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Climate change risks to transport infrastructure

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This paper discusses climate risks to transport infrastructure in Northern Ireland and how they will change with a changing climate. Adaption measures to improve the resilience of transport infrastructure to these climate risks are also discussed.

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Key Points

- The Travel Survey for Northern Ireland (TSNI) shows there is heavy reliance on cars and the road network in NI, with 70% of all journeys in NI made by car and 87% of journeys of one mile or over made in a car.
- In a YouGov poll taken on behalf of ICE in 2020, only 11% of adults in NI agreed that the level of investment in NI's infrastructure 2010-2020 was adequate for the region's needs and growth.
- The Transport Minister bid £120 million for road maintenance in 2021. The NI Audit Office estimated the current cost to clear the road maintenance backlog is £1.2 billion.
- The daily maximum and minimum temperature extremes in the UK, including NI, are just over 1ºC higher than pre-industrial levels. In NI, the annual mean rainfall has increased 6.4% from 2010 to 2019.
- Following the lowest emissions pathway scenario, by 2050 in NI winter rainfall will have increased by 3%, temperatures will have increased by 1.1ºC, and the sea level will have increased by 14 cm compared to a 1981-2000 baseline.
- Increasing temperatures can cause damage to pavements, roads, bridges, and rail tracks. There is no strategy in NI to protect roads from softening due to heat in the future. There is no rolling programme of maintenance and inspection of bridges for signs of climate related deterioration from flooding and heat.
- Heavy rainfall events and flooding are becoming more common. Flooding can damage the structural integrity of roads, railway tracks and bridges. The roads in NI are very vulnerable to heavy rain due to current structural deterioration. Data from the DfI shows that there were 9961 reports of flooding along roads from 1st August 2017 to 19th October 2021. Despite there being several flood management strategies, they do not include consistent indicators of resilience to flood risk across transport infrastructure.
- A coastal screening tool developed by Climate Central shows that rising sea levels could flood the coastline of Belfast by 2050. There is no common strategy in NI for coastal flooding and erosion risk management.
- The stability of slope can be negatively impacted in several ways by climate change. However, there are no detailed landslide susceptibility maps along transportation infrastructure in NI.
- There is no overall document that is a strategy for adapting transport infrastructure to a changing climate.

Executive Summary

The condition and quality of transport infrastructure is critical to the economic and social wellbeing of Northern Ireland (NI). Despite investment schemes, some of the transport infrastructure in NI has been poorly maintained increasing its vulnerability to climate risks.

The International Panel on Climate Change (IPCC) stated that human-induced warming reached approximately 1ºC above pre-industrial levels in 2017 and is following a warming trend, the future projection of which depends on the emissions pathway that is taken. Following the lowest emissions pathway scenario, by 2050 in NI winter rainfall will have increased by 3%, temperatures will have increased by 1.1ºC, and the sea level will have increased by 14 cm compared to a 1981-2000 baseline. Because of this warming, climate risks to transport infrastructure are changing. These include high temperatures, increased extreme rainfall events and flooding, sea level rise causing increased coastal flooding and erosion, and increased likelihood of landslides.

High temperatures can cause damage to pavements, roads, bridges, and rail tracks. In July 2021, NI recorded its highest-ever temperature which caused a speed restriction on trains due to high track temperatures and caused bitumen in some roads to soften. Although there are reactive measures to reduce the impact of heat on transport infrastructure, there is no current strategy in NI for inspecting bridges or rail track for buckling due to heat.

Heavy rainfall events and flooding are becoming more common in NI. Flooding can damage the structural integrity of roads, railway tracks and bridges. Data from the DfI shows that there were 9961 reports of flooding along roads from 1st August 2017 to 19th October 2021. Flood hazard maps have been produced in accordance with the EU Floods Directive to indicate areas that have been determined by the government to be at significant risk of flooding. Although there are multiple flood management documents for NI, none include consistent indicators of resilience to flood risk across transport infrastructure.

Global sea level rise increases the risk of coastal flooding and erosion which endangers transport infrastructure on the coast. No single Executive Department has the responsibility for coastal erosion risk management. The third UK Climate Change Risk Assessment stated that "*the available evidence indicates that the risk to infrastructure services from coastal flooding and erosion is not currently being managed in Northern Ireland*".

The stability of slope can be negatively impacted in several ways by climate change. Despite much of NI transport infrastructure being built alongside slopes, there are no detailed landslide susceptibility maps of transportation infrastructure in NI.

There is currently no overall strategy for adapting transport infrastructure to a changing climate.

Contents

1 Background

Roads and railways are used to transport people, goods, and services on a national and international scale. The condition and quality of transport infrastructure can have a huge impact on social wellbeing, economic growth, and planning. The Eddington Transport Study stated that "*there is clear evidence that a comprehensive and high-performing transport system is an important enabler of sustained economic prosperity*".[1] There can be huge social and economic costs where transport infrastructure fails or is damaged in some way with delays to travel, lengthened journey times, repairs works and further maintenance. If transport infrastructure is particularly old or is poorly maintained, it is more vulnerable to damage. The damage is highly likely to be caused by weather-induced events: coastal and river flooding, extreme temperatures, high winds, and landslides. In 2012 it was reported by the European Commission that 30-50% of road maintenance costs in Europe are attributed to 'weather stresses' (8-13 billion €/yr).[2] The magnitude and recurrence of these events are increasing due to climate change.[3] In 2010, annual costs related to extreme precipitation and flooding in the UK cost an estimated £50 million.[4] A UNECE Expert Group estimated that by the 2040s, this figure could be up to £500 million.[5]

Transport infrastructure in Northern Ireland (NI) is vulnerable to climate-related risks. The UK Government is required under the Climate Change Act to publish a Climate Change Risk Assessment (CCRA) every five years. National summaries of this report are made for Northern Ireland (NI), England, Scotland and Wales. The Third UK CCRA for NI published in 2021 assessed 61 risks and opportunities from climate change to NI.[6] They found that climate change poses high risk to transport and transportation infrastructure from high and low temperatures, high winds, lightning, slope/embankment failures, river, surface water and groundwater flooding, and coastal flooding. The report outlines that the rate of occurrence and magnitude of these risks will increase in the future due to climate change. This research paper discusses the quality and condition of transport infrastructure in NI, the risks to transportation infrastructure due to climate change in NI, and the resilience of transport infrastructure.

[1] Eddington R. The Eddington Transport Study. Main Report: Transport's Role in Sustaining the UK's Productivity and Competitiveness. 2006.

[2] European Commission, Impacts of Climate Change on Transport: A focus on road and rail transport infrastructure, 2012

[3] S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

[4] UNECE, UNECE study maps transport infrastructure at high risk due to climate change in Pan-European region and Canada, 2020

[5] UNECE Expert Group, Climate Change Adaption and Transport – UK and Rail, November 2011

[6] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021

2 Transport infrastructure in Northern Ireland

In Northern Ireland (NI), the public road network is just over 25,000 km[7] and was estimated to have a net worth of £32 billion in 2016[8]. There are five railway lines making up around 350 km of rail network in NI.[9] The Dublin Enterprise line connects with the Republic of Ireland. The public transport network covers 43 million miles per annum and provides 83% of the NI population direct access to public transport.

The bus network is centred on Belfast, with the majority of routes stemming from the city. Seven of the bus routes cross the border into Republic of Ireland. In 2020-2021, there were 1,089 Ulsterbuses, 280 Metro buses and 32 Gliders on the roads. In the same year, the average age of Ulsterbuses, Metros and Gliders was 10.2 years, 8.5 years and 2.7 years, respectively.[10] Glider vehicles were introduced in September 2018. In 2019-2020 there were 68.3 million bus passenger journeys and 15.1 million rail passenger journeys.[11] The number of passenger journeys on NI's public transport increased by over 4.5 million between 2015 and 2019.[12]

2.1 Regulatory framework

The Department for Infrastructure (DfI) is the sole road authority in NI and is responsible for its maintenance and upkeep. The DfI also control and regulate all public transport in NI. DfI sponsor the Northern Ireland Transport Holding Company (NITHC), which is a public corporation, established under the Transport Act (NI) 1967,[13] to oversee bus and rail services. Services are operated by three private limited subsidiary companies, Ulsterbus, Metro and Northern Ireland Railways (NIR), trading jointly as Translink.

The DfI provide capital grant to Translink for NIR to help maintain and develop the rail infrastructure (including the track, stations, bridges, equipment and associated plant machinery).[14]

2.1.1 Key policies

The development of the transportation network over the last decade or so to present is based on the following strategic policy:

1. Regional Development Strategy (RDS) – Guides the development of NI up to 2025 and beyond. The importance of the RDS is underpinned by Article 5 of the Strategic Planning (Northern Ireland) Order 1999. The latest published is the

[7] Department for Infrastructure, Northern Ireland transport statistics 2020-2021 press release, 30 September 2021
[8] ICE, An infrastructure advisory body for Northern Ireland, 2020
[9] OpenDataNI, Northern Ireland Railways NIR Railway Network, 2015
[10] Department for Infrastructure, Northern Ireland Transport Statistics 2020-2021, 2021
[11] Department for Infrastructure, Northern Ireland transport statistics 2020-2021 press release, 30 September 2021
[12] Grant Thornton, Economic Impact of Public Transport in Northern Ireland, 2019
[13] Transport Act (Northern Ireland) 1967, Section 53
[14] Department for Infrastructure, Railway transport funding, Accessed: 29th November 2021

'Regional Development Strategy 2035'[15] which outlines a framework and guidelines to provide long term policy direction.

2. The Regional Transportation Strategy (RTS) – Makes a significant contribution towards achieving the longer-term transportation vision outlined in the RDS 2025. One of its main Strategic Objectives is to "improve connectivity within the region" by completing the work identified in the current RSTN TP.

3. Regional Strategic Transport Network Transport Plan 2015 (RSTN TP) - Presents a range of transport initiatives to manage, maintain and develop Northern Ireland's Strategic Transport Network.

4. Investment Strategy for Northern Ireland (ISNI) – Approach to be used by government to make informed decisions as to the investment priorities for Northern Ireland over the ten-year period 2005-2015. This was revised to ISNI 2008-2018, published in 2018 with an investment of £3.1bn in roads infrastructure. ISNI 2011-2021, published in 2012, updates the Investment Strategy in line with the new budget period. The strategy is focussed on prioritising infrastructure programmes that will deliver the best return in the period ahead.[16]

Strategic Road improvements are managed under three programmes[17]:

1. The Forward Planning Schedule - A list of major road improvement schemes identified for preliminary development. The highest priority schemes will be considered for progression into the Preparation Pool.

2. The Preparation Pool - High priority schemes to be advanced through the statutory processes. Progression into the Construction Programme is dependent on the level of funding available at the time.

3. The Construction Programme - A list of major road improvement schemes currently under construction.

2.2 The importance of transport infrastructure in NI

Transportation infrastructure is critical to the working population in NI, and, therefore, the economy of NI. The Travel Survey for Northern Ireland (TSNI)[18] shows there is heavy reliance on cars and the road network in NI, with 70% of all journeys in NI made by car and 87% of journeys of one mile or over made in a car.[19] Of the 40% of NI's working population that live within 5 km of work, 70% drive and 7% use public transport.

[15] Department for Regional Development, Regional Development Strategy, March 2012
[16] ISNI, How is ISNI 2021 being developed? Accessed: 30th November 2021
[17] Department for Infrastructure, Road improvements – overview, November 2021
[18] Department for Infrastructure, Travel Survey for Northern Ireland In-depth Report 2017-2019, 2021
[19] Department for Infrastructure, Travel Survey for Northern Ireland: Report 2015-17, July 2018

2.2.1 Movement of people

78% of this NI road network is rural and over one third (36%) of the NI population (1.8 million in 2020) live in rural areas, often travelling to urban areas daily for work.[20] The reliance on the rural road network is expected to increase with the rural population growing at a faster rate (increasing by 18% between 2001 and 2017) than the urban population (increasing by 6%).[21] The population of Lisburn and Castlereagh is projected to grow fastest of all the Local Government Districts, with net migration being the main driver of this change.[22] There is also significant net migration into Armagh City, Banbridge & Craigavon and Ards & North Down. This counter-urbanisation has been identified as a significant and cross-cutting policy issue in NI.

The road network is also critical to enable children to travel to school. In 2015-2017, the most common method of travel to or from school for the 4-11 age group was car, van or taxi. Whilst the most common method of travel to or from school for those in the 12-18 age group was bus.

2.2.2 Movement of goods

Transport infrastructure is also vital for the movement of goods into and out of NI. In 2020, the total tonnage of inward traffic in NI was 16.3 million tonnes, and outward traffic was 10.8 million tonnes. 68.6% of this traffic came through Belfast Port, while Warrenpoint and Port of Larne were the ports with the next highest levels of traffic at 11.8% and 10.1%, respectively.[23] In 2019, 867,698 road goods vehicles passed through NI ports. Given that there are currently no freight trains in Northern Ireland, nearly 100% of these goods are transported overland by heavy goods vehicles (HGV) placing huge dependency on the road network (compared to 77% for the rest of the UK).[24] In 2016, 49.3 million tonnes of freight were lifted within NI and transported by HGVs.[25] In 2020, there were just over 24,000 licensed HGVs on the roads in NI.[26] The Republic of Ireland is NI's single largest export market, equating to 6% of all sales by NI businesses. The majority of goods exported and imported to/from the Republic of Ireland will be transported by road. 31% of the exports from NI to the Republic of Ireland are food and live animals.[27] The agriculture industry also relies heavily on the road network. In 2020, there were 30,995 licensed agriculture vehicles in NI.[28]

[20] Northern Ireland Statistics and Research Agency (NISRA), Settlement 2015 Documentation, 2015
[21] NISRA, Mid-year estimates - population change, 2020
[22] NISRA, 2018-based Sub-National Population Projections for Northern Ireland- summary, 2018
[23] NISRA, Ports traffic, 2020
[24] Department for Infrastructure, Review of the Structural Maintenance Funding Requirements for DfI Roads, 11th January 2019
[25] Department for Infrastructure, Publication of Northern Ireland Transport Statistics 2016-17, 2017
[26] NISRA, Heavy Goods Vehicles, 2020
[27] NISRA, EU Exit – Trade Analysis, 2021
[28] NISRA, Agricultureal Vehicles, 2020

2.2.3 Tourism

Tourism is a growing sector of NI's economy, and it greatly benefits from reliable transport infrastructure. In 2019, visitors spent £1 billion in the local economy, an increase in spending of 8% from the previous year. A survey conducted by NISRA revealed that the top attraction in NI during 2019 was the Giant's Causeway. The Giant's Causeway can only be accessed by road.

2.3 Expenditure

Table 1 displays total expenditure per annum on roads, public transport, and active travel infrastructure in NI from 2017-2020.

Table 1 - Total expenditure on roads, public transport, and active travel infrastructure[29 30 31]

	Expenditure			
	2017-18	2018-19	2019-20	2020-21
Roads[31]	£367.4m	£436.5m	£446.6m	£449.9m
Public Transport[30]	£132.9m	£166.4m	£163.7m	£213.5m
Active Travel[31]	£3.2m	£4.2m	£3.5m	£6m

NI receives the lowest amount of funding for public transport (£84 per person) compared to England, Scotland, and Wales.[32] Translink stated that this figure decreased from £97 in 2013.[33]

Table 2 presents a breakdown of public expenditure on NI roads. It shows that total spending on roads has only incrementally increased over the last few years. In addition, there has also been a decline in the expenditure in maintenance of structures and bridges, in addition to routine maintenance.

Table 2 A breakdown of public expenditure on NI roads[34]

	Expenditure (£m)			
	2017-18	2018-19	2019-20	2020-21
New construction and improvement	107.4	129.1	140.2	143.7
Maintenance:				
- Structural & Bridges	62.0	101.6	99.8	94.7
- Routine	28.6	30.0	31.5	31.7
- Winter	9.7	5.3	6.8	8.5
Public lighting	17.6	17.4	18.1	15.7
Total	367.5	436.5	446.6	449.9

Outlined in the Autumn Budget 2021, the UK Government will provide £15 billion per year to the NI Executive, the largest annual funding settlement to NI since devolution.

[29] AQW 5191/17-22
[30] AQW 15013/17-22
[31] Department for Infrastructure, Northern Ireland Transport Statistics 2020-2021, 2021
[32] ICE, An infrastructure advisory body for Northern Ireland, 2020
[33] Grant Thornton, Economic Impact of Public Transport in Northern Ireland, 2019
[34] Department for Infrastructure, Northern Ireland Transport Statistics 2020-2021, 2021

NI will receive a block grant from 2022-2023 to 2024-2025, allowing NI to set a multi-year budget which can be important for large infrastructure projects. This funding is targeted towards local projects, including road and infrastructure improvements.[35] However, there are no details yet on how this money will be spent on transport infrastructure in NI.

2.4 The condition of transport infrastructure in NI

The condition and quality of transport infrastructure is of great importance given that the economy and social wellbeing of NI is hugely dependent on it to run. Despite the developments of NI transportation infrastructure and network, some of the infrastructure is in poor condition and there have been delays in many upgrade projects. The Institution of Civil Engineers (ICE) estimated that the ongoing deterioration of the transportation network and need for maintenance in NI exceeded £1 billion in 2016.[36] However, this figure is likely to be much higher given that the NI Audit Office estimated £1.2 billion was required to clear the backlog of structural maintenance on roads alone. [37]

In a YouGov poll taken on behalf of ICE in 2020, only 11% of adults in NI agreed that the level of investment in NI's infrastructure 2010-2020 was adequate for the region's needs and growth.[38] Many infrastructure projects have been affected by political uncertainty in NI. The Institute of Directors estimated that political stasis in NI from 2017-2020 paused or slowed down up to $2 billion worth of infrastructure projects.[39]

ICE released a report in 2020 which strongly recommended the need for an independent infrastructure advisory board for NI.[40] They highlighted that there are several issues with infrastructure provision in NI. In October 2020, the independent Ministerial Advisory Panel on Infrastructure (The Panel/MAPI) (appointed by the Infrastructure Minister) released their report stating that an Infrastructure Commission with a clear remit should be instated as soon as practical.[41]

2.4.1 Road maintenance

The condition of the road network is of particular concern due to the heavy reliance on it. In 2020, Infrastructure Minister Nichola Mallon said that years of underinvestment has led to a deterioration of NI's roads.[42] In 2015/2016, the amount that NI spent per capita on roads was half that spent in 2010/2011. In July 2021, the Transport Minister

[35] GOV.UK, Record £15 billion per year for Northern Ireland, Accessed: 29th November 2021
[36] ICE, ICE Northern Ireland Manifesto 2016: Building our quality of life, 2016
[37] Northern Ireland Audit Office, Structural Maintenance of the Road Network, 2019
[38] YouGov, 2020
[39] Belfast Telegraph, Northern Ireland business chief's fears over £2bn infrastructure projects stuck in limbo by lack of Executive, Accessed: 29th November 2021
[40] ICE, An infrastructure advisory body for Northern Ireland, 2020
[41] Ministerial Advisory Panel on Infrastructure, Turbo-charging Infrastructure to deliver cleaner, greener, sustainable and inclusive growth for all, October 2020
[42] BBC, Potholes: NI motorists paid £1.7m in compensation, Accessed: 29th November 2021

bid £120 million for road maintenance in this financial year. She has increased the rural roads fund by 50%, meaning that they have £15 million for rural roads. [43] However, the Barton report (a review of structural maintenance funding for DfI roads) identified an investment requirement of around £140 million per annum just to maintain the road network.[44] It was found that the roads making up the local road network have deteriorated at a faster rate than the trunk roads and motorways as there has been less investment in them. As previously stated, a report by the NI Audit Office estimated that the current cost to clear the road maintenance backlog is £1.2 billion.[45] The NI Audit Office report concluded:

> *Over time, these funding pressures have constrained spending on good, value for money preventative maintenance, contributing to a higher proportion of expenditure on reactive maintenance, which does not always provide value for money. More recently, funding pressures have led to lower priority defects being no longer recorded or repaired, allowing further damage to occur and accelerating the rate of network deterioration. This is likely to lead to higher costs in the future, which could have been avoided.*

In 2016/2017, England and Scotland both spent two and a half times more money per km of road than NI, and Wales spent 40% more.[46] A study by Transport Scotland estimated that for every £1 reduction in road maintenance, there is a cost of £1.50 to the wider economy. The Barton review also concluded that timely intervention into the maintenance and upkeep of roads is key as late intervention can cost as much as four times the optimum.[47] In 2019, there were 102,521 road defects recorded across NI. Between 2016 and 2019, £1.7 million in compensation was paid for vehicles damaged by defects in roads, specifically potholes.[48]

2.4.2 Rail maintenance

The majority of the railway track in NI was constructed in the 1850s. There used to be more than 1200 km of track. However, many railway tracks were decommissioned in the 1950s and 1960s.[49] There have been significant upgrades of the existing railway track in recent years, however the public is still calling for the improvement in some services by means of increasing the number of trains.[50] In addition, there have been many disruptions to the service between Belfast and Dublin (the most trafficked railway track in NI) due to reduced train speeds on a deteriorating section of track.[51] It has been estimated by Translink and Iarnród Éireann that this line required £239 million

[43] Road Maintenance Budget, Official Report: 6th July 2021
[44] Department for Infrastructure, Review of the Structural Maintenance Funding Requirements for DfI Roads, 11th January 2019
[45] Northern Ireland Audit Office, Structural Maintenance of the Road Network, 2019
[46] Department for Infrastructure, Review of the Structural Maintenance Funding Requirements for DfI Roads, 11th January 2019
[47] Department for Infrastructure, Review of the Structural Maintenance Funding Requirements for DfI Roads, 11th January 2019
[48] BBC, Potholes: NI motorists paid £1.7m in compensation, Accessed: 29th November 2021
[49] BBC, Northern Irelands' railways: What happened to the network? Accessed: 29th November 2021
[50] Belfast Telegraph, Campaigners' anger as phase three of upgrade to Derry rail line ditched, Accessed: 29th November 2021
[51] Hendry, M., Hughes, D.A. and Barbour, L., 2010. Track displacement and energy loss in a railway embankment. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 163 (1), pp.3-12.

spent on it to reduce journey times and improve its timetable. £195 million of this is for track improvements which aims to reduce journey times by 15 minutes.[52]

2.5 Climate change

The UK CCRA 2017 Evidence Report for Northern Ireland outlined that annual average temperatures in NI are similar to the UK average, which have been following a warming trend in recent decades.[53] The daily maximum and minimum temperature extremes in the UK are just over 1ºC higher than pre-industrial levels. The International Panel on Climate Change (IPCC) stated that human-induced warming (averaged over the whole globe) reached approximately 1ºC above pre-industrial levels (temperatures in the period 1850-1900) in 2017.[54]

In a 2018 report, the IPCC predict that global warming is likely to reach 1.5ºC between 2030 and 2052 if warming increases at its current rate.[55] The IPCC explained that if all anthropogenic emissions were reduced to zero by 2018, warming of 1.5ºC above pre-industrial levels would not be likely to occur. Therefore, global warming of 1.5ºC depends on the future rates of emissions.

Under the Paris agreement, countries across the globe came together to set goals to reduce emissions in the aim of limiting global warming to 1.5ºC. Climate-related risks to the built (e.g., food security, water supply and health) and natural environments (e.g., species loss and extinction), are heightened under 1.5ºC compared to present, however they are lower than that at 2ºC warming.

The IPCC is in the process of releasing its Sixth Assessment Report (AR6) to inform international climate policy.[56] The first part of this report stated that:

> *it is unequivocal that human influence has warmed the atmosphere, ocean, and land.*

This report states that global warming of 1.5 and 2ºC will be exceeded during the 21st century unless there are 'deep' reductions in greenhouse gas (GHG) emissions. The changes in the climate system become larger, and the climate-related risks become more severe with increasing warming. The report states that human-induced global warming is already affecting weather patterns and climate extremes across the globe. The UK Climate Projections 2018 (UKCP18) report outlines that the decade 2009-2018 has been on average 1% wetter than 1981-2010 and 5% wetter than 1961-1990 for the UK overall.[57] Total rainfall from extremely wet days increased by about 17% in the

[52] BBC, Belfast-Dublin Enterprise train service needs £239m, Accessed: 29th November 2021
[53] Committee on Climate Change, UK Climate Change Risk Assessment 2017 Evidence Report – Summary for Northern Ireland, 2017
[54] IPCC, Global Warming of 1.5ºC, 2018
[55] IPCC, Global Warming of 1.5ºC, 2018
[56] IPCC, AR6 Climate Chane 2021: The Physical Science Basis, 2021
[57] Met Office, UK Climate Projections 2018, 2021

decade 2008-2017 for the UK overall. In NI, the annual mean rainfall has increased 6.4% from 2010 to 2019.[58]

2.5.1 Climate Change in NI

Representative Concentration Pathways (RCP) are scenarios of concentrations of GHG emissions that result in differing levels of global warming by 2100, relative to pre-industrial levels[59]:

- RCP2.6: emissions are highly reduced, resulting in global warming of 1.6ºC by 2100.
- RCP8.5: GHGs continue to be emitted unmitigated and global warming reaches 4.3ºC by 2100.
- RCP4.5 and RCP6.0: two medium stabilisation pathways, that result in warming of 2.4ºC and 2.8ºC by 2100, respectively.

Table 3 - NI climate predictions compared to a 1981-2000 baseline average for 2050 and 2080 based on different RCP pathways[60]

	RCP2.6		RCP6.0		RCP8.5	
	2050	2080	2050	2080	2050	2080
Summer rainfall (%)	-11	-10	-11	-15	-	-
Winter rainfall (%)	+3	+7	+3	+10	-	-
Annual temperatures (°C)	+1.1	+1.2	+1.2	+2.1	-	-
Sea level (cm)	+14	+27	-	-	+16	+58

Hogarth et al. 2021 came up with a best estimate for Great Britain Mean Sea Level rise as 1.62 mm/year, with a standard error of 0.1 mm/ year, adjusted for vertical land movement. It is estimated that the acceleration of sea level rise from early 19th Century is 0.01 mm/year^2 with a standard error of 0.003 mm/year^2.[61]

Currently, NI does not have any separate climate change legislation. However, NI GHG emissions contribute to the UK total under the Climate Change Act 2008. Since the 1990 baseline, emissions in NI have fallen by 16%. However, since the Climate Change Act 2008, emissions have fallen much slower in NI than the UK as a whole. Emissions per capita are also higher in NI, at 11 tCO_2e per capita compared to 7 tCO_2e for the whole of the UK. Agriculture is the largest contributing sector of GHG emissions in NI, at 30%. Whilst 27% of emissions in NI are from the transportation sector. These figures compare with 6% and 27%, respectively, for the rest of the UK.[62]

[58] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[59] Met Office, UKCP18 Guidance: Representative concentration Pathways, 2018
[60] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[61] Hogarth P, Pugh DT, Hughes CW, Williams SD. Changes in mean sea level around Great Britain over the past 200 years. Progress in Oceanography. March 2021, vol 192 102521.
[62] Committee on Climate Change, Reducing emissions in Northern Ireland, February 2019

3 Climate risks to transport infrastructure in NI

Climate risks to transport infrastructure have always existed, however, as the climate is changing in NI the risks are also changing. In this section, climate risks to transport infrastructure in NI are discussed: high temperatures, extreme rain and flooding, sea level rise and landslides. For each risk, adaption measures to improve the resilience of transport infrastructure implemented in NI and other countries are discussed.

Firstly, overall policy for resilience of transport infrastructure to climate risks in NI is discussed.

3.1 Resilience in policy for NI

According to the United Nations Framework Convention on Climate Change, 'adaption' to climate change can be defined as the adjustment of a natural or human system in response to climatic risks. Whereas 'mitigation' is an intervention to reduce the sources or enhance the sinks of GHG emissions.

The difficulty in adapting infrastructure to improve its resilience against climate risks is the uncertainty involved. There is uncertainty in terms of how much the climate will change in the future, the timeframe over which the climate will change and the severity of climate-related risks. It is also difficult for decision makers to determine the key investment area to adapt due to the gap between the impact and tangible action.[63] However, this uncertainty does not validate inaction. Rather, it has been argued that this means that future approaches need to include adaptive decision making.

In response to the risks and opportunities identified in the CCRA for NI, the first NI Climate Change Adaption Programme (NICCAP1) was published in 2014. This included strategic objectives for adaptation to climate change for the period 2014-2019. NICCAP2 was published in 2019 (covering 2019-2024) as a continuation of the process of adapting NI to a changing climate.[64] NICCAP2 addressed five key priority areas that each had associated objectives, which included infrastructure services. The objective/vision for infrastructure services was to have "*Transport & Network Services that are resilient to the impacts of Flooding & extreme weather*". They highlight that infrastructure sectors tend to be interdependent so when one sector fails, it impacts other areas of infrastructure. For example, the supply of electricity is crucial for the railways network.

NICCAP2, published in 2019, responded to the CCRA for NI published in 2017[65], rather than the most recent published in 2021. NICCAP2 outlines examples of policies and

[63] Lydon, M., Lydon, D., Stevens, N.A., Taylor, S., Early, J. and Marshall, A., Understanding the barriers to NET-ZERO transport for rural roads: a Northern Ireland case study. Journal of Infrastructure Preservation and Resilience, 2021, 2(1), pp.1-16.

[64] Department of Agriculture, Environment and Rural Affairs, Northern Ireland Climate Change Adaptation Programme 2019-2024, September 2019

[65] Committee on Climate Change, UK Climate Change Risk Assessment 2017 Evidence Report: Summary for Northern Ireland, 2017

strategies which contribute to the delivery the objective/vision for infrastructure services. The following are those that involve transport infrastructure:

- The 'Regional Development Strategy 2035'[66] published in 2012 informs the spatial aspects of the strategies of all government and the supporting guidance it contains is designed to deal with the major issues of climate change, population growth and movements, transportation and how investment should be focused on the main hubs and clusters.
- The 'Strategic Planning Policy Statement 2015'[67] published in 2015 is a key document for the delivery of the reformed two-tier planning system that was introduced in April 2015 by DfI. It assists with building resilience into the built and natural environment and addressing and managing significant flood risk across NI.
- The 'Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015-2040)'[68] published in 2016 recognises that extreme weather resulting in flooding of properties and infrastructure is expected to be a significant long-term risk associated with climate change for NI. It states all policies must factor in the future implications of climate change on both quality and quantity of water resources and ensure that measures are put in place to preserve service delivery during extreme weather events.
- Climate Change adaptation is also underpinned by NI infrastructure related legislation, for example 'The Water and Sewerage Services Act (NI) 2016'[69]. The Act contributes to making our transport and network services resilient to the impacts of flooding and extreme weather.

A key action that the DfI is carrying out to towards improving the resilience of transport infrastructure in NI under the objective laid out in NICCAP2 is contributing to the review and update of the manual Design Manual for Roads and Bridges (DMRB)[70], alongside Highways England, Transport Scotland and the Welsh government. This is a series of standards and advice notes relating to the design, assessment and operation of roads in the UK. The manuals have been updated to includes allowances which must be made to adapt to climate change. Re-publication was completed in 2021.[71]

3.2 High temperatures

Increasing global temperatures are causing an increase in the number and intensity of heat waves in the UK, as well as drier summers.[72] This can cause damage to pavements, roads and bridges. Heat can also cause the buckling of rail tracks and

[66] Department for Regional Development, Regional Development Strategy, March 2012
[67] Department for Environment, Strategic Planning Policy Statement for Northern Ireland (SPPS), September 2015
[68] Department for Infrastructure, Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015-2040), March 2016
[69] Water and Sewerage Services Act (Northern Ireland) 2016
[70] Standard for highways, Design Manual for Roads and Bridges, Accessed: 29th November 2021
[71] ICE, Sustainable development in the Design Manual for Roads and Bridges (DMRB), webinar, July 2020
[72] Met Office, What is a heatwave? Accessed: 29th November 2021

speed restrictions on rail lines.[73] In July 2021, NI recorded its highest-ever temperature for the third time in less than a week (31.4ºC at a weather station in Armagh), a record that had previously stood for 45 years. This heatwave caused travel disruption as Translink placed a speed restriction on trains due to high track temperatures.[74] In addition, Infrastructure Minister Nichola Mallon said that the high temperatures also affected the road network as the heat caused bitumen in some roads to soften.[75]

3.2.1 Impact on roads

Most roads will not begin to soften until they hit 50ºC. This can happen when temperatures regularly reach 20ºC, as the dark asphalt road surface absorbs a lot of heat. If temperatures are warm through the night, the roads cannot cool down. When bitumen softens, it can rise to the top making the road more susceptible to ridging and rutting.[76] A heatwave in the UK in 2003 resulted in damages to road surfaces from Cornwall to Cumbria. A study found that this cost an estimated £40.6 million in road maintenance.[77]

3.2.2 Impact on bridges

Heat can also cause buckling and cracking of bridges. A study that looked into the impact of climate change on steel bridges in the US found that current temperature extremes are not likely to cause severe issues. However, with the predicted increase in temperatures the integrity of bridges is at risk.[78] They found that one in four bridges in the US is at risk of collapsing by 2040. Increased temperatures can also threaten bridges with higher carbon concentrations in the atmosphere. A study into the risk of corrosion in concrete structures indicated that by the year 2100 the risk of carbonation induced corrosion may increase by more than 400% in some regions in Australia.[79] An additional risk to bridges can occur if decreased precipitation during the summer causes groundwater tables to drop significantly, which could result in higher consolidation settlement affecting bridges on shallow foundations and pile foundations.[80]

[73] UNECE, UNECE study maps transport infrastructure at high risk due to climate change in Pan-European region and Canada, Accessed: 29th November 2021

[74] Irish Examiner, Northern Ireland highest-ever temperature record broken for third time in less than a week, Accessed: 29th November 2021

[75] Department or Infrastructure, Minister Mallon reiterates call for public to use water wisely as Met Office issues amber warning for extreme heat, Accessed: 29th November 2021

[76] Transport Network, Local roads and the climate challenge, Accessed: 29th November 2021

[77] Hunt, A., Study on the economic effects of the 2003 heat wave on transport. 2007, In Institute of Asphalt Technology National Conference.

[78] Palu S., Mahmoud H., Impact of climate change on the integrity of the superstructure of deteriorated US bridges. Plos one. 2019; 14(10)

[79] Stewart, M.G., Wang, X. and Nguyen, M.N., Climate change impact and risks of concrete infrastructure deterioration. 2011, Engineering Structures, 33(4), pp.1326-1337.

[80] Toll D.G., Abedin Z., Buma J., Cui Y., Osman A.S., Phoon K.K., The impact of changes in the water table and soil moisture on structural stability of buildings and foundation systems: systematic review CEE10-005 (SR90).

3.2.3 Resilience to heat

There is no current strategy in NI for inspecting bridges or rail track for buckling due to heat.

The aforementioned study that found one in four bridges in the US are at risk of failing by 2040 due to extreme heat caused by climate change suggested that efficient maintenance is required to keep the expansion joints in bridges functional. They state that this is vital to avoid the undesirable thermal demand exacerbated due to climate change.[81] Other studies conclude that bridges can be adapted to climate change by regularly updating codes and construction standards to account for the changing climate. Protective surface coatings and barriers can be placed on bridges to control the potential increase in corrosion due to higher rates of atmospheric CO_2. In addition, it is also argued that future bridges should be built taking into account future changes in groundwater level.[82]

In a response to the softening of roads due to heat in the south of the UK, the highway authorities spread granite dust to absorb soft bitumen to stabilise the surface. Polymers can also be used to raise the softening point of asphalt road surface to about 80º, preventing tarmac from softening in hot weather. Another method is to dress the road with thin surfacing course systems that also contain polymer modified binders. These dressings can seal road surfaces. However, modified asphalts are more expensive and, therefore, only tend to be used on heavily trafficked roads. Dr Howard Robinson, chief executive of the Road Surface Treatments Association, estimates that less than 5% of all the UK's road surfaces contain polymer modified asphalt.[83]

Over the last five years, Cumbria has been successfully trialling recycled plastic as a bitumen substitute in roads. The material is known as MR6 and is produced by a local firm, MacRebur.[84] By reducing the use of bitumen in asphalt, the carbon footprint of road construction can be reduced. In addition to being a 'greener' alternative to bitumen, it has also been found to be stronger and have an improved softening point temperature (resistance to heat).[85]

Network Rail, the company which owns and operates rail infrastructure in Great Britain, has a New Measurement Train that monitors and records track condition information at speeds of 125 mph. It helps to locate and identify faults before they become an issue.[86]

[81] Palu S., Mahmoud H., Impact of climate change on the integrity of the superstructure of deteriorated US bridges. Plos one. 2019; 14(10)

[82] Nasr, A., Kjellström, E., Björnsson, I., Honfi, D., Ivanov, O.L. and Johansson, J., Bridges in a changing climate: a study of the potential impacts of climate change on bridges and their possible adaptations. 2021. Structure and Infrastructure Engineering, 16(4), pp.738-749.

[83] RSTA, Why are our roads melting? Accessed: 29th November 2021

[84] Plasgran, Cumbria trailblazes by trialling 'plastic road', Accessed: 29th November 2021

[85] K4D, Using waste plastic in road construction, Accessed: 29th November 2021

[86] Network Rail, New Measurement Train, Accessed: 29th November 2021

3.3 Extreme rainfall and flooding

As discussed above, it is expected that the amount and intensity of rainfall will increase during winter in NI due to climate change. These conditions increase the risk of river and surface water flooding, as the amount of water that enters a river system or water body in a short timeframe, exceeds the amount that can be discharged. Flooding can be defined as the covering of normally dry land by water.[87] Flooding that starts particularly rapidly as of a result of intense precipitation causes the most disruption to transport systems.[88] This type of flooding is particularly problematic in urban areas due to the higher proportion of impermeable surface that prevent the infiltration of water into the ground. Flash flooding can exceed the capacity of urban drainage systems. The impacts of flooding on transport infrastructure can be direct (e.g. physical damage to transport infrastructure and road/rail closure) or indirect (disrupt traffic flow, interrupt business and cause increased emissions).[89] It has been estimated that flooding can cost around £100,000/hr for a main road affected.[90]

3.3.1 Flooding events in NI

NI is already experiencing the effects of climate change, with increased mean rainfall and increased intensity of extremely wet days over the last decade. During the evening to the morning of 22nd to 23rd August 2017, the north-west of NI experienced 60-70 mm of rain (63% of the average rainfall for August) in the space of 8-9 hours. The heavy rainfall resulted in widespread flooding. 210 roads were closed or impacted, and 89 bridges required remedial action, including the collapse of the Glenrandal Bridge in Claudy.[91]

3.3.2 Impact on roads

Data from the DfI shows that there were 9961 reports of flooding along roads from 1st August 2017 to 19th October 2021. Their sources of flooding are not described. Figure 1 displays a heat map with the location of these records. From this map it can be observed that a high density of flooding along roads has occurred in and around Belfast. There are also high-density spots in Newcastle, Strabane and around Derry/Londonderry.

[87] Department for Infrastructure, Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015-2040), March 2016

[88] Department for Transport, Transport Resilience Review: A review of the resilience of the transport network to extreme weather events, July 2014

[89] Pregnolato M, Ford A, Wilkinson SM, Dawson RJ. The impact of flooding on road transport: A depth-disruption function. Transportation research part D: transport and environment. 1st Aug 2017;55:67-81.

[90] Arkell, B. P. Darch, G.J.C, Impacts of climate change on London's transport network, 2006, Municipal Engineer 169, 231-237

[91] Department for Infrastructure, Northern Ireland Flood Risk Assessment (NIFRA) 2018, December 2018

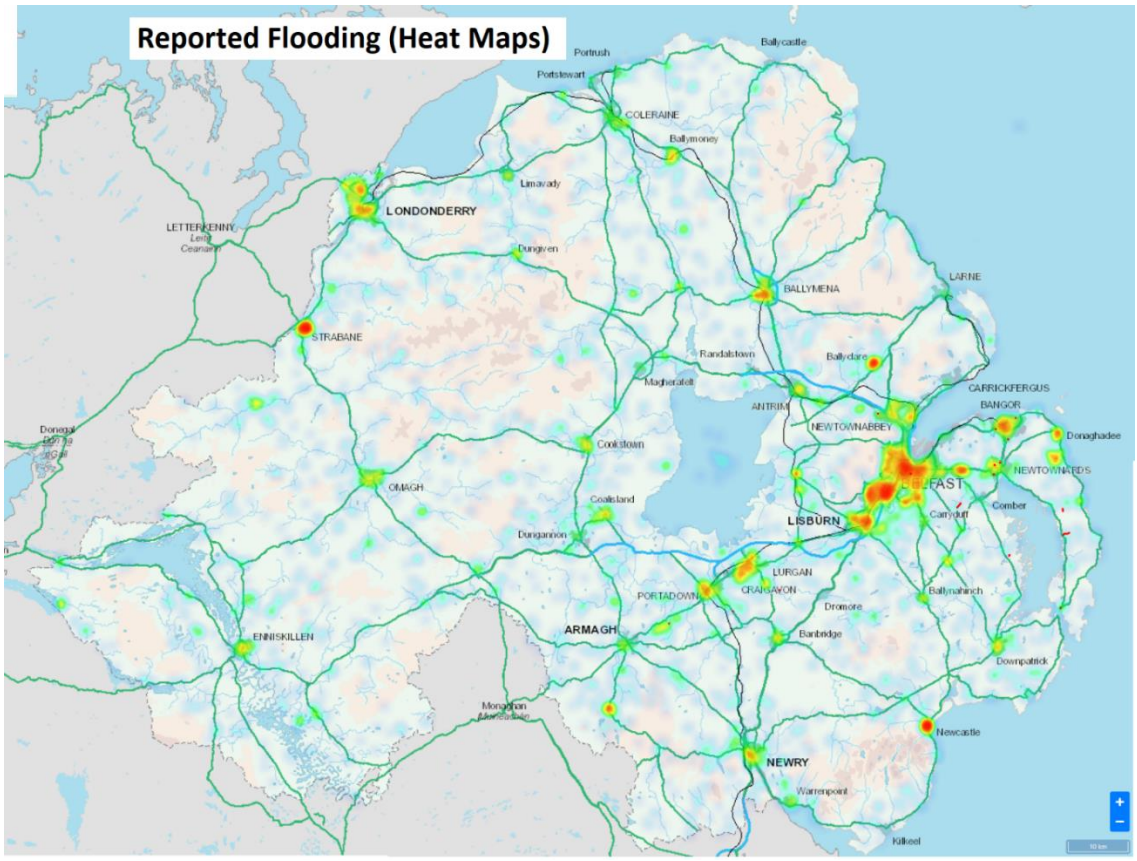

Figure 1 - A heat map showing all the records of flooding on roads, dating from 1st August 2017 to 19th October 2021.

Figure 2 displays the number of reports of flooding along roads from 1st January 2018 to 31st December 2020 alongside monthly average rainfall for NI (1981-2010)[92]. The months with the highest number of reports were November (25.6%), February (20.5%) and December (16.0%). These months have some of the highest average rainfall rates. There is no clear reason why the monthly average rainfall is so high in January, yet the amount of reported flooding incidents is relatively low.

From 1st June 2020, the DfI started recording associated data that resulted in road closures. In this period there were 4402 floods recorded along road, 89 of these were recorded to be passable with care, two resulted in partial closure of the road and 17 resulted in full closure of the road. Table 4 displays a breakdown of these road closures by area.

Table 4 - Area breakdown of road closures due to flooding in NI from June 2020 - October 2021

	Passable with care	Partial closure	Full closure
Antrim and Newtownabbey	4		3
Ards and North Down	1	1	2
Armagh City Banbridge and Craigavon East			
Armagh City Banbridge and Craigavon West	1		2

[92] Met Office, UK climate average, Accessed: 29th November 2021

Belfast North			
Belfast South			1
Castlereagh and Lisburn	16		3
Causeway Coast and Glens East	28	1	1
Causeway Coast and Glens West	3		2
Fermanagh and Omagh East	4		
Fermanagh and Omagh West	4		1
Londonderry and Strabane	5		
Mid and East Antrim	8		1
Mid Ulster North	3		
Mid Ulster South	9		1
Newry Mourne and Down East	1		
Newry Mourne and Down West	2		
Total	89	2	17

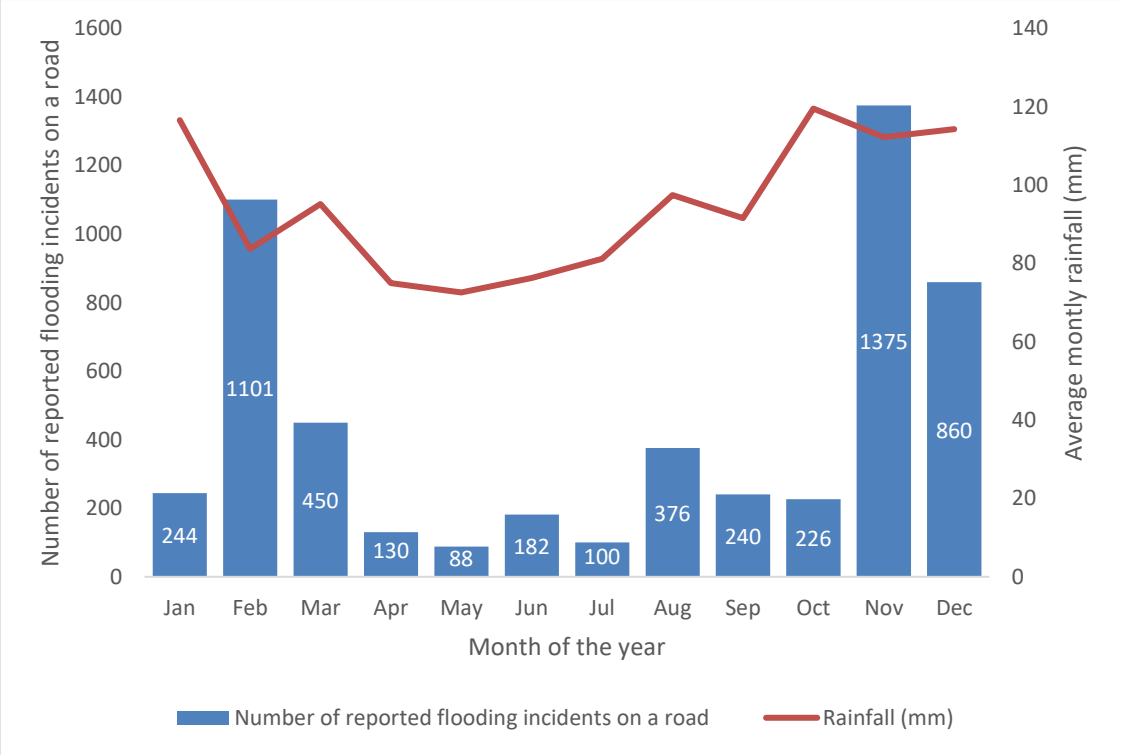

Figure 2 - Number of report flood incidents per month from January 2018 to December 2020 and average monthly rainfall

Rainfall is seen as one of the major causes of deterioration to roads in creating and widening cracks and initiating potholes. Potholes form when water infiltrates the road surface, breaking the tarmac as it expands and contracts. The problem of potholes can be exacerbated by heavy rain and flooding which can weaken the foundation of roads, if they are not structurally sound.[93] As the rate and intensity of rainfall events increases, the rate of deterioration will also increase, albeit with some uncertainty.[94]

[93] Transport Network, Local roads and the climate challenge, Accessed: 29th November 2021
[94] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021

Given that the current condition of roads in NI is poor, especially rural roads, the problem will be exacerbated by rainfall.

3.3.3 Impact on rail

The Third UK CCRA for NI found that currently 183 km of railway lines are at a 1:30 risk of surface water flooding and that 87 km of railway lines at a 1:75 risk to river flooding.[95] The risk of river flooding to railway lines is estimated to increase by 50% by the 2080s in a +4ºC by 2100 scenario. Under the same scenario, the risk of railway lines flooding by surface water increases by 137%. This highlights that despite the use of flood defences, the risk is still not being managed effectively.

3.3.4 Impact on bridges

A study that modelled bridges in the UK found that increased winter precipitation and river flows will increase scour at bridges, potentially increasing the rate of failure to an average of one bridge per year in the UK. Bridges should be priority assets for adaptation due to their long service lives (50 - 100 years) and high cost of retrofitting.[96]

Scour is one of the most common causes of road bridge failure. It is the erosion of material from the bed/banks of a stream around a bridge due to the water flow itself. This compromises the structural integrity of the bridge.[97] Scour was the cause of a partial collapse (20 m section) of the Victorian masonry railway viaduct on the Dublin-to-Belfast main line.[98] The bridge had been inspected and passed as safe days before the collapse following warnings to Irish Rail/Iarnród Éireann.

3.3.5 Flood hazard maps

Flood hazard maps have been produced in accordance with the EU Floods Directive to indicate areas that have been determined by the government to be at significant risk of flooding. The DfI published the 'Northern Ireland Flood Risk Assessment 2018' (NIFRA 2018)[99] in 2018. This document contains maps that have been developed for each of the flood sources (rivers, seas, and surface water) and were produced using predictive flood models.

For river sourced flooding topographic surveys of river channels, bridges, culvers, weirs and flood defences were used in the models. The surface water flood maps have been developed using a relatively new technique, and therefore, they should be used with caution. The probability of an event happening was also taken into consideration with low, medium and high event annual exceedance probability (AEP) scenarios, in addition to a climate change scenario. Based on the mapping, the risk levels of various

[95] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[96] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[97] IDVA, Scour and its relation to the collapse of bridge, Accessed: 29th November 2021
[98] New Civil Engineer, Scour revealed as cause of Irish bridge collapse, Accessed: 29th November 2021
[99] Department for Infrastructure, Northern Ireland Flood Risk Assessment (NIFRA) 2018, December 2018

receptors (properties, key infrastructure, road length, etc.) to adverse impacts due to flooding could be quantified. This mapping identified 45 flood risk areas in NI with surface, fluvial and coastal flooding sources. Out of these, twelve were identified to be Areas of Potential Significant Flood Risk and nine as Transitional Areas of Potential Significant Flood Risk.

To assess the impact of climate change on flood risk, they used the medium probability scenario for each source of flooding (1% AEP for rivers and 0.5% AEP for surface water) assessing for the 2080s epoch. This means that they included areas that will be susceptible to increased flood risk due to climate change. On this basis, they identified 69 receptor counts of key infrastructure at risk of river source flooding in NI and 150 receptor counts of key infrastructure at risk of surface water flooding.

Following on from the NIFRA 2018, the Flood Hazard and Flood Risk Mapping for NI was published online on the Flood Maps (NI).[100] The draft for the second cycle of the Flood Risk Management Plan (FRMP) 2021-2027 was published for public consultation in December 2020. This takes the NIFRA 2018 assessment into account, in addition to a methodology on the calculation of damages.

3.3.6 Resilience to flooding

The DfI has overall responsibility for flood risk management and policy in Northern Ireland. DfI Rivers carries out a rolling programme of planned inspection of watercourses to identify where maintenance work is required. Details of the proposed work are included in an explanatory notice, published every year.[101] The work may include the construction, repair or protection of flood defences, culverts, revetments, and watercourse structures. Currently, there are about 60 flood and sea defence systems across NI which offer protection to major towns and agricultural land.[102]

Other important organisations for the management of flooding in NI are: (1) NI Water who implement a prioritised programme of maintenance of public sewer and drainage infrastructure; and (2) DfI Roads who implement a prioritised programme of maintenance of road drainage infrastructure.[103] NI Water published 'Our Strategy 2021-2046' in 2021[104] which recognises the climate emergency as one of six strategic risks for the next 25 years.

DfI Rivers is also the competent authority for the EU Floods Directive[105], which came into force in 2007. This requires a Flood Risk Management Plan (FRMP) to highlight flood hazards and risks in the areas of Potential Significant Flood Risk in NI from rivers,

[100] Department for Infrastructure, Flood Maps NI, Accessed: 29th November 2021
[101] Department for Infrastructure, Rivers maintenance and flood management, Accessed: 29th November 2021
[102] Department for Infrastructure, Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015-2040), March 2016
[103] Department for Infrastructure, 2nd Cycle - Flood Risk Management Plan 2021-2027, December 2020
[104] NI Water, Our Strategy 2021-2046, 2021
[105] Directive 2007/60/EC of the European Parliament and of the council on the assessment and the management of flood risks (EU Floods Directive)

the sea and surface water. The draft for the second cycle of the FRMP (2021-2027) was published for public consultation in December 2020.[106] This includes flood risk hazard and risk maps, as well as mapping for climate change as discussed in Section 7.2 from NIFRA 2018. It also sets out how the relevant authorities will work together and with local communities to manage flood risk.

Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015- 2040) [107] outlines a Flood Risk Management Strategy that is based on five key aims:

1. Deliver sustainable flood resilient development – key points in terms of transport infrastructure include: (a) avoiding development in flood risk areas; (b) where possible, surface water drainage systems should not be connected to the combined sewer system; (c) make space for surface water management in development plans; and (d) design for drainage exceedance.
2. Manage the catchment to reduce flood risk - key points in terms of transport infrastructure include: (a) use Sustainable Drainage Systems (SuDs) measures where possible in urban areas; and (b) effective watercourse inspection and maintenance.
3. Provide sustainable integrated drainage in rural and urban areas - key points in terms of transport infrastructure include: (a) reduce the amount of rainwater in combined sewers.
4. Improve flood resistance and resilience in high flood risk areas - key points in terms of transport infrastructure include: (a) develop and maintain accurate information on flood risk; (b) continue a flood defence and alleviation programme.
5. Be prepared for extreme weather events - key points in terms of transport infrastructure include: (a) effective flood emergency planning and delivery structures.

One of the actions towards NICCAP2 and outlined in the Regional Development Strategy 2035 was also to increase the number of SuDs introduced in new developments. SuDs reduce the risk of surface water flooding. It achieves this by slowing down the flow of run off through the use of permeable surfaces, storage tanks and ponds. Some SuDs systems also have the added benefit where they can help improve water quality, biodiversity and create landscape features whilst helping transport and network services to become resilient to the impacts of flooding and extreme weather. NI Water will retrofit SuDS where it helps to reduce the risk of flooding and facilitates storm separation.[108]

The Strategic Planning Policy Statement 2015[109] outlines that the planning system should work towards climate change adaption by avoiding development in areas with

[106] Department for Infrastructure, 2nd Cycle - Flood Risk Management Plan 2021-2027, December 2020
[107] Department for Infrastructure, Sustainable Water - A Long-Term Water Strategy for Northern Ireland (2015-2040), March 2016
[108] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[109] Department for Environment, Strategic Planning Policy Statement for Northern Ireland (SPPS), September 2015

increased vulnerability to climate-related risks, including flooding, landslides and coastal erosion.

Translink are carrying out an ongoing programme of repairs to structures following storm damage which includes activities such as rock armouring and masonry repairs. In addition, they have recently replaced three bridges and strengthened embankments on both the Dublin and Antrim Branch lines.[110] However, there is no official plan for on-going assessment and maintenance of bridges in NI.

'Design of highway drainage systems'[111] and 'Design of highway structures for hydraulic action'[112] are DMRB documents that have been updated to account for the impacts of climate change. The documents outline new requirements for allowances for increasing rainfall due to climate change. For highway drainage, it stipulates:

> *calculation of a 20 % uplift in peak rainfall intensity together with a sensitivity test to 40 % uplift in peak rainfall intensity shall be undertaken and documented within the report describing the technical basis of the drainage design.*

In addition, the new DMRB documentation outlines that Flood Risk Assessments for the project must apply the latest climate change allowances in accordance with relevant national legislation requirements. For NI, these the relevant standards require use of the allowances quoted within the DfI Flood Risk Guidance.[113]

The general deterioration of roads in NI, especially rural roads, due to lack of funding over the years could be exacerbated with predicted future heavy rain events. The improvement of these roads is based on funding from the DfI. However, as discussed, the Transport Minister only bid £120 million for road maintenance in the financial year of 2021 when the Barton report identified an investment requirement of around £140 million per annum just to maintain the road network.[114]

3.4 Sea level rise

Global sea level rise increases the risk of coastal flooding and erosion through four main effects: waves, astronomical tides, storm surges and relative mean sea level. Coastal erosion which can be defined as the removal of material from the coast by wave action, tidal currents and/or the activities of humans, typically causing a landward retreat of the coastline.[115] Coastal erosion can be a risk to transport infrastructure where land retreats to a point where it causes flooding, rock falls, loss of land and damage to infrastructure. In 2008 it was estimated that 17.3% of the UK coast is

[110] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[111] Design Manual for Roads and Bridges, CG 501 Design of highway drainage systems, March 2020
[112] Design Manual for Roads and Bridges, CD 356 Design of highway structures for hydraulic action, March 2020
[113] Department for Infrastructure, Technical Flood Risk Guidance in relation to Allowances for Climate Change in Northern Ireland, February 2019
[114] Department for Infrastructure, Review of the Structural Maintenance Funding Requirements for DfI Roads, 11th January 2019
[115] British Geological Survey, Coastal Erosion, Accessed: 29th November 2021

suffering from coastal erosion. 19.5% of the Northern Ireland coast is suffering erosion, compared to 23.1% of the Welsh and 11.6% of the Scottish coastlines.[116] 32% of the coast has some form of manmade protection.

The risks of coastal flooding impacting transport infrastructure in the UK is increased where infrastructure is exposed at the coast. The impact of flooding can be amplified due to human activity disturbing nature's defences. In addition, human activity can also undermine flood defences by coastal engineering, land claim, river basin regulation works (especially construction of dams), dredging, vegetation clearing, gas mining and water extraction.[117]

Coastal flood risk increases disproportionately for an equivalent global warming level compared to flood risk from other sources (such as river and surface water flooding).[118] The NI flood risk assessment plan developed coastal flood maps considering flood defences and the extent portrayed is the maximum extent of inundation over the model run. In reviewing the climate change model, they identified 150 receptor counts of key infrastructure at risk of coastal source flooding in NI. A coastal screening tool developed by Climate Central (a US-based non-profit organisation) shows that rising sea levels could flood the coastline of Belfast by 2050. This tool also shows rising sea levels could flood much of Newtownards, the Ards Peninsula and low-lying farmland around the coast of Lough Foyle in Co Derry/Londonderry.[119]

3.4.1 Impact on roads

Despite improvements in flood defences, coastal flooding incidents have still taken place over recent years. Belfast Harbour experienced its worst tidal surge in January 2014 caused by a high tide, low pressure, and strong winds. This caused almost £1.4 million worth of damage to roads including the collapse of Whitechurch Road, damage to the main coastal route between Millisle and Ballywalter, and damaged flood defences.[120]

3.4.2 Impact on rail

The Third UK CCRA for NI estimated that 20 km of railway lines and three railway stations in NI are at 1:75 chance or greater risk of coastal flooding.[121] They also predict that in the absence of further adaptation and in a +4°C at 2100 scenario (low population growth), by 2080 the length of railway track exposed to coastal flooding could potentially double in Northern Ireland (100% increase).

[116] Masselink, G. and Russell, P., CCIP Annual Report Card 2007-2008 Scientific Review - Coastal Erosion and Coastal Geomorphology, 2009
[117] Eurosion, A guide to coastal erosion management practices in Europe: lessons learned, Accessed: 29th November 2021
[118] Sayers, P. et al. (2020). Next generation exploration of UK future flood risks: High resolution climate, population and adaptation futures. Proc. FLOODrisk 2020 - 4th Eur. Conf. Flood Risk Manag., 6.
[119] Climate Central, Coastal Risk Screening Tool, Accessed: 29th November 2021
[120] BBC, £1.4m roads repair bill after Northern Ireland storms, Accessed: 29th November 2021
[121] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021

3.4.3 Resilience to sea level rise

No single Executive Department has the responsibility for coastal erosion risk management.[122] The Executive's policy on coastal protection is determined by what is commonly known as the "Bateman Formula". Under this long-standing "Formula", central government departments have a responsibility to construct, maintain and repair the coastal defences in their possession. For example,

- The DfI's Rivers Agency (RA) has powers to maintain 26km of sea defences and two tidal barriers designed to reduce the risk of flooding (but not coastal erosion) to low lying coastal land;
- DfI's Transport NI has responsibility for coastal defences that protect the public road and railway network;
- The Department of Agriculture, Environment and Rural Affairs (DAERA) is the marine licensing authority for deposits in the marine area below the mean high water spring tide, and also has responsibility for marine and coastal conservation;
- DAERA is also the marine planning authority for Northern Ireland and published the Marine Plan for NI in 2018[123]. This plan discusses the consideration of how the marine area will need to adapt to climate change.

The DfI and DAERA commissioned the Baseline Study and Gap Analysis of Coastal Erosion Risk Management in Northern Ireland report which was published in 2018. The aim of this was to complete a vulnerability assessment of the NI coastline, understand the needs of stakeholders and decision makers with a marine and coastal interest and identify areas of work required to inform a policy of coastal erosion. The main outcome from the assessment was that there is currently insufficient reliable data to inform coastal management decision-making.[124]

The Infrastructure Minister signed a contract awarding the design and construction phase of a "£17 million Belfast Tidal Flood Alleviation Scheme" to Lagan Construction Ltd. It is hoped that the new tidal defences will cover an area of over five miles extending along the tidal River Lagan. This was in response to the Climate Central flood mapping from rising sea levels.[125]

The CCRA3 evidence report for NI states that "*the available evidence indicates that the risk to infrastructure services from coastal flooding and erosion is not currently being managed in Northern Ireland*".[126] There is also less detailed information on coastal change in NI, than other nations.

In Scotland, the Dynamic Coast project, funded by a consortium including Scottish Environment Protection Agency, provides strategic evidence on the extent of coastal

[122] AQW 797/16-21
[123] Department of Agriculture, Environment and Rural Affairs, Marine Plan for Northern Ireland, Accessed: 29th November 2021
[124] Department for Infrastructure, Baseline Study and Gap Analysis of Coastal Erosion Risk Management NI, January 2019
[125] Department for Infrastructure, Minister Mallon signs off on £17 million flood alleviation scheme in Belfast, Accessed: 29th November 2021
[126] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021

erosion in Scotland. They are improving the evidence on coastal change, improving the awareness of coastal change, and supporting decision-makers to ensure Scotland's coast can adapt to the changing climate.[127] The Dynamic Coast was commissioned by the Centre of Expertise for Waters (CREW) to provide the strategic evidence base on the extent of coastal erosion in Scotland. A key recommendation was to recognise that maintaining natural coastal defences is a key element in resilience and adaptation strategies.[128]

There is new planning policy advice (Technical Advice Note (TAN) 15: Development, flooding and coastal erosion) on flooding and coastal erosion in Wales which will take effect on 1st December 2021. TAN 15 provides planning advice that informs local development plans and decisions on planning applications in areas at risk of flooding and coastal erosion.[129]

3.5 Landslides

Landslides can be defined as the movement of a mass of rock, debris, or earth down a slope under the influence of gravity. There are five key landslide mechanisms: falls, topples, slides, spreads and flows. A landslide occurs when the forces acting down-slope exceed the strength of the earth materials of the slope. When slopes are on the verge of stability landslides can be initiated by rainfall, snowmelt, changes in groundwater, earthquakes, erosion, human activity, or a combination of these factors.[130]

Transportation infrastructure is often constructed alongside slopes. If the infrastructure is built alongside a hillslope, excavation into the hill is required often resulting in a steeper slope (a cut slope). Where this occurs, ground is often required to be filled in downhill of the infrastructure (fill slope). Transport infrastructure can also be constructed on top of artificial embankments (resulting in downhill slopes either side of the infrastructure) or below ground level (resulting in uphill slopes either side of the infrastructure). Slopes alongside transport infrastructure commonly require slope stabilisation works (an engineering measure to increase the stability of a slope) to be carried out. Where the slopes partially/fully fail (i.e., a landslide occurs) and geomaterial interferes with transport infrastructure and the road subsides there can be great social and economic cost.

The stability of slope can be negatively impacted in several ways by climate change. Increased precipitation can increase the groundwater table in some regions, which can reduce the strength of soil and, therefore, reduce the stability of a slope. Rainfall is often the main trigger for slope failure. Elevated temperatures and reduced precipitation in the summer will lead to the death of some vegetation that could have

[127] Dynamic Coast, Dynamic Coast, Accessed: 29th November 2021
[128] Centre of Expertise for Water, Dynamic Coast: The National Overview (2021), August 2021
[129] Welsh Government, Written Statement: New guidance on planning for flooding and coastal erosion risks, September 2021
[130] USGS, What is a landslide and what causes one? Accessed: 29th November 2021

been acting as a soil binder. Extreme winds can result in increased erosion rates of soil slopes, destabilising slopes.[131]

3.5.1 Impact on roads

Following heavy rain in February 2021, a landslide occurred resulting in the A2 coast road having to be closed in the Glens of Antrim. The landslide occurred in a hillslope cutting.[132] In August 2020, multiple landslides occurred in NI following a heavy storm (Storm Francis). One such landslide occurred in the Slieveanorra area, in northern County Antrim, and resulted in road closure. This slide is thought to have been made up of peat with its source in a shallow hillside next to the road.[133]

Data collected by the DfI shows that there have been 517 records of obstructions on roads caused by rock falls, mud slides and embankment slips, dating from 1st November 2015 to 17th October 2021. Figure 3 displays a heat map of the location of these records. This heatmap shows that there is high intensity of landslides on roads along the coast from Portrush in the north to Carrickfergus in the south. There is particularly high intensity of occurrence in Larne and Carrickfergus. These hotspots are often situated where a road has been built alongside a hillslope. This map also shows there are obstructions along roads caused by landslides all over NI.

From June 2020, the DfI were recording how many of these obstructions resulted in road closure. From the 166 records of obstructions from June 2020 to October 2021, the following closures occurred:

- 3 roads fully closed in Causeway Coast and Glens East (occurred on same day)
- 1 road fully closed in Mid and East Antrim
- 1 road partial closed in Causeway Coast and Glen West
- 1 road partially closed in Newry Mourne and Down East

[131] Nasr, A., Kjellstrom, E., Bjornsson, I., Honfi, D., Ivanov, O.L., & Johansson, J., Bridges in a changing climate: a study of the potential impacts of climate change on bridges and their possible adaptations, 2019, 16 (4), 738-749

[132] NewsLetter, Dramatic pictures show Glens of Antrim landslide which closed road after torrential rain, Accessed: 29th November 2021

[133] The Landslide Blog, Slieveanorra: a large peat bog landslide in Northern Ireland? Accessed: 29th November 2021

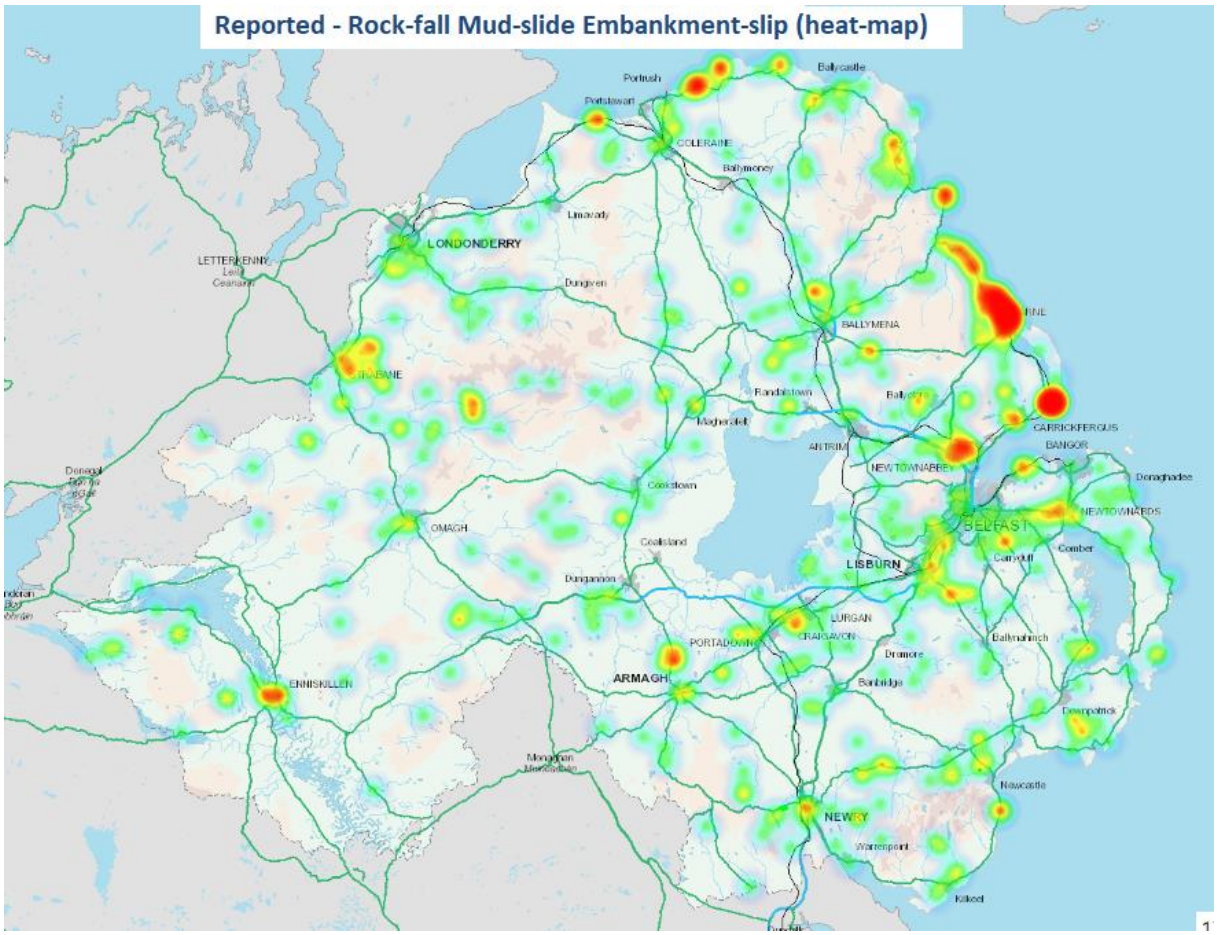

Figure 3 - A heatmap of the location of records of obstructions on roads caused by rock falls, mud slides and embankment slips, dating from 1st November 2015 to 17th October 2021

3.5.2 Impact on rail

A substantial length of the railway line that links Dublin to Belfast was constructed on peaty soils. Sections of the railway line on the peaty soils have deteriorated resulting in train speed reductions and increased maintenance. A review conducted by ICE found that the deterioration was caused by poor-quality fill and soft foundation materials (peat).[134]

3.5.3 Resilience to landslides

A limited number of studies have been undertaken to assess the threat of landslides and investigate the cost of damage or quantify the effects of adaption. This is likely due to the difficulties in collecting reliable data and evaluating the effect of adaption.[135]

[134] Hendry, M., Hughes, D.A. and Barbour, L., Track displacement and energy loss in a railway embankment. 2010, Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 163(1), pp.3-12.

[135] Kim, H.G., Lee, D.K. and Park, C., Assessing the cost of damage and effect of adaptation to landslides considering climate change, 2018, Sustainability, 10(5), p.1628.

In NI, there have been recent assessments and monitoring of slippages at certain sites, including Antrim Road at Throne neds, Colinglen Road, Comber Greenway, Ballyhornan Beach and Straidkilly.

In NI, Translink has committed to a continued geotechnical inspection regime for road and rail embankments. They have carried out a risk analysis on cuttings and embankments using available flooding information. They manage these assets during periods of heavy rainfall with additional inspections and by reducing train speeds.[136]

Landslide susceptibility maps are used all over the world to map landslide risk based on location. Guidelines are now available for integrating climate change projects into landslide susceptibility mapping.[137] In Switzerland, landslide risk mapping has been carried out for the entire Swiss national road network. This information can then be used for prioritising slope stabilisation measures and future road construction planning.[138]

In the aftermath of a landslide that derailed a train in Stonehaven in August 2020, Network Rail have produced a report providing an update on the Resilience of Rail Infrastructure. This included a review of Earthworks Management along rail tracks.[139] The executive summary stated that:

> *Pore water pressure regimes have been modified by changing weather patterns and will continue to change. Rates and magnitudes of pore water pressure changes depend on the availability and ability of water to flow into the soil profile, while strong surface flows can also cause soil erosion and flooding in their own right. Hence surface and sub-surface water management is probably the single most important factor in determining if, when and where an earthwork failure will occur.*

They suggest that a holistic approach to water management is necessary and that there needs to be significant investment in monitoring and surveillance method.

4 Potential issues for consideration

1. Some documents, like the Regional Development Strategy, are old and don't include the most recent climate trajectories based on current emissions.

2. There is no strategy in NI to protect roads from softening due to heat in the future.

[136] UK Climate Risk, Third UK Climate Change Risk Assessment Technical Report: Summary for Northern Ireland, 2021
[137] ASEAN, Guideline On Integrating Climate Change Projection Into Landslide Risk Assessments and Mapping – At The River Basin Level, 2021
[138] Swiss Federal Roads Office, Landslide Risk Mapping for the Entire Swiss National Road Network, Accessed: 29th November 2021
[139] Network Rail, A Review of Earthworks Management, February 2021

3. There is no rolling programme of maintenance and inspection of bridges for signs of climate related deterioration from flooding and heat.
4. There are several different documents for strategies to deal with flood management. It is not clear which is the more significant document in managing risk to infrastructure.
5. There are many documents discussing plans to adapt infrastructure to climate change, however, there are few actionable strategies (for example, those which could be subject to outcome-based accountability) from these that can be measured. In terms of flooding, there are no consistent indicators of resilience to flood risk across transport infrastructure. There is no policy on this.
6. There is no common strategy for coastal flooding and erosion risk management.
7. Despite the strategies in place for flood mapping and planning, the roads in NI are still very vulnerable to heavy rain due to current structural deterioration.
8. There are no other plans for coastal flooding defences in other locations that have been identified to be at risk of coastal flooding.
9. There are no detailed landslide susceptibility maps along transportation infrastructure in NI.
10. There is no overall document that is a strategy for adapting transport infrastructure to a changing climate. However, there are currently two NI climate change Bills being considered by the Northern Ireland Assembly.[140] [141] Both will require departmental (or sectoral) and public body plans in relation to adaptation and mitigation. However, there are no details on this yet, and it is not clear which, or indeed if either, will succeed.

[140] Climate Change Bill 2021, 19/17-22
[141] Climate Change (No. 2) Bill 2021, 28/17-22