Adaptation to Climate Change: Context and Overview for Transport Infrastructure Indicators

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Key Points

Report Purpose: This report provides an overview of travel patterns and transport infrastructure in Scotland. It gives some context for the CXC Climate Adaptation Indicators that together present a picture of the 'climate readiness' of transport infrastructure. It should therefore be read in conjunction with these indicators[1].

Climate Risks and Transport Adaptation Indicators: Climate risks to transport were laid out in the UK's first Climate Change Risk Assessment in 2012 (CCRA). Scotland's adaptation response to these risks is set out in the Scottish Climate Change Adaptation Plan (SCCAP). Transport Adaptation Indicators have been developed to track the risks, the exposure to them, and the extent to which Scotland is responding and adapting.

Transport and Travel Trends: The report summarises patterns and trends in travel modes and distances. Distances travelled are generally increasing. Freight volumes have decreased since the global economic turndown in 2007. Road haulage is the main mode of freight transport, and transport by pipeline also important.

Performance of the Transport System: Factors which affect performance are outlined. Data on the main causes of travel disruption shows congestion to be the major contributor of disruption (over 80%), with weather-related events causing only 1.5% of reported delays, and 7% of trunk road closures. National indicator no. 4 shows performance worsening for journeys perceived to be delayed by congestion in 2014.

Transport Vulnerability: The risk of disruption is influenced by the vulnerability of different travel modes, the location of communities and infrastructure, and the average distances covered by freight, service providers and the public. Social and economic structures, patterns of development and transport are linked in complex systems. A focus on accessibility can improve resilience and reduce the risk of climate disruption to travel.

Climate Impacts: Weather-related traffic disruption is far less frequent than disruption caused by traffic volume, roadworks, accidents and breakdowns. Weather-related factors caused 7% of trunk road closures and 1.5% of journey delays in 2013. Flooding was the biggest weather-related factor, and caused 4% of all trunk road closures. Landslides caused fewer closures than flooding but such closures were likely to last for far longer (days, or occasionally weeks).

Maintaining and Improving Resilience: Transport disruption from floods and landslides is anticipated to increase in future, albeit from a relatively minor starting point. Disruption from non-climate causes (e.g. vehicle numbers and congestion) may also increase. All such factors play a part in the overall resilience of the transport network. More nuanced measures and metrics may be needed to properly characterise the impacts to transport systems associated with climate change.

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[1] 11 indicators address direct and direct consequential climate impacts on transport. Indirect consequential impacts (eg productivity) are not captured. Gaps in coverage reflect limitations in either existing primary data or output from models.

1. Introduction

Transport infrastructure is essential for the effective functioning of modern society and the economy (HR Wallingford et al, 2012; EEA, 2014). The impacts of climate change have the potential to disrupt transport, and Scotland's National Transport Strategy recognises the need to ensure that transport infrastructure and services remain robust in the face of such challenges (Scottish Executive, 2006).

Climate risks to the transport sector were identified in the first UK Climate Change Risk Assessment (CCRA) (Thornes et al, 2012; HR Wallingford et al, 2012). In response to this, the Scottish Climate Change Adaptation Programme (SCCAP) was developed, which set out the policies and proposals intended to deliver climate change adaptation for the transport sector (Scottish Government, 2014a). ClimateXChange has developed 11 indicators of adaptation to climate change in order to track the effectiveness of the adaptation response in Scotland over time[2]. These are shown in Appendix C, Table 3.

The CCRA exercise was designed to assess the risk to transport infrastructure 'as is'. It was not designed to consider the features of travel, transport and accessibility systems that increase or reduce underlying resilience, such as trends in journey lengths and vulnerability of mode[3]. These aspects are covered by a range of reports covering both Scottish and UK level aspects[4].

This report gives a brief overview of travel, climate risks and transport vulnerability in Scotland so as to provide some context for the adaptation indicators relating to transport as covered by the CCRA. A range of information about transport infrastructure is given in Appendix A, and about travel patterns in Appendix B. Appendix C provides some detail about the UK's first CCRAs, produced in 2012, which identified the risks that are addressed by this set of climate adaptation indicators. These CCRAs will shortly be superseded by the latest round of CCRAs for the UK, which are due to be published in 2016.

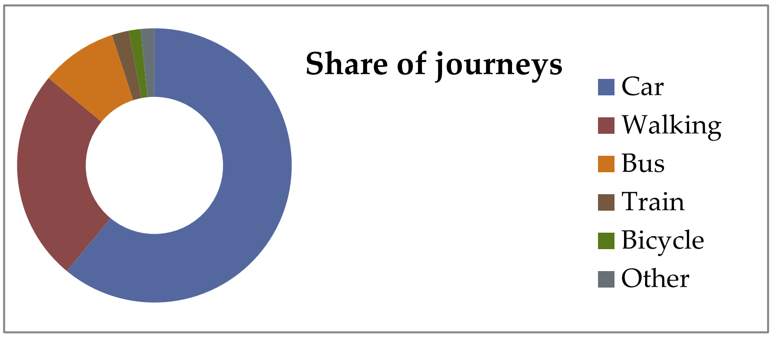
2. Travel in Scotland – Modes, Purpose and Distances

2.1 Travel trends

Personal travel modes and purpose

A detailed examination of travel patterns in Scotland is provided by each year by Transport Scotland (Transport Scotland 2015e). Commuting (23%) and shopping (22%) were the most common purposes of personal travel in 2014. The latest report shows the travel mode for trips taken in 2014 as follows:

- 61% of trips were made by car, either as driver or passenger
- 25% of trips were made on foot
- 9% were by bus
- 2% were by train
- 1.4% were by bike



Over half of all travel to school was undertaken on foot (51%). In contrast, commuting modes were as follows:

[2] These indicators will also be used in the Adaptation Sub Committee's (ASC) statutory assessment of the SCCAP

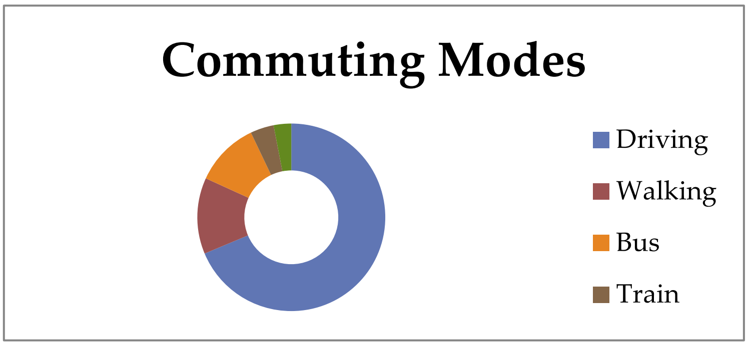
[3] There is a difference between the resilience of fixed transport infrastructure and the resilience of travel, distribution and access systems.

[4] See for example Transport Scotland's Environment and Sustainable Travel review, and Dr Steve Melia's Urban Transport without the hot air (the former at http://www.transportscotland.gov.uk/report/j323173-06.htm, and the latter at http://www.uit.co.uk/without-the-hot-air-series/sustainable-transport-volume-1

[5] In 1985/1986, Scots travelled an average of just 4,652 miles per year, of which 3,069 miles was by car.

- Driving 68%
- Walking 13%
- Bus 11%
- Train 4%
- Bike 3%

(Travel and Transport 2014 (Transport Scotland 2015e).



Journey Lengths

Annual travel per person has increased by over 50% over the last two decades, with most of the increase being due to travel by car[5]. On average, Scots travelled just over 7000 miles per year in the two-year period 2011/2012 (according to the National Travel Survey). Three-quarters of this (5,315 miles) was by car (Transport Scotland, 2014). Thus, over 20 years, the average distance travelled has increased by 2,509 miles, a rise of 54%, nearly all by car (ibid).

Travel Trends. Table 1 provides a summary of some of the main travel trends in Scotland. Some of these trends have an important influence on climate risks to transport. For example, an increase in traffic volumes increases the potential for traffic disruption from flooding. Both the modal share of journeys and average journey lengths are important factors, as they affect the performance of the transport system, particularly at peak times. Further statistics on travel infrastructure and on personal and freight travel are given in Appendices A and B.

Table 1. Travel demand in Scotland – example trends and drivers (2003 - 2013)

Trends and data (2003 - 2013). See also Appendix B	Related factors and drivers
Traffic on major and minor roads was on a steady rise until 2008 with the two subsequent years showing a slight decline. Since 2011 major roads have again seen traffic increase, and likewise for minor roads since 2013. The total number of vehicles licensed has increased by 17%, in this period, although from 2008 growth has slowed.	• Population and demography • Incomes and the state of the economy • Cost of motoring relative to other costs • Availability and cost of other forms of transport
In 2013, car ownership in urban households was noticeably lower (60-71%) than that in rural areas where 89-87% of households owned at least one car. Bus use is significantly higher in urban areas compared to rural areas.	• Accessibility of jobs and services / facilities • Traffic congestion and parking availability • Cost of motoring and parking relative to other options • Availability and cost of bus services relative to other options
Passenger journeys and passenger kilometers on Scot Rail services significantly increased between 2002/03 and 2013/14 by 33.5% and 31.25% respectively.	• Impact of a growing economy • Additional train services, improvements to stations • Attractive offers and deals for cheap travel • Cost of motoring relative to other modes
The share of journeys on foot and by bike has increased (from 15% to 25% for walking; from 0.8 to 1.4% for cycling). 51% of journeys to school are on foot. Travel to school by car	• Promotion of active travel / safe routes to school • Improved safety infrastructure (e.g. road crossings) • Increased awareness of health benefits

[5] In 1985/1986, Scots travelled an average of just 4,652 miles per year, of which 3,069 miles was by car.

Trends and data (2003 - 2013). See also Appendix B	Related factors and drivers
has slightly increased (to 24.5%), and bike use is minor but increasing (now 1.7%).	• Accessibility of schools
2005/06 saw a peak in total volume of freight carried by rail in Scotland. There has been a significant decline - 2012/13 showing a 41% reduction from this peak.	• Relative cost of road vs rail freight • Financial crisis and subsequent economic downturn

3. Performance of the transport system in Scotland

Several of the transport adaptation indicators measure disruption to the performance of transport infrastructure and the transport system (e.g. road and rail obstructions / closures, journey delays and so on - see indicators BT4, 12, 23). It is therefore useful to understand the factors that influence operational performance of the transport system, and some of its performance benchmarks before any climate disruption is considered. As noted above, boath the modal share of journeys and average journey lengths are important factors. A short summary is given here.

In the short term the operational performance of the transport system reflects the balance between travel demand and the provision of the transport infrastructure and services. Congestion and delay are the product of a mismatch between demand and capacity on part of the network. This imbalance can recur periodically at the same time and location (such as during the rush hour) or as a result of a temporary reduction in capacity (e.g. road works, traffic restrictions on a weakened bridge), or because of a change in travel patterns caused by a special event. The costs of delay will not always be borne solely by those undertaking travel. For example, loss of working hours will have consequences for businesses or other service providers. Delays in the delivery of goods can add cost to the supply chain (HR Wallingford et al 2012).

The 'intensity of use' increases the impact of any disruption, and a one hour interruption to traffic on a busy motorway could affect many thousands of road users (DfT, 2014). The numbers are far smaller when transport to remote regions is disrupted. However, these groups are often vulnerable because there may be limited or no alternative transport options available (EEA, 2014). This is a key issue for Scotland.

3.1 Performance of the Road Network

Delays and Congestion. In 2014, 11.7% of driver journeys were delayed as a result of congestion, an increase from 9.7 in 2013[6]. Figure 1 shows the trend over time. National indicator no. 4 is based on this metric, and shows a worsening performance in 2014 for the percentage of driver journeys perceived to be delayed by congestion (11.7%). Drivers in urban areas experience more delayed journeys than those in rural areas, and commuting journeys are more likely to be affected by congestion (18%) than shopping journeys (6%)[7].

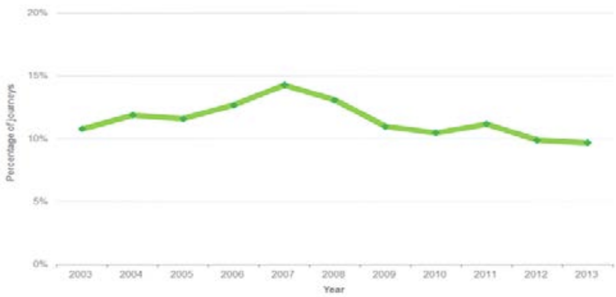


Figure 1 Journeys delayed by congestion 2003 to 2013. Source: Transport and Travel 2013 (Scottish Government, 2014)

[6] This data is derived from the Scottish Household Survey which asks respondents whether car journeys were delayed due to congestion, and if so, how much time was lost.
[7] Figures from 2013.

Cause of Delays and Disruption. The most frequently cited cause of delay in 2014 was volume of traffic (82% of all delays) followed by road maintenance works (18.9%)[8]. In contrast, bad weather was only cited as responsible for 1.5% of delays. Figure 2 presents cause of disruption data and shows the minor role played by bad weather (1.5% of delays).

Figure 3 shows that broken down or abandoned vehicles and road accidents cause the vast majority of trunk road closures, with just 7% of closures caused by events that could be exacerbated by climate-change (flood, landslide, rockfall), of which 4 % were caused by flooding (all data from the IRIS trunk roads incident log).

Clearly, weather-related traffic disruption (i.e. disruption subject to climate impacts) is far less frequent than other causes at present. However, figures do not reflect the length of the delay (route closures due to landslides may last for days). Furthermore, the cause of some road maintenance activities may be related in part or wholly to weather damage. Nonetheless, based on these figures alone, it would appear that, at present, climate impacts have a relatively minor effect on the performance of the road network as compared to other causes of disruption and delay. Further metrics (e.g. on length of delay, numbers of road users affected, the cost of re-instatement and so on) may be required in order to understand the full impact of climate impacts on transport systems.

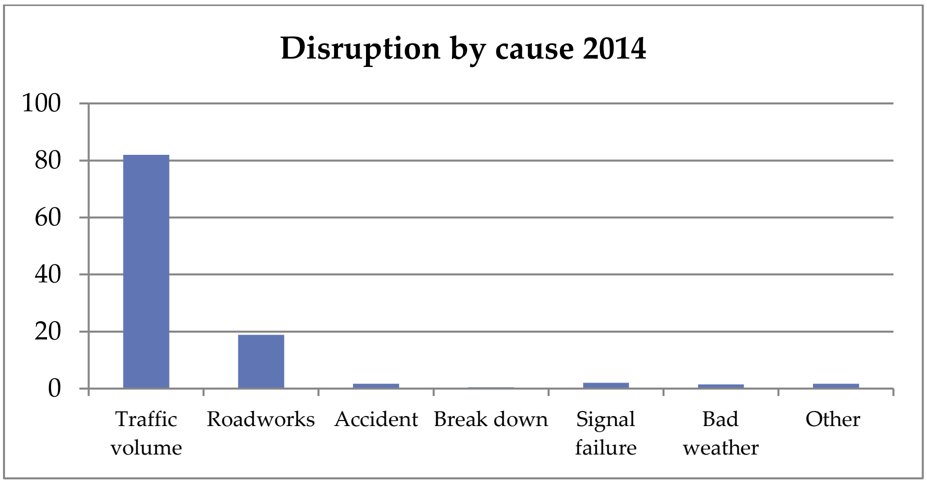


Figure 2 Journey disruption by cause Source: Transport Scotland’s Annual Travel Survey (2014).

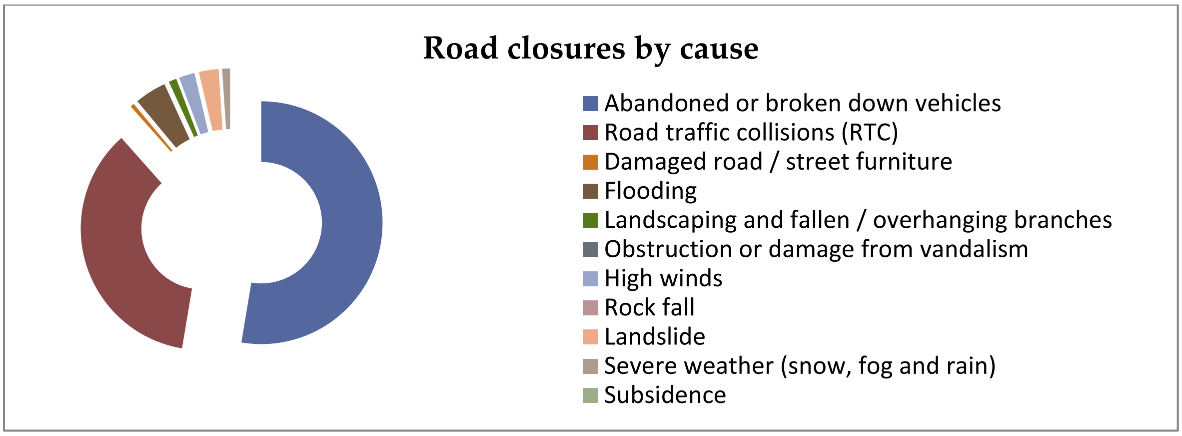


Figure 3 Trunk Road closure by cause Source: IRIS trunk roads incident log (2014)

[8] Figures exceed 100% as respondents may have cited more than one cause of disruption.

3.2 Public Transport Performance

In 2013, 10.2% of passengers experienced delayed bus journeys - a reduction from a peak of 14.4% of passenger journeys in 2008. No statistics have been published on the cause of passenger delays.

For rail travel, at the national level (i.e. Great Britain) the percentage of trains arriving at their terminating station on time rose steadily over the period 2002 to 2015 (see Figure 4). The performance of ScotRail was slightly above the national average in the year to August 2015.[9] In Scotland, 55% of all delays of 3 minutes or more were attributed to Network Rail (compared to 59% for GB as a whole).[10] Of the delays attributed to Network Rail, 27.2% were the result of external factors such as weather and fatalities. Further breakdown of these statistics is not published and so it is not possible to rank the relative importance of specific types of weather-related events (though from the data given above, it would appear that weather caused one seventh or less of all delays).

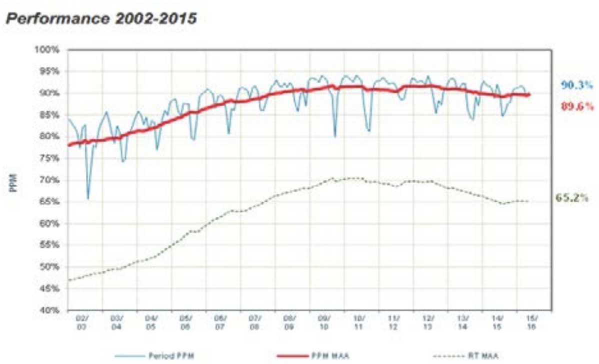


Figure 4 Percent of trains arriving on time, 2002 to 2015, Great Britain (Network Rail, 2015)

4. Key climate risks and vulnerabilities of Scotland's transport system

4.1 Climate risks and transport system interdependencies

The UK Climate Change Risk Assessment (CCRA) (Thornes et al, 2012; HR Wallingford et al, 2012) identified the following climate change risks to Scotland's transport infrastructure, all of which are associated with changing patterns of rainfall[11]:

- Pluvial, fluvial and coastal flooding to roads and rail
- Road network landslides
- Scouring of road and rail bridges

Any direct effect on the transport system is likely to have important 'cascade effects' and consequences for society, other infrastructure sectors and the wider economy (e.g. supply chain disruption and business costs from productivity losses (ASC, 2014; EEA, 2014)) [12]. This is because transport systems have many internal and external complexities and interdependencies. Some of these interdependencies are outlined in Figure 5 below. Transport adaptation indicators which measure the risk of disruption include BT2,8,9,17 and 26 (see Appendix C, Table 3).

[9] The annual average % of trains arriving on time in the year up to 22nd August 2015 was 89.6% for Great Britain and 90.9% for Scotrail.

[10] Network Rail owns and maintains the rail infrastructure. Train operating companies, such as Scotrail, operate the train services.

[11] A more detailed description of these risks is given in Appendix C.

[12] Direct and indirect effects are described by Winter et al. (2014) in relation to landslide risks.

Sector	Dependencies on Infrastructure	Impacts on other Sectors
Energy	• Water cooling in power stations and fuel refining. • ICT for control and management system of electricity and gas. • Transport for the fuel supply chain and workforce. • Gas storage and distribution relies on electricity supply.	• ICT wholly dependent on energy. • Transport dependent on fuel and increasingly electricity. • Water dependent on energy for treating, pumping and processing as well as control systems.
ICT	• Energy for all services. • Transport for maintenance workers.	• All sectors increasingly dependent on ICT for control systems, especially the smart grid. • Increasing dependence on ICT for sensing and reporting the condition of the infrastructure.
Transport	• Energy infrastructure for fuel and increasingly electricity. • ICT for management of services and networks. • Drainage infrastructure to prevent flooding. • Internal dependencies within and across modes (e.g. airports and roads).	• All sectors dependent on transport to transport workforce to sites.
Water	• Energy for treating, pumping and processing. • ICT for control systems. • Transport for workforce and supplies of chemicals for processing.	• All workplaces require water for staff. • Cooling water for some energy infrastructure.

Figure 5 Core economic activity sectors – key interdependencies and impacts of disruption (Source: DEFRA, 2011)

Note: The second column highlights interdependencies. Transport is dependent on energy infrastructure to provide fuel. The third column highlights the impacts on other sectors that could be caused by disruption of the core activity. Transport disruption can impact all other sectors if, e.g., a workforce cannot access the workplace.

4.2 Climate Vulnerabilities of the Transport Sector

Social and economic structures, land-use patterns and transport are linked in complex systems. A focus on the *accessibility* of goods and services (rather than just transport per se) can improve resilience and reduce the risk of climate disruption to travel. The features of travel and transport which increase the exposure to and impact from climate risks to society include i) the vulnerability of mode, ii) the exposure of infrastructure (location), iii) patterns of development and average journey lengths for individuals, services and goods, and iv) the presence or absence of alternative means. Modes, location and alternatives are discussed below.

Vulnerable Modes: Road and rail transport are considered most vulnerable to climate change (compared to air for example) as these modes are designed to function on a fixed infrastructure (i.e. road and rail networks) (HR Wallingford et al, 2012). In effect, re-routing road and rail transport to account for new or worsening climate risks and impacts is prohibitively expensive (e.g. moving a road or railway further up a floodplain to reduce flood risk), whereas boats and planes may be able to take different routes. Road transport in the UK is particularly exposed to climate risks as the vast majority of transport needs are met (and likely to continue being met) by roads (ibid). The road network in Scotland is approximately 65% longer than the rest of the UK relative to population size (Scottish Government, 2010), which is likely to increase the cost of maintenance relative to population size.

Rail routes have been planned to allow for historic weather conditions and associated risks (Network Rail, 2014). Thus routes crossing floodplains have been designed to avoid historic flooding zones, without considering climate change effects. Nevertheless, the climate resilience of major modern transport infrastructure is generally improving due to advances in structural design and understanding of risks (HM Treasury, 2014).

Vulnerable Locations: Roads in remote rural locations are considered to be more vulnerable to the effects of flooding as there are fewer alternative routes (SEPA, undated; also Jenelius, 2009). This is very relevant for Scotland given that a large proportion of its land area is remote (Scottish Government, 2014b). However, total numbers affected are likely to be small as compared to those affected by disruption in the central belt area. Extreme weather, such as the severe snowfall of December 2010 highlighted this vulnerability (Prior et al 2011).

Addressing Infrastructure Vulnerability: The UK Committee on Climate Change (2014) note that a strategic approach is required to increase the road network's resilience to climate impacts, through planning and design that accounts for projected climate changes. The trunk road network in the UK has been upgraded and improved relatively recently. When design standards are exceeded by extreme weather events, impacts are then managed through traffic management systems and business continuity arrangements (Committee on Climate Change, 2014). In contrast, very remote rural areas often rely on single track roads, with limited resources available for upgrading. As a result, roads serving these areas may be more susceptible and less resilient to climate change than the trunk road network (though again, the numbers affected will be relatively small).

The challenges for the rail network relate in particular to its lack of flexibility in the event of a line closure (the multiple routes available between Glasgow and Edinburgh are a notable exception). In effect, all train lines and services can be regarded as critical due to the lack of alternatives for a given route. Beyond this, the greatest challenge for increasing the resilience of rail infrastructure is the redesigning of earthworks and embankments that in large parts are 150 or more years old and at the time were not designed with climate resilience in mind (DfT, 2014). Geotechnical assets such as earthworks and embankments can fail during heavy rainfall via a number of mechanisms such as cutting failure due to water flowing over the crest of cuttings and embankment failure due to saturation during rainfall events (Network Rail, 2014).

Reducing Vulnerability – Adaptation and Robust Travel Modes

Investing in flood defences is an obvious adaptation to help address the increased risk of flooding (see BT6 and 16). Likewise, actions to reduce the impact of bridge scour and landslide events also address the physical impacts of climate change. Such investments are in line with a focus on transport infrastructure, independent of the factors which drive the need for travel (travel demand).

Until recently, relatively little attention was given to the drivers influencing trends in travel distance and mode for both personal and freight travel. Addressing trends in journey length and modal share has the potential to play an important role in reducing climate vulnerability[13]. Planning, patterns of development and transport policies all have a significant role to play in this area.

5 Conclusions

Considerable work is being undertaken to understand climate change, climate risks and impacts, and how best to address these through adaptation. The UK's first CCRAs, the SCCAP and the CXC Adaptation Indicators each address different aspects of this endeavour. For transport, the first CCRA was very much focused on flood and landslide risks to infrastructure and the SCCAP and associated indicators follow this logic through (see Appendix C, Table 3.

However, as noted earlier in this report, at present only 4% of trunk road closure incidents are due to flooding, under 3% are due to landslides (though recovery time from such closures may be lengthy), and only 1.5% of delays are due to weather-related events. High traffic volumes, breakdowns, road accidents and road maintenance cause far more disruption at present. In particular, traffic volumes are responsible for over 80% of delays.

In this setting, and based on the data available at present, bad weather (including climate impacts) appear to be a relatively minor issue at present. Nonetheless, climate impacts to transport systems will increase, albeit from a relatively minor starting point. More focused measures and metrics may be needed to characterise the threat of climate change to transport systems. One such metric would the duration of road closure incidents, as this would better reflect the impact of incidents such as landslides.

[13] Where communities and economies are distributed so as to permit shorter / more secure routes and modes for freight and personal travel, climate vulnerability is reduced. Such systems are likely to be more robust in the face of climate challenges.

Appendix A Road and Rail Transport Networks

Rodrigue et al. (2011) recognise three basic types of transport mode – land (road, rail and pipelines), water (shipping), and air. Each mode of transport has its own network. Notably some modes have exclusive use of infrastructure (rail) whereas others share infrastructure (roads).

Road network

Scotland's road network consists of almost 56,000 kilometres of road (Audit Scotland, 2011). With the exception of motorways, all roads in the UK (including Scotland) fall into the following four categories (DfT, 2012):

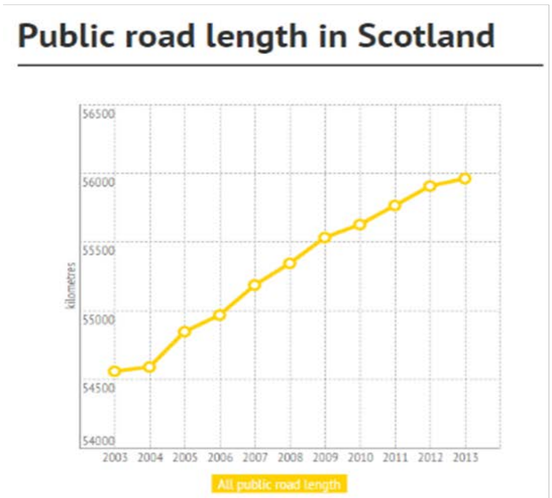
- A roads – major roads intending to provide large-scale transport links within or between areas.
- B roads – roads with lower traffic intensity than A roads, designed to feed traffic between A roads and smaller roads on the network.
- Classified unnumbered – smaller roads intended to connect together unclassified roads with A and B roads. Sometimes referred to unofficially as C roads.
- Unclassified – local roads intended for local traffic.

This classification system is intended to form a road hierarchy whereby large volumes of traffic / traffic travelling greater distances should use higher classes of roads (i.e. motorways and A roads) and smaller traffic volumes travelling shorter distances and at lower speeds should use lower classes of roads such as B roads and unclassified roads (ibid).

Motorways and A roads provide strategic links between Scotland's main cities and regions. All motorways and some A roads are referred to as trunk roads. The trunk road network in Scotland is a major national asset (currently the Scottish Ministers' single biggest asset) connecting cities, major towns, airports and ports to enable the movement of people, goods and services (Transport Scotland, 2015a). In Scotland, trunk roads are managed by Transport Scotland. The trunk road network ranges over 3,400 kilometres carrying 37% of all traffic and 63% of heavy goods vehicles (Audit Scotland, 2011; Transport Scotland, 2015a).

The remainder of the road network (i.e. all roads other than trunk roads) are referred to as local or non-trunk roads. These local roads are managed and maintained by Scotland's 32 Local Authorities. Altogether there are 26,000 kilometres of classified roads and 26,400 kilometres of unclassified roads across Scotland, all of which are managed by Local Authorities (Audit Scotland, 2011).

Between 2003 and 2013 the length of all public roads in Scotland increased by 1,402 kilometres (approximately 2.6%). The length of local roads increased more during this period. Overall, the length of local and trunk roads increased by 2.5% and 1.83% respectively, as shown on Figure 6 (Scottish Transport Statistics, 2015).



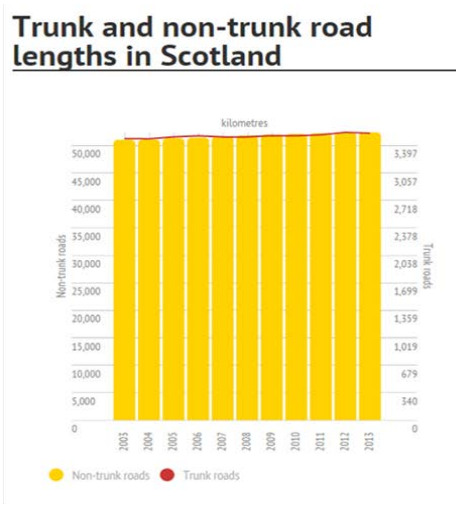


Figure 6. Length of public roads in Scotland (2003-2013) overall and by type (Source: Scottish Transport Statistics No 33, 2014 Edition)

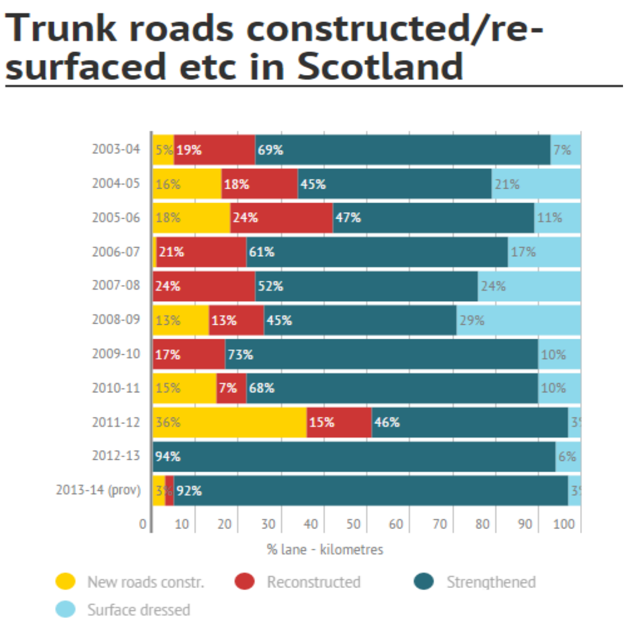


Figure 7 Trunk road maintenance activities in Scotland (2003-2013) (Source: Scottish Transport Statistics No 33, 2014 Edition)

Different approaches are adopted in the management and maintenance of Scotland's road infrastructure. Transport Scotland has assigned four contracts to Trunk Road Operating Companies (TROCs) on the basis of regional units to ensure efficient and well maintained trunk roads (Transport Scotland, 2015). Local Authorities are responsible for the management of all other public roads within their jurisdiction, except for private roads which are the responsibility of landowners.

During the period 2003 to 2013, the maintenance of trunk roads has focussed on road strengthening and reconstruction works (see Figure 8). On average, during this decade, 63% (by length in lane kilometres) of trunk road maintenance in Scotland has been for strengthening works, compared to 15 % on reconstructing, 13% surface dressing, and 10% on the building of new roads.

Figure 8. Topological map of the Scottish Rail Network (Source: Scotrail (undated))

Rail network

As shown in Figure 8, the rail network in Scotland is extensive and diverse with around 2,800 kilometres of track, 25% of which is electrified, (Transport Scotland, 2015d) and 351 stations (Scottish Transport Statistics, 2015). All maintenance and engineering work is provided by Network Rail who have sole responsibility for the safety and reliability of railway infrastructure in Scotland.

Rail lines open for traffic in Scotland

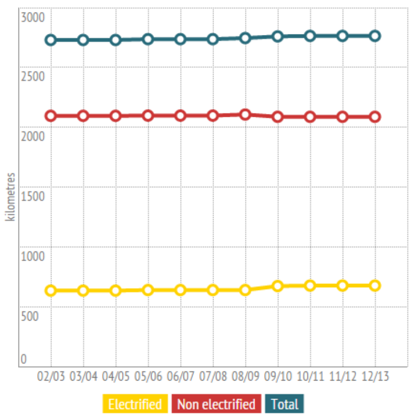


Figure 9. Length of open rail lines in Scotland (2003-2013)
(Source: Scottish Transport Statistics No 33, 2014 Edition)

The total length of open rail lines in Scotland has been relatively constant during the period 2003-2013 with only 34 kilometres (1.2%) added (see Figure 9). The focus has been on expanding the electrified rail network, increasing the open line length by 42 kilometres whereas non-electrified line availability has actually been slightly reduced – by 8 kilometres (Scottish Transport Statistics, 2015).

The Borders Railway opened to passengers in 2015, providing 48 kilometres of new railway linking Edinburgh in the north to Tweedbank in the south via ten stations including Edinburgh Waverley to the north.

Appendix B Travel patterns and trends in Scotland

There is an upward trend in traffic volumes on major roads[14] in Scotland, with peaks in 2007 and 2013 (see Figure 10). In 2013 motorways and trunk roads made up only 6.7% of the total length of the road network (trunk and local roads) but carried over 39% of the traffic. Traffic on minor roads[15] is estimated to have risen by 8.4% between 2003 and 2007 though it fell by 6% thereafter. There was then a slight increase in 2013 (Scottish Transport Statistics, 2015). The fall in road traffic volume after 2007 could be a result of a number of factors (DfT, 2015) including changes in:

- Population and demography (migration to cities as people in cities drive less than those in rural areas. The UK 2012/13 estimates were for 5,772 car miles per person per year in rural areas, compared to 2,226 miles in urban settings
- Incomes and the economy (economic trends influence car ownership and driving frequency)
- Cost of motoring (increasing fuel prices, fuel efficiency, insurance,) and
- Forms of transport (availability and cost of other modes of transport).

[14] Some metrics from the Scottish Transport Statistics series apply an alternative road classification using 'unofficial road types' as per DfT (2012) – 'major' and 'minor' roads. Generally major roads are all A roads and motorways (therefore encompassing more roads than the trunk road network which does not include all A roads) whereas minor roads are all roads that are not major roads or all roads which do not have a national number associated with them (ibid).
[15] Ibid

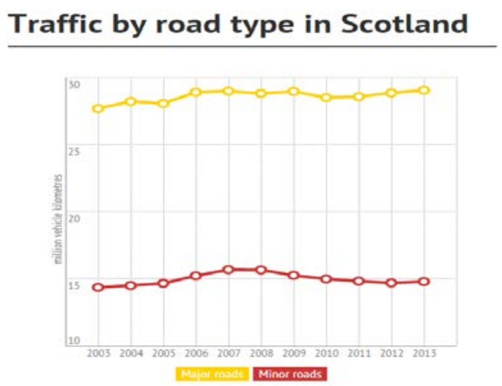
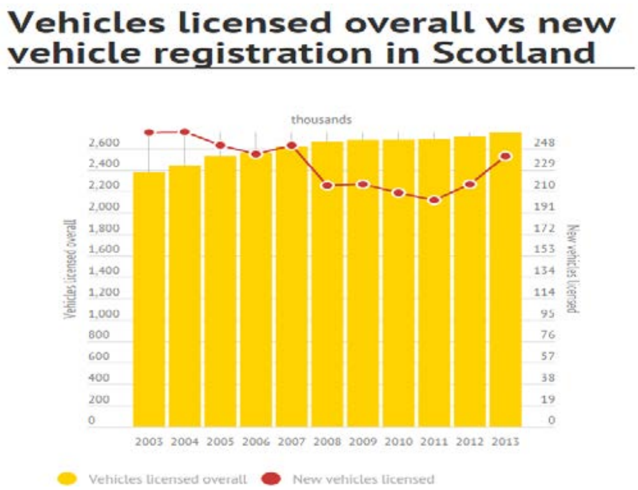


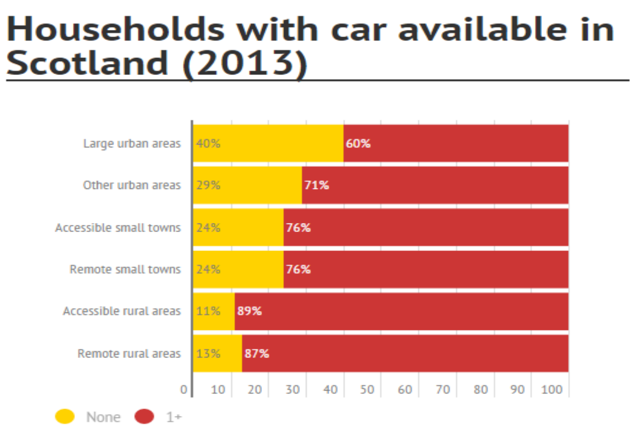
Figure 10 Traffic by road type in Scotland (2003-2013)

(Source: Scottish Transport Statistics No 33, 2014 Edition)



Since 2003 the total number of vehicles licensed in Scotland increased by 376,000 reaching 2.75 million in 2013, a 13.6% increase (see Figure 11). Similarly to the traffic volume trends however, the total number of new motor vehicle registrations fell considerably after 2007 and though the 2012 data shows around 241,400 newly registered vehicles, this is 3.9% below the 2007 figure (Scottish Transport Statistics, 2015). The global economic downturn may be a driver of this trend from 2008 onwards (SMMT, 2011), however it is evident that a downward trend was already in place before the slight peak in 2007.

Figure 11 Vehicles licensed and newly registered in Scotland (Source: Scottish Transport Statistics No 33, 2014 Edition)



In 2013, between 60-71% of urban households had access to at least one car, compared with 89-87% of those in rural areas (see Figure 12). Access to employment and resilience to emergencies and transport disruption are likely to increase the need for rural households to own at least one vehicle in contrast to urban populations where lifestyle and leisure may be dominant factors (i.e. access to private cars in urban areas may be less of a necessity). Most remote areas have more limited access to services and public transport connections therefore in emergencies access to a private vehicle can be seen as a necessity for accessing services (Scottish Government, 2001).

Figure 12 Households with car available in Scotland
(Source: Scottish Transport Statistics No 33, 2014 Edition)

The results from the Scottish Household Survey indicate that bus use is significantly higher in urban areas compared to rural areas (see Figure 13). Data from the period 2003 to 2013 shows that 83-86% of respondents who stated that they 'used the bus the previous day' lived in urban areas compared to only 6-9% from rural areas. Differentiating bus use by journey purpose, urban and rural respondents are comparable throughout the period 2003-2013. Commuting (26-30%), shopping (21-31%) and other purposes (8-18%) have compellingly been the main reasons for using the bus according to the surveyed members of Scottish population.

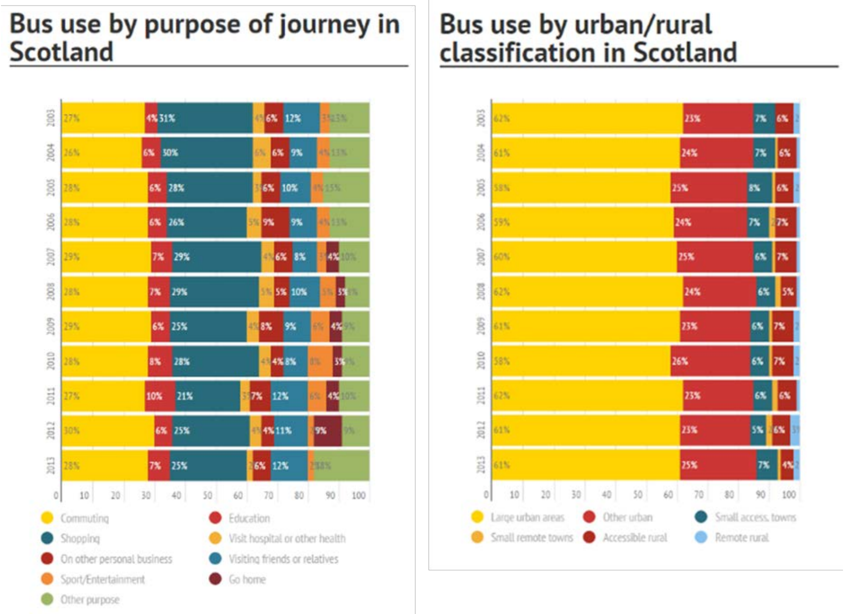


Figure 13 Bus use in Scotland by purpose of journey and urban/rural classification

(Source: Scottish Transport Statistics No 33, 2014 Edition)

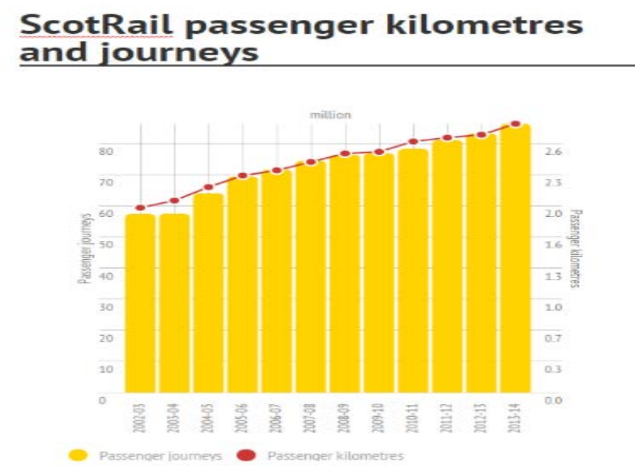


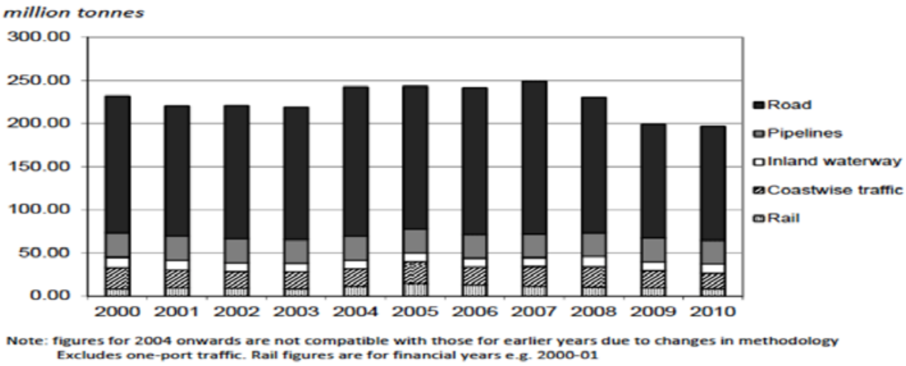
Figure 14 ScotRail passenger kilometres and number of journeys (Source: Scottish Transport Statistics No 33, 2014 Edition)

Passenger journeys on ScotRail services increased by 3.6% from 83.25 to 86.34 million in the 2013/14 financial year, representing an overall increase of 33.5% since 2002/03 (Figure 14). An equivalent trend is seen for passenger kilometres, which increased by 0.9 million kilometres (31.25%) over the same period. There are a number of possible factors driving these trends such as the impact of the country's growing economy, additional train services, revised timetables, attractive offers and deals facilitating cheaper travel, major schemes involving redesign and improvements to stations (Passenger Rail Usage, 2014).

Freight

The following table show total freight lifted in Scotland, including that remaining in Scotland[16]. Freight volumes reduced after 2007, with the reduction thought to be due to the global economic downturn.

[16] See more at: http://www.transportscotland.gov.uk/statistics/j285663-06.htm#sthash.nCK8oGCf.dpuf



[17]

Figure 15 Freight traffic lifted in Scotland by destination and commodity

Figure 15b shows the transport mode deployed per total tonne-km of freight in Scotland, the UK and the EU. While road haulage accounts for the majority of freight, transport by pipeline and rail is also significant.

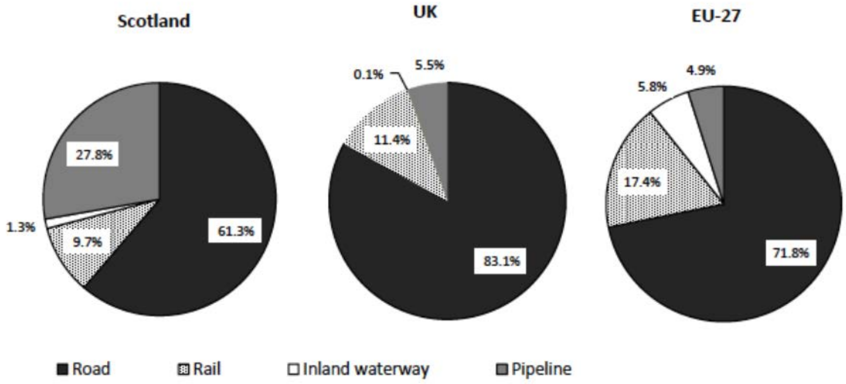


Figure 15b Freight traffic lifted in Scotland by destination and commodity

In 2012/13, 8.43 million tonnes of freight was lifted in Scotland by rail, a 41% reduction from the peak in 2005/06. Since then there has been a substantial shift in freight lifted by commodity. Of all freight lifted by rail in Scotland in 2012/13, 48% was 'minerals / coal and coke' compared to 75% in 2005/06. The volume of 'other' materials lifted in Scotland increased to 52% between 2005/06 and a peak in 2012/13. It is not clear what is driving the trends beyond the economic downturn and associated impact on output and goods carried etc.

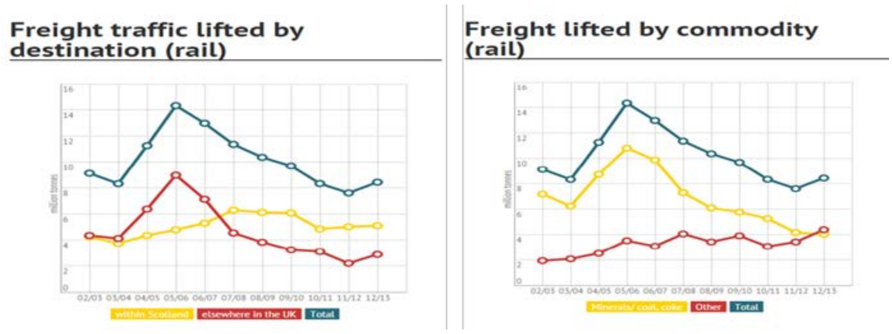


Figure 16 Freight traffic lifted in Scotland by destination and commodity (Source: Scottish Transport Statistics No 33, 2014 Edition)

[17] A good summary of freight movement is available at http://www.transportscotland.gov.uk/statistics/j285663-06.htm

Appendix C Climate change projections and implications for transport

Evidence on the risks and opportunities of climate change for Scotland was presented in the first 2012 UK Climate Change Risk Assessment (CCRA) report (HR Wallingford et al, 2012). This assessment was based on the UK Climate Change projections and provided a separate evidence report for Scotland describing and quantifying the risks from climate change up until 2100. The risk assessment approach in the CCRA involved three distinct elements: 1) a review of data on climate variability and climate projections; 2) an assessment of the impacts of projected changes on biophysical systems; and 3) a risk (and opportunities) assessment to develop an understanding of how impacts on biophysical systems might interact with socio-economic and ecological systems, leading to climate risks and impacts. The 2012 CCRAs will be superseded by new CCRA reports, which are due out in 2016.

Climate projections

The application of a climate analysis tool – UK Climate Projections 2009 (UKCP09) has resulted in multiple socio-ecological trends for Scotland projected for three different timelines and emission scenarios (low / medium / high). The data presented here is taken from the projections for a medium emissions scenario. Rainfall data from UKCP09 shows seasonal variability where precipitation increases in winter and decreases in the summer period.

The CCRA report for Scotland, referring to a study by Kay et al (2011), highlighted that peak river flows in Scotland could increase by 15% to 37% by the 2080s relative to the 1961-90 baseline. The increases on the west coast are expected to be much higher than for the east coast. Based on these projections, it is believed that flooding is likely to increase both from rivers as well as surface water (HR Wallingford et al, 2012[18]).

Historical data indicates that Scotland is already experiencing relative sea level rise and the latest projections across all scenarios show further increase across all areas (CCRA, 2012).

In terms of wind speeds, it is assumed that a noticeable change in average or extreme wind speeds in Scotland is unlikely though uncertainty is recognised. There is very little evidence on future trends in offshore winds and waves. The marine and Coastal Projections report from the CCRA (Lowe et al, 2009) suggests little change in seasonal and extreme wave heights around the Scottish coastline. For storms, the CCRA does not recognise noticeable changes in storminess in Scotland for the foreseeable future (HR Wallingford et al, 2012).

Impacts of anticipated climate changes on biophysical systems

The impact of climate change on biophysical systems creates many cause-to-consequence links that impact on socio-economic systems, resulting in capital or operational expenditure (HR Wallingford et al, 2012).

The projected winter rainfall increase is likely to result in greater volumes of runoff and higher river flows. Waterlogging could become an increasing concern as a result of increased catchment wetness, contributing to yet greater runoff during wet periods. Other significant impacts include increased flooding (both from rivers and surface water) and spill frequency and volumes from combined sewer overflows (HR Wallingford et al, 2012).

Risk and frequency of landslips will also increase as a result of increased winter rainfall. Typically, the rainfall-induced debris flows in Scotland are characterised by a sliding failure within a wet and soft soil on a hillside. Depending on multiple conditions (slope, stream channel, obstacles etc.) the sliding material is deposited in a fan or debris lobe where the slope slackens at its foot – typically where infrastructure such as a road or railway line may be located (Winter et al, 2013).

The projected increase in sea level rise for Scotland could result in an increase in frequency of very high tides and storm-surges, leading to more frequent and severe coastal flooding and loss of low lying land particularly in areas where the coastline is more susceptible to erosion (i.e. soft coastlines).

Climate change risks for transport infrastructure

All transport infrastructure in Scotland can be exposed to climate risk, noting that risk is a function of the likelihood of an event taking place (e.g. flooding) and the consequences of the event (i.e. the significance of the

[18] The next CCRA will make use of a new study, also commissioned by the ASC.

impacts). Road transport is particularly exposed as the majority of transport needs in Scotland are provided by road. The first Scotland CCRA had a particular focus on flooding as the main climate risk for transport infrastructure as it was (and still is) is considered to be the greatest risk to the road, as well as the wider transport network. Table 2 provides a summary of the transport infrastructure risk assessment from the 2012 CCRA.

Table 2. Summary of transport infrastructure climate change risk assessment from CCRA 2012

CCRA Risk	Description of risk
Flooding of transport infrastructure – road and rail ***(CCRA risks FL8a and FL8b)***	• Based on a central estimate of risk, the impacts of road and rail infrastructure flooding are anticipated to be medium consequence (negative) by the 2020s and 2050s and high consequence (negative) by the 2080s with medium confidence (HR Wallingford et al, 2012). • A likely increase of at least 10% and 20% in the length of transport infrastructure at significant likelihood of flooding is expected by the 2050s and 2080s respectively. • Increased frequency of flooding – for example a coastal road may have a 0.5% annual probability of being flooded today rising to 2% in 50 years' time - i.e. a fourfold increase (Thornes et al, 2012). • Predicted trends for coastal flooding (increase in rainfall and sea level rise) suggests negative impacts on low lying roads in coastal areas (damage to roads, road closure, or occurrence of road safety hazards). • Waterlogging affecting the road drainage infrastructure (loss of functionality due to heavy sedimentation). • Delayed construction and maintenance activities.
Disruption to road traffic due to flooding ***(CCRA TR1)***	• Based on a central estimate of risk, the impacts of road traffic disruption as a result flooding are anticipated to be low consequence (negative) by the 2020s and 2050s and medium consequence (negative) by the 2080s with medium confidence (HR Wallingford et al, 2012). • Increased disruption to road and rail traffic for increasing number of passengers. • Increased likelihood of road traffic accidents as a result of flooding incidents.
Landslide risks on the road network ***(CCRA risk TR2)***	• Based on a central estimate of risk, the impacts of landslide risks to the road network are anticipated to be low consequence (negative) by the 2020s and 2050s and medium consequence (negative) by the 2080s with medium confidence (HR Wallingford et al, 2012). • Up to 200km of trunk road in Scotland could be impacted by landslide by the 2020s, and 330km by the 2050s and 2080s. • The road network in Highlands are recognised to be the most vulnerable due to the area's particular geology and geomorphology. • Increased likelihood of the relocation of roads. • Increasingly negative economic and social consequences particularly for remote communities as roads are often the only access routes, making landslides particularly disruptive (Winter et al, 2013).
Scouring of road and rail bridges (***CCRA risk TR6)***	• Based on a central estimate of risk, the impacts of scouring of road and rail bridges are anticipated to be low consequence (negative) by the 2020s and medium consequence (negative) by the 2050s and 2080s with medium confidence (HR Wallingford et al, 2012). • Scouring is often associated with high flows and flooding and is therefore an area of increasing concern with climate change. • Loss of stability, structural damage or failure of transport infrastructure is a consequence of significant bridge scour. • Bridges built pre-20th century tend to be more susceptible to scour due to their structural design (spread foundations) and more limited understanding of scour issues at the time of construction. • Trends in river flows are as follows: 5-10% increase by the 2020s; 15-20% and 20-30% increases may be expected by the 2050s and 2080s.

Table 3 below shows the set of 11 transport adaptation indicators developed in response to the first CCRA, and based on the risks shown above in Table 2.

Table 3 Transport adaptation indicators developed in response to risks set out in the first CCRA

Ref	Indicator Type	Title of Indicator
BT2	Risk	Risk of road closures as a result of flooding
BT4	Impact	Flood events affecting the road network
BT6	Action	Road network benefitting from flood protection measure
BT8	Risk	Railway network at risk of flooding
BT9	Risk	Disruption risk to railway services as a result of flooding
BT12	Impact	Flood events affecting the railway network
BT16	Action	Railway network benefitting from flood protection measures
BT17	Risk	Risk of traffic disruption as a result of flooding
BT23	Impact	Road closures due to landslides
BT26	Risk	Road and rail bridges vulnerable to scour
BT30	Action	Remedial action to improve scour resilience of bridge assets

References

Audit Scotland (2010). *Mainstreaming Scotland's roads – a follow-up report* [online]. Available at: http://www.audit-scotland.gov.uk/docs/central/2010/nr_110216_road_maintenance.pdf [accessed 03/09/15]

Borders Railway (2015). *Borders Railway maps and plans pages* [online]. Available at: http://www.bordersrailway.co.uk/planned-works/maps-plans.aspx [accessed 03/09/15]

Committee of Climate Change (2014). *Managing climate risks to well-being and the economy – Adaptation Sub-Committee Progress Report 2014* [online]. Available at: http://www.theccc.org.uk/wp-content/uploads/2014/07/Final_ASC-2014_web-version-4.pdf [accessed 03/09/15]

Department for Environment Food and Rural Affairs (2009). *Adapting to climate change UK Climate Projections* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69257/pb13274-uk-climate-projections-090617.pdf [accessed 03/09/15]

Department for Environment Food and Rural Affairs (2011). *Climate Resilient Infrastructure: Preparing for a Changing Climate* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69269/climate-resilient-infrastructure-full.pdf [accessed 03/09/15]

Department for Transport (2012). *Guidance on road classification and the Primary Route Network* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315783/road-classification-guidance.pdf [accessed 03/09/15]

Department for Transport (2014). *Transport Resilience Review – A review of the resilience of the transport network to extreme weather events* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335265/transport-resilience-review-print.pdf [accessed 03/09/15]

Department of Transport (2014). *Statistical Release 10 April 2014 Vehicle Licensing Statistics: 2013* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/302409/vls-2013.pdf [accessed 03/09/15]

Department of Transport (2015). *Road Traffic Statistics Statistical Release 21 May 2015* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/428671/annual-road-traffic-estimates-2014.pdf [accessed 03/09/15]Geurs, K. and van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12(2), 127-140

HR Wallingford (2012). *A climate change risk assessment for Scotland*. HR Wallingford, Wallingford, UK.

Jenelius, E. (2009). Network structure and travel patterns: explaining the geographical disparities of road network vulnerability. *Journal of Transport Geography*, 17(3), 234-244.

Kay, A.L., Crooks, S.M., Davies, H.N. and Reynard, N.S. (2011). *An Assessment of the Vulnerability of Scotland's River Catchments and Coasts to the Impacts of Climate Change*. Work Package 1 Report (Draft). Report produced for SEPA, April 2011

HM Treasury (2014). *National Infrastructure Plan 2014* [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381884/2902895_NationalInfrastructurePlan2014_acc.pdf [accessed 03/09/15]

National Records of Scotland (2015) Scotland's Census [online] Available at: http://www.scotlandscensus.gov.uk/ [accessed 04/09/2015]

Network Rail (2014). *Scotland Route Weather Resilience and Climate Change Adaptation Plan* [online]. Available at: http://www.networkrail.co.uk/publications/weather-and-climate-change-resilience/ [accessed 03/09/15]

Office of Rail Regulation (2015). *Passenger Rail Usage 2014-15 Quarter 3 Statistical Release* [online]. Available at: http://orr.gov.uk/__data/assets/pdf_file/0013/17302/passenger-rail-usage-2014-15-q3.pdf [accessed 03/09/15]

Prior, J. and Kendon, M. (2011). The disruptive snowfalls and very low temperatures of late 2010. *Weather*, 66: 315-320

Rodrigue, J. (2013). *The Geography of Transport Systems THIRD EDITION*. New York: Routledge, 416 pages.

Scotrail (undated) Project Mapping. Scotland rail network maps [online]. Available at: http://www.projectmapping.co.uk/Reviews/scotland_scotrail_maps.html [accessed 03/09/15]

Scottish Executive (2006). *Scotland's National Transport Strategy* [online]. Available at: http://www.gov.scot/Resource/Doc/157751/0042649.pdf [accessed 03/09/15]

Rural Poverty and Inclusion Working Group (2001). *Poverty and social Exclusion in rural Scotland* [online]. Available at: http://www.gov.scot/Resource/Doc/159178/0043304.pdf [accessed 03/09/15]

Scottish Government (2010) *Scottish Transport Statistics No.29 2010 Edition* [online] Available at: http://www.gov.scot/Publications/2010/12/17120002/0 [accessed 06/03/15]

Scottish Government (2014a). *Climate Ready Scotland: Scottish Climate Change Adaptation Programme* [online]. Available at: http://www.gov.scot/Resource/0045/00451392.pdf [accessed 03/09/2015]

Scottish Government (2014b) *Urban / Rural Classification 2013 – 2014* [online]. Available at: http://www.gov.scot/Resource/0046/00464780.pdf [accessed 03/09/15]

Scottish Government. (2014c) Let's get Scotland walking: The national walking strategy. Available at: http://www.gov.scot/Publications/2014/06/5743 [Accessed 6 Sept 2015].

Scottish Government (2015). *Scottish Transport Statistics (No 33) 2014 Edition* [online]. Available at: http://www.transportscotland.gov.uk/statistics [accessed 03/09/15]

SEPA (undated). National Flood Risk Assessment Methodology [online]. Available at: http://www.sepa.org.uk/media/99914/nfra_method_v2.pdf [accessed 03/09/15]

Skinner, I., van Essen H., Smokers, R., and Hill, N. (2010). *Towards the decarbonisation of EU's transport sector by 2050 Final report produced under the contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc*; see www.eutransportghg2050.eu

SMMT (2011). Economic downturn causes dip in July's new car market [online]. Available at: http://www.smmt.co.uk/2011/08/economic-downturn-causes-dip-in-july%E2%80%99s-new-car-market/ [accessed 03/09/15]

Standing Advisory Committee for Trunk Road Assessment (1994) Trunk Roads and the Generation of Traffic, Department, Department of Transport.

Transport Scotland (2014). Personal Travel 2014. Available at: http://www.transportscotland.gov.uk/statistics/statistical-trends/personal-travel [accessed 14 September 2015]

Transport Scotland (2015a). *Key facts about the trunk road network in Scotland* [online]. Available at: http://www.transportscotland.gov.uk/road/maintenance/key-facts-about-trunk-road-network-scotland [accessed 03/09/15]

Transport Scotland (2015b). *Borders Railway pages* [online]. Available at: http://www.transportscotland.gov.uk/project/borders-railway [accessed 03/09/15]

Transport Scotland (2015c). *Operating Companies pages* [online]. Available at: http://www.transportscotland.gov.uk/road/maintenance/operating-companies [accessed 03/09/15]

Transport Scotland (2015d). Rail in Scotland pages [online]. Available at: http://www.transportscotland.gov.uk/consultations/j203179-03.htm [accessed 03/09/15]

Transport Scotland (2015e). Travel and Transport in Scotland 2014. Available at: http://www.transportscotland.gov.uk/report/j389989-00.htm [accessed 14 September 2015]

Winter, M.G., Harrison, M., Macgregor, F. and Shackman, L. (2013). Landslide hazard and risk assessment on the Scottish road network. *Geotechnical Engineering*, Vol. 166 - GE6. p. 522 –539

Winter, M.G., Palmer, D., Sharpe, J., Shearer, B., Harmer, C., Peeling, D. and Bradbury, D. (2014) Economic assessment of landslide events. *Proceedings of World Landslide Forum* 3, 2-6 June 2014.