THEME 1 – INFRASTRUCTURE

Overview

A resilient, efficient and well-maintained system of interconnected infrastructure networks is key to the functioning and economic development of Glasgow City Region. A number of plans and strategies support the case for greater investment both for, and through the city region's infrastructure (Box 1) The activities associated with each of these will need to be reviewed with current and future climate risks and opportunities in mind.

Box 1. Glasgow City Region plans and strategies that relate to infrastructure

- Glasgow City Region Economic Strategy and Action Plan
- City Deal Infrastructure Fund
- Glasgow City Region Strategic Transport Plan
- Glasgow City Region Digital Connectivity Strategy
- Utility and infrastructure organisations' investment, corporate and climate adaptation plans

Key climate related risks and opportunities

Climate change will affect the city region's infrastructure in a number of ways by:

- **Disrupting the complex systems of infrastructure networks** meaning climate change impacts such as extreme weather events and high temperatures can impact other infrastructure providers even when their own assets have not been directly affected.

- **Increasing risk of disruption to infrastructure due to flooding and storminess**, particularly to the many assets and services located along the coast and river banks. Sea level rise and increased frequency and severity of storms, high waves and severe weather will increase the risk of damage from coastal flooding, as well as backing up or overwhelming existing sewer systems leading to sewer flooding. There are particular risks to bridges which often carrying multiple services (gas, water, electricity, telecoms etc.) as well as traffic. Increased river flows can affect bridges due to localised riverbank erosion, undermining structures, scour and exposure of buried cabling and pipework.

- **Increasing the risk of landslides and disruption to transport infrastructure** – with the severity and frequency of rainfall events, extreme temperatures, high winds and changes in vegetation growth rates, and changes in freeze thaw ratios affecting slope stability and embankment conditions.

- **Disrupting water-based transport and trade** in and out of the city region as sea levels rise and flooding and storms become more common. These changes could pose a range of risks to ports and waterways, with implications for both passengers and cargo.

- **Increasing the number and size of wildfires** due to projected drier summers and higher soil moisture deficits.

- **Reducing impacts from extreme cold events as they become less frequent and severe** and cause less disruption to infrastructure during the winter months.

The key infrastructure related risks and opportunities and their urgency score are shown in Box 2.

Box 2. Infrastructure related risks and opportunities

Ref	Risk / Opportunity Description	Urgency Score
Risks		
IN1	Risks of cascading failures from interdependent infrastructure networks	Build capacity and understanding
IN2	Risks to infrastructure services from river and surface water flooding	Sustain current action
IN3	Risks to infrastructure services from coastal flooding and erosion	More action needed
IN4	Risks of sewer flooding due to heavy rainfall	Sustain current action
IN5	Risks to bridges and pipelines from high river flows and bank erosion	Sustain current action
IN6	Risks to transport networks from slope and embankment failure	Watching brief
IN7	Risks to energy, transport and ICT infrastructure from storms and high waves	More action needed
IN8	Risks to energy, transport and ICT infrastructure from extreme heat	More action needed
IN9	Risks to infrastructure from increase in vegetation growth rates	Sustain current action
IN10	Risks to infrastructure from wildfires	Watching brief
IN11	Risks to water-based transport and trade infrastructure (ports, canals, harbours, etc.) from sea level rise, floods and storms	Build capacity and understanding
Opportunities		
IN12	Potential benefits to water, transport, digital and energy infrastructure from reduced extreme cold events	Watching brief

Next steps to creating climate resilient infrastructure

- Continue to invest in reducing flooding from all sources, and begin early discussions to manage the potential impacts of coastal erosion on railway infrastructure on the North Bank of the Clyde.

- Take further action in relation to the impacts of storms and high waves. In particular, more risk assessment and adaptation planning are needed for the Erskine Bridge.

- Undertake further work to ensure the city region's infrastructure is prepared for future temperature rises and heatwaves. The impacts of rising summer temperatures are already being felt, and key infrastructure providers such as SGN, Scottish Power Energy Networks and Glasgow Airport need to improve the clarity of their plans to manage these risks for the city region.

- Build understanding and capacity in relation to infrastructure interdependencies, building on insight from the Infrastructure Operators Adaptation Forum, with a particular focus on building resilience of mobile and fixed telecommunications infrastructure that keeps the Glasgow City Region connected to the world and open for business.

- Build capacity, understanding and networks to better understand the potential risks to passenger ferries, cargo and ports.

- Review how future climate projections are addressed in local and applicable national infrastructure strategies and plans (see Box 1).

Sector context

A resilient, efficient and well-maintained system of interconnected infrastructure networks is key to the functioning of Glasgow City Region. Investment in infrastructure fit for the future is a key priority of the Scottish Government (Scottish Government, 2015a), the Glasgow City Region (Glasgow City Region, 2017) and individual organisations. Research from the Scottish Cities Alliance found that transport infrastructure is the number one criterion considered by foreign investors when making an investment decision on whether to locate in a particular region. Infrastructure development is at a crucial point, with the City Deal's flagship Infrastructure Fund creating a 'once in a generation opportunity to deliver a step-change in the economic potential of the region and drive economic growth' (Glasgow City Region, 2017).

National Priorities

National infrastructure priorities are governed by a wide portfolio of legislation, strategies and regulations, and governance is shared between national and local government, public agencies and private sector organisations. Together, these support the Scottish Government's National Performance Framework Outcomes and the following sustainable development goals:

Table 1. National Performance Framework and Sustainable Development Goals related to infrastructure

National Performance Framework outcomes	Sustainable Development Goals
We value, enjoy, protect and enhance our environment We have thriving and innovative businesses, with quality jobs and fair work for everyone We live in communities that are inclusive, empowered, resilient and safe We have a globally competitive, entrepreneurial, inclusive and sustainable economy	7 AFFORDABLE AND CLEAN ENERGY 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 11 SUSTAINABLE CITIES AND COMMUNITIES

The Scottish Government's Infrastructure Investment Plan (Scottish Government, 2015a) notes 'infrastructure investment is central to the Scottish Government's economic strategy and vision' and that 'we need to invest in ways that help us tackle the challenges presented by climate change'.

The UK Adaptation Reporting Power grants the Secretary of State the power to require key national organisations to regularly report on the current and future effects of climate change on their organisation and their proposals for adaptation. There have been two rounds of adaptation reporting, providing a strong evidence base for risks and a firm foundation on which to build future action (GOV.UK, 2015). A third round will be completed by 2020.

The Scottish Climate Change Adaptation Programme sets the goal of 'A Scotland with well-managed, resilient infrastructure … providing access to the amenities and services we need.' Under this goal, objectives for infrastructure in Scotland include understanding the impacts of climate on infrastructure, providing knowledge, skills and tools to manage these impacts, and increasing the resilience of networks to sustain and enhance the services they provide.

Glasgow City Region priorities

Infrastructure investment is at the heart of the Glasgow City Region's Economic Strategy, which notes that resilient infrastructure assets are critical to achieving its vision. The £1.13 billion Infrastructure Fund established through Glasgow City Region City Deal provides an extraordinary opportunity to enhance infrastructure networks and ensure they are fit for the future. The investment is expected to deliver a sustainable uplift in GVA of 4% (circa £2.2bn p.a.) for the City Region. This uplift should generate additional tax revenues of some £20.7bn over the 40-year lifespan of the fund, and support an increase in the economy of around 29,000 jobs.

To further these goals the Glasgow City Region Economic Action Plan commits to greater alignment of infrastructure investment to ensure economic benefits of this investment is maximised, to establish a Regional Infrastructure Forum, and to use the City Deal Infrastructure Fund to lay the foundation for the expansion of Smart City technology. The Glasgow City Region will also work with SPT, Transport Scotland

and the Scottish Government to align transport priorities, and will develop a Glasgow City Region Strategic Transport Plan and a City Region Digital Connectivity strategy. Glasgow Airport is a key node in the regions infrastructure system and a number of projects are planned to maximise the economic impact of the airport across the region.

These varied interventions and investments will set the roadmap for infrastructure for the foreseeable future and are key opportunities to ensure our changing climate does not hold back growth or reduce the liveability and attractiveness of the region.

Risks to infrastructure

IN1: Risk of cascading failures from interdependent infrastructure networks

Current / future level of risk	Unknown
Adaptation shortfall	More significant
Benefits to further action	Yes
Urgency score	Build capacity and understanding

Risk description

Infrastructure networks exist within a complex system of interdependencies. Even a small disruption in one sector (for example electricity distribution or transport) can adversely affect the resilience of multiple other sectors. Climate change impacts such as extreme weather events can therefore still impact infrastructure sectors even when their own assets have not been directly damaged or disrupted. In addition, as links and conduits in larger national and international networks, infrastructure within the Glasgow City Region can also be adversely affected by climate impacts that happen elsewhere.

Evidence for Glasgow City Region

Outputs from various research projects are beginning to quantify the scale of interdependency risks at the national level, but the scale of the risk locally remains largely unknown. In the city region, a NERC-funded project delivered by University of Edinburgh brought together Scottish Water, BT, SGN, Scottish Power Energy Networks, SEPA, and Inverclyde Council to begin to understand these interdependencies. The project mapped interdependencies between providers using methods developed by the Infrastructure Operators' Adaptation Forum and simulated a decade of future weather and draw out the interdependencies and cascade consequences as a result of climate change. The project highlighted a range of dependencies between road, rail, water, gas, electricity and telecommunications infrastructure and has begun conversations about how to address these within the city region.

IN2: Risk to infrastructure services from river and surface water flooding

Current / future level of risk	High
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Sustain current action

Risk description

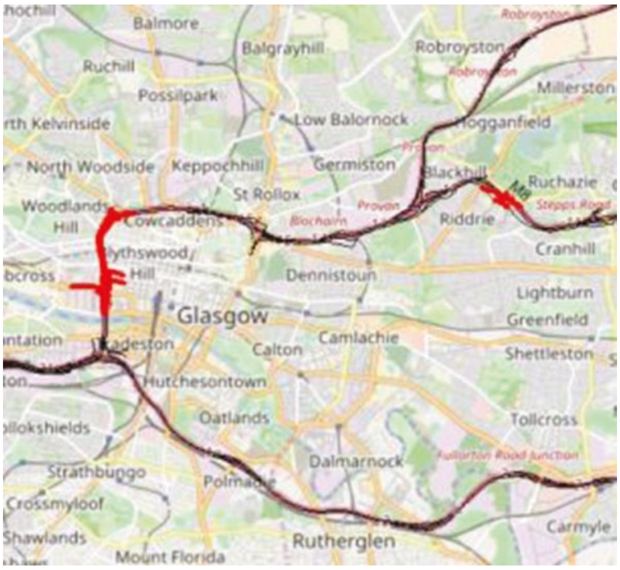
Flooding and the damage and disruption it causes are some of the biggest risks facing infrastructure in the city region now and in the future, and these are projected to grow under climate change. The impacts across different services is varied, but the combined effects will impact on the productivity of the economy, the budgets of public services, and the ability of people to engage in day-to-day activities.

Evidence for Glasgow City Region

Road: the effects of flooding are likely the most significant, visible and frequent climate impact on the national road network (Transport Scotland, 2011). The city region has 8,705Km of roads, comprising 515km of Trunk Road, and 8,191 km of Local Authority Roads (Transport Scotland, 2017).

391km of road is at risk of surface water flooding, including the M73, M8, M80 and M74, and 32.7km of roads in the Local Plan district are at risk of river flooding (SEPA, 2015). The boundary of the Local Plan district assessed by SEPA in the Clyde and Loch Lomond Flood Risk Management strategy is larger

Figure 5. Areas of trunk road most exposed to future flooding nationally, within Glasgow City Region. (Source: AECOM, 2017)



than the Glasgow City Region so the exact area of road at current risk within the Glasgow City Region is likely to be lower. In addition, modelling has shown 76 sections of the national trunk road network are currently at the highest level of exposure to flooding (covering all types) (AECOM, 2017). This includes some sections within the Glasgow City Region, but also major access routes up to the west coast of Scotland.

Newer road schemes will have been designed, and are being designed, with climate change impacts on flooding taken into consideration, therefore it is the older parts of the existing road network which are likely to be the most vulnerable to the effects of flooding and changes in the frequency and intensity of storms (Transport Scotland, 2011).

The number of road sections nationally at this highest level of exposure to flooding is projected to increase from 76 to 179 by the 2030s and to 568 sections by the 2050s under a high emissions scenario. In the city region, a number of sections of the M8 have been identified as most exposed nationally.

Rail: As with roads, current levels of flooding already cause significant damage and disruption to rail operations within Scotland and this has the potential to increase with climate change. Surface water is the biggest risk to the rail network, with 127km of railways at risk of a 1 in 200-year flood event, and 16.5km at risk of river flooding (SEPA, 2015).

Increased flooding has the potential to affect many aspects of rail services and infrastructure, including closure of lines, failure of lineside equipment due to inundation, damage or blocking access to stations, depots and offices, damage to bridges, and increased scour of embankments (Network Rail, 2015). In order to manage these risks, physical resilience to extreme weather is one of Network Rail's three key pillars of its ongoing maintenance strategy (Network Rail, 2018a) and identifies a number of specification actions to reduce risk, including improving track drainage and targeted maintenance at high risk sites.

Subway: Glasgow's subway passes under the River Clyde and the River Kelvin. Correspondence with SPT has indicated that the risk of flooding at stations is low, and subway water ingress has been reduced as part of the current refurbishment works.

Air: Glasgow Airport 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) (DfT, 2017). Airport buildings and essential surfaces such as runways and aircraft stands will be at increased risk of flooding due to climate change, both from the rivers and from surface water accumulation (Glasgow Airport 2011, 2015). SEPA also identified the airport as being at risk of both river and surface water flooding (SEPA, 2015). Flooding of assets could result in significant disruption and damage to the airport, with knock-on effects for the region. Control measures and mitigating actions have been identified and medium to long term risks (2020-2050s) are largely noted as moderate.

Energy (Electricity Generation and Distribution and Gas Supply): There are 570 utilities assets at risk of surface water flooding, and 110 at risk of coastal flooding (SEPA, 2015). However, it is difficult to understand specific risks to different infrastructure types as for surface water flooding this includes electricity substations, fuel extraction sites and gas regulation sites, whilst for coastal flooding it includes electricity sub stations, telecommunications, oil refining, and distribution, gas regulating and mineral, and fuel extraction sites.

Flooding of electricity sub-stations was identified as the risk of highest concern by Scottish Power Energy Networks (SP Energy Networks, 2011, 2015). Flooding can cause significant damage to sub-stations and interrupt supply. Similar concerns exist for the gas distribution network with the flooding of

Pressure Reducing Installations (PRIs) and supporting infrastructure (Southern Gas Networks and Scotland Gas Networks, 2011; SGN, 2015). Floods can cause considerable damage to PRIs, threatening supply security and affecting pipelines. This is particularly so when PRIs are close to or cross rivers, as flooding can cause damage or erode supporting groundworks. The adaptation reporting power reports do not specify how many assets are at risk in the Glasgow City Region, but Climate Ready Clyde are working with SGN to clarify initial assets identified through Clydeplan's Strategic Flood Risk Assessment.

Clydeplan's Strategic Flood Risk Assessment (Clydeplan, 2017a) uses SEPA flood maps to identify functional sites at risk to a 1 in 200-year return period for river and coastal flooding, or a 1 in 200 year (+ climate change) for surface water. The assessment identified three substations in Glasgow, Inverclyde and Renfrewshire at risk of flooding of a 1 in 200-year flood event. However, the only site identified with a moderate degree of risk was the substation located at Drumchapel, with 14% of the site covered by the mapping.

There are also four power generation sites at risk of flooding – three hydroelectric plants at risk from river flooding and Greengairs Landfill Gas site in North Lanarkshire at risk of surface water flooding (Clydeplan, 2017a). This equates to around 20.3MW of power generation.

IN3: Risk to infrastructure services from coastal flooding and erosion

Current / future level of risk	Medium
Adaptation shortfall	Significant
Benefits to further action	Yes
Urgency score	! More action needed

Risk description

Many of the city region's infrastructure assets and services are located along the coast and river banks. Climate change is expected to cause sea level rise and increase the frequency and severity of storms and severe weather, placing assets and services at a risk of damage from coastal flooding and erosion.

Evidence for Glasgow City Region

Rail: The Clyde and Loch Lomond Flood Risk Strategy highlights that there are 2.8km of railway lines at risk of coastal flooding (SEPA, 2015). In addition to this work, the National Coastal Change Assessment has 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.

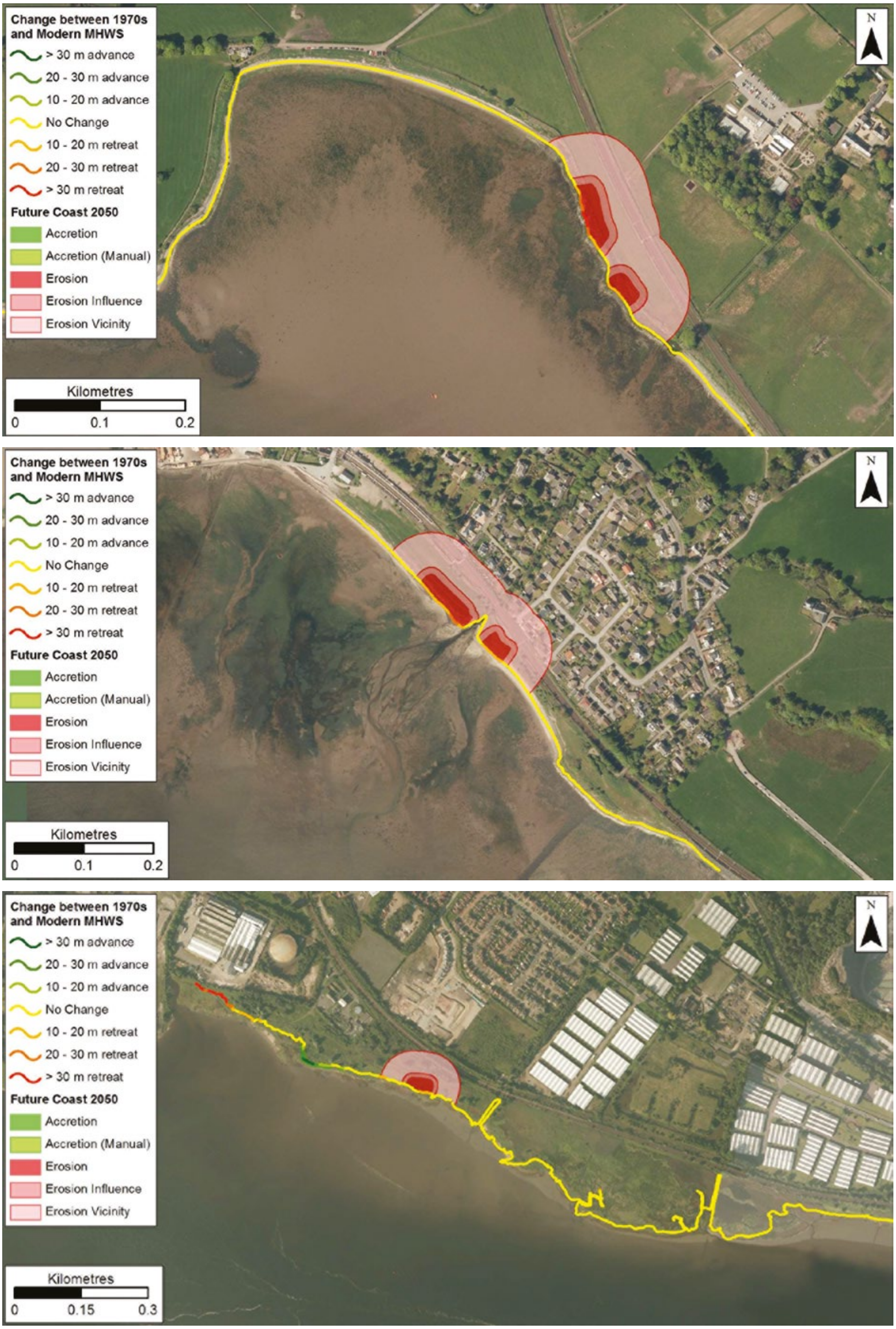
Table 2. Electricity substations at risk of flooding (Source: Clydeplan, 2017a)

Name	Location	% of site	Risk category	Flood Type
Drumchapel	Glasgow	14.43%	Moderate	Pluvial, Fluvial
Inverkip	Inverclyde	1.4%	Minimum	Pluvial
Glenifer Braes	Renfrewshire	1.3%	Minimum	Pluvial

Table 3. Electricity production stations at risk of 1:200 year flood event (Source: Clydeplan, 2017a)

Name	Location	Operator	Generation type	Capacity (MW)	Risk Category	% affected	Flood Type
Greengairs	North Lanarkshire	Shanks McEwan	Landfill Gas	3.8	Minimum	2.5%	Pluvial
Blantyre	South Lanarkshire	Innogy	Hydroelectric	0.575	Extreme	100%	Fluvial, Pluvial
Bonnington	South Lanarkshire	Scottish Power	Hydroelectric	11	Moderate	39%	Fluvial
Stonebyres	South Lanarkshire	Scottish Power	Hydroelectric	5	Moderate	30.1%	Fluvial

Figure 6. From top to bottom: possible future coastline position in 2050 at east of Ardmore Point, around Cardross and at Dumbarton Castle bay. (Source: Hansom et al., 2017)



The first section of the rail line identified as at risk of coastal erosion is located on the shore to the east of Ardmore Point. Here, the coastline has built out 25m since 1980 but then eroded landward by 10m between 1990 and 2011. Although undeveloped and undefended, the main West Highland rail line which runs north of Glasgow to Helensburgh lies close to the shore.

The second area is around Cardross. The beach fronting the town has undergone substantial change since the survey of 1896, particularly where the small stream exits. Surveys show that the 1896 coastline lies 40 m seaward of the 2012 shore suggesting rapid erosion. By 1970 the shore was within 17 m of the modern 2012 shore, with 170 m of urban frontage shore eroding over the recent period at 0.7 m/yr. In terms of future vulnerability, the shoreline is undefended. Currently, direct impacts are limited to recreational land and access tracks. However, projections indicate that up to 250m of rail track, 13 residential homes and two railway bridges may eventually be impacted by continued erosion.

The final section at risk of coastal erosion is Dumbarton Castle Bay. The saltmarsh coastline to the east of Dumbarton Rock has undergone variable amounts of erosion since 1896. As with many saltmarsh fringing shores, the degree of erosion is variable. One area has receded up to 80m since 1968, and further recession has occurred elsewhere of 20m between 1963 and 2012. Although the erosion zone here affects undefended saltmarsh, the vicinity of future erosion captures some 100 m of mainline rail track that lies 70 m landward.

The locations identified are not currently included in the Scotland Weather Resilience and Climate Change Adaptation Plan for Scotland (Network Rail, 2018a). Similarly, it is not included as a priority in the Network Rail's Strategic Business Plan 2019 – 2024 for Scotland (Network Rail, 2018b). However, Network Rail have already been undertaking work to protect from erosion and flooding more broadly. The Weather Resilience and Climate Change Adaptation plan highlights that Rock Armour Plating has already been installed to protect the sea wall face at Gourock Station.

Given the long lead in times, complex stakeholder networks, and significant funding needed for successfully defending or relocating infrastructure, as well as the uncertainty on the effects of climate change on erosion rates, there would be benefit in the next five years to starting these discussions on an appropriate way forward.

Roads: There are 53km of Roads within the Clyde and Loch Lomond Local Plan District at risk of coastal flooding, including 1.2km of the M8, 1km Primary roads, 23km A roads, 7.5km B roads, 12km minor roads (SEPA, 2015).

Energy: As noted above, Scottish Power Energy Network identified flooding of electricity sub-stations (including from coastal flooding) as the highest level of concern in their 2011 and 2015 adaptation reports. SEPA identified 50 utilities sites at risk of coastal flooding (SEPA, 2015), including electricity substations, fuel extraction sites, energy production sites and telecommunications sites (SEPA, 2015).

An assessment of the marine and coastal environment estimated that under a high emissions scenario the risk of coastal flooding will increase as sea levels in the Firth of Clyde rise by a projected 0.47m by the 2080s (Hansom et al., 2017). The assessment has identified risks in the 2080s to a coastal route and the harbour in Inverkip; industrial estates, development opportunities and infrastructure in Greenock; the A770, sections of railway; a proposed road and an industrial estate in Gourock; the former Exxon site in West Dunbartonshire; and a golf course in Renfrewshire. Mapping only covered a limited extent of the River Clyde, meaning the scale of impacts identified are likely to be an underestimate.

IN4: Risk of sewer flooding due to heavy rainfall

Current / future level of risk	Medium
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Sustain current action

Risk description

Increased instances of heavy rain and sea-level rise both have the potential to back-up or overwhelm existing sewer systems and lead to sewer flooding. Much of Glasgow City Region's sewer systems are 'combined' – taking both rainfall and foul water from kitchens and toilets. During heavy rainfall, sewage can overflow from manholes and gullies and flood land, rivers and gardens. In the worst cases, sewage can even flood homes. This risk is worsened by other activities which affect drainage capacity, such as urban creep, illegal connections, cross-connections, blockages due to disposal of inappropriate items and build ups from fats, oil and grease.

Evidence for Glasgow City Region

The amount of sealed surface across all local authorities in the Glasgow City Region is increasing, removing opportunities for drainage into the soil and increasing pressure on drainage infrastructure (ClimateXChange, 2016). At the Climate Ready Clyde workshop held on 8 November 2017 (Climate Ready Clyde, 2017a), stakeholders ranked this risk as of highest concern in the infrastructure sector. Scottish Water representatives explained customers share this concern, ranking sewer flooding as the area of highest concern in recent surveys.

The existing sewer system is a combination of historic and new, and in many places will struggle to accommodate even a 1 in 30-year flow. Newer elements of the sewer network are designed to accommodate rainfall from a 1 in 30-year return period scale event. Any rainfall event with a higher return period will likely overwhelm the sewer system and result in surface water flooding, even where newer elements have been incorporated. The number of properties at risk of sewer flooding within Glasgow City Region is relatively low. Scottish Water currently have 842 properties on their internal register (Birrell, V., 2018), which consists of validated incidents of sewer flooding. These are made up of both domestic and non-domestic properties, and are confirmed through a rigorous investigation process. The register is used to inform future work to reduce risks of sewer flooding.

Table 4. Confirmed risks of sewer flooding to properties in Glasgow City Region (Source: Birrell, V., 2018)

INTERNAL PROPERTIES	
Flooding likelihood	Properties at risk
2 in 10	105
1 in 10	85
1 in 20	51
Total	**241**

EXTERNAL PROPERTIES ONLY	
Flooding likelihood	Properties at risk
2 in 10	462
1 in 10	359
1 in 20	21
Total	**842**

IN5: Risks to bridges and pipelines from high river flows and bank erosion

Current / future level of risk	Medium
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Sustain current action

Risk description

Bridges are key linkages in many infrastructure networks often carrying multiple services in the body of the structure (gas, water, electricity, telecoms etc.) as well as traffic. Damage to bridges can therefore have multiple impacts, including to cultural heritage as many road and rail bridges are listed buildings (ASC, 2016). High and fast river flows can cause localised riverbank erosion undermining structures, increased scour, exposure of buried cabling and pipework, and lead to build-up of debris under structures.

Evidence for Glasgow City Region

Stakeholders explained at the 8 November 2017 workshop that there are many bridges in the Glasgow City Region. These are maintained by several different agencies. There is high confidence in the data available on the condition of structures (although not all publicly available) and good maintenance procedures are in place. However it was noted that even a minor structural failure could cause a significant problem for infrastructure networks.

There have been substantial increases in winter river flows from 1961-2004, with the River Kelvin seeing an increase of 69% (ASC, 2016). Peak flows across Scotland are projected to continue to increase over the next century. The risk to bridges is largely recognised in the current adaptation plans of the key infrastructure providers reviewed.

IN6: Risks to transport networks from slope and embankment failure

Current / future level of risk	Low
Adaptation shortfall	Not Scored
Benefits to further action	Not Scored
Urgency score	Watching brief

Risk description

Increases in the severity and frequency of rainfall events, changes in soil moisture levels, extreme temperatures (both high and low), changes in vegetation growth rates, and changes in freeze thaw ratios can all affect slope stability and embankment conditions, which are prominent features of transport infrastructure. High winds can also impact on slope stability by up-rooting trees. As the climate changes, these events may have a greater impact.

Evidence for Glasgow City Region

Road: The Scottish Government's Scottish Road Network Landslide Study (Scottish Executive, 2005) notes that the main conditions contributing to landslips are extended periods of heavy rainfall (antecedent rainfall) and intense rainfall events. Based on the UKCP02 climate projections, the study identified 10 areas of High Risk for landslips in Scotland but none of these were in the Glasgow City Region. An updated study for Transport Scotland in light of the new UKCP09 projections found that under a medium UKCP09 scenario (Jacobs, 2011), risk levels from landslides were broadly similar and recommended that current adaptation strategies in place would be sufficient to manage the risk. No evidence was found relating to assessments of the local road networks, but these are less important than the strategic transport networks.

A further study of the road network's exposure to flooding and landslides has identified the A83 as a section of trunk road with potentially high exposure. The scoring of other sections in the city region are estimated to rise to the highest score of exposure by the 2050s under a high emissions scenario. Whilst not within the city region, the A83 acts as a gateway route from Glasgow to the West of Scotland, meaning it is a key route for underpinning a wider tourism strategy.

Rail: Network Rail's Climate Change Adaptation Report (2015) notes the condition of rail embankments can be adversely affect by both an increase in flooding (washing material away) and decreases in rainfall (causing desiccation of material leading to track geometry faults). It is not known how many rail embankments are present in the Glasgow City Region, however both the 2015 adaptation report and the Route Strategic Plan for Scotland (2018) list actions to increase resiliency of earthworks across the network, including increased maintenance for slopes classified as 'poor' and increased monitoring.

IN7: Risks to energy, transport and ICT infrastructure from storms and high waves

Current / future level of risk	Medium
Adaptation shortfall	Significant
Benefits to further action	Yes
Urgency score	More action needed

Risk description

Storms bring a range of hazards to infrastructure, including flooding, damage to structures from high winds, blockages from debris, uprooting of trees, high waves and lightning strikes. Scotland as a whole is likely to see an increase in the annual frequency of windstorms by 10-15% under a temperature rise of 3-4 degrees (Air Worldwide and Met Office, 2017). Wind is also a key component in determining wave height. Increased risk of high winds also raises the chances of overtopping of coastal defences and contributes to long term degradation of coastal infrastructure, increasing the need for monitoring and maintenance.

Evidence for Glasgow City Region

The above research has estimated that such changes could lead to an increase in average annual insured losses (AAL) for Scotland of 10%. Equivalent figures for the Glasgow City Region are not available. Road, rail, energy and telecoms infrastructure operators all currently manage risks associated with storm conditions as part of normal operations. However, future changes could have significant implications for the operation of a range of infrastructure services.

Figure 7. Most exposed trunk road section for high winds (Source: AECOM, 2017)

Road: the A898 Erskine Bridge connecting West Dunbartonshire and Renfrewshire currently has the highest category of exposure to high wind impacts in Scotland, and that this rises to one of the highest possible risk scores by the 2050s (AECOM, 2017).

Rail: High winds can cause damage/blockages to rail lines due to objects/debris falling onto the tracks and can also uproot trees adjacent to, or part of, rail earthworks (Rail Safety and Standards Board, 2016 and Network Rail, 2015). Even where trees do not fall onto the track, this uprooting can weaken the structural integrity of earthworks and increase the risk of failure. However, there was no assessment identified of risk to Glasgow City Region.

Aviation: There are a wide range of storm risks including wind damage to assets, aircraft and staff, disruption to schedules, risk to aircraft while taking off, risk of changes in direction of prevailing winds across the runway, risks of lightning strikes (Glasgow Airport, 2011, 2015). Planes are particularly vulnerable to lightning when taking off, landing or refuelling, leading to suspension of activities during lightning events. Whilst a range of risks from storms have been identified, these have classed by the Airport as low through to the 2050s. However, it has not been able to be assess risks directly relating to wind due to uncertainty stemming from suitable wind projections (Glasgow Airport 2011, 2015).

Energy: Many electricity assets could be affected by storms, including overhead lines and transformers affected by increasing lightning activity (SP Energy Networks, 2015). During extreme events maintenance teams may have limited safe access to isolate and repair faults, extending the duration of the loss of supply to customers. SGN highlight similar concerns, with the main risks from storms coming from disruption to transport routes which in turn affect operations (Southern Gas Networks and Scotland Gas Networks, 2011; SGN, 2015).

Telecommunications: Mirroring many of the risks above, Fixed Line Telecoms and Mobile Telecoms are both vulnerable to storm events due to damage to masts and towers, misalignment of microwave dishes, and damage to cables and cable heave from uprooted trees (TechUK, 2017). Data centres are at lower risk of direct damage but are still reliant on other services such as electricity supply and transport access. However, no assessment of assets at risk in Glasgow City Region was identified as part of this work.

IN8: Risks to energy, transport, and ICT infrastructure from extreme heat

Current / future level of risk	Medium
Adaptation shortfall	Significant
Benefits to further action	Yes
Urgency score	! More action needed

Risk description

Many elements of transport, digital, and energy infrastructure are affected by high temperatures. High temperatures increase the risk of railway lines buckling, leading to damaged trains and increasing maintenance and disruption of services. High temperatures can also degrade road and pavement materials, increasing maintenance and repair costs. As well as impacts on the physical materials and functioning of infrastructure, extreme high temperatures increase the risk of heat stress to staff, which may constrain maintenance schedules.

Evidence for Glasgow City Region

Rail: Based on 2006/07 to 2013/14 data, heat-related delays on the railway total 723 minutes per year on average, costing £0.02m per year in Schedule 8 costs (the compensation payments to train and freight operators for network disruption) for the entire of Scotland (Watkiss et al., , 2018).

Table 5. Network Rail key climate change risks to rail infrastructure from heat and high temperatures (Source: Network Rail, 2015)

Asset associated with risk	Consequence
Track	Risk of buckling, breaks and derailment. Reduced opportunities for track maintenance
Overhead line equipment	Failure of point operating equipment
Overhead line equipment	Sag of overhead line and risk of dewirement
Lineside equipment	Failure of temperature controls and overheating of electronic equipment
Staff	Poor working conditions for staff in extreme weather conditions

These heat related delays would be expected to increase, though the increase in hot and very hot days are modest for Scotland. Temperatures greater than 31C exceed track thresholds and can result in the need for reduced speeds to minimise buckling. The number of temperature exceedances above that 31C threshold are expected to increase from rate of 0.6 per year to 6.4 by the 2040's in Southern Scotland (RSSB, 2016). Network Rail's second adaptation report (Network Rail, 2015) highlights a range of climate change risks associated with high temperatures and extreme weather (see Table 5).

No formal evidence of the risks to the rail network in Glasgow City Region were identified, though the summer 2018 heatwave caused speed restrictions across the network and rail buckling in North Lanarkshire.

Aviation: Many of the risks identified in Glasgow Airport's Climate Change Adaptation Reports (Glasgow Airport, 2011, 2015) relate to temperature extremes, since extreme heat impacts on airport operations in a variety of ways, including reducing the lift available to aircraft due to 'thin air', reducing aircraft engine efficiency, overheating of aircraft on stands, potential changes in bird behaviour increasing

Table 6. High or very high risks to electricity distribution infrastructure from heat and drought (Source: SP Energy Networks, 2015).

Business function	Description	Risk	Likelihood	Impact
Overhead line cable, bridges and towers	Overhead line conductors affected by temperature rise, reducing rating and ground clearance	High	Possible (3)	Moderate (3)
Underground lines, tunnels and cable routes	Underground cable systems affected by increase in ground temperature, reducing ratings	High	Possible (3)	Moderate (3)
Underground lines, tunnels and cable routes	Underground cable systems affected by summer drought and consequent ground movement, leading to mechanical damage.	High	Unlikely (2)	Significant (4)
Transformers	Transformers affected by urban heat islands and coincident air conditioning demand leading to overloading in summer months	High	Possible (3)	Moderate (3)
Network Access	Maintenance programme may be impacted as increased temperatures may increase loads during summer reducing opportunity for planned outages and network reinforcement to enable maintenance. Temperature increases could thus lead to a possible reduction in the flexibility of the network (because of the change in load balance through the year	High	Possible (3)	Moderate (3)

the chance of bird strike, overheating of critical buildings/equipment, heat damage to road and apron surfaces, increased demand for cooling, increased fire risk and negative impacts on air quality making it harder for the airport to comply with standards.

Electricity – SP Energy Network's Climate Adaptation report (SP Energy Networks, 2015) highlights a range of risks to electricity related to higher temperatures and drought that were rated as High or Very High by the 2080s, based on a high emissions scenario, using the 90% probability level. However, these impacts in Scotland are likely to be modest, especially in the short and medium term.

IN9: Risks to infrastructure from increase in vegetation growth rates

Current / future level of risk	Medium
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Sustain current action

Risk description

Changes in the type and rate of vegetation growth could have a positive or negative impact on infrastructure generally. In some areas, changes in vegetation may help to stabilise grounds, while in other locations vigorous plants and roots may cause damage.

Under the medium scenario in UKCP09 Glasgow's growing season could extend by 40 days by 2050 (Scottish Cities Alliance, 2014). This is a complex, interacting risk as whilst temperature increases vegetation growth, this in turn increases risks of tree falling related to storms and high winds. It may also require changes to maintenance timetables to ensure that maintenance does not inadvertently encourage growth.

Evidence for Glasgow City Region

Electricity: Tree-related faults on the UK's electricity distribution network significantly increased between 1990 and 2006 (ASC, 2016) and Scottish Power Energy Network's adaptation reports note vegetation management is one of their biggest annual costs (SP Energy Networks, 2011, 2015).

Roads: The Scottish Executive considered the change in the growing season, would lead to additional maintenance costs for vegetation control for roads (Scottish Executive, 2005). This will also create additional on-costs as maintenance activity requires traffic management, causing transport delays and 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. However, in recent years this has increased to 3 or more cuts.

Rail: Changes in the timing of the seasons can affect the timing of leaf fall and may require changes to the timing of vegetation management operations as cutting at the wrong time can encourage rather than slow growth.

As well as the danger of falling trees and entanglement, increased root growth can change the structural integrity of embankments and earthworks, damaging pavements and roads and interfering with underground infrastructure. While operators currently have robust vegetation management plans in place, issues of ownership can often hamper maintenance efforts, with Network Rail estimating 60% of national disruption due to windblown trees comes from land they do not own.

IN10: Risks to infrastructure from wildfires

Current / future level of risk	Medium
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Watching brief

Risk description

Projected increases in drier summers and higher soil moisture deficits are expected to lead to a large increase in the number and size of wildfires in Scotland, with associated increased demand for management.

Evidence for Glasgow City Region

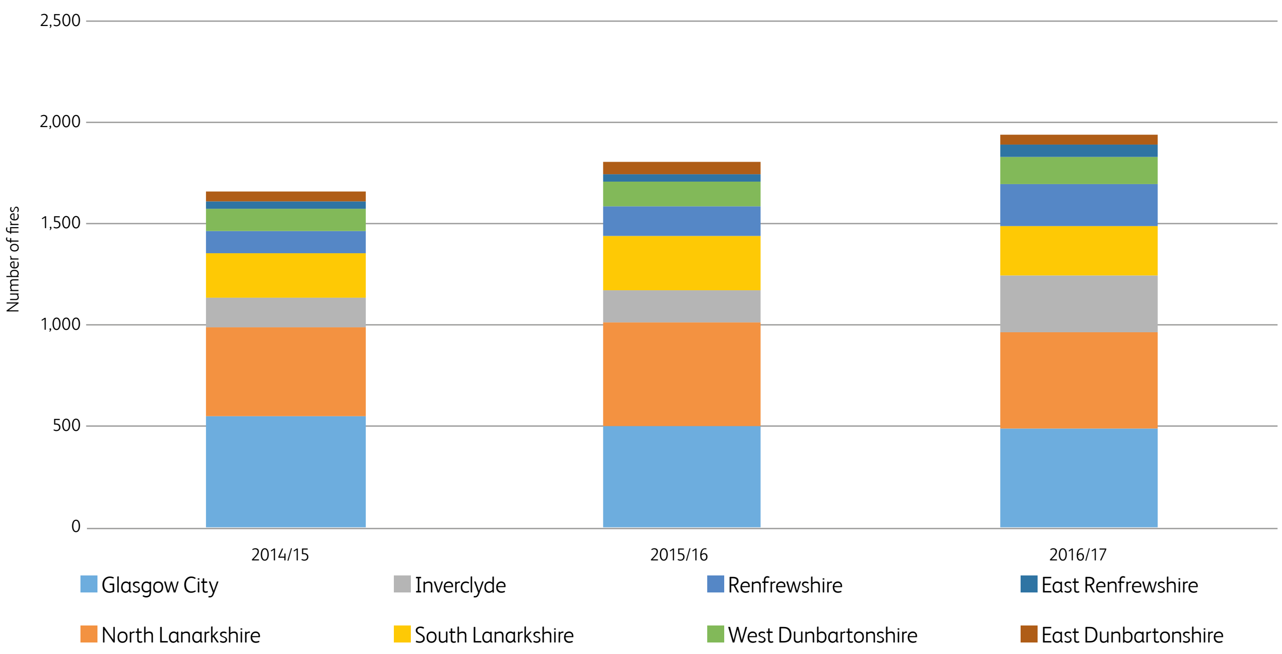
Scottish Fire and Rescue do not record and publish data on wildfires in Scotland. Instead they record these as a type of secondary fire, known as grassland. Secondary fires from grassland include: "Grassland etc., including heath, hedges, railway embankments and single trees". (HM Inspectorate of Constabulary for Scotland and HM Fire Service Inspectorate for Scotland, 2002). Secondary fires can fluctuate due to weather conditions throughout the year.

The number of secondary grassland fires in the city region has increased from 1,654 in 2014/15 to 1,943 in 2016/17. Whilst Glasgow has the biggest proportion of fires, this has been reducing, whilst all seven other authorities in the city region have seen increases. There are some caveats to these figures. Firstly, the records do not differentiate motives, so it is not possible to distinguish between accidental and deliberate fires. Secondly, there is not data available from over a long enough period to understand whether recent rises are part of a long-term trend linked to climate, or just short-term fluctuations linked to activities of the public, policies and resourcing.

Wildfires pose a particular danger to Pressure Reducing Installations, but the level of risk is site specific (Southern Gas Networks and Scotland Gas Networks, 2011; SGN, 2015). However, no sites were able to be identified for the city region as part of this assessment. Other infrastructure sites are also vulnerable to damage from wildfires, particularly those in rural areas.

As well as causing direct damage to assets, wildfires can reduce local visibility and lead to disruption of services and increased risk to drivers. From consultation with organisations in the city region, general wildfire risk in the Glasgow City Region was felt to be low, but some specific assets may need additional protection (Climate Ready Clyde, 2017a).

Figure 8. Secondary grassland fires by Local Authority for Glasgow City Region. (Source: Scottish Fire and Rescue, 2017)



IN11: Risks to water-based transport and trade infrastructure (ports, canals, harbours, etc.) from sea level rise, floods and storms

Current / future level of risk	Medium
Adaptation shortfall	Significant
Benefits to further action	Yes
Urgency score	Build capacity and understanding

Risk description

Water based transport and trade in and out of Glasgow City Region could be disrupted by a mix of future sea level rise and floods, and storms. These changes could pose a range of risks to ports and waterways, with implications for both passengers and cargo.

Evidence for Glasgow City Region

The Clydeport terminals at Glasgow and Greenock, along with sites outside the Glasgow City Region at Ardrossan and Hunterston, together process 5.4 million tonnes of cargo a year. There are also four regular ferry services in the Glasgow City Region (Wemyss Bay to Rothesay; Kilcraggan to Gourock; and Hunter's Quay to McInroy's Point and Renfrew to Yoker). Calmac's Wemyss Bay to Rothesay route carries over 700,000 passengers a year, whilst there are 32,000 sailings a year between Hunter's Quay to McInroy's Point (Western Ferries, 2018). Finally, the Greenock Ocean Terminal acts a major port for cruise ships. In 2018 it is scheduled to receive 59 cruise calls, with over 100,000 passengers coming through the terminal (Clydeport, 2018).

Rises in sea level could increase scour potential for vertical structures such as sea walls. Coastal structures will be particularly vulnerable where defence foundations are exposed to stronger and near continual wave action (ASC, 2016). Port operators also cite some benefits from higher sea levels, including reducing the potential need to dredge harbours and channels (ASC, 2016).

Climate change will increase levels of erosion and silting in waterways, adding to maintenance costs (Scottish Canals, 2017). At the same time, increasingly frequent extreme weather events will require more robust risk management processes and contingency arrangements. Historic structures, already requiring careful maintenance, will be particularly vulnerable.

Specific sea level rise assessments have been conducted for major ports in Scotland (ASC, 2016), but that these were not submitted as part of the second round of the Adaptation Reporting Power. While these updated assessments were not available for inclusion in this assessment, the table below shows Passenger and Vehicle Ferry terminals identified as at risk of flooding from a 1 in 200-year (plus climate change) scale event (Clydeplan, 2017a). In particular, the Renfrew Ferry and Western Ferries terminal are particularly exposed.

The assessment also identified that a small area (0-10%) of Clydeport's King George V dock in Glasgow is at risk of a 1 in 200 year plus climate change coastal flooding, however, no public information is available on climate change risks to Clydeport operations.

Disruption due to storms

The majority of current disruption to ferry services is due to high winds. Scotland as a whole is likely to see an increase in the annual frequency of windstorms by 10-15% under a temperature rise of 3-4 degrees (AIR Worldwide and Met Office, 2017). It should be noted however, that climate projections show a high level of uncertainty on changes to wind speeds (ASC, 2016).

Table 7. Passenger and Vehicle Ferry Terminals at risk of flooding in Glasgow City Region (Source: Clydeplan 2017a)

Name	Location	Risk Type	Risk Category	%age
Greenock Ocean Terminal	Inverclyde	Coastal, pluvial	Moderate	12.22
Gourock Ferry	Inverclyde	Coastal, pluvial	Moderate	13.8
Wemyss Bay Ferry	Inverclyde	Coastal, pluvial	Moderate	20.96
Western Ferries terminal McInroy's Point	Inverclyde	Coastal	Extreme	56.11
Renfrew Ferry	Renfrewshire	Coastal	Extreme	93.31

Opportunities for Infrastructure

IN12: Potential benefits to water, transport, ICT and energy infrastructure from reduced extreme cold events

Current / future level of risk	Unknown
Adaptation shortfall	Less significant
Benefits to further action	Not Scored
Urgency score	Watching brief

Opportunity description

Cold weather (including snow and ice) is a major cause of disruption to transport services, and electricity transmission and distribution. A warming climate may reduce the number or severity of extreme cold events, with associated reduced disruption across infrastructure services.

Evidence for Glasgow City Region

The average number of extreme cold days is likely to diminish over the course of the century. Cold winters will still be possible, but are expected to become increasingly unlikely. There may be opportunities arising from fewer snow and ice days reducing winter disruption and maintenance costs.

However, frequent fluctuations around freezing point can be more damaging to equipment and surfaces than sustained periods of below freezing temperatures. As with slope stability (see IN6), a change in the freeze thaw ratio may be a significant factor in determining the level of resources required for maintenance. A reduction in the frequency of extreme cold events also reduces the capacity to respond in the rare cases when they do occur, with some anecdotal correspondence with Transport Scotland indicating that they perceive the potential for increased vulnerability. With climate variability projected to rise, winter planning may become more difficult even if the impacts overall are reduced.