# Climate Change Risks Facing Scotland's Transport Infrastructure

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## 1 Abstract

Scotland's climate is experiencing a gradual increase in mean temperatures, as well as a gradual shift in the seasonality of precipitation. Also, there has been an increasing frequency of severe weather events in recent years, such as storms, heavy precipitation, droughts and periods of unusually hot weather. These trends are projected to continue and intensify due to anthropogenic climate change.

These changes have the potential to significantly impact on Scotland's transport infrastructure and can cause asset and network disruption and damage. In addition, there are health and safety concerns and reputational risks for transport infrastructure owners and operators to mitigate.

For Scotland's transport infrastructure to become increasingly resilient in the face of a changing climate, effective and targeted action must be taken to minimise this disruption, damage and cost. Furthermore, existing transport infrastructure design, construction, maintenance and operational policies and standards are typically based on historical climate data, but attention now needs to shift to future predictions. Transport infrastructure owners and operators must therefore adapt their programmes, strategies, activities, policies and standards for these changes. Adapting to climate change will be necessary regardless of the extent to which emissions are reduced, as historic emissions are already changing the climate and will continue to do so in the decades to come.

This paper provides an overview of climate change adaptation policy and legislation in Scotland, recent climate change impacts that have affected Scotland's transport infrastructure, and key messages from the new UKCP18 climate change projections. This paper also outlines innovative approaches that have been taken to assess and quantify risk. The studies featured were based on UK climate change projections (Defra, 2019), an assessment of existing asset data and disruption records, and stakeholder consultation. The robust results and outcomes are being used to identify which parts of transport infrastructure networks are most at risk and require targeted action to minimise the future disruption, risks and costs associated with severe weather-related response and repair. This is also being used to inform the development of adaptation plans and future investment decisions.

## 2 Introduction

Scotland is already experiencing the effects of climate change, and this brings both risks and opportunities. Climate projections for the next century indicate that climate trends observed over the second half of the last century will not only continue, but are likely to intensify (Scottish Government, 2019). This will mean that Scotland will experience warmer and wetter winters, and drier and hotter summers. There will also be an increasing frequency of severe weather events, such as storms, heavy precipitation, droughts and periods of unusually hot weather. Periods of very cold weather, snow and ice will decrease in frequency, but will still occur.

These continual changes may have significant impacts on the design, construction, maintenance and operation of Scotland's transport infrastructure. For example, drier and hotter weather could lead to more incidents of infrastructure subsidence and heat damage to pavements and structures; more frequent heavy precipitation events could lead to increased incidences of flooding in low-lying areas and floodplains, as well as landslides; and sea level rise may make some networks and assets temporarily or permanently inaccessible. These impacts will lead to disruption to services and increased operational, maintenance and emergency repair costs. Communities, businesses and localities that rely on the networks will be affected if part of a network becomes inaccessible as a result of the impacts of climate change or a severe weather event (World Road Association, 2015).

Scotland's transport infrastructure owners and operators are already taking action to better understand, prepare for, and adapt to climate change risks (and opportunities). Climate change policy and legislation, as well as climate change data and projections available through the UK Climate Impacts Programme (Defra, 2019), are being used to inform and shape these assessments. By taking action now, Scotland's transport infrastructure will be able to more effectively withstand the effects of the changing climate, and will maximise the opportunities associated with collaboration and knowledge sharing within the sector.

The following sections outline climate change adaptation policy in Scotland, climate change impacts and future projections, and examples of where action is being taken to assess climate change risks and resilience across transport infrastructure.

## 3 Climate change adaptation policy and legislation in Scotland

The Climate Change (Scotland) Act 2009 (Scottish Government, 2009) placed a duty on Ministers to lay a programme for climate change adaptation before the Scottish Parliament as soon as reasonably practicable after the first UK Climate Change Risk Assessment (UK CCRA) in 2012. The Act also set the target of reducing $CO_2$ emissions by 80% before 2050, which the transport sector has a key role in making happen.

The Act also requires an annual report on progress and for the advisory body, the Committee for Climate Change's Adaptation Sub Committee (ASC), to prepare a report within two years, setting out its independent assessment of the progress made on objectives, proposals and policies set out in the programme (Scottish Government, 2019).

The first Scottish Climate Change Adaptation Programme (SCCAP) was launched in 2014 (Scottish Government, 2014), with the aim of increasing the resilience of Scotland's people, environment and economy to the impacts of a changing climate. To date, four annual progress reports have been published, with a further independent assessment being conducted during 2019.

In 2011, a Transport Sector Action Plan was developed under the Scottish Climate Change Adaptation Framework to identify the impacts of climate change on the sector, and appropriate actions to build resilience to these impacts (Scottish Government, 2011).

Policies and programmes have been put in place to address specific risks facing transport infrastructure, such as bridge scour, which is noted as a key risk in the SCCAP (Scottish Government, 2014). Transport Scotland has developed an ongoing programme of scour repair and resilience works based on inspections of known assets and location vulnerable to scour. Transport Scotland has also developed a High Wind Strategy and National Wind Management Guidelines (Transport Scotland, 2009).

Some of Scotland's existing environmental legislation arises from membership of the EU. Therefore, new policies and programmes related to climate change adaptation may need to be developed following the UK's exit from the EU. If such policies and programmes are changed or developed, it will be necessary for them to be designed in a way so as to avoid any increase in climate risk.

## 4 Climate change impacts and future projections

### 4.1 Recent trends and events

Scotland has experienced a gradual increase in mean temperatures over recent decades, and gradually shifting seasonality of rainfall. The increase in annual rainfall experienced across the UK over the past few decades has been most prevalent in Scotland. The decade from 2008 to 2017 was on average 4% wetter in Scotland than the 1981-2010 average (Defra, 2019).

In addition, Scotland has experienced an increasing frequency of severe weather events over recent years, predominantly involving high winds and heavy rainfall, which has affected its transport infrastructure. Impacts have included storms and heavy rainfall causing rail disruption, flight cancellations and bridge closures, all of which have surmounted to significant economic impacts to the nation.

The following examples of severe weather events in Scotland over the past 10 years, from Met office case studies, highlight the impact that severe weather has had on Scotland's transport infrastructure (Met Office, 2019).

- In March 2019, Storm Freya brought strong winds and heavy rain to the UK, particularly affecting southern Scotland. This led to dangerous driving conditions and an increase in the rate of road traffic collisions.
- In September 2018, Storm Ali caused strong winds and heavy rain, resulting in extensive power outages and travel disruption across Scotland. A wind speed of 102mph was recorded on the Tay Road Bridge. Trees falling onto rail lines caused cancellations, and cruise passengers were stranded in Greenock.
- There were several days of exceptionally high temperatures during the summer of 2018, exceeding 30°C in Scotland's central belt and parts of the Highlands on the hottest day (June 28th). Severe storms were also encountered, along with the high temperatures, during that summer. In June 2018, high winds from Storm Hector affected roads, rail, and power supplies across Scotland, and caused ferry cancellations.
- Persistent heavy snow in February and March 2018 caused several road closures, traffic collisions and cars being left stranded overnight on the M80. Strong winds caused drifting of the snow, which contributed to the road closures. The snow forced the closure of Glasgow airport on 28th February 2018 as the 'Beast from the East' met Storm Emma.
- On 3rd January 2012, the most severe storm in 13 years occurred in the central belt of Scotland, with gusts of over 81mph. The high winds resulted in fallen trees which blocked roads and rail lines; rail services from Edinburgh to Glasgow and Inverness to Aberdeen were suspended. The fallen trees also damaged power lines causing around 100,000 homes and businesses in Scotland to be without electricity. Edinburgh and Glasgow airport experienced flight cancellations and several ferry services were delayed.
- Scotland experienced some of the most severe impacts of the storms that hit the UK on 8th December 2011, which led to widespread travel disruption. The estimated cost of this disruption to the Scottish economy was around £100 million. The Forth, Tay, Skye and Erskine bridges experienced closures, ferries were delayed and flights cancelled. Rough seas partially washed away a causeway on the island of Hoy, Orkney. Damage to power lines from trees and debris caused 150,000 homes to be without power.
- In some areas of the Scottish Highlands around 30cm of snow and temperatures falling to -15°C, were experienced between December 2009 and January 2010, affecting transportation across the country.

### 4.2 Future climate change projections

UK Climate Projections form part of the Met Office Hadley Centre Climate Programme, which is supported by the Department of Business, Energy and Industrial Strategy (BEIS) and the Department for Environment, Food and Rural Affairs (Defra, 2019). UK Climate Projections 2018 (UKCP18) use cutting-edge climate science to provide climate observations and climate change projections to 2100 for the UK and globally and builds upon previous UKCP09 data. The future climate conditions are expected to differ from the present-day baseline climatic conditions.

UKCP18 provides probabilistic projections over land and provides a set of high-resolution spatially-coherent future climate projections at a 12km scale for the UK. UKCP18 provides climate change projections in different formats and timeframes. Data for pre-defined 30-year periods (for example 2010-2039, 2040-2069, and 2070-2099) are available at annual and seasonal levels for changes to mean and maximum/minimum climatic conditions.

To model and predict future climate, it is necessary to make assumptions about the economic, social and physical changes to our environment that will influence climate change. Representative Concentration Pathways (RCPs) is a method for capturing those assumptions within a set of scenarios. The conditions of each scenario are used in the process of modelling possible future climate evolution. RCPs specify concentrations of greenhouse gases that will result in total radiative forcing increasing by a target amount by 2100, relative to pre-industrial levels. The RCPs represent a broad range of climate outcomes and are neither forecasts nor policy recommendations. They include a wide range of assumptions regarding population growth, economic development, technological innovation and attitudes to social and environmental sustainability. Each pathway can be met by a combination of different socioeconomic assumptions.

For a given emissions scenario, UKCP18 provides information on known uncertainties in future climate change and therefore, should be seen as a source of broad guidance that forms a useful starting point for risk assessments. Climate projections can be presented across a range of probability levels, ranging from 10% probability to 90% probability:

- 10% probability level – this demonstrates what the future change is unlikely to be less than. There is a 90% chance the projected change will be more than this.
- 50% probability level – this is known as the central estimate, with an even chance of it occurring and not occurring.
- 90% probability level – this demonstrates what the future change is unlikely to be more than. There is a 10% chance the projected change will be more than this.

UKCP18 shows that, for Scotland:

- Annual mean temperature will continue to rise. By the end of the century, mean summer temperature could be up to 7.5°C higher, and mean winter temperature could be up to 5.5°C higher. Implications may include heat stress to assets and operations.
- Warmer winters may reduce the disruption caused by low temperatures, snow and ice.
- There will be greater seasonality of rainfall with more in winter (up to 12% more) and less in summer (up to 40% less). This may lead to greater variations in ground water levels and a higher risk of ground movement.
- Wetter winters and an increased frequency of days with heavy and/ or prolonged rainfall may lead to increased flood risk and damage to assets from heavy rainfall and surface water run-off.
- The number of days when the temperature is greater than 22°C will gradually increase. This is likely to have an impact on the operational procedures and maintenance regimes for assets that are already susceptible to high temperatures. Increases in maximum daily temperatures may also compromise employee comfort and their ability to perform duties during high temperature periods

- The annual number of prolonged dry spells lasting a minimum of 10 days is projected to increase in frequency in the future. This could potentially create issues associated with water shortages, subsidence and ground movement, and deterioration of moisture sensitive assets.
- The annual frequency of prolonged cold weather events (5+ days) is projected to reduce. This may provide benefits for Scotland's transport infrastructure in terms of reduced cold weather disruption to services and operations, reduced asset deterioration and reduced health and safety issues associated with snow, ice and extreme cold weather.
- Sea level around the UK is projected to increase. Sea level rise projections for South West of Scotland are significantly lower than the global mean and minimum values. However, any sea level rise will have an impact on the physical geography of the coastline (such as coastal erosion and loss of land) and therefore have an impact on infrastructure and assets located in these areas. In the most severe case, it could cause a complete loss of land and associated infrastructure.

Quantitative projections for changes to wind speed, and for the frequency of storm events, have not been developed under UKCP18. This is largely due to the uncertainty in climate model simulations. The slightest shift in patterns of atmospheric pressure can lead to large changes in local weather patterns and the prevailing wind directions for a particular location. However, UKCP18 does provide some qualitative evidence to suggest that daily mean wind speeds across Scotland are likely to increase, particularly during winter periods. Furthermore, global climate changes the North Atlantic Oscillation (NAO), a measure of the pressure variations of winter weather, predicting a move to a more predominantly positive phase. This means that during winter months, on average, the UK will be windier, wetter and milder.

## 5 Assessing climate change risk and resilience: Project examples

### 5.1 Transport Scotland Climate Change Risk and Adaptation Assessment

Climate records indicate that Scotland is gradually becoming warmer and drier in summer and milder and wetter in winter. There is also evidence of an increasing frequency of severe weather events such as storms, very hot weather, droughts, and periods of heavy and/ or prolonged precipitation. Climate projections indicate that this change will continue, with more severe weather events becoming even more common. These changes have the potential to cause significant disruption to Scottish transport infrastructure.

As such, in 2015, AECOM was commissioned by Transport Scotland to establish the current levels of exposure of the Scottish trunk road network to climate change and severe weather-related risks, and how this level of exposure will develop as a result of climate change. This project was delivered through a series of interlinked and complementary tasks, as illustrated in Figure 1.

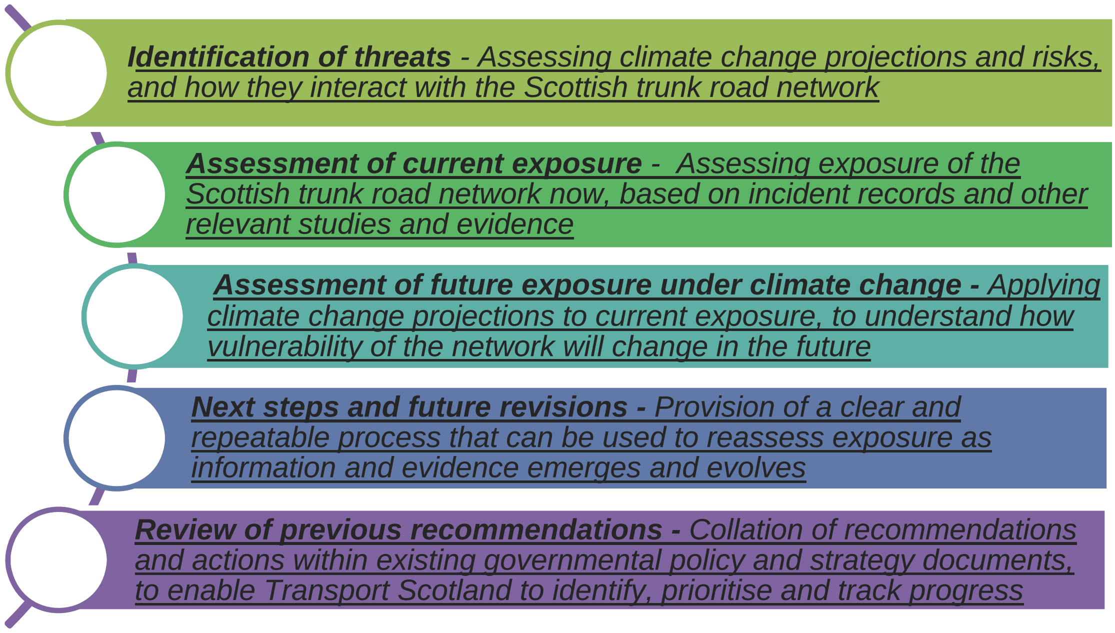


**Figure 1: Project Methodology**

UK Climate Impacts Programme (UKCIP) climate change projections (Defra, 2019), Scottish Environment Protection Agency (SEPA) flood map data (SEPA, 2019), Transport Scotland's incident database, and relevant research and studies were reviewed and analysed. This information was used to develop the assessment methodology and to obtain a better understanding of trunk road network exposure to severe weather impacts and risks. Four bespoke assessments were undertaken to determine which particular sections of the trunk road network are currently most exposed extreme weather, and how this exposure will change as a result of climate change.

Transport Scotland's incident database was used to assess and analyse exposure of the network to flooding, landslides, high winds and snow and ice over a three-year period (2013-2016). The analysis of severe weather-related incidents was used to understand the current level of vulnerability of the Scottish trunk road network to the risks associated with severe weather events. The analysis was supplemented by the following sources of information:

- For Flooding: an analysis of Potentially Vulnerable Areas (PVAs) – as identified by SEPA (SEPA, 2019).
- For Landslides: the Scottish Road Network Landslide Study (Transport Scotland, 2008).
- For High Winds: existing Transport Scotland High Wind Management Strategies.
- For Snow and Ice: locations of snow gates and snow poles across trunk road network.

The above sources of information were used as they provide an indication of which parts of the network have been identified as particularly vulnerable to specific types of severe weather risk, due to their location and/ or prevalence of past events and/or severity of impacts. Current levels of exposure were then calculated through a combination of recent recorded events and the complementary evidence, giving each network section an exposure score, as shown in Table 1.

**Table 1: Exposure scoring**

| Score | Criteria |
|---|---|
| -1 or less | No Exposure |
| 0 | No/ Very Low Exposure |
| 1 | Low Exposure |
| 2 | Medium Exposure |
| 3 | High Exposure |
| 4 | Very High Exposure |
| 5 | Extreme Exposure |
| 6 | |
| 7 | |

Future exposure scores for each individual trunk road network section were then calculated using current exposure scores and future climate change projections, specifically those presented in Table 2.

**Table 2: UKCP09 Weather Variables used to determine future exposure levels**

| Impact Type | UKCP09 Weather Variable used to determine future exposure levels |
|---|---|
| **Flooding** | Change in precipitation on the wettest day (winter) for 2030s and 2050s |
| **Landslides** | Change in precipitation on the wettest day (winter) for 2030s and 2050s |
| **Snowfall and ice coverage** | Change to average daily minimum temperature (winter) for 2030s and 2050s |
| **High Winds** | No climate change projections available through UKCP09; qualitative assessment only |

The risk assessments were undertaken using GIS and data analysis techniques to determine the extent to which sections of the network were exposed to the different types of severe weather, and how this exposure might change due to climate change. This led to the development of risk registers for the entire trunk road network and for the four extreme weather event types, up to the 2050s.

The outcomes of this study are being used by Transport Scotland to identify which parts of the network require prioritisation for minimising future disruption and costs associated with severe weather-related response and repair. Study findings are also being used to help to inform and facilitate the development of adaptation plans and support future investment decisions. Through facilitating a link between the Roads Asset Management Plan (RAMP) (Transport Scotland, 2016) and climate change risk, this work informs future investment decisions and aligns Transport Scotland with requirements of the Scottish Climate Change Adaptation Programme (Scottish Government, 2014).

The repeatable nature of the approach has meant that Transport Scotland is able to undertake the assessment on a rolling and increasingly efficient basis, whilst ensuring consistently generated results and removing the potential for subjectivity in the results.

### 5.2 Other approaches

AECOM worked with the World Road Association to develop an International Climate Change Adaptation Framework for Road Infrastructure (World Road Association, 2015). This framework guides road authorities through identifying relevant assets and climatic variables for assessment, identifying and prioritising risks, developing a robust adaptation response and integrating assessment findings into decision-making processes. The framework provides a life-cycle and iterative approach to climate change adaptation.

The framework was developed through extensive research and consultation with road authorities globally. It facilitates the identification and replication of lessons learned from other countries and takes account of the varying levels of preparedness and adaptive capacity and knowledge from country-to-country and region-to-region. It guides road authorities through a process of increasing the resilience of their networks and assets through the stages presented in Table 3.

**Table 3: World Road Association Framework Climate Change Adaptation Assessment Stages (World Road Association, 2015)**

| Stages of assessment | UKCP09 Weather Variable used to determine future exposure levels |
|---|---|
| Stage 1: Identifying Scope, Variables, Risks and Data | ➢ Establishing assessment scope, aims, tasks and delivery plan<br>➢ Assessing vulnerability and adaptive capacity<br>➢ Assessing climate change projections and scenarios |
| Stage 2: Assessing and Prioritising Risks | ➢ Assessing impact severity<br>➢ Assessing impact probability<br>➢ Establishing risk scores and a risk register |
| Stage 3: Developing and Selecting Adaptation Responses and Strategies | ➢ Identification of adaptation responses and strategies<br>➢ Selection and prioritisation of adaptation responses and strategies<br>➢ Development of an adaptation action plan or strategy |
| Stage 4: Integrating Findings into Decision Making Processes | ➢ Incorporating recommendations into decision-making processes<br>➢ Education, awareness, training and effective communication<br>➢ Developing a business case and future planning and monitoring |

This framework provides a repeatable and adaptable structure that can be used by transport infrastructure owners and operators to help identify and adapt to climate change risks.

AECOM has also been involved in work to understand the climate change risks facing inland waterways across Scotland. This infrastructure faces risks associated with a changing climate and severe weather due to location, age, condition and the nature of the assets. It is therefore important that climate change risks and resilience are effectively integrated into decision making for new infrastructure and the maintenance of existing infrastructure, so as to ensure cost-effective resilience and longevity of these networks of assets.

To ensure targeted, prioritised, resource-efficient adaptation measures, the project identified infrastructure most at-risk from the effects of climate change and severe weather up to the end of the century; the severity and likelihood of climate change impacts on individual assets; and opportunities for economically proportionate adaptation actions. This assessment promotes the role of Scotland's inland waterways in maintaining and promoting Scotland's identity and historic sense of place and culture, whilst maintaining user access, safety and enabling a platform for tourism and regeneration.

The following five tasks were undertaken as part of the assessment of climate risk:

- Review of climate change projections for Scotland's inland waterway locations.
- Review of potential risks: Severe weather and climate change risks facing each asset category and associated vulnerability.
- Stakeholder consultation: To allow knowledge and experience of relevant stakeholders in relation to evolving operational risks to be incorporated into the Risk Assessment.
- Risk Assessment: Identification of the extent to which each asset is vulnerable to severe weather and climate change risks.
- Identification of adaptation opportunities: Generic and asset-specific recommendations to enhance resilience of Scotland's inland waterway network to severe weather and climate change risks.

To understand the current and future levels of risk of Scotland's inland waterway networks to the risks associated with climate change and severe weather events, exposure to flooding, hot weather, dry spells and snow and ice was assessed through an analysis of following relevant supporting materials:

- Outputs of the UKCP09 Weather Generator tool for selected locations;
- The overall vulnerability of the overarching asset category to each severe weather type;
- The Condition Grade for each individual asset assessed, as recorded in asset databases; and,
- The potential outcome of an asset failing and the effect of failure on public risk should an asset be adversely impacted (Consequence of Failure).

This allowed for the most at-risk assets to be identified and for an understanding of how risk will change over time, in light of climate change, to be established. In addition to the risks posed by severe weather and a changing climate, other environmental risks that are influenced by and contribute to a changing climate, such as deforestation and land use change, were considered to provide a holistic assessment.

## 6 Conclusions

Climate change has the potential to significantly impact Scotland's transport infrastructure and can cause asset and network disruption and damage. In addition, there are health and safety considerations and reputational risks for transport infrastructure owners and operators to mitigate. For Scotland's transport infrastructure to become increasingly resilient in the face of a changing climate, effective and targeted action must be taken to minimise this disruption, damage and cost.

Approaches to identifying and adapting to climate change risks are constantly evolving within the transport sector, with examples of innovation and good practice continuing to emerge. It is important that transport infrastructure owners and operators take account of legislation and policy, as well as the ever-developing scientific understanding and evidence around climate change and its impacts, when looking to understand, prepare for and adapt to the impacts.

Assessing, understanding and responding to climate change risks is most effectively achieved through an integrated and collaborative approach involving a range of stakeholders. Assessing and addressing climate change risks in an integrated and collaborative way ensures the interests of these different groups are taken into account, information is shared, and the resources and knowledge available to address risks are maximised.

Climate change risks and impacts should also not be assessed and addressed in isolation. They can be strongly linked to other risk types (both natural and human-induced) and other forms of environmental, social and economic impact. Climate change impacts may lead to new risks emerging and/ or existing risk and impacts becoming more apparent (World Road Association, 2015).

As a result of the interdependencies and interconnectivities between transport infrastructure and other sectors, and also between climate risks and other risk types (such as other natural hazards and security risks), investing in climate change adaptation responses can be seen as investing in the wider economy and increasing the resilience wider infrastructure and society. For the same reason, climate change risks should not be considered in isolation and should always form part of a holistic approach to risk management (World Road Association, 2015).

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