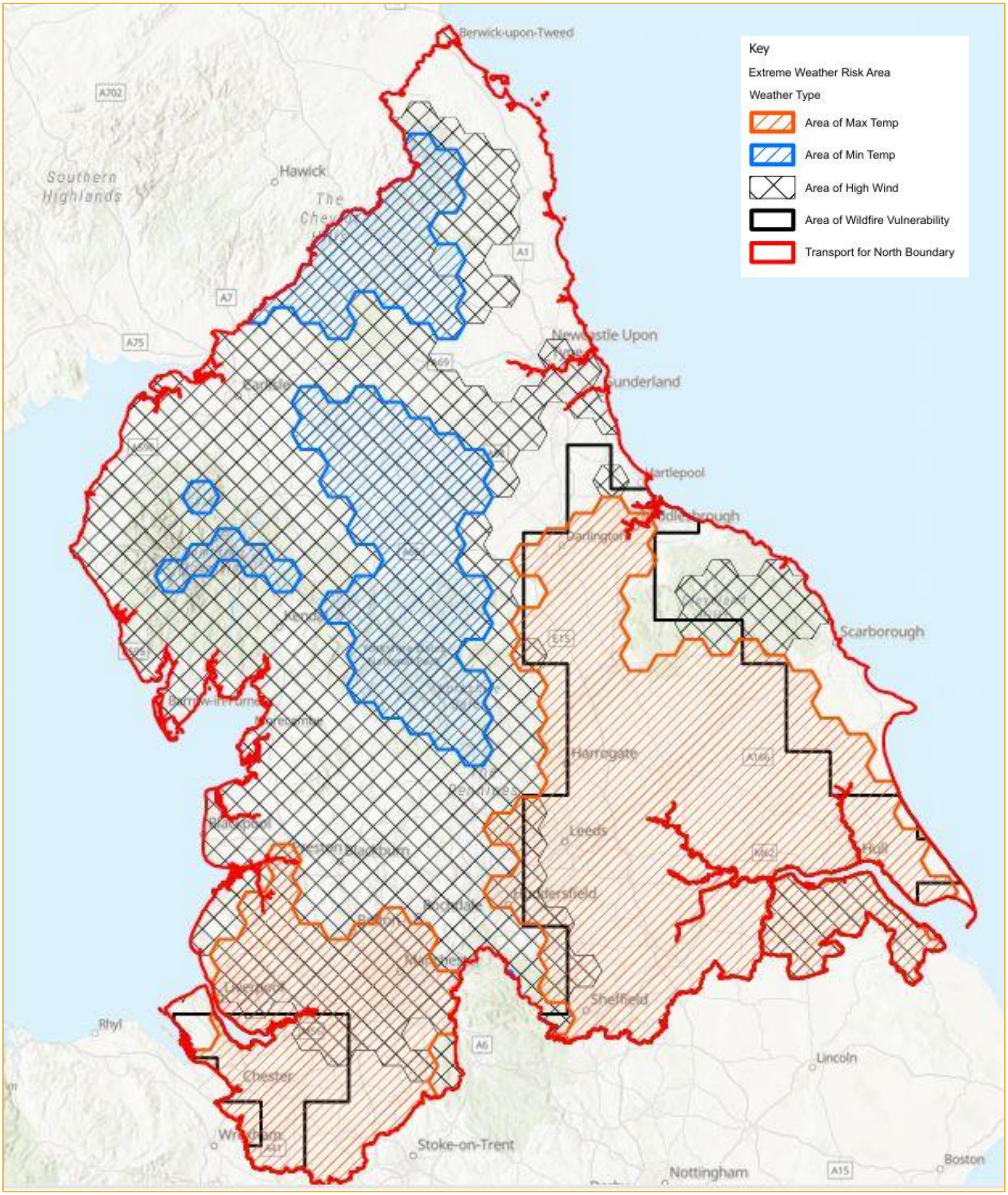

Figure 4.5: Extreme weather areas across the TfN area

Due to low availability of information that could be used to quantify the impact of specific weather patterns (e.g. high winds impacting vehicles such as HGVs), the severity of risk to the transport network was based on the level of demand for each corridor section. The spread of combinations of likelihood and impact are shown in **Table 4.9**.

Table 4.9: Likelihood and impact scores for extreme weather for all road sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	3	13	21	17	4	58
2	-	-	1	6	1	8
3	1	4	5	9	3	22
4	1	3	8	8	3	23
5	16	91	165	253	159	684
Total	**21**	**111**	**200**	**293**	**170**	**795**

The only sections with a high likelihood of very low temperatures and high winds are those in areas of higher elevation such as across the Pennines, including the A66, A591 and A685. However, these all have low impact scores due to relatively low traffic flows.

When the two variables are multiplied, the RAG band allocation was determined, as shown in **Table 4.10**.

Table 4.10: Final extreme weather RAG bands for all road sections

RAG band	Corridors per band	% Total
Green (Negligible climate vulnerability potential)	38	5%
Pale Amber (Minor climate vulnerability potential)	43	5%
Amber (Moderate climate vulnerability potential)	106	13%
Red (Major climate vulnerability potential)	193	24%
Dark Red (Severe climate vulnerability potential)	415	52%
Total	**795**	

Due to the skewed distribution of likelihood scores towards the higher risk end of the range because of the large areas of coverage for the different weather inputs, many sections across the region have been assessed as having a probable or certain likelihood of experiencing impacts from extreme weather. Over half of the road sections have been assigned the maximum RAG band, with a probable or certain likelihood and a major or severe potential impact, making them most vulnerable to weather related climate change.

The most notable sections that meet the criteria for this ranking include the busiest connection routes across the region. These are particularly concentrated in the southwest area around Manchester and Liverpool (such as the M6, M62, and M56), mainly due to a combined risk of wildfires, high temperatures and storm damage. Other key transport links such as the A1(M), A19, and M180 (all at risk of high temperatures/ wildfires) also achieved the maximum score for both likelihood and impact.

4.3.2 Rail Vulnerability to Extreme Weather

As with the assessment for the road network, most of the rail corridors analysed received the highest possible likelihood score due to the combination of multiple potential extreme weather conditions across the region. The only area where this wasn't the case universally was north of Durham, with lines from Newsham towards the Scottish border all receiving the lowest likelihood rating. The Newcastle region can be seen in **Figure 4.6**.

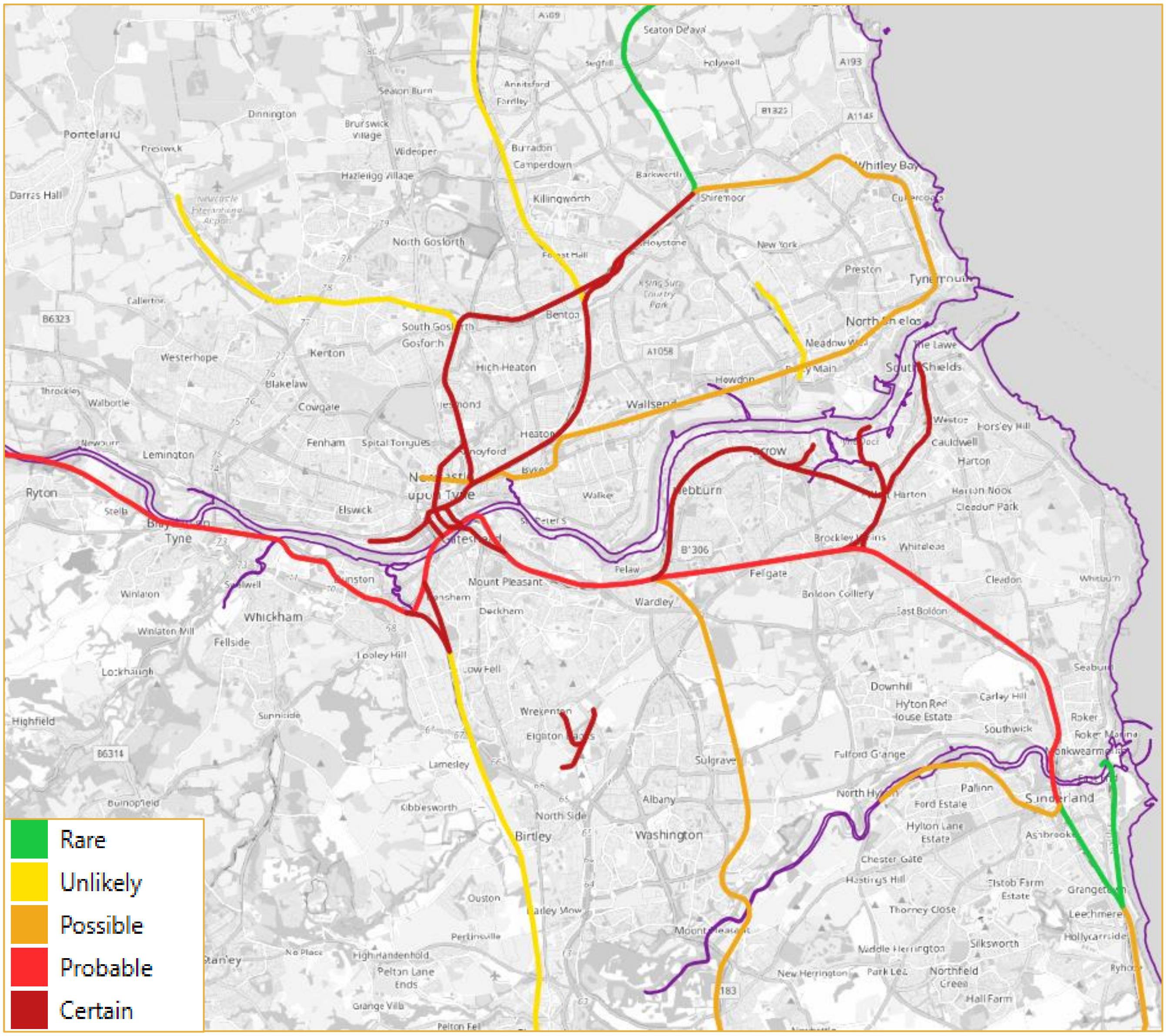

Figure 4.6 Extreme Weather Likelihood for the rail network in the Newcastle area

The impacts from extreme weather conditions are expected to be greatest around Manchester, Sheffield, Newcastle and York. The distribution of all rail sections across the risk matrix can be seen in **Table 4.11**.

Table 4.11: Likelihood and impact scores for extreme weather for all rail corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	2	2	-	-	7	11
2	1	2	-	-	3	6
3	2	2	-	-	2	6
4	3	1	-	-	1	5
5	70	62	2	3	28	165
Total	**78**	**69**	**2**	**3**	**41**	**193**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.12**.

Table 4.12: Final Extreme Weather RAG bands for all rail sections

RAG band	Corridors per band	% Total
Green (Negligible climate vulnerability potential)	7	4%
Pale Amber (Minor climate vulnerability potential)	84	44%
Amber (Moderate climate vulnerability potential)	66	34%
Red (Major climate vulnerability potential)	4	2%
Dark Red (Severe climate vulnerability potential)	32	17%
Total	**193**	

As with the risk to rail sections from slope integrity, the grouping of likelihood scoring towards the top end of the scale means that the severe rated sections are found in the same urban areas around Manchester, Selby, York and Newcastle.

4.4 Ground stability

Metric: Ground Stability in Areas with Shrink-Swell Soils and Soluble Rock Formations
Description: This metric examines the risk of ground subsidence due to shrink-swell soils and soluble rock formations under future climate conditions. The focus is on areas within the TfN area known for these geological features, assessing how predicted changes in rainfall and temperature might exacerbate subsidence risks, leading to infrastructure damage and service interruptions.
Impact Consideration: Predicted climate changes could increase the frequency and severity of ground subsidence, particularly in areas with specific soil and rock characteristics, affecting both road and rail infrastructure.
Data Sources used in the assessment: ○ **BGS GeoClimate Shrink–Swell Dataset**: Soil and geological data prone to subsidence. ○ **UKCP18 Projections**: Climate predictions impacting soil moisture and stability. ○ **Provisional Agricultural Land Classification: Natural England**, showing areas with soil types prone to swelling and shrinking, which is critical for understanding subsidence risks. ○ **Susceptibility to Groundwater Flooding: British Geological Survey**, relevant for regions where water-induced soil expansion or contraction may exacerbate ground stability concerns. ○ **Sites of Special Scientific Interest (SSSI): Natural England**, for mapping sensitive areas that could be impacted by ground instability due to climate factors.

4.4.1 Road Vulnerability to Ground Stability

Across the north of England, the risk of shrink-swell impacting on ground stability is relatively low. The main regions of probable likelihood of stability issue impacts, are around Middlesbrough (**Figure 4.7**) and Doncaster. No corridor sections within the TfN area met the maximum category criteria for risk likelihood.

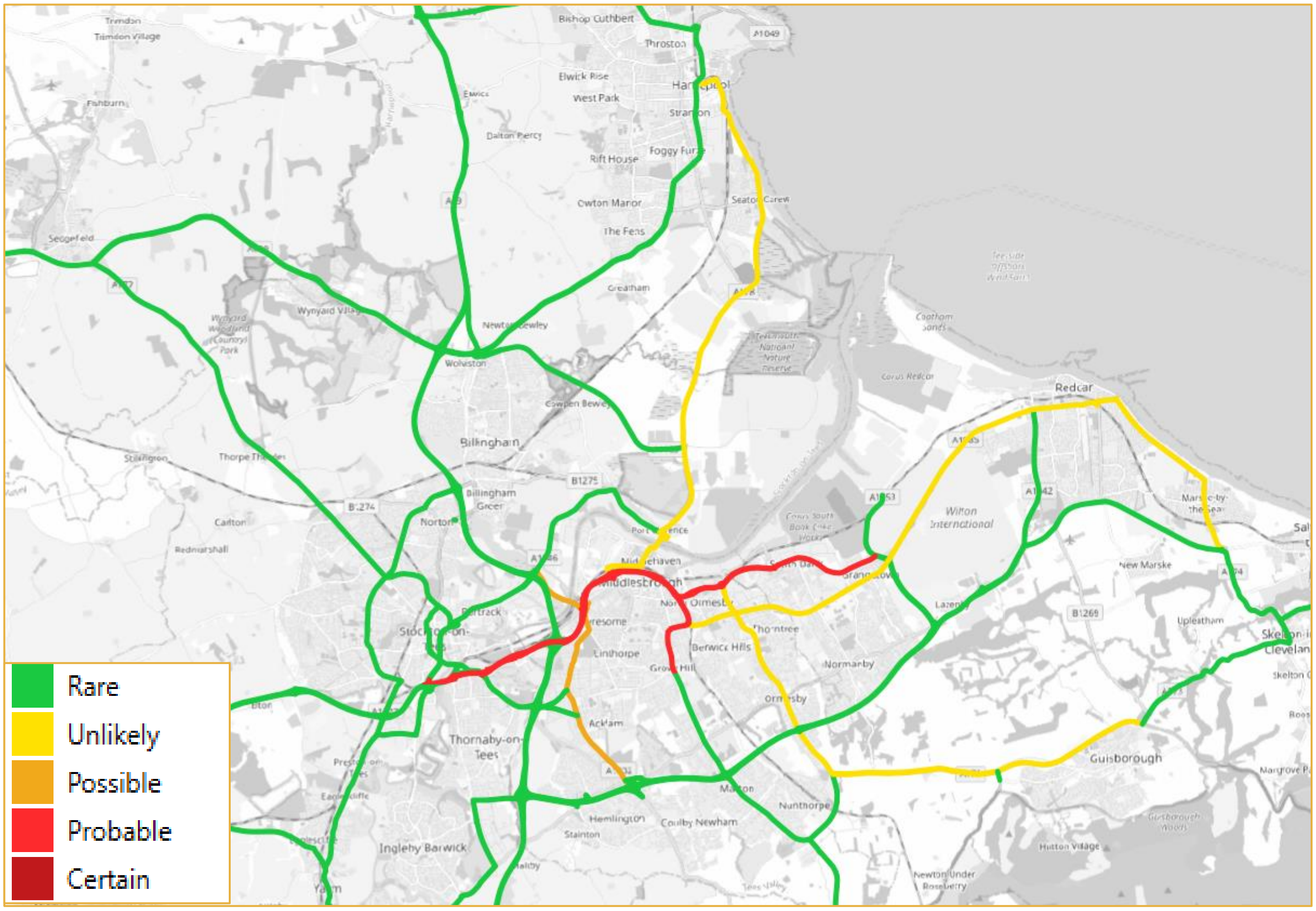

Figure 4.7: Ground stability failure likelihood for road corridors in the Middlesbrough area

The distribution of potential impact is provided in **Table 4.13**.

Table 4.13: Likelihood and impact scores for ground stability for all road corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	21	111	200	288	166	786
2	-	-	-	2	2	4
3	-	-	-	1	1	2
4	-	-	-	2	1	3
5	-	-	-	-	-	-
Total	**21**	**111**	**200**	**293**	**170**	**795**

Due to the low likelihood scores for this metric, the result of multiplying these with the impact scores results in a more even distribution across the RAG bands, seen in **Table 4.14**.

Table 4.14: Final ground stability RAG bands for all road sections

RAG band	Corridors per band	% Total
Green (Negligible climate vulnerability potential)	332	42%
Pale Amber (Minor climate vulnerability potential)	454	57%
Amber (Moderate climate vulnerability potential)	4	Less than 1%
Red (Major climate vulnerability potential)	4	Less than 1%
Dark Red (Severe climate vulnerability potential)	1	Less than 1%
Total	**795**	

The A66 through Middlesbrough is the only section which falls into the severe (dark red) risk bank, due to both high traffic flow and significant overlap with a possible area of shrink-swell activity. The adjacent A172 is in the major risk (red) band. The A18 and A630 around Doncaster contribute other sections to the major risk (red) band.

4.4.2 Rail Vulnerability to Ground Stability

The low probability of ground stability issues across the North of England has a consistent effect on the likelihood scores for rail sections as it did for the road corridors, with only 12 of the 193 sections scoring more than 1 on the likelihood scale. These were focused around the areas of Middlesbrough and Doncaster; the distribution in the latter region being shown in **Figure 4.8**.

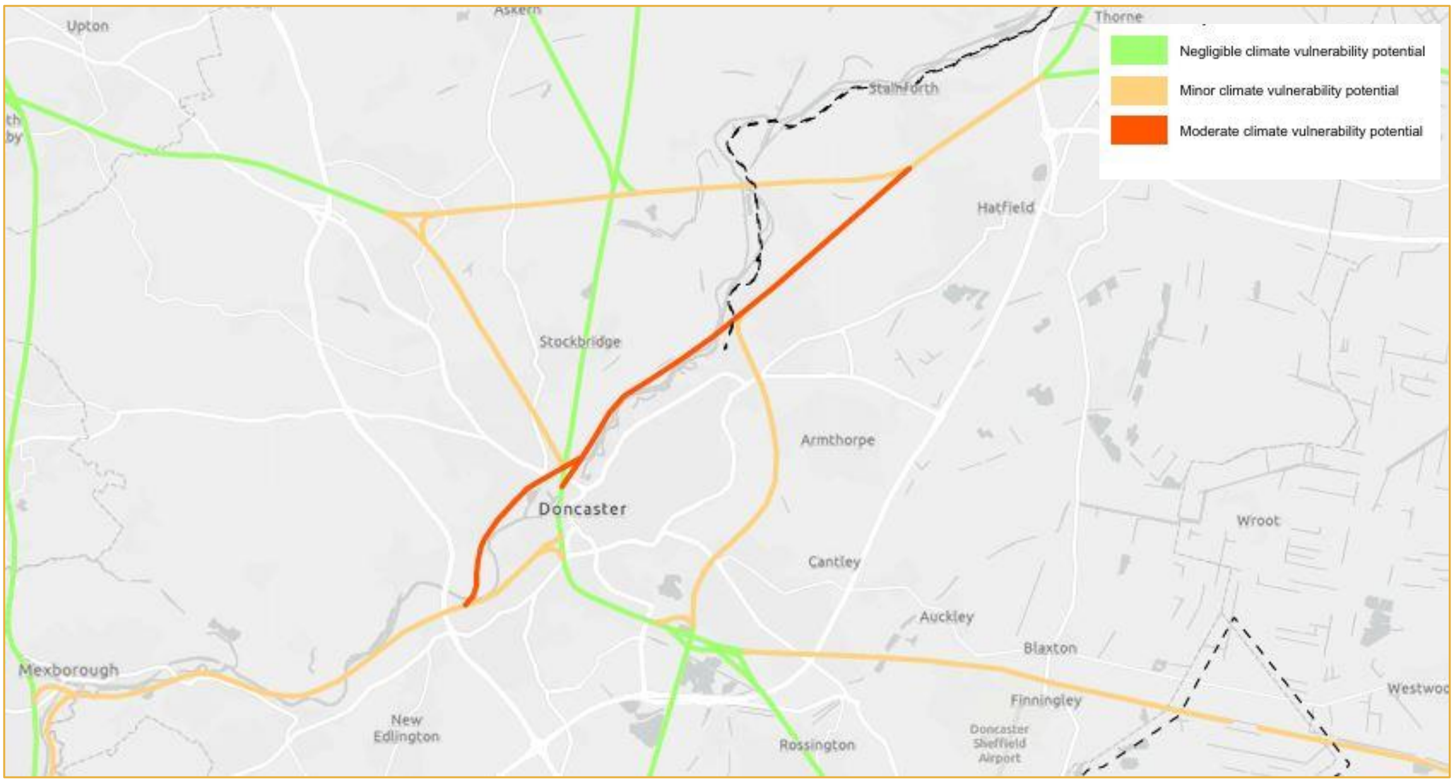

Figure 4.8 Ground stability failure likelihood for rail corridors in the Doncaster area

The distribution of all rail sections across the risk matrix can be seen in **Table 4.15**. The impact distribution mirrors that from the extreme weather assessment.

Table 4.15: spread of likelihood and impact scores for flooding for all rail corridor sections

	Impact					
Likelihood	**1**	**2**	**3**	**4**	**5**	**Total**
1	73	62	2	3	41	181
2	4	4	-	-	-	8
3	-	2	-	-	-	2
4	1	1	-	-	-	2
5	-	-	-	-	-	-
Total	**78**	**69**	**2**	**3**	**41**	**193**

The likelihood and impact scores are multiplied to give the RAG rating for each section. The number of sections in each band is shown in **Table 4.16**.

Table 4.16: final flooding RAG bands for all rail sections

RAG band	Corridors per band	% Total
Green (Negligible climate vulnerability potential)	141	73%
Pale Amber (Minor climate vulnerability potential)	51	26%
Amber (Moderate climate vulnerability potential)	1	1%
Red (Major climate vulnerability potential)	-	-
Dark Red (Severe climate vulnerability potential)	-	-
Total	**193**	

4.5 Overall Assessment Findings

4.5.1 Aggregate Road Findings

When combining the four metrics to review the different vulnerabilities of each section, an overall score can be determined. Using the metrics analysed, the aggregate scores across the region ranged from 5/100 to 63/100, with the resulting distribution across the bands in a RAG assessment shown in **Table 4.17**. The spread of these bands in comparison to the contributing four metrics is shown in **Figure 4.9.**

Table 4.17: Total aggregate road RAG impacts across the TfN area

RAG band	Score	Number of Sections	% of Total
Green (Negligible climate vulnerability potential)	1-20	142	18%
Pale Amber (Minor climate vulnerability potential)	20-30	219	28%
Amber (Moderate climate vulnerability potential)	30-40	263	33%
Red (Major climate vulnerability potential)	40-50	167	21%
Dark Red (Severe climate vulnerability potential)	50-100	4	Less than 1%
Total		**795**	

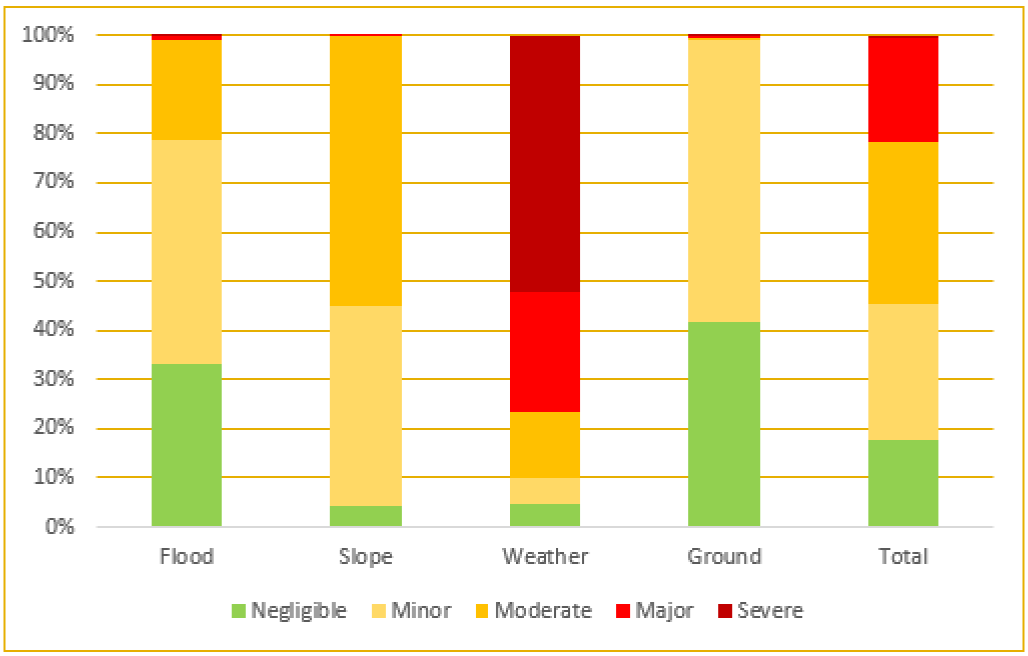

Figure 4.9: Distribution of metric outcomes across RAG Bands for road

Four road sections were assigned to the severe risk total RAG band, suggesting these are the sections most vulnerable to climate change. These are:

- A66 through central Middlesbrough;
- A1032 in central Middlesbrough;
- A178 from Middlesbrough to Hartlepool; and
- A65 in Kendal.

From this assessment, the Middlesbrough area is at particularly severe risk relative to the rest of the TfN area. Whilst flood risk in the area is low, the other three metrics all scored in the top 20% of all sections for each of the three roads highlighted.

4.5.2 Aggregate Rail Findings

The four metrics assessed have been combined to review the different vulnerabilities of each section, so an overall score can be determined. When evaluating this combination, the aggregate scores across the region ranged from 7/100 to 59/100, the distribution of which is shown in **Table 4.18**. The comparison to the four underlying metrics is available in **Figure 4.10.**

Table 4.18: Total Aggregate Rail RAG Impacts Across the TfN area

RAG band	Score	Number of Sections	% of Total
Green (Negligible climate vulnerability potential)	1-20	92	48%
Pale Amber (Minor climate vulnerability potential)	20-30	54	28%
Amber (Moderate climate vulnerability potential)	30-40	11	6%
Red (Major climate vulnerability potential)	40-50	13	7%
Dark Red (Severe climate vulnerability potential)	50-100	23	12%
Total		**193**	

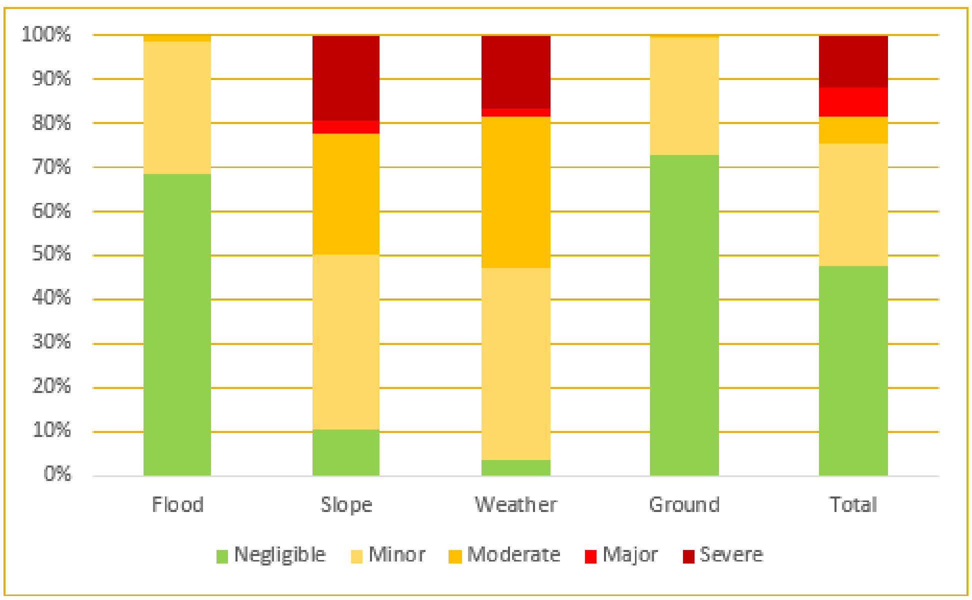

Figure 4.10: Distribution of Metric Outcomes across RAG Bands for rail

The most significant outcome is the higher percentage of rail corridor sections that fall into the highest aggregate severe category when compared to the assessment across the road network. The 23 sections in this band are all reaching the 50-point threshold for this rating due to severe scores in both the Slope and Weather metrics. All of these 23 sections score the maximum 25 points in the Slope integrity risk metric. For Extreme Weather, all 23 sections apart from track from Newcastle to Sunderland (receiving 20 points) scored the maximum 25.

The railway network identified as most vulnerable to climate change are:

- York to Scarborough;
- York to Northallerton;
- Middlewood to Westfield in Sheffield;
- Leeds to Castleford; and
- Selby to Garforth.

4.5.3 Overall Conclusions

The outcomes across the four metrics assessed for both road and rail corridors provide a well-distributed scoring for the total RAG categorisation. Of the 988 sections of corridor analysed, 27% have been assigned the overall highest risk level of severe, which helps to quickly focus attention from the entire region onto the most vulnerable regions. These are generally clustered around certain focal points, which could then be analysed further for more detailed understanding of future risks. The RAG bands for all corridors, and how these compare to the contributing metrics, is shown in **Figure 4.11**.

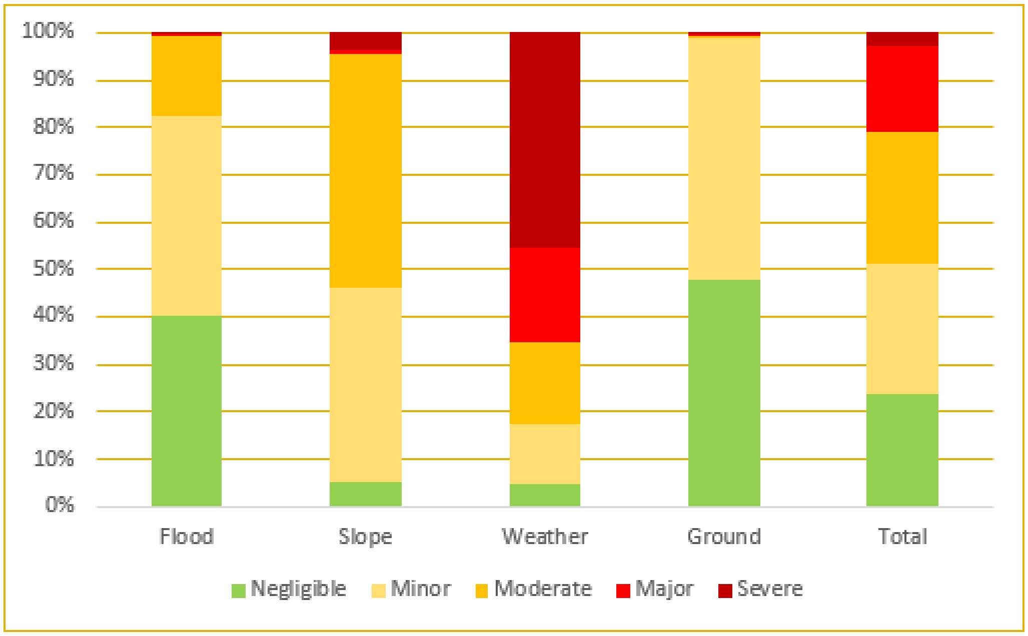

Figure 4.11: Distribution of Metric Outcomes across RAG Bands for road and rail

Across the TfN infrastructure network, the following have been highlighted through our assessment as areas most vulnerable to climate change:

Roads:

- A66 through central Middlesbrough;
- A1032 in central Middlesbrough;
- A178 from Middlesbrough to Hartlepool; and
- A65 in Kendal.

Rail:

- York to Scarborough;
- York to Northallerton;
- Middlewood to Westfield in Sheffield;
- Leeds to Castleford; and
- Selby to Garforth.

As a result, the areas that are recommended as priorities for further investigation are parts of North Yorkshire, West Yorkshire, South Yorkshire and Cumbria.

5. Summary and Conclusions

The assessment was designed to consider infrastructure vulnerability to climate change on a broad scale across the Transport for the North region. It provides a high-level assessment, which disaggregates impacts to help identify those sections of infrastructure which are most vulnerable to climate change.

By using a risk assessment for four climate resilience metrics, it concludes which sections may be more vulnerable to climate change and in need detailed assessment and potential resilience measures. The outputs can be used for investment prioritisation and embedding climate resilience thinking into decision making. The outputs of the study have shown that there are a number of areas where more detailed assessments may be warranted to explore the vulnerabilities identified in greater detail.

This work is intended to help support TfN in incorporating climate resilience into its decision-making processes and across its workstreams. It is also available for use by TfN's local transport partners to understand potential transport vulnerability issues in their area. The recommendations in section 5.1 are designed to set out possible next steps for TfN and its partners, along with any refinements and other uses for the outputs of the assessment.

Sections with the highest aggregate scores indicate areas where multiple climate-related risks converge on the most highly utilised parts of the network, leading to a greater risk of damage and potentially a greater disruption impact. By pinpointing these high-risk corridors, TfN can work collaboratively with partners responsible for managing the transport networks, helping to make evidence-based recommendations to partners of those areas for further investigation.

Additionally, identifying sections with the highest scores in specific fields, such as flooding or wildfires, will help in understanding the predominant risks faced by different parts of the transport network.

For sections with high scores, subsequent more granular analysis is recommended, by applying a full framework assessment over a smaller geographical area. It is at this scale that opportunities could also be identified, such as nature-based solution approaches and co-benefits (whereby if an improvement is made to one area there could be benefits to another).

5.1 Potential Future Applications and Recommendations

The following have been identified as potential future workstreams, to strengthen the understanding of vulnerability to climate change across the network for TfN and their local transport partners.

1. Consider developing an approach to assess road diversion routes available for those sections identified as most vulnerable, or those sections with lower relative traffic flows but where they provide vital connectivity (e.g. key rural routes or trans-Pennine routes).

2. Application of a full framework assessment to the sections identified as the most vulnerable and identify potential opportunities to provide more resilience.

3. Engage with existing strategic partnerships (e.g. Nature North), local authorities and transport infrastructure operators (e.g. National Highways) for data-sharing purposes to incorporate their data into the outputs of the assessment.

4. Consider using a weighting for each resilience metric depending on priority of vulnerabilities.

5. Utilise the outputs of the study to understand the vulnerability of key freight routes and secondary (alternative) routes, to prioritise adaptation for resilient supply chain networks.

6. Embed climate resilience assessments into decision making processes to ensure any future extreme impacts that face the transport network from climate change are considered.

7. Consult with local authorities to utilise the outputs of the study within wider place-making strategies.

The methodology could be readily be applied to other datasets, where a spatial boundary could be applied and then analysed against the findings (RAG ratings) of the climate vulnerability metrics. Potential interest areas to understand climate vulnerability, include:

- Social infrastructure;
- Natural resources (and understanding opportunities for nature solutions to climate change); and
- Other infrastructure users, such as the aviation industry or cyclists.

6. References and Glossary

6.1 References

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6.2 Glossary of Key Terms

Term	Definition
Hazard	An event that may cause negative outcomes, e.g. snow.
Risk	The potential outcome from a hazard, e.g. avalanche
Metric	The indicator used to measure a risk, e.g. cost of repairs.
Variable	A numerical measurement used to determine the scale of a metric, e.g. number of buildings damaged per year.
Likelihood	The frequency at which a risk occurs.
Impact	The severity of a risk when it does occur.
Corridor	A complete infrastructure asset and its immediate surrounding area.
Section	A discrete segment of a corridor assessed for climate vulnerability, up to a maximum length of 25km.
Network	The overall distribution of transport assets across a region.

Appendices – available upon request

Appendix A: Climate Data, Geology, and Environmental Trends

Appendix B: Completed Framework Assessment

Appendix C: Mapping

Appendix D: Data Repository