THEME 1 – INFRASTRUCTURE

Infrastructure investment is at the heart of the Glasgow City Region's Economic Strategy (GCR, 2017). The £1.13 billion Infrastructure Fund provides an opportunity to enhance infrastructure networks and make them fit for the future. This investment is expected to deliver a sustainable uplift in GVA of 4% (c. £2.2bn p.a.) for the City Region and additional tax revenues of some £20.7billion over the 40-year lifetime of the fund, as a result of the uplift in GVA at net national level. It is also estimated to support an increase in the economy of around 29,000 jobs. The Strategy notes resilient infrastructure assets are critical to achieving its Vision.

Infrastructure is a key sector that is already affected by weather extremes and is likely to be significantly affected by future climate change. Most of the concerns relate to the risk of extreme events, on the infrastructure itself (damage), but also on the disruption. Given the long lifetime involved in infrastructure, there is a degree of lock in to future climate change, and thus early planning of future climate risks is required, especially for new infrastructure investment.

Road Infrastructure

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**
- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**

Flood related damage is a key risk for the road network. The potential economic costs include the direct damage costs that result from these events, but also the indirect economic costs from disruption, notably from travel time delays, the latter which can be valued using standard DfT Economic Appraisal values.

The Scottish Executive Scottish Road Network Climate Change Study (2005) looked at the potential flood risk, as well as the additional risks from road surface drainage, especially from heavy precipitation events. This study was updated in 2011, with the Transport Scotland Scottish Road Network Climate Change Study (Jacobs 2011) using the UKCP09 projections. It also used the UKCP09 weather generator. This considered that the existing trunk road network was most vulnerable with increases incidence of flooding and disruption.

The SEPA (2015) Flood Risk Management Strategy set out current risks, including the potential road network at risk and with estimates of the annual average damages. This is shown in the table below.

The values indicate current annual damages of around £4 million from current floods. These values provide a useful baseline for an analysis of the future costs of climate change. The analysis also provides the increase in properties at risk from climate change (by the 2080s). Using these increases from climate change as a proxy, the marginal increase from climate change is estimated at around £0.2 million per year from climate change for the Glasgow network for river floods, £0.4 million per year for coastal floods and £0.5 million per year for surface floods, by the 2080s, i.e. a total increase (above baseline) of just over £1 million/year.

As noted above, SEPA is currently undertaken a new National Flood Risk Assessment (NFRA), that will be published in the near future. This will provide updated estimates of the road related flood risks.

The Jacobs report (2015) also estimates the potential risk of flooding, looking at a 1 in 100 year return period. It reports that for Glasgow, climate change would increase the road network potentially at risk from 64 km currently to 90 km by the 2050s under a medium scenario (an increase of 26 km).

Table 14. Summary of flood risk from the Flood Risk Management Strategy – Clyde and Loch Lomond Local Plan District (SEPA, 2015).

Impact	River flooding (Clyde)	Coastal	Surface Water
Network risk	32.7 km at risk	53 km at risk	391 km at risk
Annual Average damage	2% roads (£350,000) 3% vehicles (£650,000	5% roads (£940,000) 3% vehicles (£540,000)	7% roads (£1.4 million) 2% vehicles (£400,000)

Most recently, AECOM (2017), assessed the risks of climate change for the Scottish trunk road network. This identified 76 trunk road network sections (2% of all sections) that are currently at the highest level of exposure to flooding ('Extreme Exposure'). Climate projections indicated that nationally, 179 sections were classed as having 'Extreme Exposure' by the 2030s and, 568 sections by the 2050s. This includes major trunk roads in Glasgow.

The study also highlighted that the A898 connecting West Dunbartonshire and Renfrewshire has the highest level of exposure to high wind impacts, and that this rises to one of the highest possible exposure scores by the 2050s.

There has been one very detailed study of the potential risks of climate change to coastal roads, undertaken for Transport Scotland (Milne et al, 2016). This selected a case study site for a section of the A78 that runs along the west coast of Scotland between Skelmorlie and Largs (i.e. West of Glasgow). Much of this section is low-lying land and is very close to the high-water mark: it is already vulnerable to periodic flooding. The analysis looked at the impacts of a sea level rise increase of 0.2 – 0.39m by 2100, but did not consider storms. The analysis found a significant increase in the risk of flooding (almost a doubling) under climate change. The damage costs and travel time delays of the benchmark flood event were estimated for a historic event, the 3 January 2014 flood. Using a traffic model, the analysis estimated the costs of this event (including travel time). It then looked at the change in flood events with climate change and looked at the occurrence of such an event in the future. The annualised results below, showing the direct damage costs, and then the total costs (including travel delays) with and without future traffic growth. If future traffic growth is included, the user costs rise very significantly, though this is due to the combination of an increased climate signal affecting a very much larger baseline level of traffic.

- **In6: Risks to transport networks from slope and embankment failure.**
- **In5: Risks to bridges and pipelines from high river flows and bank erosion.**

There have been a number of large-scale landslides affecting the road network in Scotland, notably in 2004, when a series of landslides led to major road closures and disruption following intense rainfall events. These events led to the commissioning of the 2005 Scottish Road Network Landslide Study and the 2005 Road Network Climate Change Study. These slope failure and landslide events have high economic costs, from the direct damages and repair, but also from the disruption and travel delays they cause.

There are a number of possible risk factors involved in slope and embankment failure. Rain is a potential cause of landslide events, from long periods of rainfall or from shorter intense storms and extended periods of heavy rainfall, though other factors such as surface water (increasing erosion or affecting stability), and changes in soil moisture condition and also involved, as well as land management practice. These events are highly localised and very site specific.

Table 15. Coastal flooding annual direct (top) and user (bottom) direct consequential economic impacts (2012 prices) for low medium and high emission scenarios (central estimates). (Source Milne et al. 2016).

Event Year	Present	2025			2050			2100		
	(2010-12)	L	M	H	L	M	H	L	M	H
Frequency (events/year)	1.1	1.2	1.2	1.2	1.2	1.3	1.5	1.8	2.2	2.5
Annual cost (£)	33,640	36,698	36,698	36,698	36,698	39,756	45,872	55,047	67,279	76,453

Event Year	Present	2025			2050			2100		
	(2010-12)	L	M	H	L	M	H	L	M	H
Frequency (events/year)	1.1	1.2	1.2	1.2	1.2	1.3	1.5	1.8	2.2	2.5
Annual cost (£): No Traffic Growth	148,816	162,345	162,345	162,345	162,345	175,874	202,931	243,517	297,632	338,218
Annual Cost (£): With Traffic Growth (at ×2.40)	148,816							2,024,980	2,474,975	2,812,472

The climate change forecasts for Scotland indicate that in the winter months, rainfall will increase, therefore potentially increasing landslide hazard frequency and/or magnitude, whereas in the summer months the frequency may decrease, but with a possibility of increasing intensity. The road transport study (Jacobs 2011) using the UKCP09 weather generator, estimated the change for the Glasgow area for the 2080s (medium emission scenario) for rainfall and for the soil moisture deficit (average annual pattern of the development and replenishment of soil moisture deficit for grass vegetation cover). It reports that the average duration that a deficit will occur is projected to barely change in the future, although the maximum magnitude of the soil moisture deficit does increase. The report concludes that the increase in rainfall combined with the changes in seasonal soil moisture condition, as suggested by climate change projections, could result in reductions in slope stability.

One further source of slope and embankment failure is due to freeze-thaw cycles. The road transport study (Jacobs 2011) using the UKCP09 weather generator, estimated a reduction in freeze-thaw days per year (a proxy for freeze-thaw cycles), with a reduction for Glasgow of -22 to -26 freeze-thaw days by the 2080 (for the low and high emission scenarios). This compares to the observed number of 38 freeze-thaw days for Glasgow per year currently. This would be expected to reduce failures due to freeze-thaw cycles.

There are some data on the economic costs of landslides from historic events. These can have very large economic costs from the combination of direct damage and emergency response, remediation costs and travel delays (immediately after, and for long periods afterwards). Current ongoing work is assessing the economic costs of landslides on the road network. While this is not yet published, an analysis of previous events shows high economic costs for the 2004 events. These are similar in size to the impact of major flood events on the transport network.

The AECOM (2017) study found that in terms of landslide risks, 7 trunk road network sections in Scotland (approximately 0.02% of all sections) are currently classed as having ‘Very High Exposure’ to landslides, with no sections being classified as having ‘Extreme Exposure’. However, with climate change, their projections indicate that 9 sections will be classed as having ‘Very High Exposure’ by the 2030s. By the 2050s, 8 sections have ‘Very High Exposure’, with a further 6 sections being classed as having ‘Extreme Exposure’. However, these at-risk sites where not located in the Glasgow region.

It is difficult to estimate quantitatively the potential economic costs of climate change on landslides. To assess the potential indicative costs, for this analysis, we assume that the increase in risks mirrors the increase in heavy precipitation, using previous events (economic costs and frequency). Based on this, we estimate that potential marginal cost (of climate change) for Glasgow City Region would be likely to be lower than £0.25 million/year for the 2050s when annualised. However, the large-scale disruption of large-scale events means that the impact they have in a particular year, could be large and thus are still important.

- **In9: Risks to transport, digital and energy infrastructure from extreme heat.**

The Scottish Executive Study (2005) considered the potential impacts of climate change and high temperatures on roads, building on an earlier study on the Maximum Road Temperatures in Relation to Surface Deformation in Scotland (1993). It reported there were almost no historic impacts of extreme heat on the road network in Scotland and concluded that deformation due to prolonged high road surface temperature was not a significant concern. The analysis was updated in the road transport study (Jacobs 2011) using the UKCP09 weather generator. This estimated the number of additional hot days per year with maximum temperatures over 25°C and 30°C. The results indicated an additional +2 to +3 days above 25°C in the 2020s for Glasgow (relative to the observed baseline of 4.5 days per year and modelled based of 1 – 2 days per year in the period 1961-1990). This increased to +9 to +20 additional days by the 2080s (for the low and high scenarios, with a full range of +3 to +60 days). The results indicated only an additional 0.1 days above 30°C even by the 2080s for Glasgow (with a full range of +0 to +3 days). While there can be higher temperatures at the road surface, the level of increase in hot days does not suggest a large risk. The 2011 report also concludes that the magnitude of these increases are unlikely to be a significant concern with regard to the durability of surface dressings. The estimated economic costs of this risk are therefore considered to be low, though there is an issue whether the current projections take account of the urban heat island effect in the city.

Table 16. Summary of flood risk from various sources within the Flood Risk Management Strategy – Clyde and Loch Lomond Local Plan District (SEPA, 2015).

Impact	River flooding (Clyde)	Coastal	Surface Water
Railway routes currently at risk	16.5 km at risk	2.8 km at risk	127 km at risk (includes West Coast line and Glasgow to Edinburgh)

- **In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season.**

The observational data does show that the growing season in Scotland has lengthened since the early 1960s by on average 33 days from a combination of earlier onset and later cessation. The Scottish Executive Study (2005) considered the potential impacts of climate change on the Growing Season, reporting this would increase, leading to additional maintenance costs for vegetation control. This will lead to additional costs from maintenance activity and traffic management and delays (increased travel time). The study reported that a minimum of two cuts per year has historically been adequate to control the height of grassed roadside verges, centre reserves and junction areas on the Scottish trunk road network, but that in recent years, this had increased to 3 or more cuts. The study indicated an increase in the growing season of 22 +/- 10 days by the 2020s from the 1961-90 baseline period. The update of this report (Jacobs, 2011) used the UKCP09 weather generator to look at the potential increase in the growing season[13], but there were issues with the data. It highlighted that the increase in temperature and growing season, combined with the increase in rainfall, could have implications for landscape design. The study also reported a potential increase of 50 days in the growing season for UKCP09 (assumed to be for the 2080s) for the Highlands (up from 150 days to 200 days) and highlighted the values for Sothern Scotland would be likely to be higher. There are not good data on current maintenance costs along the road network – but it is possible there would be additional economic costs from climate change (as well as financial costs for road network management).

- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events.**

Some of the positive effects of climate change include the reduced winter maintenance costs for the road network. The AECOM study (2017) reports that as climate change projections indicate that exposure levels reduce across the network as winters become warmer and the frequency of very cold days, snow and ice reduces, transport related impacts will fall. This will potentially include the reduced risks of road transport accidents. The economic benefits of these reductions could be significant, given the likely reductions in the number of frost days and freeze thaw cycles and snow days, though there is no quantified information to consider the size of these benefits.

Rail Infrastructure

Similar to the road network, the rail sector is affected by current climate variability and extremes, and climate change poses a potential future risk. The potential economic costs include the direct damage costs that result from the extreme events, but also the indirect economic costs from disruption, notably from travel time delays.

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**
- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**

Flood related damage is a key risk to the rail network in the Glasgow region. The SEPA (2015) Flood Risk Management Strategy set out current risks, including the potential rail network at risk and with estimates of the annual average damages. This is shown in the table below.

As noted above, SEPA is currently undertaken a new National Flood Risk Assessment (NFRA), that will be published in the near future. This will provide updated estimates of the flood risk below.

13 This looks at the Growing season start: This is the start date for the growing season (calculated as Julian days), where the growing season is assumed to start on the 5th consecutive day with a mean daily temperature of 5˚C or greater. Growing season end: This is the end date for the growing season (calculated in Julian days), where the growing season is assumed to end on the 5th consecutive day with a mean temperature of 5˚C or less. Growing season length: the number of days between the start and end of the growing season.

The Jacobs report (2015) estimated the potential risk of flooding for the rail network, looking at a 1 in 100 year return period, reporting that for Glasgow, this would increase the rail line potentially at risk from 32.9 km currently to 41.7 km by the 2050s with a medium scenario (an increase of 8.9 km).

The evidence suggests an increased risk to the rail network from the increases in river, coastal and surface floods. This will mean the length of track at risk above will increase, noting that there will be increased rail services in the future from increased demand, but also from the planned proposals for a number of new rail lines in the city. However, there is a lack of robust data to estimate future impacts, so a number of approaches have been used to explore the potential scale.

The flood analogues presented in the previous chapter reveal the disruption and economic costs of recent events, for example, the analysis of the 2015 floods on rail in the region identified economic costs of £1.7 million from this one event. The changes in estimated change (%) in peak flows for the Clyde (Sayers et al, 2015) were shown earlier in this chapter. For river floods, the type of event seen in 2015 (a 1 in 100 year event) could become a 1 in 40 year event, or possibly even a 1 in 20 year event, by the mid-century. This would increase the frequency of these types of events, though the increase in equivalent annual cost for a 2015 flood type event would still be low (less than £1 million per year, when annualised).

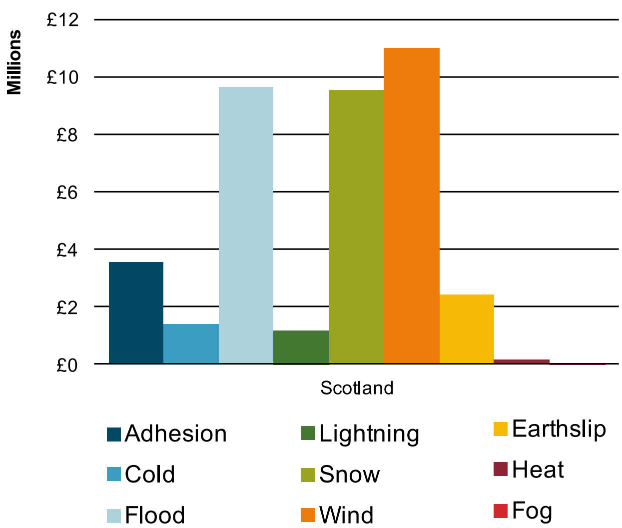
Scotland Route has developed a Weather Resilience and Climate Change Adaptation (WRCCA) plan (Network Rail, 2014). This includes an analysis of the current impact of weather and seasonal events on delays. The Schedule 8 performance costs (the compensation payments to train and freight operators for network disruption) are shown below. This shows the dominance of floods, snow and wind delays. The impact of wind is the most important (28% of delays) with the majority of these events are from objects being blown onto the line (wind-related delays total 56,106 minutes per year on average). Flooding accounted for 23.6 per cent of delay minutes (46,444 minutes per year on average) from 2006/07 to 2013/14 for Scotland Route. Note these are for all Scotland and not just Glasgow region.

The WRCCA figures indicate current costs of approximately £1 million per year each for both wind and flood related damage, for the Scotland Network. These provide a useful baseline for a future indicative analysis. Schedule 8 cost per delay minute (compensation payments) in CP5 will be on 62 per cent higher, thus baseline costs will increase. For floods, the increase in peak flows for the Clyde region (based on the projections from Sayers et al, 2015) can be used to estimate the indicative increase in flood related costs. This implies a broad increase of around £0.3 million per year from climate change by the 2080s for the Glasgow City Region network. For wind, there is less robust information on the potential increase in storm intensity or frequency with climate change, but based on ABI (2017), we assume a 15% increase in wind related damages. This implies an increase of £0.1 million per year from climate change

Figure 4. Scotland Route weather attributed Schedule 8 costs 2006/07-2013/14. (Source: Network Rail WRACC Plan, 2014).

Weather-related impact	Schedule 8 costs*	Projected future impacts	Prioritisation
Wind	£0.99 million	Wind changes difficult to project however generally projected to increase	High
Flooding	£0.91 million	Up to 25 per cent increase in February mean daily precipitation	High

* Annual average 2006/07 to 2013/14,



by mid-late century for Glasgow region. This does not include the increased travel time for travellers.

There is also some information from Phase 2 of the Tomorrow's Railway and Climate Change Adaptation (TRACCA), which assessed the climate change risks for the London – Glasgow West Coast Main Line (WCML) as a case study. There was also some information in the RSSB (2016) analysis of railways and climate change, which identified the impacts of climate change related floods on control, command and signalling. It also identified the risks from flooding could affect energy supply and highlighted the issues of cascading risks.

- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events.**

Alongside the impacts above, there would be a reduction in snow related disruption for the rail network. Current snow related disruption in £0.98m/year, for the total Scotland Route. Thus, the reductions in snow related damage could be similar in magnitude to the increase in flood related damages above. There would also be reduced damage from the reduced cold, frost and freeze-thaw cycles.

- **In9: Risks to transport, digital and energy infrastructure from extreme heat.**

There are range of impacts from extreme heat on the railways, which include damage (track buckling) through to delays from reduced speeds (to avoid track damage). There have been increases in hot summers in the UK and these are projected to increase under future climate change. However, as reported in the WRCCA, Scotland Route doesn't currently suffer from much heat-related problems. Based on 2006/07 to 2013/14 data, heat-related delays total 723 minutes per year on average, costing £0.02m per year in Schedule 8 costs (all of Scotland). These heat related delays would be expected to increase, though the increase in hot and very hot days are modest for Scotland (see earlier projections). The TRACCA project (Tomorrow's Railway and Climate Change Adaptation) did identify the number of temperature exceedances of relevance for track thresholds (and the need for reduced speeds to reduce the risks of buckling). It identified the number of exceedances in Southern Scotland of temperatures >31C would rise from 0.6 currently to 6.4 by the 2040s. This would still lead to a low annual cost for the Glasgow region, based on the current Schedule 8 costs (though these would not fully capture travel time costs).

There will also be increases in air conditioning to cool electrical equipment in lineside and central buildings and a risk of increased overheating for passengers during hot conditions. Overheating of trains is a particular issue for non-air-conditioned trains (in terms of passengers), whereas for air-conditioned trains it will increase cooling demand (though the increases will be far lower than the decreases in train winter heating demand). However, given the increases in hot days, the increased economic costs are considered to be low in the medium term for the Glasgow region.

- **In6: Risks to transport networks from slope and embankment failure.**
- **In5: Risks to bridges and pipelines from high river flows and bank erosion.**

The current costs of embankment related delays for railways are also quantified in the WRCCA analysis. Based on 2006/07 to 2013/14 data, earthslip-related delays totalled 9,654 minutes per year on average, costing £0.25m per year in Schedule 8 costs (all of Scotland). This is 4.9 per cent of weather-related delay minutes. Analysis in the RSSB report (2016) identified the issue of freeze-thaw effects on rock cuttings and earthworks. The road transport study (Jacobs 2011) using the UKCP09 weather generator, estimated a reduction in freeze-thaw days per year (a proxy for freeze-thaw cycles), with a reduction for Glasgow of -22 to -26 freeze-thaw days by the 2080 (for the low and high emission scenarios). This compares to the observed number of 38 freeze-thaw days for Glasgow per year currently. There would therefore be a likely economic benefit to railway embankments for this indicator, from reduced freeze-thaw cycles in Glasgow. However, other impacts not covered, notably heavy rainfall and landslide risk, could offset these benefits.

For coastal floods and storm surges (including increased wave heights), there are additional factors, due to the processes of increased erosion. The National Coastal Change Assessment (Dynamic Coat Change study, Rennie et al, 2017) identified three sections of the West Highland rail line which are at risk of future coastal erosion, potentially affecting connectivity of the City Region to Fort William, Mallaig and Oban. One of these is Dumbarton Castle Bay (Site 81) where the erosion vicinity captures some 100 metres of mainline rail track that lies 70 metres landward: this was identified as a cause for concern in the future. This section of shore has been the subject of more detailed study commissioned by the Firth of Clyde Forum and conducted by ARUP and Glasgow University (SNH, 2016).

The RSSB (2016) report also identifies the issue of bridge scour following floods, and the failure of earthwork following flooding, although it did not identify thresholds or future frequencies of exceedance.

- **In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season.**

Finally, in terms of increased vegetation growth, there is likely to be an increase in maintenance costs for railways. The Scottish Executive Study (2005) considered the potential impacts of climate change on the Growing Season, concluding this would increase. Current estimates of vegetation management for the Glasgow rail sector are not available, but there would be increased costs. There are also other potential effects are also associated with vegetation. There can also be changes in leaf fall that could affect delays (though the effects of climate change are unclear), as well as changes in vegetation and wind related damage risks (trees, branches on lines) and increased management costs.

Airport Infrastructure and transport

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**
- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**
- **In9: Risks to transport, digital and energy infrastructure from extreme heat.**
- **In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season.**
- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events.**

Glasgow Airport (DfT, 2017) has over 9 million terminal passengers each year and 84 thousand aircraft landings and take-offs, with 75% of flights on time (within 15 minutes of schedule). Weather related events, such as the heavy snow of December 2017, have led to major disruption at the airport, and such events can have important economic costs from the passenger disruption and travel time costs.

Looking to the future, there are potential risks to airport infrastructure and air passenger and freight transport from climate change. There have been a series of climate change adaptation reports for the airport (Maclachlan, 2011: Crichton 2016). The first risk assessment (2011) identified 34 risks in the short and medium to longer term. Risks in the short term were generally low, though the risk levels generally rise in significance towards mid-century. The most significant risks from climate change were projected to be longer term changes to temperature and precipitation extremes, though it was highlighted changes in the wind regime could be important.

The potential risks to Glasgow Airport buildings from flooding and storms includes the potential direct impacts (damage to buildings) but also will lead to indirect costs in terms of air transport disruption, with travel time delays and cancellations. The airport is located adjacent to two tidal rivers, although at elevation above these. The earlier studies on Glasgow Airport (Maclachlan, 2011) concluded there was a moderate risk of groundwater flooding and possible subsidence by the 2050s. It also set out the existing controls and emergency contingencies, citing an earlier flood risk assessment (2005) and highlighted that there are numerous weather-related contingency plans and procedures already in place.

The projections of storm intensity and frequency for Northern Europe and Scotland are uncertain. There is a general trend of a modest increase over some areas of Northern Europe (consistent with more zonal westerly flows), although the changes are not that robust (Vautard et al, 2016). The ABI study (2017) projected increases in storm damage for Scotland, based on increases in intensity. These additional events could affect scheduling (delays) as well as damage (to buildings and standing aircraft, ancillary vehicles, etc.).

The potential changes in snow and for related disruption are likely to involve a mix of positive and negative effects. There are likely to be a reduction in snow related disruptions. The potential changes to fog related disruption are uncertain: the airport CRA projects a decrease in fog related disruptions, but other sources indicate a potential increase in winter months.

There are also a number of potential economic costs from increasing temperatures and heat extremes, although these are considered low or modest for the airport. These include:

- Overheating of buildings, increasing cooling demand, but also note there will be reduced heating costs in winter (which are likely to be larger than heat related increases);
- Overheating of critical buildings and operations;
- Extreme heat damage to airport infrastructure including road and runway surface, though these are considered low especially as runway surfaces are designed with higher standards;
- Increased use of aircraft cooling (auxillary power units or fixed power) – when sustained temperatures are above 25-30 degrees;
- Increased fire risks;
- Impact of heat waves on air quality.

There re also potential risks, from changes in wind direction and frequency, affecting runway use and scheduling, from changes in lightning strikes as a result of changes in storm intensity or frequency (though risks are considered low), increases in vegetation growth and maintenance costs, and the potential for some air transport related risks (reduced lift, etc.) though the latter are considered low.

However, there is a lack of information to allow quantification and valuation of these risks. Overall, the economic costs are not considered to be large, at least in the short-medium term. The one issue that is identified is the potential future airport expansion, because of the risks of increased flooding in the future with climate change.

Water transport

- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**
- **In12: Risks to water-based transport and trade infrastructure (ports, canals, harbours, etc.) from sea level rise, floods and storms.**
- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events.**

The Clydeport terminals at Glasgow and Greenock process millions of tonnes of cargo a year. There are additional risks from climate change (sea level rise and erosion).

There are also regular ferry services in the Glasgow City Region, carrying over 700,000 passengers a year. The majority of current disruption to ferry services is due to high winds. As highlighted earlier, these are projected to increase.

Scottish Canals (Corporate Plan 2017-2020) identified that climate change will increase levels of erosion and silting in waterways, adding to maintenance costs, while extreme weather events will require more robust risk management processes and contingency arrangements.

While there are some water transport related risks, there is generally a lack of quantified analysis or studies in this area, which makes it difficult to analyse the potential economic costs of impacts.

Energy Infrastructure

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**
- **In5: Risks to bridges and pipelines from high river flows and bank erosion.**
- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**
- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events.**

Table 17. Summary of flood risk from various sources within the Flood Risk Management Strategy – Clyde and Loch Lomond Local Plan District (SEPA, 2015).

Number at risk	River flooding	Coastal	Surface Water
Utility assets (Includes: electricity sub stations, telecommunications, oil refining and distribution, gas regulating and mineral and fuel extraction sites.	110	50	270

The impacts of weather and climate change on energy infrastructure will have direct impacts, from potential damage and repair costs. It will also lead to impacts on the supply of energy: this leads to the loss of electricity supply for customers, which has high economic costs and can be valued using the Value of Lost Load (VOLL).

The SEPA FRM Strategy has estimates of the number of assets at risk of flooding in the Clyde and Loch Lomond Local Plan District (note these estimates will be updated in the new FRM later this year). These are shown below.

Floods have the potential to damage energy infrastructure, including sub-stations. The Clydeplan flood risk assessment identified three substations at risk of flooding (see the GCRCROA). Furthermore, the SP Energy Networks climate change adaptation report acknowledged these risks (SP Energy Networks, 2015), for winter flooding (probable relative likelihood) and surface water flooding (possible relative likelihood), identifying that both have 'significant' potential impacts. The report also assessed the potential risk of extreme sea flooding on substations, assessing the risk to be possible (relative likelihood) but with 'extreme' potential impacts. The risk to the underground cables from drought leading to ground movement was considered unlikely (relative likelihood) but with significant relative impact. It also considered the risk of reduced ice on the lines will be reduced as extreme cold events become rarer (though they will still occur).

- **In9: Risks to transport, digital and energy infrastructure from extreme heat.**

The risks of extreme heat to the transport network was discussed in earlier road and rail sections. The relative impacts for Scotland from extreme heat are considered low. The SP Energy Networks study identifies that i) overhead line conductors could be affected by temperature rise, reducing rating and ground clearance (possible likelihood, moderate impact), ii) underground cable systems could be affected by increase in ground temperature reducing ratings (possible likelihood, moderate impact, iii) transformers could be affected by temperature rise, reducing rating (possible likelihood, minor impact), iv) substation switchgear could be affected by temperature rise, reducing rating (possible likelihood, minor impact) v) network access and maintenance programmes could be affected from increased loads reducing outages (possible likelihood, moderate impact). The SP report identifies the risk of higher temperatures and the effect of transmission efficiency and line height (sagging with higher temperatures, below minimum height levels), though the impacts in Scotland are considered to be modest, especially in the short and medium term.

- **In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season.**

The issue of increasing vegetation growth was outlined in the earlier road and rail sections. There is projected to be an increase in maintenance costs associated with vegetation control. The Scottish Power risk report considered the relative likelihood of overhead lines being affected by interference from vegetation due to prolonged growing season as almost certain (likelihood) with climate change but with a moderate impact, although it also highlights that vegetation management is one of the largest annual recurring maintenance tasks undertaken by network operators. No information is available on current maintenance costs, but if these could be sourced, an indicative estimate of the potential increase from climate change would be possible.

There are also some other potential changes from vegetation growth, which include risks related to wind. This includes the damage costs and repair costs from changes in the frequency or intensity of events, but also a much larger cost from the supply outages and value of lost loads to customers. There is a potentially large impact of climate change on electricity transmission lines, although this is included partly through the increased costs of vegetation management above (vegetation control is primarily undertaken to reduce the risk of wind-blown vegetation damage). The direct economic costs of power outages from extremes was captured in the 2017 storm analogue (presented in the previous chapter). The potential increase in storm damage (ABI, 2017) would be expected to increase the costs of these events. The lack of quantified estimates of current damages and future risk, as well as current operational costs, makes it difficult to estimate the economic costs of climate change for energy infrastructure. These are likely to be modest, but major events could have important large-scale economic costs, from the direct damage and the potentially large costs of lost electricity supply.

Electricity Generation (Renewables)

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**

Hydropower plants can be potentially affected by climate change, primarily from the effects on precipitation and river flows, though other factors such as evaporation and evapotranspiration, runoff and river discharge (peak and low flows). Hydropower accounts for 1.65 GW of capacity in Scotland, although wind now dominates renewable supply, and Scotland is a net exporter of electricity to the UK (Energy in Scotland, 2018).

Clydeplan's Strategic Flood Risk Assessment (2017) identified four power generation sites at risk of flooding – three hydro-electric power generation plants at risk from river flooding and Grengairs Landfill Gas site in North Lanarkshire at risk of surface water flooding. This is 20.3MW of power generation.

The impacts of climate change on hydro generation varies strongly according to the type of hydro generation (storage or run of river), but also the climate change projections, noting the high uncertainty. Any impacts could have direct effects on any plants located in the Glasgow region, but could also have indirect effects by affecting the supply of electricity into the region.

Precipitation in Scotland is projected to increase under climate change, especially in winter. The changes in runoff, discharge and evapotranspiration largely follow these patterns, i.e. the extra precipitation will partly contribute to increased evapotranspiration and partly runoff, increasing discharge levels. This will have potential benefits in terms of increased generation, however, there will be changes in the risks of peak flows and possible extremes, which can cause damage to hydro plants. The changes in peak flows (from Sayers et al, 2015) provide some indication of the increase in possible risks, although these are still likely to fall within the design standards for the plant. The economic costs are considered low when annualised.

The potentially lower levels of summer rainfall might reduce discharge levels. Some studies indicate increases in the magnitude and frequency of short droughts for the UK (less than 18 months) but there is low confidence (LWEC, 2016) and this is not anticipated to be a major issue for West Scotland. The overall impact on average generation is unlikely to be significant, as the lower electricity demand in summer means this is normally a time for planned maintenance. For this reason, the overall economic costs to hydro are considered low.

Gas Infrastructure

- **In2: Risks to infrastructure services from river, surface water and groundwater flooding.**
- **In3: Risks to infrastructure services from coastal flooding and erosion.**
- **In5: Risks to bridges and pipelines from high river flows and bank erosion.**
- **In8: Risks to energy, transport and ICT infrastructure from storms and high waves.**
- **In9: Risks to transport, digital and energy infrastructure from extreme heat.**
- **In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season.**
- **In13: Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events..**

There are climate risks to SGN's Pressure Reducing Installations (PRIs), pipelines and supporting infrastructure from flooding and other weather-related events. These can directly damage infrastructure, but can also lead to supply disruptions.

There is also some information available in SGNs (formerly SGC's) adaptation report (2015). This considered that while risks exist, none of these were considered to be high. Below ground assets are more liable to flooding and are being replaced and relocated where necessary. Above ground assets such as Pressure Reducing Installations (PRIs), critical sites such as data centres, and pipelines in close proximity to watercourses may also be at risk. Given the level of available information, it is difficult to quantify, even indicatively, the potential economic costs of climate change on the gas network. Given the SGN finding, it is assumed that potential economic costs are modest.

In the longer-term, warmer temperatures will reduce overall gas demand in the region, which will have impacts on the overall gas system in terms of infrastructure requirements and operational costs. There will also be some changes in future infrastructure, reflecting mitigation actions: SGN are working to decarbonise gas and heat through biomethane and hydrogen development among other areas to ensure they are fit for the future..

Water Infrastructure and Supply

Risks to public water supplies from drought and low river flows

Climate change is projected to disrupt water cycles, though these changes will not be uniform, with differences between wet and dry seasons and between years, from changes in precipitation, temperature and evapo-transpiration, etc. As well as risks to water resources (and deficits) across multiple sectors, there are also risks to water infrastructure and water quality, as well as specific activities that depend on water (e.g. hydro-power, river transport).

In Scotland, annual river flows have been increasing over recent decades (LWEC, 2016), especially winter flows, and these are expected to increase further under climate change. There is no evidence of observed decreasing summer low flows: the future climate projections are uncertain, though there are some models that project a decrease in summer flows at the UK level.

In looking at future risks, it is important to take account of socio-economic trends, and notably the increase in water demand. This will increase due to population and economic growth, but it will also change due to climate change (e.g. warmer temperatures are associated with higher water demand, especially on hot days). There are a number of studies that have assessed future water resources – and the supply and demand balance – in Scotland.

A study undertaken as part of UKCCRA 2 (HRW Wallingford, 2015) looked at the projections for water availability in the UK under climate change. This analysed the supply-demand balance and found that at the UK level, deficits are projected to be widespread by the 2050s (a deficit of 5- 19% of total demand) under a high population growth and a high climate change scenario, and grow further by the 2080s (8 – 29%), with a reduction in the amount of water available for public water supply, in the absence of further adaptation. This takes account of the increase in future demand. However, it reported a very different pattern for Scotland, with a surplus at a national level under central scenarios, even in the 2050s and 2080s. Under a central scenario (low population, no additional adaptation and medium climate change projection), there is only one water resource zone (Edinburgh) in Scotland (2050s and 2080s) with a supply-demand deficit of greater than 5 Ml/d. Under a high scenario (high population, no additional adaptation, high climate change projection), six Water Resource Zones in Scotland were projected to have a deficit of greater than 5 Ml/d by the 2050s.

However, for Glasgow, due to its very large projected yields in relation to demand, a significant surplus of over 80 Ml/d was estimated, even under a high scenario in the 2080s. The report therefore concluded that Glasgow appears to be particularly resilient to climate change because the projected yield, even under a high emissions climate future, is not the constraint on Deployable Output. Given these regional estimates, the economic costs of climate change on public water supplies are considered very low.

The Scottish Water 2016 Water Resource Plan (2015) also assessed the potential vulnerability to climate change. This used a 1 in 40 year dry year (2.5%) as the basis for planning drought resilience (yield level of service). It highlighted that climate change is expected to increase the variability of rainfall patterns, and the study undertook a vulnerability assessment of water availability based on climate change scenarios at 2040, assessing different climate change scenarios. This found a wide range of impacts, depending on the projections used, but with potentially a lower level of service at the National level (which could result in more frequent water shortages for some customers), especially for the worst-case scenario. The report concluded that given the uncertainty, there was not a business case for investment (adaptation), but it did highlight that the more vulnerable zones require increased early planning.

Risks to water infrastructure

As with other utilities, there are also additional risks from extreme events on water infrastructure.

- **In4: Risks of sewer flooding due to heavy rainfall.**

There is a potential risk from the increased frequency of urban drainage capacity being exceeded, resulting in urban flooding and increases in the discharge of pollution into watercourses (LWEC, 2015). The risks of surface water flooding are captured in the next section, thus the main additional cost of relevance here is the secondary effects of sewer flooding, with the discharge of pollution into water (impacts on water users and ecosystems) and the high clean up and restoration costs if discharge affects surface land areas.

Scottish Water (2018) have identified over 43,000 properties across Scotland currently at some level of risk of sewer flooding. This risk was also ranked of highest concern in the infrastructure sector by stakeholders (see GCRCROA). There is currently insufficient information to quantify and monetise these risks and this is identified as a future priority for analysis.

Other

- **In1: Risks of cascading failures from interdependent infrastructure networks.**

An emerging theme in the 2nd UK Climate Change Risk Assessment is the risk of converging and cascading interactions among risks, especially for infrastructure. These lead to important indirect (cascading) economic costs, which can include interdependent infrastructure linkages, for example, with the importance of electricity supply or transmission infrastructure for ICT for critical infrastructure or transport networks. The main interdependencies are likely to be in the nexus around energy, water, transport and ICT, and are likely to emerge from major extreme events, i.e. floods, storms or extreme heat. These risks may not arise locally to the Glasgow City region, i.e. the cascade of risks may be from other locations in Scotland or Great Britain. At the current time, there is insufficient information to assess the potential economic costs. However, any event could have high economic costs, from the combination of multiple impacts (travel time, energy supply, etc.).

As reported in the GCRCROA, a NERC-funded project, delivered by University of Edinburgh with Scottish Water, BT, SGN, Scottish Power Energy Networks, SEPA, and Inverclyde Council is looking to understand these interdependencies. At this time, there is insufficient information to consider the risks and the magnitude, but this is highlighted as a future area for consideration.

- **In7: Risks to subterranean and surface infrastructure from subsidence.**

While subsidence risk is important at the UK level, the risks for Scotland in general are low, due to soil types. Nonetheless, there will be particular risks in vulnerable areas, as shown in the dry summer of 2013. There is limited data on risks to subterranean infrastructure as a whole, making it difficult to gauge current levels of risk but this is not considered a major economic risk.

- **In11: Risks to infrastructure from wildfires.**

While this is a potential important risk for Scotland, the direct risks to the Glasgow region are considered low, especially given precipitation projections, though localised risks to infrastructure sites may exist.