ClimateReadyClyde

TOWARDS A CLIMATE READY CLYDE: CLIMATE RISKS AND OPPORTUNITIES FOR GLASGOW CITY REGION

ECONOMIC ASSESSMENT

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EXECUTIVE SUMMARY

This report presents the first phase findings of the study 'The Economic Implications of Climate Change for Glasgow City Region'. The report has been prepared by Paul Watkiss Associates for Climate Ready Clyde (CRC) and Sniffer. The aim of the study is to address the current gap on the economic impacts of climate change for Glasgow City Region, and to provide information on the economic benefits of managing these risks and adapting successfully.

This initial phase of the work has focused on two related sets of analysis. The study has considered the economic costs of recent significant extreme weather events in Glasgow City Region (flooding, heatwaves, and storms). It has then gone on to assess the future economic costs of climate change in the region, estimating the indicative economic costs of the risks and opportunities identified in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA). The study has assessed these economic costs and benefits in terms of social welfare, which considers both market and non-market impacts.

Current economic costs of weather and climate extremes

The task has assessed the economic costs of four recent historic events for the region. These events were:

- December 2015 river floods;
- July 2012 surface water floods;
- October 2017 wind storm;
- 2013 warm and dry summer.

The costs of the 2015 river flooding event are estimated at £4 million to £10 million and the costs of the July surface floods estimated at £1 to 2 million. In both cases, these costs were dominated by property flooding damage, as well as rail transport disruption and travel time losses. It is stressed that the actual costs of these events are actually likely to have been much higher, but there is a lack of recorded data on impacts which prevents more complete valuation. A first recommendation is that capturing the impacts (and costs) of extreme events more effectively in GCR would be useful.

While these two events were significant, the number of properties that were flooded was low when compared to the total number of properties at risk in the region. The study has therefore looked at the theoretical costs of a larger event, such as occurred during the 1994 floods. This shows that economic costs from a large flood event could easily run to £tens of millions for a single event and would have major consequences for the region. Events of this size would also lead to wider disruption and economic costs and could have important budgetary impacts on public sector organisations.

The estimated costs of the 2017 storms are more difficult to estimate, due to data gaps on the reported impacts, but an indicative estimate is that the event could have had economic costs in excess of £20 million, with costs dominated by property damage and electricity outages. Similarly, an analysis of the 2013 warm and dry summers has found limited data, but the possible costs are estimated at £20 million, dominated by excess mortality (non-market impacts).

Critically, all four of these weather events are projected to increase in frequency in Glasgow City region under climate change. For these large-scale events, economic costs would be greater than the direct cost (e.g. as borne by households) from the disruption of wider economic activity.

Future economic costs of climate change

The second task has been to assess the future economic costs of climate change in the Glasgow region. The analysis has considered each of the 60 or so climate risks and opportunities identified in the GCRCROA.

The study has undertaken a detailed literature review for each of these risks, then used the findings to assess the potential economic costs for each of the risks and opportunities. The degree of quantification and monetisation of each risk has depended on the data available. Monetised estimates of climate damages currently exist only for flood risks to property. In other cases, notably health and energy, previous estimates of impacts have been used to monetise risks and opportunities. Finally, for the majority of risks, only qualitative data exist. In this case, indicative estimates have been made, based on the available information and expert judgement.

The results of the analysis find that the future economic costs of climate change are likely to be dominated by a small number of risk categories. These are:

- River, surface and coastal floods leading to property damage for residential houses;
- River, surface and coastal floods leading to property damage for business and industry;
- And to a lesser extent, flood related disruption to transport (road and rail), including damage to infrastructure and impacts on travel time.

These impacts will all lead to large financial as well as economic costs. It is stressed that many of these economic impacts will disproportionally affect socially deprived and vulnerable groups. There are strong geographical patterns for the distribution of risks across local authorities, reflecting differentiated flood risks. There are also potentially significant economic costs (non-market) from increasing heat extremes (health related mortality and morbidity) in the longer term.

It is highlighted that there is a lack of quantifiable estimates for some categories, notably the natural environment theme. While the direct contribution of agriculture, forestry and the natural environment to the economy is low in Glasgow City Region (due to the predominately urban land area), the potential impact on ecosystem services (non-market) could be potentially large.

The results also show, however, that there will be large economic benefits for the Glasgow region from climate change. Again, these are dominated by a small number of categories, notably:

- Large financial and economic benefits in terms of reduced winter energy use for heating, for both the residential sector and business/industry;
- Large economic benefits from reduced cold related health impacts;
- And to a lesser extent, financial and economic benefits from reduced cold weather-related expenditure and disruption for infrastructure and transport.

These benefits will also fall disproportionally to socially deprived and vulnerable groups, however, they are more evenly spread across all geographical areas of the City Region.

Given the partial coverage of risks, it is difficult to aggregate all the 60 or so risks (and opportunities) and provide a headline economic cost of climate change for the Glasgow region. Nevertheless, it is possible to provide some insights into the potential scale of aggregate impact.

As outlined in the Glasgow City Region Economic Strategy 2017 – 2035 (GCR, 2016), Glasgow generates around one third of Scotland's Gross Value Added (GVA), estimated at over £40 billion. The results indicate that the annual economic costs of climate extremes and climate change by mid-century (the 2050s) in the Glasgow City Region could be several hundred £million/year by the 2050s (for the combined impact of current extremes and future climate change). While this is high, it is modest when compared to the regional economy (i.e. around 1% of current GVA). Nonetheless, as these are annual damages, they will reduce regional growth. Furthermore, as highlighted above, many of these impacts will fall on disadvantaged and vulnerable groups. The study also estimates that climate change will lead to large aggregate annual economic benefits for the region, primarily from the reduction in winter heating (reducing costs) and the reduction winter related mortality and morbidity (economic benefits). These economic benefits are likely to be of a similar order of magnitude to the economic impacts.

However, the consideration of annual costs only masks a very important finding. The result reveal that climate change will increase the likelihood of large economic shocks from major extreme weather events. These are not adequately captured when presenting results only as average annual impacts. These major events, i.e. river, coastal and surface water floods, and to a lesser extent windstorms, are all projected to increase in the Glasgow City region due to climate change, and there is a greater likelihood of large events with vary large direct costs. These events will have large direct costs, but will also lead to large indirect costs (potentially increasing overall costs by 50%). Such events could have major impacts on infrastructure investment (such as the City Deal) and could have important implications for public budgets, because of the very large costs that fall in a particular year. They can also lead to extremely large costs for those affected, whether individuals or businesses.

Finally, the results reinforce the need to accelerate work on mitigation. The analysis of different mitigation and adaptation scenarios shows that the potential economic costs (overall and for extremes) would be significantly reduced under low emission pathway, i.e. consistent with 2°C of warming. They could also be significantly reduced with cost-effective adaptation.

Recommendations and next steps

This phase 1 study has assessed the potential economic costs and benefits of the risks and opportunities from climate change in the Glasgow City Region. It finds that climate change could have a material impact on the region. A number of recommendations are made in light of these findings:

- To consider future climate impacts as part of any refresh of the Regional Economy Strategy and Action plan;
- To consider future climate risks (climate risk screening), including the analysis of economic costs, in individual decisions on future investments in the City Region – notably within the City Deal – and to assess potential adaptation measures to reduce these costs;
- To consider the economic costs and benefits for the City Region adaptation strategy and other relevant plans, strategies and activities;
- To explore the potential for developing new finance mechanisms for adaptation.

The next phase of this study – phase 2 – will progress a number of these areas, investigating the potential economic case for adaptation. It will build on the information in this report to identify and assess strategic adaptation options for Glasgow City Region. It will also provide some headline estimates of the potential costs and benefits of adaptation, then undertake case studies to explore adaptation options using an iterative risk management approach.

INTRODUCTION

This report presents the phase 1 findings of the study on 'The Economic Implications of Climate Change for Glasgow City Region'. The report has been prepared by Paul Watkiss Associates for Climate Ready Clyde (CRC) and Sniffer.

The objectives of this project are to *assess the macroeconomic costs and benefits of adapting to climate change across the Glasgow City Region through to i) 2050 and ii) 2080.*

Glasgow City Region consists of the eight local authority areas of East Dunbartonshire, East Renfrewshire, Glasgow, Inverclyde, North Lanarkshire, South Lanarkshire, Renfrewshire, and West Dunbartonshire. This area comprises the largest city region in Scotland and one of the largest in the United Kingdom, with a population of over 1.75 million people. It is a key driver of economic growth for the Scottish economy.

The aim of the study is to address a current gap on the economic impacts of climate change, and to provide information on the economic benefits of managing these risks successfully for Glasgow City Region and Climate Ready Clyde.

The study is broken into two phases.

Phase 1 of the study has two main tasks. First, to consider the economic costs of three significant climate events in Glasgow City Region (e.g. flooding, heatwave, storms) and second, to assess the future economic costs of climate change in the region, including both direct and indirect impacts.

Phase 2 of the study builds on this information to identify and assess strategic adaptation options for Glasgow City Region. This phase will provide some overall headline estimates of the potential costs and benefits of adaptation, and it will undertake case studies to explore adaptation options using an iterative risk management approach. It will also provide recommendations for future policy and research.

This report presents the findings of phase 1 of the study.

METHODOLOGY

The methodology used for this study reflects the guidance in the Invitation to Tender, for a robust but high-level approach that complements the existing assessment in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA).

It focuses on the overall economic impacts to Glasgow City Region, but also considers the implications on the key sectors (as identified by the City Region Economic Strategy).

The aim is to monetise risks and opportunities of climate change as far as possible, expressing the risk in terms of the effects on social welfare, as measured by individuals' preferences using a monetary metric. This provides a way to help assess the relative importance of different climate change risks in the Region, providing a common metric to compare direct impacts within and between sectors. The use of monetary values also helps to build the case for tackling risks (and to take advantage of opportunities). It is stressed that this approach captures the relevant costs and benefits to government and society. It values both market and non-market impacts, and includes consideration of environmental, economic and social costs, not just financial impacts. The methodology for the monetary valuation mirrors the approach used in the First UK Climate Change Risk Assessment and is based on the guidance from HM Treasury Green Book[1]

For phase 1 of the study, the starting point has been to assess a number of historic events, to examine the current economic costs of climate variability in the Region. The study has collated information on these events, then estimated the economic costs including non-market impacts.

The study has then gone on to assess the potential future economic costs of climate change in the Glasgow City Region. This has been based on the Glasgow City Region climate risk and opportunity assessment (GCRCROA)) which has been undertaken in parallel by the Climate Ready Clyde Secretariat. This has identified approximately 62 risks and opportunities in the region, split across six themes:

- Infrastructure;
- Built Environment;
- Society and Health;
- Natural Environment;
- Business and Industry.
- International and Cross Cutting.

For each of these risks and opportunities, the study has collated the available information on potential risks, and where possible, it has estimated their economic costs. For some risks, direct economic cost estimates were already available (primarily flood related costs for buildings). For other risks, existing quantitative estimates were available, and these have been monetised using unit costs, for example for the energy and health sectors, and to a lesser extent, some transport risks. Finally, where no quantitative information was available, indicative estimates of the order of magnitude of the economic costs have been made using the available information and expert judgement.

This approach allows the compilation of the potential economic costs for a large number of risks. These estimates are from a range of studies, often using different socio-economic and climate scenarios/ projections. There is therefore an issue of direct comparability. Where possible, estimates have been provided for low and high future change scenarios, for the 2050s and 2080s, aligned to the UKCP09 projections (Murphy et al, 2009). The study has also sought to report on uncertainty, as this is particularly important for the subsequent analysis of adaptation. Nonetheless, the results are not as harmonised as they would be from a new primary study that undertook quantitative impact assessment and monetisation using a set of consistent scenarios.

Estimates have been reported in terms of constant prices (2017) for the future time periods without uplifts or discounting. The results are presented in this way to facilitate direct comparison, over time, and between sectors. However, the use of these values in subsequent analysis (e.g. in cost-benefit analysis)

1 http://www.hm-treasury.gov.uk/data_greenbook_index.htm. This is the primary source of guidance for public sector economic analysts.

would need adjustments into discounted present values for economic appraisal.

The analysis has considered the current economic costs of weather and climate extremes (often called the adaptation deficit), the future marginal costs of climate change, and the total economic costs of current weather and future climate change together. This allows relevant information for policy makers, who have to deal with the overall impact, as well as information on the likely increase required from current conditions. Where possible it has also reported on the assumptions on socio-economic change assumed in future projections.

For the subsequent analysis of adaptation options, an iterative risk management framework will be used, applying the framework developed in CCRA2 (Warren et al, 2016). This developed a typology of three early adaptation interventions:

1. Low-regret actions to reduce risks associated with current climate variability;
2. To intervene early to ensure that adaptation is considered in decisions that have long lifetimes;
3. To fast-track early adaptation steps for decisions that have long lead times or where information can improve adaptation decisions in the future.

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TASK 1: ECONOMIC COST OF HISTORIC EVENTS

Introduction

The first task focuses on the current economic costs of climate variability in the Glasgow City region, looking at recent major weather extremes. This provides the key starting point for understanding current climate risks, their economic significance and the existing adaptation deficit.

The analysis has assessed the financial[2] and economic[3] costs of four recent weather events that have impacted on the Glasgow City Region. Following discussion and agreement with the Climate Ready Clyde secretariat, the four events selected were:

- December 2015 river flooding;
- July 2012 surface water flooding;
- October 2017 wind storms;
- 2013 warm and dry summer.

These events have been chosen as they are representative of extreme weather events which are projected to become more frequent under future climate change, and which are likely to lead to high financial and economic costs. They therefore provide information for the future economic cost assessment in the next chapter. However, at the same time, it is important to stress that many potentially important climate change risks and economic costs will arise from slow onset changes, not just extreme weather events, for example with warming annual and seasonal temperatures and sea level rise.

Method

The costing methodology used comprises of two elements (Metroeconomica, 2004). The first stage is to quantify the impacts of the weather-related events and the second stage is to value these impacts. More specifically the method is in the following box:

Cost (or benefit) = the number of physical units in year *times* the economic unit value

Specifically:

The cost (or benefit) of a weather-related event on a specific vulnerable receptor (or group of receptors), under selected climate and socio-economic scenarios (£ per event in year *t*)

equals

The predicted 'physical' impact on the vulnerable receptor(s), under selected climate and socio-economic scenarios (the number of physical units affected by the event in year *t*)

times

The appropriate economic unit value or 'price' (£ per affected unit in year *t*)

This does mean that if data are not available on impacts, then valuation is not possible. In the sections below, data have been gathered from a range of primary and secondary sources in the City Region, including local government and other stakeholders, as well as contemporary accounts in the media.

December 2015 river floods

Flooding is currently a major risk for the Glasgow City Region, and one of the major sources of this is river flooding in the Clyde catchment. Indeed, the area has a long history of flooding with large numbers of people and properties being affected. The SEPA Flood Risk Management Strategy (SEPA, 2015) reported on these historical events, citing that the most significant flooding event occurred between 10 and 12 December 1994. This was caused by prolonged heavy rainfall over a 48 hour period, when previous peak river flows were exceeded in all major catchments. In Glasgow, over 700 residential properties and many non-residential properties were flooded, with major transport disruptions (roads and rail) and three fatalities, and a further 500 properties where flooded elsewhere in the catchment.

2 Financial: Valued from the standpoint of the individual household or organisation involved.

3 Economic: Valued from the standpoint of the nation as a whole. This includes non-market values.

The 2015 flood event

The event has been documented in a report by the Centre for Ecology and Hydrology (Marsh et al., 2016). This reports that "A remarkably persistent and exceptionally mild cyclonic episode beginning in early-November 2015 and lasting around fourteen weeks brought severe, extensive and protracted flooding which impacted most damagingly on northern Britain, Northern Ireland and parts of Wales". In Southern Scotland the most extreme rainfall occurred in November and December; the Clyde catchment received 190% of its average rainfall for these two months and this is characterised as an event with a minimum return period (i.e. frequency) of 1 in 100 years.

The daily precipitation for Glasgow over this two-month period is presented in Figure 1. It shows daily rainfall exceeding 25mm (1 inch) on seven days in this period, and during a 2-day period over December 5th-6th – coinciding with Storm Desmond –rainfall totalled 114mm.

The sustained event of 4-6 December was noteworthy for its widespread geographic extent, from Speyside to the Borders and Dumfries and Galloway through Tayside, Central, Stirlingshire and the Clyde Valley. The impacts were significant. Across this whole area, at least 150 properties were flooded (including about 100 in Hawick, 15 in Dumfries, 17 in Blair Atholl, 14 in Stirlingshire – Stirling, Aberfoyle and Callander), with evacuations in Hawick, Newcastleton, Aviemore, Langholm. There were numerous road closures and disruption to traffic and extensive flooding to farm-land.

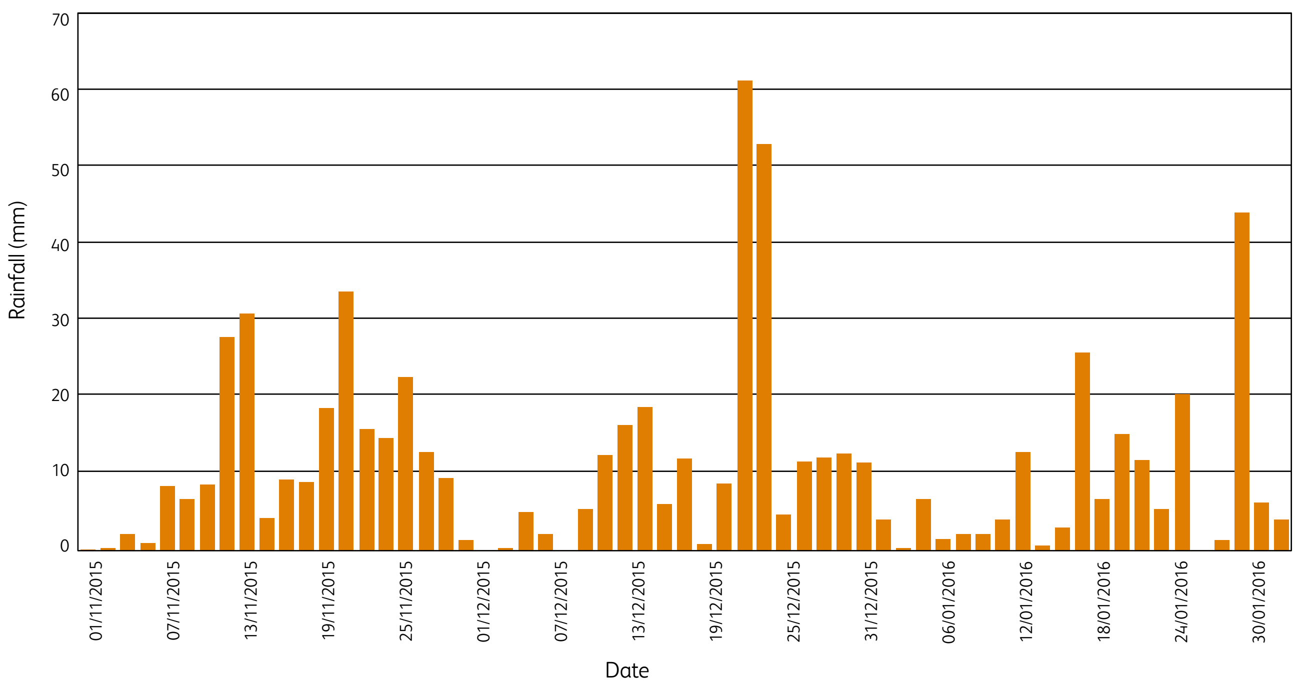
This case study assesses the impacts that resulted from this rainfall event in the Glasgow region. The impacts covered in this case study are:

- Direct physical damage to residential property (repairs plus clean-up);
- Direct physical damage to non-residential property (repairs plus clean-up);
- Direct impact on human health (mortality, injuries and anxiety);
- Short-term disruption to rail services;
- Direct physical damage to buildings with historical and cultural heritage value;
- Evacuation of households (cost of temporary accommodation);
- Additional electricity needed for equipment to dry properties;
- Forgone output (value added) from short-term disruption to non-residential properties;
- Emergency services;
- Second-order economic impacts on surrounding area.

Properties flooded.

For this analysis, detailed flood incidence data was collected from SEPA for the period. This records 14 individual properties were flooded, as well as three

Figure 1. Glasgow rainfall November/December 2015.



streets. The number of exact properties that were flooded is not known but has been estimated at 50 in the region. In the absence of specific insurance data, unit damage costs of £36,600 and £11,250 have been used for residential and non-residential property, respectively. These are consistent with data from the Multi-Coloured Manual (FHRC, 2016[4]) for flood depths averaging 60 centimetres for less than 12 hours.

Health Impacts

In addition to the material damages to property caused by floods, there are often associated health impacts, including risks to life, hypothermia and injuries during, or immediately after, the flood. There are also longer term physical and psychological health effects during the weeks or months following a flood (e.g. increased stress levels, mild, moderate, and severe depression, following floods). There are no reliable reports of the health consequences of the 2015/2016 floods in Glasgow region. However, there are algorithms from the UK that can be used to estimate the potential risks of death and physical injury as a result of an individual flood event. These are known to be determined by three broad sets of characteristics including flood characteristics (depth, velocity, etc.), location characteristics (inside/outside, nature of housing) and population characteristics (age, health, etc.).

Previous work (Defra, 2006) has developed an algorithm that combines flood characteristics to provide quantitative estimates of the number of injuries and premature deaths as a consequence of a given flood event. This is used here as a proxy. From Defra (2006) the number of deaths/injuries is calculated using the general equation:

$N(I) = N * X * Y$

Where:

$N(I)$ = number of injuries/deaths;
N = population within floodplain;
X = proportion of population exposed to a risk of injuries/death;
Y = proportion of those at risk who will suffer injuries/death.

4 FHRC (2016) calculates the effect of flood waters of varying depths and durations on every component of a residential property's inventory (content) and building fabric (structure), and; building structure, fabric and services, fixtures and fittings, moveable equipment, and inventory or stock, for non-residential effects.

Flooding is also associated with increased rates of anxiety and depression. These illnesses commonly stem from geographical displacement (and relocation to temporary accommodation), damage to the home and possessions, and the stress of the cleaning up and repair work (Hajat et. al. (2005). To explore this impact, we take the results of a study in the UK by Reacher et. al. (2004) on post flood incidence on mental health and apply these to the Glasgow context. The Reacher et. al. study used a questionnaire to elicit the impacts on mental and physical health of the October-November 2000 floods in Lewes, UK. It found the prevalence of psychological stress was four times greater in the flooded population than in the un-flooded population in the town. Using this multiplier of 4, it is straightforward to calculate the size of the population impacted by psychological stress. This uses a baseline prevalence rate of 8% of depressive disorders across the EU (European Communities, 2003) and assumes that "psychological stress" the term used by Reacher et. al. is equivalent to "depressive disorders".

These impacts can then be valued, using existing Government Guidance. The values for injuries should ideally be comprised of three components that in total, give the overall impact on social welfare. These elements are: medical costs; the cost in terms of lost productivity, and disutility, i.e. pain or suffering and concern and inconvenience to family members and others. However, the empirical evidence on the valuation of injuries from floods is very sparse. In lieu of contextual-based data, we use the values for injuries identified in HM Government guidance, Department for Transport (2017).

For psychological stress, the main impact is mild depression (Reacher et. al. 2004), thus we use valuation estimates associated with the treatment of this illness. The cost of treating depression has previously been studied. Bower et al (2000) investigated the cost-effectiveness of three types of treatment, notably non-directive counselling, cognitive behaviour therapy and usual general practitioner care for patients with depression in the UK. For this study, we assume that the psychological stress lasts for eight months, which is the average length of a depression period (Klein and Wender, 1993), and we assume a 4-month treatment period. We use the costs for cognitive behaviour therapy and non-directive therapy to define a range for the unit costs to be applied to the mild depression end-point. The mid-point value is £1000 (2017 prices). This cost-based value neglects any valuation of the "pain and suffering" component of the total willingness-to-pay to avoid this illness. One study, Floyd et al. (2003) has addressed the valuation of this component. The study, using a contingent valuation survey, confirmed that flooding caused physical effects in the short-term and psychological effects in the short and longer-term. The latter included memory of the stress from flooding and damage, and the stress of recovering after an event, including that arising from settling claims with insurers and dealing with builders and repairers. A single value of £100 per household per year was presented. There appears to be no other study that has been undertaken and whose results could be used to test convergent validity. The single result from Floyd et. al. (2003) is therefore transferred directly to the current context and updated to 2017 prices.

Rail Passenger Time Lost

Media reports of the 2015 event highlight widespread travel disruption across the Glasgow region.[5] For example, Abellio ScotRail suspended services between Carlisle and Glasgow Central, and there was major disruption to rail services in the north of England and in Scotland on 5 and 6 December, affecting other services operated by Abellio ScotRail, as well as the Caledonian Sleeper. As a result of flooding and landslides along the West Coast Main Line (WCML) between Preston and Carlisle, all services between northern England and Scotland via the WCML were suspended on 6 December, with passengers advised not to travel. Landslides and flooding also closed some main roads in Scotland.

There is an absence of quantitative data on the extent of these disruptions in the GCR. Consequently, we have undertaken a simple indicative analysis based on aggregated data. Transport Scotland (2016) provides data on passenger numbers to/from Glasgow stations and distribution of train journey distances. These are used – in combination with travel time values from Department for Transport (2017) – to provide an estimate of the value of passenger journey time losses. Thus, from this data we find that:

- Total long delays and cancellations are estimated on the basis that the rail system was disrupted for the equivalent of a one-day period over December 5-6th, 2015;
- 50% of 93.2 million train journeys beginning or ending in Scotland are in the Glasgow region;
- Median distance travelled is 35 miles, equating to a journey time of 45 minutes;
- Value of travel time is £5/hour (non-work time) and £30/hr (work time) (DfT, 2017). Time losses are assumed to be split equally between work and non-work time.

Note that lack of quantitative data means that we are unable to make estimates of the costs associated with disrupted rail freight transport or road transport.

Emergency services

Quantitative data has been collected from three local councils to investigate the additional costs of the flood. South Lanarkshire Council received £40,000 of funding from the Scottish Government to distribute £1,500 grants to those properties and businesses affected by flooding between June 2015 and January 2016 whilst West Dunbartonshire had an allocation of £25,500. However, as these amounts are compensation payments for property damage, they duplicate the property damage costs calculated separately above and are not added to the estimates. Separate emergency works in North Lanarkshire – entailing 2,742 workers requested by the council to clear debris – cost around £140,000. This total is included in the observed cost estimates.

Other

There were additional recreational impacts from the event and the organisers of Glasgow Loves Christmas were forced to close the George Square attractions (Christmas markets, ice skating rinks, rides etc.) due to high winds. In Scottish rugby, the Pro12 fixture between Glasgow Warriors and Leinster was postponed due to a waterlogged pitch on 5 December (Scotstoun stadium, in Glasgow). It has not been possible to cost the impact of these events.

Total Costs of the 2015 Event

The Table below presents the results of the observed 2015 Winter flooding event. This provides a quantitative analysis of the scale of the event in economic terms. The costs associated with property damage and transport disruption are of a similar scale whilst health costs are around one-tenth of each of these impacts. Whilst total costs are given at just under £4million, we consider it is very likely that the true costs – based on complete datasets of property damage, transport impacts and emergency service expenditures – would be closer to £10 million.

5 http://www.bbc.co.uk/news/uk-scotland-south-scotland-35014930

Table 1. Summary Results: 2015 Winter Flooding – Observed: Glasgow City Region (lower bound).

No of Res. Properties	50
No of Business Properties	0
Total property cost	1,830,000
No of Injuries	2
No of Mental stress cases	26
Total Health cost	160,000
Emergency services	140,000
Transport cost	1,680,000
Total (£)	**£3,810,000**

Assessing the potential theoretical risk of a major extreme river flood event

The actual number of properties flooded in the 2015 event was low relative to the number of properties at risk from river flooding in the region. A more substantial flood event could therefore lead to much higher economic costs. To investigate this, the study has looked at the possible risks of more extreme events, using the disaggregated modelling data from the Mapping Flood Disadvantage report. This identifies the numbers of properties, and related costs, likely to be inundated by flood water with a 1 in 100 year return period. These are presented in the Table below, along with the potential impacts associated with the other impact categories considered above. The aim is to highlight the potential magnitude of large-scale events. This shows that the properties at risk from a large event vary from £5 million for Inverclyde up to £35 million for Glasgow City.

Domestic property damages dominate, primarily reflecting the fact that damage to non-domestic properties is valued less per m^2. For illustration, the potential transport disruption is also included, based on an extrapolation of the 2015 event. It is stressed that road transport disruption is omitted and would have potentially large additional economic costs. While it would not be expected that all areas, or even all areas within an authority, would experience major flooding at the same time, and many of these risks are now being addressed through the flood risk management plans, the table highlights that a large-scale event could lead to very significant economic and financial costs, even with the current climate. These could have impacts on the public finances as well as large impacts to residential and business sectors.

It is noted that the SEPA is currently undertaken a new National Flood Risk Assessment (NFRA)[6], that will be published in the near future. This will provide updated estimates of the flood risk below.

6 https://sepaweb.maps.arcgis.com/apps/Cascade/index.html?appid=323aefe6abcf4f859acabca202c30f9b

Table 2. Illustrative Economic Risks (£) for 1:100 year Fluvial Flooding events.

Local Authority	No. of Properties	Cost- Domestic Properties (£)	Costs – Business Properties (£)	No. of injuries	No. of Mental Health cases	Total Health costs (£)	Emergency Service Costs (£)	Rail Transport costs (£)	Total Economic Costs (£)
East Dunbartonshire	327	5,980,000	1,840,000	8	82	580,000	140,000	200,000	8,740,000
East Renfrewshire	481	8,800,000	2,710,000	11	121	860,000	210,000	170,000	12,750,000
Glasgow City	1324	24200,000	7,450,000	32	334	2,360,000	570,000	1,130,000	35,740,000
Inverclyde	212	3,880,000	1,200,000	5	53	380,000	90,000	150,000	5,690,000
Renfrewshire	1159	21,210,000	6,520,000	28	292	2,070,000	500,000	320,000	30,620,000
West Dunbartonshire	887	16,230,000	4,990,000	21	223	1,580,000	380,000	170,000	23,350,000
North Lanarkshire	788	14,420,400	4,430,000	19	198	1,410,000	340,000	630,000	21,230,000
South Lanarkshire	1039	19,010,000	5,850,000	25	262	1,850,000	440,000	580,000	27,730,000

June/July 2012 surface water floods

There has also been a long history of surface water related floods within the Glasgow region. The most notable recent such occurrence (SEPA 2015) was the floods of the 30 July 2002 in Glasgow, when an estimated 1 in 100 year flood resulted in 500 properties being flooded along with serve disruption to road and rail services. The estimated cost of damages was in the region of £100 million (SEPA, 2015). As well as properties, these floods affected road and rail networks.

The Summer months of June and July 2012 were notable for a series of intense storms across the UK. The Glasgow region suffered from higher than average rainfall over this period and two events resulted in more than 25mm of rain – on June 21st and July 17th.

The same method has been applied as for the Winter 2015 floods above to investigate this event.

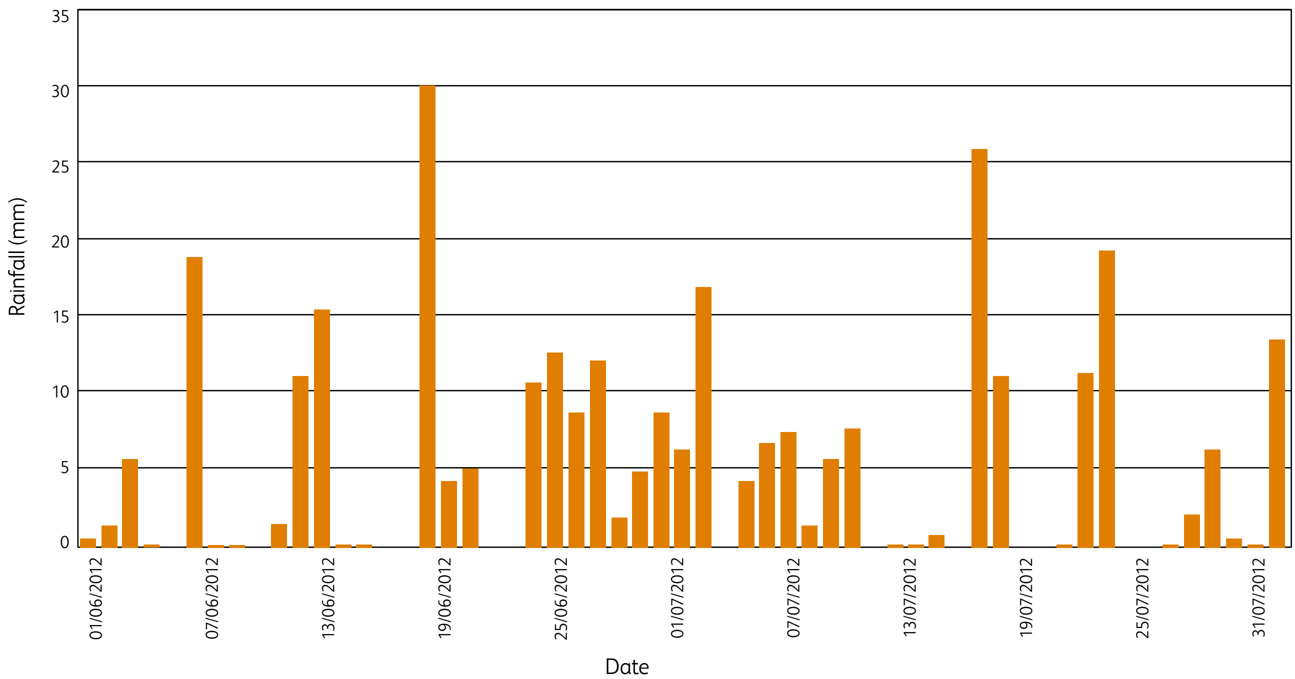
Properties flooded and health impacts
Although there is no formal compilation of flood impact data for 2012 event, at least one road was flooded to a depth of 3 feet. Properties along this road are a mix of residential and non-residential. In the absence of observed data, we assume that 20 properties – ten residential and ten non-residential. Health impacts are also estimated using the same methodology as for the 2015 event.

Transport
Media articles report that as a result of the event, a number of roads were severely flooded, and cars and drivers were stranded in flood water. On the M74 motorway, one lane was closed due to surface water. Queen Street and Dalmarnock train stations were shut temporarily. Rail services to Edinburgh were halted for two hours because of flooded tracks. At Central Station, flooding on the low-level line resulted in services to Rutherglen being cancelled. In the absence of definitive data on the extent of the disruption, we assume that the Glasgow regional train network was suspended for a period of two hours. We adopt the same unit cost assumptions as the for the 2015 event.

Emergency services
Emergency works in North Lanarkshire – involving 3,333 workers, requested by the council to clear debris – cost around £140,000. This total is included in the observed cost estimates.

The table below presents the results of the observed 2012 Summer flooding event. Property damage dominates the costs, with transport disruption and emergency service costs being about 40% and 30%

Figure 2. Glasgow rainfall June/July 2012.



of property costs, respectively. Whilst total costs are given at under £700,000, it seems likely that the true costs – based on complete datasets of property damage, transport impacts and emergency service expenditures – would be closer to £several million.

Table 3. Summary Results: July 2012 Flooding – Indicative observed, Glasgow City Region (lower bound).

No of Res. Properties	10
No of Business Properties	10
Total property cost	480,000
No of Injuries	0
No of Stress cases	10
Total Health cost	13,000
Emergency services	140,000
Transport cost	190,000
Total	**823,000**

Assessing the potential of a major extreme surface water flood event

The actual number of properties flooded in the 2012 event was low, when compared to the number of properties at risk from surface water flooding in the region. As with the analysis above, the study has looked at the possible risks of more extreme events, using the available disaggregated modelling data from the Mapping Flood Disadvantage report. This identifies the numbers of properties, and related costs, likely to be inundated by surface flood water with a 1 in 100 year return period. These are presented in the Table below, along with the potential impacts associated with the other impact categories considered above. The aim is to highlight the potential magnitude of large-scale events. This shows that the properties at risk from a large event vary from about £10 million for East Dunbartonshire and East Renfrewshire up to £66 million for Glasgow City. This provides an indication of the potential magnitude of large-scale events. Again, it is highlighted that road transport disruption is omitted and would have potentially large economic costs. While it would not be expected that all areas, or even all areas within an authority, would experience major flooding at the same time, and many of these risks are now being addressed through the flood risk management plans, this does serve to highlight that a large-scale event could lead to very significant economic and financial costs.

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.

Table 4. Illustrative Economic Risks (£) for 1:100 year Pluvial Flooding events.

Local Authority	No. of Properties	Cost- Domestic Properties (£)	Cost Business Properties (£)	No. of injuries	No. of Mental Health cases	Total Health costs (£)	Emergency Service Costs (£)	Transport costs(£)	Total Economic Costs (£)
East Dunbartonshire	383	7,010,000	2,150,000	11	229	960,000	140,000	20,000	10,280,000
East Renfrewshire	360	6,590,000	2,030,000	16	337	1,420,000	130,000	20,000	10,180,000
Glasgow City	2,584	47,290,000	14,540,000	44	929	3,900,000	940,000	130,000	66,790,000
Inverclyde	568	10,390,000	3,200,000	7	149	620,000	210,000	20,000	14,440,000
Renfrewshire	1,362	24,920,000	7,670,000	38	813	3,420,000	500,000	40,000	36,550,000
West Dunbartonshire	652	11,930,000	3,670,000	29	622	2,610,000	240,000	20,000	18,470,000
North Lanarkshire	826	15,120,000	4,650,000	26	553	2,320,000	300,000	70,000	22,460,000
South Lanarkshire	1,917	35,080,000	10,780,000	34	729	3,060,000	700,000	60,000	49,680,000

October 2017 storm

Windstorms are responsible for some of the largest weather-related damage costs in the UK. As an example, the total financial costs of Storm Desmond across the UK were estimated at £900m[7]. The third case study documents the costs on the Glasgow region on October 16th, 2017, as a result of Storm Ophelia – the Eastern-most Atlantic hurricane on record. Wind speeds of 122km/hour were recorded in parts of Southern Scotland.

Impacts that are considered included:

- Property damage;
- Transport disruption;
- Emergency services.

Property

There is currently no consolidated record of the incidence of property damage as a result of the wind-storm, though there are a range of anecdotal and news reports of impacts. For example, property damage in Albert Road, Crosshill, where the storm tore off roofs, side of a building and brought down trees was reported. In the absence of verified data being available we utilise insurance data from a previous windstorm of similar intensity, on January 7th and 8th 2005. Not all property is, however, insured. It is assumed, based on previous studies[8], that 60% of damages are insured.

Transport

The incident log from Transport Scotland documents that a number of local roads were temporarily blocked by debris from the storm – primarily fallen trees. These incidents were, however, not quantified.

7 http://pwc.blogs.com/press_room/2015/12/uk-flooding-pwc-estimates-insurance-losses-from-storms-eva-and-desmond-.html.

8 See e.g. the Foresight study on Flooding and Coastal Defense (www.foresight.gov.uk).

Network Rail also recorded a total of six line closures on mainline and local services, though again the time delays are not known. Consequently, no quantitative estimates are made.

Emergency Services

Glasgow City Council confirm that during the wind storm they attended 87 locations throughout the City dealing with dangerous/fallen trees/branches. The Arbor team consisting of 9 operatives attended all locations. This effort involved 23 days at 9 operatives per day working 10.5 hours per shift, equivalent to 2,173.5 hours. In addition to these hours, during the same period 8 Operatives worked overtime at nights which equated to 96 hours (these hours were paid at time and a half). Note that this does not include hours taken by the local depots to remove timber that had been cut up by the Arbor Team. To estimate resource costs, a value of £50 per hour is assumed.

Results

The Table presents the estimated (rather than reported) economic costs of the impacts identified. In the absence of data on transport disruption, the main cost comprises of property damage. We would expect, however, transport disruption to be significant due to the value of all disrupted journeys.

Table 5. Estimated Results: Windstorm, Glasgow City Region, October 2017.

Property Claims	6000
Total prop cost (£)	20,000,000
Of which insured loss	*12,000,000*
Emergency services (LA) (£)	130,000
Transport disruption costs (£)	TBC
Total estimated cost (£)	**20,130,000**

Summer 2013 heatwave

Historically Scotland has not experienced major heatwaves, at least in absolute temperatures compared to other parts of the UK or Europe. However, the potential increase in hot days, and heat extremes, are a greater risk under future climate change, at least in terms of the relative increase from current levels.

In the UK, the most recent heatwave event was in 2013. This also corresponded to the second warmest July on record in Scotland. Temperatures were about 2˚C warmer than the Scottish average for the month. Maximum temperatures for July and August 2013 are presented below. Hours of sunshine were 45% above average.

Impacts that are considered included:

- Property damage;
- Health;
- Transport disruption.

Property

Glasgow City Council reported that at their mineral consolidation project at Munro Road, a number of properties suffered damage in 2013. They attributed this to the very dry summer causing the local clay to shrink. Shrinkable clays are not common in Glasgow, so this is considered an isolated incident. On this basis we assume ten properties to have been damaged in the first instance. To value this we use a unit value of £10,000 adopted by Graves & Phillipson (2000) in their analyses of climate change impacts on subsidence incidence for the Building Research Establishment. Additionally, increased energy consumption for cooling was reported and universities reported renting fans temporarily. There was also incidence of glass buildings overheating resulting in automatic fire brigade call outs, and associated fines (Glasgow Caledonian University reported this anecdotally in regards to one of their newest buildings).

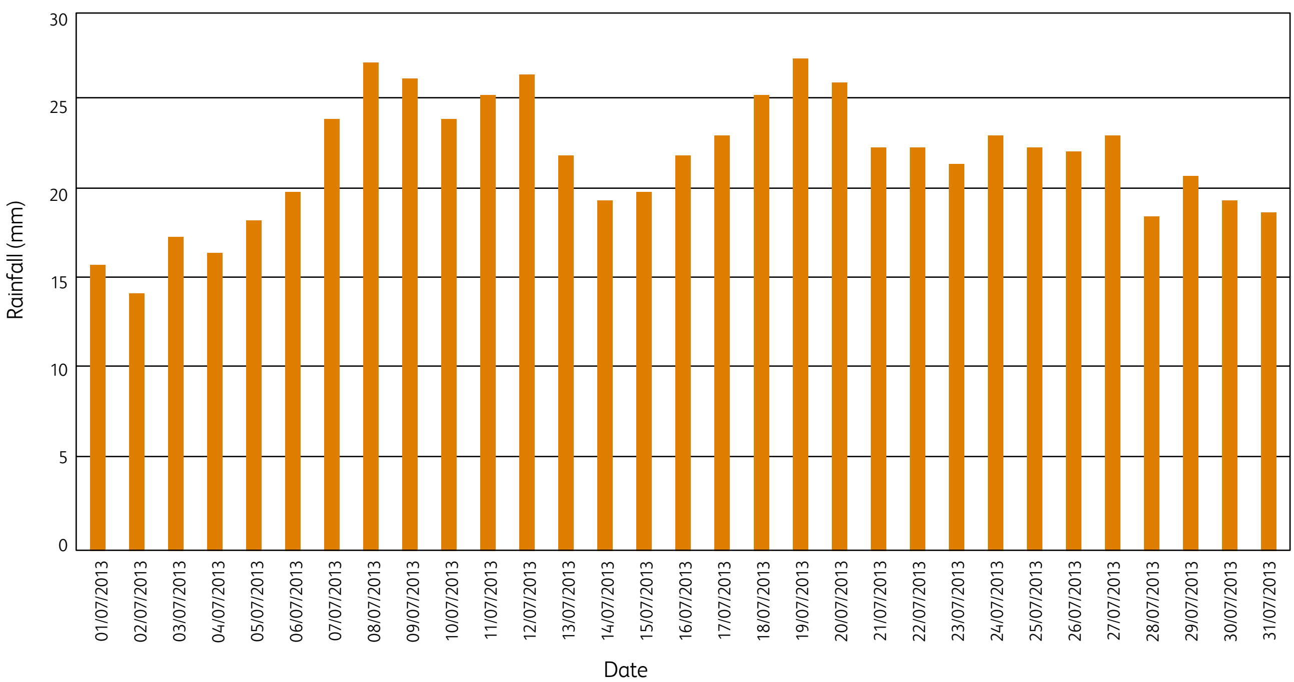
Transport

Widespread rail disruptions with point failures due to thermal expansion led to 1 in 10 rail journeys being delayed on the 19th July, 2013. These values have been combined with DfT values to estimate the value of time lost.

Health

Heatwaves are associated with excess mortality and hospital admissions, as a result of cardiovascular and respiratory illness. These additional cases are common in all locations, and should be seen in the context of the change in relative temperature, as well as the absolute temperature (i.e. a heat wave for Scotland is very different in absolute temperature terms to a heat wave in Seville).

Figure 3. Daily Maximum Temperatures – Glasgow, July, 2013.



There are no reported statistics for the increase in heat related mortality and morbidity in Scotland for the 2013 event. However, a study by Green et al. (2016) reports cumulative excess of 195 deaths in over-65 year-olds and 106 deaths in under-65 year-olds in England. A simple transfer, based on population, results in a possible number of excess deaths being approximately 30 in Scotland, and based on population, around 10 cases for the Glasgow region. This transfer takes into account that while temperatures were not as high in Scotland as in England in this period, it is likely that the Scottish population is less well acclimatised to higher temperatures.

In order to value these mortality effects in economic terms we adopt the unit value for a value of a prevented fatality, (VPF) that is used in transport appraisal by the Department for Transport. This value is £1,889,000 per case (2017). However, the valuation of mortality risk from heat waves is subject to particular uncertainty, because the population affected is primarily the elderly and those with existing conditions. As a sensitivity, therefore, we use the value of a life-year (VOLY) suggested by the Interdepartmental Group on Costs and Benefits (IGCB, 2010). The IGCB suggests a VOLY-equivalent of £60,000[9]. In order to incorporate length of life time into our monetary estimates we have assumed that each additional death is associated with a loss of six months of life on average[10]. Morbidity incidence is estimated by adopting the mortality: morbidity ratio of 1:102, and a unit value of £625 per case, as used in the first UK Climate Change Risk Assessment (Hames and Vardoulakis, 2012), updated to 2017 prices.

Results

The Table presents estimates of the costs of the summer 2013 heatwave in Glasgow. As the above description reports, these estimates are partial and subject to sizeable uncertainties. For example, if we adopt the VOLY assumptions highlighted above, mortality risks would be valued at only £336,000. Nevertheless, they serve to highlight the possible extent of the health risk from high temperatures, and the potential need to take measures to avoid these in the future. Indeed, a news report[11] at the time highlights the fact that – unlike England – Scotland has no official heatwave warning system in place.

9 Noise & Health – Valuing the Human Health Impacts of Environmental Noise Exposure" The Second Report of the IGCB(N)

10 Dr Sotiris Vardoulakis, Health Protection Agency and sectoral report author, personal communication

11 BBC Scotland, July 19th 2013. http://www.bbc.co.uk/news/uk-scotland-23377981

Table 6. Indicative Results: Heatwave, Glasgow City Region, Summer 2013.

Subsidence no. of properties	10
Subsidence – cost	100,000
Mortality – no. cases	10
Mortality – cost (VPF) (Sensitivity with VOLY)	18,890,000 (600,000)
Morbidity – no. cases	1,020
Morbidity – cost	714,000
Transport disruption	60,000
Total **(Sensitivity with VOLY)**	**19,764,000** **(1,474,000)**

Other extremes

The other main extreme event not captured in the examples above are coastal storm and storm surge, leading to flooding. The most recent and notable coastal floods were reported in January 2014 (SEPA, 2015), when the entire west coast of Scotland experienced major coastal flooding. Areas that were affected include Helensburgh, Dumbarton, Rothesay, Greenock, Port Glasgow and Gourock. A previous event in 1991 involved a tidal flood in Dumbarton when an extreme high tide coincided with a moderately high river flow and resulted in considerable damage.

Wider economic and multiplier effects

The economic impacts of extreme weather events – whether experienced today or in terms of increased risks from future climate change – will include both direct and indirect effects.

The direct effects include the direct damage and losses, both tangible (e.g. property) and intangible (e.g. health) borne by those affected. The indirect impact costs include the consequential or secondary impacts that arise from the event (IPCC, SERX, 2014). The indirect effects range from changes in household income and expenditures through to wider impacts on the economy, including the linkages through from one sector to another.

For example, with a major flood, as well as the direct costs to those property owners affected and the immediate disruption to transport, the disruption during and following the event will affect the supply of goods and services, resulting in higher market prices. Similarly, with a storm, there will be direct effects which will be captured by the immediate cost to those immediately impacted– such as the cost of repairing storm damage. However, there will also be indirect effects of these repair costs since they represent expenditures that might have otherwise been made in other sectors or other regions, or not at all. These indirect effects are therefore likely to lead to a change in the distribution of household incomes that are then spent on other goods and services – the induced effect. For example, the storm leads to reconstruction that pulls resources away from production in other sectors, affecting incomes across these sectors.

The impact of these wider effects can be captured with the use of multipliers that are estimated through the analysis of the linkages between sectors. These multipliers are either Type I or Type II. A Type I multiplier includes the indirect, or knock-on, effects, whilst a Type II multiplier also includes the induced effect.

Multipliers do exist for the Glasgow area, disaggregated on a sectoral basis. Most recently, these have been estimated by Hermannson (2016). In general terms, these indicate a multiplier of around 1.5, which means for a very large-scale event, the economic costs could be 1.5 times greater than the direct cost (e.g. as borne by households) alone. These indirect costs would feed through and impact regional GVA figures. Note, in some cases, large scale events can have positive economic effects, at least for some sectors of the economy, from the increased expenditure on construction.

Conclusions

This Chapter provides a summary of some of the most significant costs associated with four historical weather events. In doing so, it serves to highlight climate risks, and associated sectoral impacts, that might be prioritised in developing adaptation strategies. An overview of the four events is given in the table below. As highlighted in the text above, these estimates are based on reported data, and are considered to be significant underestimates due to data gaps.

Whilst there are gaps and there is a high degree of uncertainty associated with all of the identified events, the analysis shows that individual extremes could have potentially high economic and financial costs for the region. Importantly, all of the four climate risks are projected to increase in frequency under future climate change scenarios.

Further data would allow a more complete analysis. The major data gaps that could be filled include:

- Flood events (2012 and 2015) – property damage: Scottish Water;
- Flood events (2012 and 2015) – rail transport disruption: Network Rail;
- 2017 Wind storm damage: local councils;
- All events, road transport disruption.

Finally, given that better awareness of the costs of current events is likely to help in building the case for future action, a recommendation is that capturing the impacts (and costs) of current extreme events more effectively in the region would be extremely useful.

Table 7. Summary costs associated with extreme events: Glasgow City Region (£million).

Impact category	Winter 2015 River Flooding#	Summer 2012 Surface Flooding#	Autumn 2017 Windstorm	Summer 2013 Heatwave
Property	1.8	0.5	20*	0.1
Health	0.16	0.01	-	20(1.3)**
Emergency Services	0.14	0.14	0.13	-
Transport	1.7	0.19	N/A	0.06

Key

N/A = Data Not available;

(-) = Not relevant;

* = estimated, based on transfer from similar event;

** = estimated, based on non-financial costs associated with change in risk of premature death.

lower bound estimates, based on data. Likely costs considered to be much higher (see text).

TASK 2: FUTURE ECONOMIC COSTS OF CLIMATE CHANGE

Introduction

The second task has undertaken a forward-looking analysis of the economic costs and benefits of climate change in the Glasgow City Region. Given the available time resources, detailed new integrated assessment and modelling was not possible, but there is sufficient information currently available to assess the potential economic costs (and benefits) for future time periods.

The analysis considered the impacts of slow onset events (e.g. sea level rise), but also the potential changes in extremes (e.g. heavy precipitation and heat waves). The latter link to the analysis of the climate extremes in the previous chapter, and the potential increase in the frequency in extreme weather events. The study has assessed all of the risks identified in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA), shown below.

THEME 1 – INFRASTRUCTURE

- In1: Risks of cascading failures from interdependent infrastructure networks.
- In2: Risks to infrastructure services from river, surface water and groundwater flooding.
- In3: Risks to infrastructure services from coastal flooding and erosion.
- In4: Risks of sewer flooding due to heavy rainfall.
- In5: Risks to bridges and pipelines from high river flows and bank erosion.
- In6: Risks to transport networks from slope and embankment failure.
- In7: Risks to subterranean and surface infrastructure from subsidence.
- 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.
- In11: Risks to infrastructure from wildfires.
- 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.

THEME 2 – BUILT ENVIRONMENT

- BE1. Risks to homes from flooding
- BE2. Risks to building fabric from moisture, wind, storms and driving rain
- BE3. Risks to significant heritage properties from landslides, flooding or coastal erosion
- BE4. Risks to traditional and historic buildings from moisture, wind and driving rain
- BE5. Increased maintenance of green space due to rising temperatures and severe weather
- BE6. Increased cooling demand in buildings as a result of rising temperatures
- BE7. Risks to homes from sea level rise
- BE8. Risk of overheating of buildings from increased energy efficiency/insulation
- BE9. Potential for improved physical and mental health from increased use of parks and green space due to warmer weather
- BE10. Opportunities for local food growing from warmer temperatures and increased growing season
- BE11. Reduced heating demand to buildings from rising temperatures
- BE12. Increased viability of renewable electricity and heat from changing weather conditions

THEME 3 – SOCIETY AND HEALTH

- SH1: Risks to people and communities from flooding.
- SH2: Increase in summer temperatures and heatwaves leading to increased morbidity and mortality.
- SH3: Risks to business continuity of health and social care from extreme weather.
- SH4: Increased patient demand on NHS services from high winds, snow and ice, floods, cold weather.
- SH5: Risks to the viability of coastal communities from sea level rise.
- SH6: Risks to health from changes in air quality.
- SH7: Risks to health from vector-borne pathogens.
- SH8: Risks to Sport and leisure activities from severe weather, higher temperatures and increased precipitation.
- SH9: Potential benefits to health and wellbeing from reduced cold.

THEME 4 – NATURAL ENVIRONMENT

- NE1: Risks from changes in agricultural productivity and land suitability.
- NE2: Risks to soils from increased seasonal aridity and wetness.
- NE3: Risks from changes in forest productivity and land suitability.
- NE4: Risks to species and habitats due to inability to respond to changing climatic conditions.
- NE5: Risks to natural carbon stores and carbon sequestration.
- NE6: Risks to agriculture and wildlife from water scarcity and flooding.
- NE7: Risks to freshwater fish species from higher water temperature, phenology and changes to hydrological regimes.
  NE8: Risks of land management practices exacerbating flood risk.
- NE9: Risks to agriculture, forestry, landscapes and wildlife from pests, pathogens and invasive species.
- NE10: Risks to agriculture, forestry, landscapes and heritage from changes in frequency and/or magnitude of extreme weather and wildfire events.
- NE11: Risks to the natural environment from sea level rise.
- NE12: Risks and opportunities for marine species, fisheries and marine heritage from ocean acidification and higher water temperatures.
- NE13: Opportunities from changes in agricultural productivity and land suitability.
- NE14: Opportunities from changes in forest productivity and land suitability.
- NE15: Opportunities from new species colonisations.

THEME 5 – BUSINESS AND INDUSTRY

- BI1: Risk to new and existing business sites from river, surface water and coastal flooding.
- BI2: Risks to business operations from water scarcity
- BI3: Risks to business from reduced employee productivity due to infrastructure disruption and higher temperatures in working environments
- BI4: Risks to business from disruption to supply chains and distribution networks
- BI5: Opportunities for products and services to support adaptation to climate change
- BI6: Increased tourism revenue from increased temperatures

THEME 6 – INTERNATIONAL AND CROSS-CUTTING

- It1: Risks from weather-related shocks to international food production and trade.
- It2: Imported food safety risks.
- It3: Risks and opportunities from long-term, climate-related changes in global food production.
- It4: Risks to the UK from climate-related international human displacements.
- It5: Risks to the UK from international violent conflict.
- It6: Risks to international law and governance.
- It7: Opportunities from changes in international trade routes.

The study reviewed the available literature of relevance for each of these risks, and assessed the level of quantified risks, using a combination of existing estimates, new valuation, and expert judgement, to estimate their potential economic costs (or benefits).

In undertaking this task, the analysis has differentiated the results by climate and socio-economic scenario. Most of the available information is still based on the UKCP09 Low / Medium / High projections (Murphy et al, 2009), though there are some more recent studies that use the Representative Concentration Pathways (RCPs 2.6, 4.5, 6.0 and 8.5). The focus has been to capture the range of outcomes and the uncertainty around future estimates, rather than only focusing on central projections.

The study has also looked at the distributional effects of the climate change impacts, building on previous work for the Joseph Rowntree Foundation (PWA, 2016), that has found that climate change has strong distributional differences (on different groups) according to income and deprivation level.

Projected Climate Change

In the analysis below, a range of approaches has been used to derive estimates. In a few cases, there are existing economic estimates, although this is limited primarily to flood property damages. In other cases, there are existing impact estimates, which have been monetised using unit values (based on standard Government appraisal methods and values). However, a large number of risks do not have any quantified analysis, and for these, this study has attempted to quantify the indicative economic costs. In this case, indicative estimates have been made, based on the available information and expert judgement.

In terms of future projected climate change, the study has primarily used the UKCP09 projections (Murphy et al, 2009). These UKCP09 projections set out that the average maximum daily temperature in Western Scotland in July is expected to increase by 2.2°C, reaching 19°C by the 2050s, and by 3.7°C, reaching 20.5°C by the 2080s. Furthermore, they project that in Western Scotland, the average minimum daily temperature in July is projected to increase by 2.4°C, reaching 12.2°C by 2050s, and by 3.8°C reaching 13.7°C by the 2080s. Projections for mean daily precipitation for all parts of Scotland show a significant increase in the winter months and a decrease in summer months. In Western Scotland the greatest increase in precipitation is expected to occur in December. The mean daily precipitation is projected to increase by 20 per cent, reaching 7.3mm per day by the 2050s, and by 40 per cent, reaching 8.5mm per day by the 2080s. The greatest reduction is also likely to occur in June, when the mean daily precipitation is projected to decrease by 16 per cent by the 2050s, to 2.4mm per day, and by 24 per cent, to 2.2mm per day by the 2080s.

Table 8. Changes in daily mean (summer and winter averages), and summer-mean daily maximum and minimum temperatures, by the 2050s under the Medium emissions scenario. (Source: UKCP09 Murphy et al. 2009).

Variable	Mean temperature, winter °C					Mean temperature, summer °C					Mean daily maximum temperature, summer °C					Mean daily minimum temperature, summer °C				
Probability level	10%	50%	90%	Wider range		10%	50%	90%	Wider range		10%	50%	90%	Wider range		10%	50%	90%	Wider range	
West Scotland	1.0	1.9	3.0	0.8	3.3	1.1	2.4	3.8	1.0	4.4	0.9	3.0	5.2	0.9	5.9	0.9	2.4	4.2	0.9	4.7

Table 9. Changes in annual-, winter- and summer-mean precipitation (%), by the 2050s under the Medium emissions scenario. Source: UKCP09 (Murphy et al. 2009).

Variable	Mean temperature, winter °C					Mean temperature, summer °C					Mean daily maximum temperature, summer °C				
Probability level	10%	50%	90%	Wider range		10%	50%	90%	Wider range		10%	50%	90%	Wider range	
West Scotland	-6	0	+5	–7	+6	+5	+15	+28	0	+30	–26	–12	+1	–27	+6

It is highlighted that these data will be updated with the forthcoming publication of UKCP18.

For river flooding, the study has looked at the potential change in risk using the data from Sayers et al (2015) on the estimated change (%) in peak flows for the Clyde for different time periods and projections, shown below. Note that these use a different set of projections associated with 2˚C and 4˚C scenarios (global mean temperature from pre-industrialisation) and a High ++ scenario, as used in the Second UK Climate Change Risk Assessment (CCRA2).

Table 10. Changes in Peak Flows for the Clyde. (Source: Sayers et al. 2015).

	2˚C	4˚C	High ++
2020s	8	17	56
2050s	14	23	98
2080s	20	34	183

Sayers et al (2015) also provide some analysis of the change in return periods with different levels of increased peak flows, for example a 10% increase in peak flow would reduce the return period of a particular flow from a 1:100 to a 1:50 year event. This would suggest that a 1 in 100 year river flooding event today would drop to a 1 in 50 (2˚C) or 1 in 37 (4˚C) year event by the 2020s, and a 1 in 37 (2˚C) to 1 in 21 (4˚C) year event by the 2050s. Under a high ++ scenario, these changes would be much higher.

The change in coastal impacts in the studies cited are either based on the UCP09 projections or the more recent analysis from the CCRA2 from Sayers et al (2015. The latter include projections for different coastal regions of the UK: the relevant values for West Scotland are shown below. This also provides important information on high-end scenarios, in which risks – and economic costs – may rise disproportionately.

Table 11. Sea Level Rise (metres). (Source: Sayers et al. 2015).

	2˚C	4˚C	High ++
2020s	0.02	0.13	0.15
2050s	0.08	0.31	0.56
2080s	0.16	0.54	1.30

The change in surface water flooding are usually assessed with the change in precipitation on the wettest day (winter) or the change in the 99th percentile of daily precipitation in a season as a proxy for this. The AECOM study (2017), based on UKCP09, reports the average increase projected across Scotland is 5-7% by the 2030s, 10-12% by the 2050s. The Jacobs (2015) study reports a 20% increase in in the rainfall depth (intensity) of storm events that cause pluvial flooding by the 2050s for all of Scotland.

It is noted that the 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 future flood risks under climate change.

The UKCP09 weather generator has also been used by some of the literature reviewed, notably the Jacobs (2011) report. This estimated that by the 2080s:

- There would be a 66% reduction in Glasgow in frost days;
- A 45 day reduction in the winter period for Glasgow;
- A reduction in freeze-thaw days.

The values are provided below.

Table 12. Reduction in the number of days per year of frost by the 2020s and 2080s compared to the 1961 – 1990 baseline. (Source: Jacobs. 2011).

Emission Scenario	Glasgow 2020s	Glasgow 2080s
High	-21 [-12 to -27]	-33 [-24 to -39]
Medium	-20 [-10 to -27]	31 [-19 to -38]
Low	-20 [-10 to -27]	-40 [-23 to -37]

Table 13. Increase in the number of hot days per year with maximum temperature greater than 25˚C [top] and 30˚C [bottom] compared to the 1961 – 1990 baseline. (Source: Jacobs. 2011).

Number of hot days greater than 25˚C		
Emission Scenario	**Glasgow 2020s**	**Glasgow 2080s**
High	+3 [+1 to +8]	+20 [+8 to +60]
Medium	+2 [+1 to +8]	+15 [+5 to +38]
Low	+3 [+1 to +7]	+9 [+3 to +25]

Number of hot days greater than 30˚C	
Emission Scenario	**Glasgow 2080s**
High	+0.1 [-3 to +3]
Medium	+0.1 [-3 to +3]
Low	+0 [-2 to +2]

A further study by Jacobs (2015), the Low Carbon Resilient Cities study, also reported the results from the UKCP09 weather generator for Glasgow. It reports for the UKCP09 medium scenario, by the 2050s, there would be an increase in the summer growing season of 40 days and a reduction in the winter period of 30 – 50 days. It also reports that heat wave occurrences will go from close to negligible probability at present, to a probability as high as 1 in 3 years in Glasgow. The latter finding seems to conflict with the evidence from the 2011 study, but it is explained as the Jacobs study reduced the threshold values and assumed a heat wave (in Glasgow) was defined as a Daily Maximum temperature > 26C, Daily Minimum temperature > 13C, for a minimum of 3 consecutive days.

The future projections of wind storms are more uncertain. There is no evidence within the UKCP09 projections of an increase in the frequency or intensity of storms in the UK[12]. While UKCP09 reports that shifts in the position of the North Atlantic storm track are possible, there is considerable uncertainty, with inconsistent projections between different models. The weather generator also does not provide wind outputs. However, other recent studies do indicate a potential increase in wind storms for the UK. Recent analysis of a set of European regional climate models has found a general trend of a modest increase over Northern Europe (consistent with more zonal westerly flows) in winter, and modest decreases along Western coastal areas in the summer, although the changes are not that robust (Vautard et al, 2016). Most recently, ABI (2017) assessed the change in wind track, wind speed and average annual loss (AAL) for the UK from climate change. It reports up to a 10 – 15% increase in AAL for Scotland for 3°C of change. It also stresses the importance of the increase in probability of very major events (1 in 100 or 1 in 200 year events).

12 http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87875&filetype=pdf

Economic Costs

The estimated economic costs are presented by risk below. It is stressed that care is needed in interpreting these estimates, many of which are indicative. There are a number of factors of relevance.

First, it is important to differentiate between the baseline economic costs (current risks and future risks without climate change), the total costs of current economic costs and future climate change together, and the marginal economic cost (or benefit) of climate change i.e. the ‘additional’ cost of climate change. This is particularly important for floods and energy, where there are large current impacts. As highlighted earlier, in this analysis we consider all these estimates where possible.

Second, in looking at future risks, it is also important to take account of future socio-economic trends. These influence the economic costs that arise from climate change, for example, the population affected or the assets at risk. Most studies assess the impacts of future climate change on future socio-economic levels, as a failure to do so implies that future climate change will take place in a world similar to today.

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).

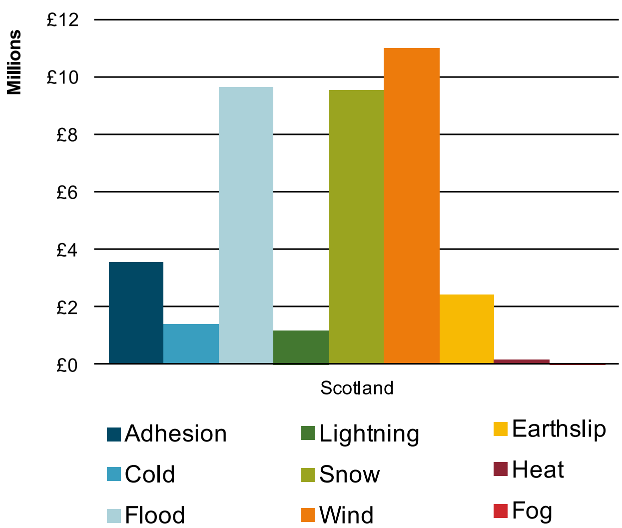
Scotland Route has developed a Weather Resilience and Climate Change Adaptation (WRCCA) plan (Network Rail, 2014). This includes an analysis of the current impact of weather and seasonal events on delays. The Schedule 8 performance costs (the compensation payments to train and freight operators for network 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.

THEME 2 – BUILT ENVIRONMENT

The second theme relates to the built environment.

Flooding and other risks to property

BE1: Risks to homes from flooding
BE7: Risks to homes from sea level rise

Flooding is currently a major risk for the Glasgow City Region, and the evidence on current risks are well developed. The SEPA (2015) Flood Risk Management Strategy set out the current risks, including the potential economic costs of flooding. These estimates are presented below, though it is highlighted that SEPA is currently undertaken a new National Flood Risk Assessment (NFRA) that will be published in the near future and will update these figures. The 2015 FRM reports the properties at risk and the associated annual average damages[14] as shown in the Table.

14 Annual Average Damages are the theoretical average economic damages caused by flooding when considered over a very long period of time. It does not mean that damage will occur every year: in many years there will be no damages, in some years minor damages and in a few years major damages may occur. High likelihood events, which occur more regularly, contribute proportionally more to Annual Average Damages than rarer events. Within the Flood Risk Management Strategies Annual Average Damages incorporate economic damages to the following receptors: residential properties, non-residential properties, vehicles, emergency services, agriculture and roads. They have been calculated based on the principles set out in the Flood Hazard Research Centre Multi-Coloured Handbook (2010). Source SEPA (2015)

Note that this includes some areas that are outside the GCR, but the majority of AAD are within the Glasgow region.

For **river flooding**, the report identifies that within the Clyde catchment, approximately 7,800 residential properties and 1800 non-residential properties are at risk of river flooding. The equivalent annual average damages are £22 million/year. The breakdown of AAD is as follows:

- 60% residential properties (£13 million);
- 29% non-residential properties (£6.4 million);
- 5% emergency services (£1.1 million);

The breakdown of property risk and annual average damage by area is shown below.

Reporting on the UKCP09 high emissions scenario for 2080s, the FRM Strategy identifies that average peak river flows for the Clyde basin are projected to increase by 44%. This would potentially increase the number of residential properties at risk of river flooding from approximately 7,800 to 12,000 and the number of non-residential properties from approximately 1,800 to 2,900.

The River Leven (Dunbartonshire) catchment includes West Dunbartonshire. The 2015 FRM reports that there are approximately 990 residential properties

Table 18. Summary of flood risk from various sources within the Flood Risk Management Clyde and Loch Lomond Local Plan District (Source: SEPA, 2015).

	Total number of properties at risk (residential and non-red)	Annual Average Damage
River flooding		
River Clyde catchment group*	9600	£22 million
River Leven catchment**	1100	£4.2 million
Coastal flooding		
Clyde and Loch Lomond coastal area***	4,900	£19 million
Surface water flooding		
Clyde and Loch Lomond Local Plan District****	19,000	£20 million

*Includes some councils outside of the region, i.e. full list is Dumfries and Galloway Council, East Ayrshire Council, East Dunbartonshire Council, East Renfrewshire Council, Falkirk Council, Glasgow City Council, Inverclyde Council, North Ayrshire Council, North Lanarkshire Council, Renfrewshire Council, Scottish Borders Council, South Lanarkshire Council, Stirling Council, West Dunbartonshire Council, West Lothian Council.

** Includes Argyll and Bute Council, Stirling Council, West Dunbartonshire Council

*** Includes Argyll and Bute Council, Glasgow City Council, Inverclyde, Council, Renfrewshire Council, North Ayrshire Council, South Lanarkshire Council, West Dunbartonshire Council

**** includes Argyll and Bute Council, Dumfries and Galloway Council, East Ayrshire Council, East Dunbartonshire Council, East Renfrewshire Council, Falkirk Council, Glasgow City Council, Inverclyde Council, North Ayrshire Council, North Lanarkshire Council, Renfrewshire Council, Scottish Borders Council, South Lanarkshire Council, Stirling Council, West Dunbartonshire Council, West Lothian Council.

Table 19. Flood Risk Management Clyde and Loch Lomond Local Plan District (Source: SEPA, 2015).

	Residential and non-residential properties at risk of river flooding	Annual Average Damages
Glasgow City	3,500	£9.8 million
Paisley and Johnstone	1,600	£2.7million
Rutherglen	650	£2.5 million
Kirkintilloch	570	£740,000
Clydebank	290	£720,000
Giffnock and Thornliebank	270	£1.6 million
Coatbridge and Airdrie	210	£440,000
Cambuslang	190	£600,000
Hamilton	180	£980,000
Barrhead	150	£340,000

Table 20. Flood Risk Management Clyde and Loch Lomond Local Plan District (Source: SEPA, 2015).

	Residential and non-residential properties at risk of river flooding	Annual Average Damages
Alexandria and Balloch	610	£2.4 million
Dumbarton	360	£1.3 million
Strathblane	30	£90,000
Geilston	10	£23,000

Table 21. Flood Risk Management Clyde and Loch Lomond Local Plan District Coastal flooding (Source: SEPA, 2015).

	Residential and non-residential properties at risk of coastal flooding	Annual Average Damages
Dumbarton	1,700	£11 million
Glasgow City	1,000	£2.4 million
Renfrew	660	£1.2 million
Rothesay	490	£870,000
Gourock/Greenock/Port Glasgow	400	£360,000
Renton	110	£410,000
Clydebank	70	£1.8 million
Port Bannatyne	70	£150,000
Kilchattan Bay	20	£90,000
Ardnadam	10	£60,000
Geilston	10	£50,000
Helensburgh	10	£40,000

predicted to be at risk of river flooding in this area, of which 360 are in Dumbarton. Approximately 160 non-residential properties are predicted to be at risk of river flooding in this area.

Reporting on the UKCP09 high emissions scenario for 2080s, the FRM Strategy identifies that average peak river flows for the Leven catchment may increase by 44%. This would potentially increase the number of residential properties at risk of river flooding from approximately 990 to 1,230 and the number of non-residential properties from approximately 160 to 230.

For **coastal flooding**, the 2015 FRM reports there are approximately 3,600 residential properties and approximately 1,300 non-residential at risk of coastal flooding in the Clyde region. The equivalent annual average damages are £19 million. The damages are distributed as follows:

- 59% non-residential properties (£11 million);
- 27% residential properties (£5.2 million);
- 5% emergency services (£1.0 million).

Reporting on the UKCP09 high emissions scenario for 2080, the FRM Strategy identifies the projected average sea level increase for the Clyde and Loch Lomond Local Plan District is approximately 0.47m by 2080. This may increase the number of residential properties at risk of coastal flooding from approximately 3,700 to 7,500 and the number of non-residential properties from approximately 1,300 to 2,400. Coastal flood modelling by SEPA has not taken into account the impacts of climate change on wave overtopping or storminess, which could increase the number of people affected by coastal flooding.

For **surface water flooding**, within Clyde & Loch Lomond District, the 2015 FRM reports there are approximately 13,000 residential and 6,300 non-residential properties at risk of surface water flooding, predominately in the area of Glasgow and surrounding urban areas. Surface water flooding within these heavily urbanised areas is often associated to flooding from urban watercourses. In many areas, flooding of this type presents the greatest flood risk. The Annual Average Damages caused by surface water flooding are approximately £20 million. The damages are distributed as follows:

- 47% residential properties (£9.4 million);
- 44% non-residential properties (£8.8 million).

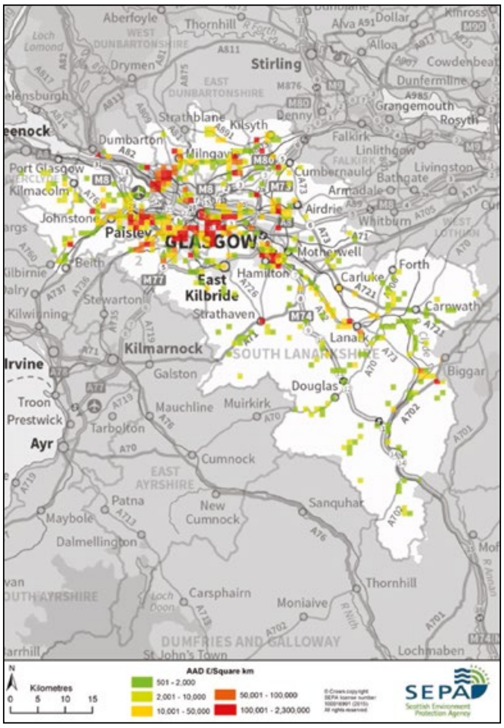
Reporting on the UKCP09 high emissions scenario for 2080, the FRM identifies that climate change may lead to 20% increase in rainfall intensity. Under these conditions it is estimated that the number of residential properties at risk of surface water flooding may increase from approximately 13,000 to 18,000 and the number of non-residential properties from approximately 6,300 to 8,500.

The geographical patterns of the three flood related risks (river, surface and coastal) from the FRM are shown below, showing the different distribution by area. The FRM estimates have been used as a basis on which

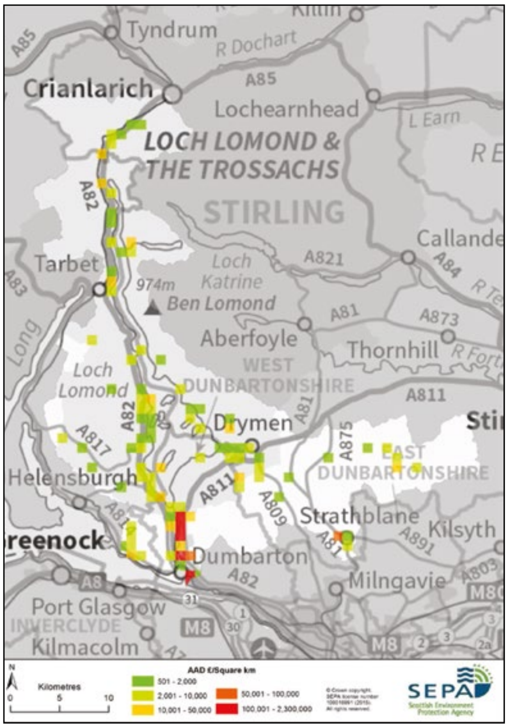
Table 22. Flood Risk Management Clyde and Loch Lomond Local Plan District Surface flooding (Source: SEPA, 2015).

	Residential and non-residential properties at risk of surface water flooding	Annual Average Damages
Glasgow City	8,400	£4.4 million
Paisley and Johnstone	1,700	£1.1 million
Gourock / Greenock / Port Glasgow	890	£1.5 million
Clydebank	540	£440,000
Dumbarton	480	£410,000
Coatbridge / Airdrie	390	£330,000
Rutherglen	380	£260,000
East Kilbride	340	£560,000
Alexandria and Balloch	320	£900,000
Giffnock and Thornliebank	250	£110,000

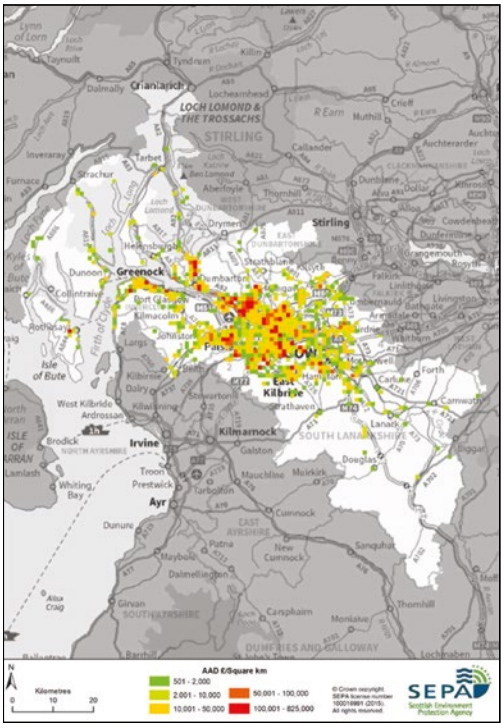
Figure 5 Annual Average Damages from Flooding. Source Flood Risk Management Plan Strategy (SEPA, 2015).



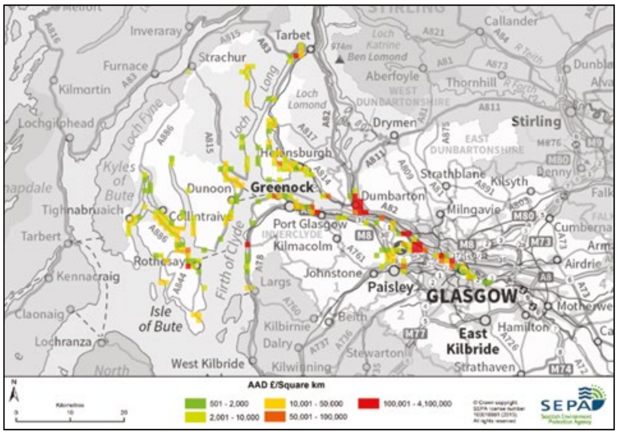
River (Clyde)



River (Leven)



Surface



Coastal

Table 23. Estimated current and indicative future AAD under climate change (2080s). Source current damage from FRM Strategy (Source: SEPA, 2015) plus future climate increase (estimates this study).

Category	River Flooding £Million/yr		Coastal Flooding £Million/yr		Surface Flooding £Million/yr	
	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)
Residential prop.	13	20.0 (7.0)	5.2	10.8 (5.6)	9.4	13.0 (3.6)
Non-residential	6.4	10.3 (3.9)	11	20.3 (9.3)	8.8	11.9 (3.1)
Emergency services	1.1	1.7 (0.6)	1	2.0 (1.0)		
Vehicles	0.65	1.0 (0.4)	0.54	1.1 (0.5)	0.4	0.5 (0.1)
Roads	0.35	0.4 (0.1)	0.94	1.8 (0.9)	1.4	1.9 (0.5)
Agriculture	0.18	0.3 (0.1)	0.016	0.0 (0.0)		
Total	22	33.7 (12.2)	18.7	36.0 (17.3)	20	27.3 (7.3)

Table 24. Current Flood Damages from CCRA2 for Scotland (Source: Sayers et al. 2015).

National (Scotland)	Current
Residential properties at risk of flooding	180,000
At risk > 1 in 75	97,000
non-residential properties at risk of flooding	42,000
At risk > 1 in 75	25,000
EAD residential (direct)	£42 million
EAD non-residential (direct)	£120 million
Total (direct and in-direct)	£280 million

Table 25. Estimated EAD (£) from flooding (all cause) for Scotland (Source: Sayers et al. 2015).

Current EAD (£)	Future period	2°C	4°C	High ++
Residential				
42,000,000	2020s	46,000,000	61,000,000	83,000,000
	2050s	60,000,000	84,000,000	180,000,000
	2080s	73,000,000	120,000,000	310,000,000
Non-residential				
120,000,000	2020s	130,000,000	150,000,000	180,000,000
	2050s	150,000,000	200,000,000	370,000,000
	2080s	170,000,000	270,000,000	600,000,000
TOTAL				
280,000,000	2020s	300,000,000	360,000,000	450,000,000
	2050s	350,000,000	480,000,000	930,000,000
	2080s	420,000,000	670,000,000	1,500,000,000

to estimate the potential increase in AAD from climate change. The resulting impacts are shown below. These results should be considered indicative, as they are not based on detailed modelling. They also do not include socio-economic change (population, housing). Note that a more detailed analysis of climate risks will be undertaken in the new FRM.

The results show that the estimated AAD increases from £60 million currently to £97 million by 2080s, an increase of £37 million. The values for residential flooding damage increase from £28 million to £ 44 million (an increase of £16 million) and the values for non-residential increase from £26 million to £ 42 million (an increase also of £16 million).

A further set of flood risk costs for Scotland are available from UK CCRA2, from the Projections of future flood risk in the UK (Sayers et al, 2015). This has a similar set of flood risk data to the SEPA FRM data, although there are differences in the data used, the geographic area and the assumed flood risk return periods. The main advantage of the CCRA2 analysis is that it considers both future climate and socio-economic change, and has information for different future climate scenarios and time periods, with a 2°C, 4°C and H++ scenario, as well as three population growth projections (low, high and no growth). It also considers the potential benefits of adaptation in reducing risks.

At the national level, the Sayers et al. study estimates 180,000 residential properties and 42,000 non-residential properties are currently at risk in Scotland, with 97,000 and 25,000 at greater than 1 in 75 year risk of flooding. This includes some 200,000 people at a 1 in 75 year risk, of which 42,000 are in deprived areas. The estimated expected annual damage is £42 million for residential (direct), 120 million non-residential (direct) and £280 million for the total costs (direct and indirect costs).
The study also estimates the future EAD (equivalent annual damage) for Scotland under climate change. The values are shown below, assuming no population growth. The study also presents the impacts of population growth (not shown here).

The estimates of the impacts of climate change on flooding for the Glasgow region for the 2080s for residential properties from the study are shown below. The estimated flooding impacts include fluvial, coastal and surface water risks, under the 2 and 4°C climate projection by the 2080s. The baseline number of properties at risk in the region is higher in the Sayers study than the FRM, but the EAD is lower (residential AAD in the FRM Strategy is £28 million by comparison). The exact reasons for these differences are not clear. The Sayers study reports a marginal increase in EAD for the Clyde and Loch Lomond region of £7 million for the 2°C scenario and £17 million for the 4C scenario. This highlights the large increase in marginal costs with higher warming scenarios.

The CCRA2 estimate above is for residential properties only, and does not include non-residential impacts, or the total flood damage costs. Based on the relative increase for Scotland as a whole, the likely total damages for the region would be 3- 4 times these residential costs alone.

The Sayers et al study also analyses the potential impact of adaptation in reducing costs. This finds that very significant reductions in damage costs (EAD) can be achieved with relatively low-cost adaptation.

There is an additional study that estimate future flood impacts – the NHS Scotland study for Glasgow (JBA 2016). This assessed the potential increases for 2035 for a 1 in 100 year flood, with the estimated increase in properties flooded below. This also has lower estimated numbers of properties at risk than the SEPA (2015) FRM Strategy.
Finally, there is a study of coastal risks by Hallegate

Table 26. Properties at risk and Residential Expected Annual Damage from flooding (all sources). Clyde and Loch Lomond region (Source: Sayers et al. 2015).

	Current	Scenario	2080s climate change
Number residential properties	31,000	2°C	34,000 [9%] (12000*) [14%]
	(11,000*)	4°C	41,000 [29%] (13000*) [33%]
Residential EAD (£)	£12 million	2°C	£19 million [54%]
		4°C	£29 million [140%]

* of which number in deprived areas.

et al (2013). This includes estimated present and future flood losses from coastal impacts for the 136 largest coastal cities globally and includes Glasgow. This estimates that current mean annual losses from coastal flooding are low ($4 million/year), but with 20 cm and 40 cm scenarios of sea level rise, these would rise to $95 million per year and $824 million per year (respectively) in the absence of adaptation. These estimates include the socio-economic trends and thus rising exposure and asset values. The study also found that with adaptation, mean annual costs could be kept at current levels.

Overall, a clear finding is that the economic costs of residential and property damage from climate change in the region are likely to be large. It is stressed, however, that there is already action underway to deal with these. The level of flood risk due to surface water flooding in the greater Glasgow area led to the establishment of the Metropolitan

Table 27. Estimated current properties flooded and estimated increase from climate change by 2035. (Source: JBA, 2016). Top NHS Glasgow and Clyde. Bottom. NHS Lanarkshire.

Estimated Current Properties Flooded – 100-yr. Flood (0.01)			
Local Authority	Fluvial	Coastal	Surface Water
East Dunbartonshire	327	N/A	383
East Renfrewshire	481	N/A	360
Glasgow City	1324	304	2584
Inverclyde	212	195	568
Renfrewshire	1159	444	1362
West Dunbartonshire	887	1216	652
Total	4390	2159	5909

Estimated Current Properties Flooded by 2035 – 100-yr. Flood (0.01)			
Local Authority	Fluvial	Coastal	Surface Water
East Dunbartonshire	24%	N/A	21%
East Renfrewshire	6%	N/A	12%
Glasgow City	36%	6%	21%
Inverclyde	23%	21%	12%
Renfrewshire	14%	2%	15%
West Dunbartonshire	27%	5%	13%
Total	24%	6%	17%

Estimated Current Properties Flooded – 100-yr. Flood (0.01)			
Local Authority	Fluvial	Coastal	Surface Water
North Lanarkshire	788	N/A	826
South Lanarkshire	1039	N/A	1917
Total	1827	N/A	2743

Estimated Current Properties Flooded by 2035 – 100-yr. Flood (0.01)			
Local Authority	Fluvial	Coastal	Surface Water
North Lanarkshire	16%	N/A	15%
South Lanarkshire	30%	N/A	18%
Total	24%	N/A	17%

Table 28. Vulnerability of Historic Properties in Glasgow City Region. (Source: Historic Environment Scotland, 2018).

Risk Rating	Landslides / Slope Instability	Groundwater Flooding	Fluvial Flooding	Pluvial Flooding	Coastal Erosion	Coastal Flooding
Very High	0	2	1	0	1	1
High	5	7	2	1	1	1
Medium	14	10	0	3	0	0
Low	0	0	16	15	17	17

Glasgow Strategic Drainage Partnership (MGSDP)[15]. Similarly, as part of the FRM Strategy and Local Flood Risk Management Plans, extensive flood protection projects are being introduced that will reduce current – and therefore future – risks.

- **BE2: Risks to building fabric from moisture, wind, storms and driving rain**

The impacts of wind damage is of potential relevance. Wind storms are responsible for major economic costs in the UK and there have been several major events in Scotland in recent years. The wind storm analogue presented in the previous chapter provides an estimate of the wind damage for the region, with an estimate for a large-event of £20 million for property damage. This provides a baseline for possible future damages. Based on ABI (2017), we assume a 15% increase in wind related damages (for a mid-century medium warming scenario). There is no good data to provide an annualised equivalent damage, but using this event and assuming an increase in the frequency of events, this might imply an annual cost of around £1 million/year, though the marginal costs of the climate change impact would only be 15% of this.

Currently 21,200 (2.5%) of homes across the Glasgow City Region are affected by rising or penetrating damp and 58,500 (7%) from condensation. There is no literature available quantifying the change in moisture and rain related damages with climate change, noting this may include positive as well as negative impacts. Further work to investigate this category might therefore be useful.

15 The MGSDP is formed from organisations that are involved in the operation of the sewerage and drainage network within the Greater Glasgow area, including among others: local authorities; Scottish Water; SEPA and Scottish Canals.

Heritage and Historic Properties

- **BE3: Risks to significant heritage properties from landslides, flooding or coastal erosion**
- **BE4: Risks to traditional and historic buildings from moisture, wind and driving rain**

There is data in the SEPA (2015) Flood Risk Management Strategy on the potential sites at risk from flooding. These sites include; scheduled monuments, gardens and designed landscapes, battlefield sites, World Heritage sites and listed buildings:

- For river flooding, there are approximately 108 designated cultural heritage sites at risk of river flooding within the Clyde catchment;
- For coastal flooding, there are approximately 40 designated cultural heritage sites are at risk of coastal flooding within the catchment;
- For surface water flooding, there are approximately184 designated cultural heritage sites at risk of surface water flooding;
- In addition to the work by SEPA, Historic Environment Scotland has also assessed the vulnerability of the 19 properties in care in Glasgow City Region to climate change.

The Dynamic Coastal Change Assessment (2017) looked in detail at the coastal areas and identified the areas of cultural heritage. The Scottish Natural Heritage report (Hansom et al, 2017) looked at the potential impacts of sea-level rise and storm surges due to climate change in the Firth of Clyde. However, even with these studies, it is very difficult to estimate the potential economic costs for this impact, not least because of the challenge of monetising current natural and cultural heritage value.

Cooling and Heating Demand including Overheating

- **BE8: Risk of overheating of buildings from increased energy efficiency/insulation**

Temperature is one of the major drivers of energy demand in the UK, affecting winter heating for both the residential and service sectors. Climate change will therefore have positive effects on future energy demand by reducing winter heating. These responses are largely autonomous and can be considered as an impact or an adaptation. These future changes are quite complex to assess, especially as they need to be seen in the context of other drivers (e.g. changing housing stock, insulation levels, income, prices) and because they are influenced by future mitigation policy (both in terms of energy efficiency levels, but also energy source and energy prices).

Information on current energy demand is available from the Scottish Energy Statistics (2018). These show that heating is predominantly supplied by gas (79%) and also show that Scotland has higher consumption of gas, per household, when compared to the UK average (Average domestic gas consumption per consumer was 13,443 kWh/year for Scotland, as compared to 13,202 kWh for Great Britain and 13,082 kWh for London, in 2016). This reflects the colder climate in Scotland and as a results gas consumption is 3% higher than in Great Britain on average.

The influence of temperature on energy demand can be assessed with the indicator of heating degree days (Jenkins et al, 2008), which is a metric to account for the effect of weather on energy consumption[16] and by implication, the amount of heating needed. The number of heating degree days in Scotland are higher than Great Britain on average, though the values for West Scotland are lower than for Scotland overall (but still around 15% higher than for GB). The number of heating degree days in the UK – and for Scotland – have been falling (as captured in the UKCP 09 observation trend reports, Jenkins et al, 2008[17]), with reductions of 13% for West Scotland from 1961-2006. However, other factors are also important in looking at changes in actual demand, and average energy consumption in Scotland is falling as a result of greater energy efficiency uptake.

There are different methods for assessing the future impact of climate change on heating demand – with econometric analysis or impact functions, the latter based on heating degree days. A detailed analysis was undertaken for the UK CCRA1 (HR Wallingford, 2012), which included specific data for Scotland (and West Scotland) and the changes in energy demand from this study have been used here. It is noted that there are considerable uncertainties with these projections, because they depend on the assumed population growth and household density, housing stock, the technology and efficiency of heating, insulation level, the fuel mix for heating, income and prices.

Changes in energy demand can be valued in monetary terms. Average annual domestic gas bills are an important part of household expenditure, averaging around £624/year in South Scotland (in 2016)[18], thus reductions from climate change will be important to household expenditure. However, valuation involves further challenges, not least over the changes in prices over time. In CCRA1, the estimates of economic benefits from reduced heating demand were estimated using UK appraisal guidance. This used the long-run variable cost of energy supply, specifically the DECC guidance on valuing energy use and GHG emissions (BEIS, 2018). However, these exclude taxes and charges, and for this study, we consider it more useful to use the full retail (market) price (including taxes), which for South Scotland in 2016 was a price of 4.16p/kWh. Note that energy savings leads to further economic benefits from the reduction in air pollution and the reduction in GHG emissions (making the achievement of policy targets less costly), and these can also be valued. Analysis in CCRA1 found that in terms of GHG emission reductions, these additional economic benefits were significant. It is also noted that the emissions reductions from reduced winter heating will also be an important benefit in helping the achievement of Scotland's greenhouse gas emission reductions[19].

16 An annual measure of the extent to which daily temperatures suggest that buildings may require some form of space heating, based on the daily temperature being below a threshold of 15.5°C. There are two ways of calculate HDD – a simple summation of the number of degrees Celsius the mean temperature is below 15.5°C for each day and a weighted summation.

17 http://ukclimateprojections.metoffice.gov.uk/23048

18 based on consumption of 15,000kWh for direct debit. https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics. Note that the average price varies considerably with year.

19 Scotland is advancing low carbon and renewable heat technologies can support emissions reductions whilst also potentially offering economic opportunities to reduce industry and household costs, with renewable heat targets.

The previous energy demand changes have been combined with the new valuation estimates and the results are shown below, presented as the marginal change from climate change alone. As can be seen in the table, the total benefits from climate change in reducing winter heating, as well as the benefits for individual households are large.

Table 29. Glasgow City Region benefits (£million/year]) from climate change to households from reduced heating demand (current retail prices). Marginal change from climate change only.

	2020s*	2050s	2080s
Low p10		44	70
Low p50	25	97	126
Central p50	68	118	141
High p50	111	136	167
High p90		176	242

*For 2020s, values are Medium p10,p50,p90

Table 30. Average household saving (£/year per household) (current retail prices) from climate change.

	2020s	2050s	2080s
Low p10		53	84
Low p50	30	116	150
Central p50	81	141	168
High p50	133	163	200
High p90		211	290

Table 31. Annual % reduction in household heating demand in West Scotland, based on CCRA results.

% reduction	2020s	2050s	2080s
Low p10		9	15
Low p50	5	21	28
Central p50	15	26	32
High p50	25	31	38
High p90		40	55

A number of caveats are noted with these estimates:

- The numbers above only include gas heating. In Scotland, around 20% of homes use electricity for heating. The benefits to these households are likely to be larger/household, due to the higher cost of delivering heating through electric power;
- The values assume constant (current) retail prices. It is stressed that the use of the long-run variable cost of energy supply values would lead to lower values, as these are around 40% of the retail costs. These long run prices rise slightly in future years;
- The benefits of falling gas use would have additional GHG mitigation and air quality benefits. The benefits of GHG emission reductions are high, due to future carbon prices in future years, especially post 2030. Indeed, these economic benefits, if valued using the future BEIS carbon values, are similar in magnitude to the direct household savings;
- There is an issue of potential rebound effects, as climate change reduces energy use and therefore energy bills, it will increase consumers' disposable income, in turn leading to greater consumption of energy (or other products and services).

It is worth stressing that benefits of reduced winter heating will have positive distributional effects, as it will benefit those on low incomes the most (in relative terms). It will also help reduce fuel poverty. As low-income households spend a higher proportion of incomes on fuel (10%), these groups will experience largest relative benefits.

These estimates have been compared to other sources. A report for CXC (2015) reports that under a medium emissions scenario, a reduction of 642 to 924 HDD is projected for Scotland as a whole by the mid-21st century, corresponding to 19%–29% of current values. It also estimates a reduction of 23%–37% by the late 21st century. These are broadly in line with the estimates above. The Jacobs report (2015) reports a baseline for Glasgow of 334 HDD and a reduction by the 2050s of 56 HDD, though this uses the simple calculation method for HDD, and finds a 17% reduction from climate change by mid-century.

There are also winter heating related benefits for the non-residential sector. These are potentially as large as the domestic sector: industrial and commercial gas consumption makes up 41% of all gas consumed in Scotland. For the analysis here, we have taken current commercial and industrial gas use in Scotland. The reduction in heating demand has been estimated using the same scaling factors as for domestic analysis above (based on CCRA1). These values should only be considered as approximate, but they do show the potential scale of benefits. The valuation uses current commercial retail prices, which are significantly lower than domestic prices, but even so, the potential economic benefits are very large.

Table 32. Total Glasgow City Region benefits (£million/year] to non-residential buildings (current retail prices) from climate change reducing heating demand.

	2020s*	2050s	2080s
Low p10		19	32
Low p50	10	45	60
Central p50	31	56	67
High p50	53	65	80
High p90		85	118

These would also lead to high economic benefits from the reduction in GHG emissions.

Overall, the combined benefits for residential and non-residential buildings are therefore very large, indicatively estimated at more than £100 million/year (current prices) by mid-century. These values do not include the additional benefits of reduced greenhouse gas emissions.

Table 33. Total Glasgow City Region benefits (£million/year] (current retail prices) from climate change reducing heating demand. Residential and Non-Residential benefits.

	2020s*	2050s	2080s
Low p10		64	102
Low p50	35	142	185
Central p50	99	174	208
High p50	164	202	247
High p90		261	360

- **BE6: Increased cooling demand in buildings as a result of rising temperatures**
- **BE11: Reduced heating demand to buildings from rising temperatures**

Temperature is also a driver of energy demand for cooling. However, there are not good statistics on the current levels of UK cooling demand, nationally or by area, due to the low levels of current demand.

Similar to heating, there is a commonly used metric for assessing the influence of climate on cooling energy demand: cooling degree days[20]. The current levels of cooling degree days in the UK are low, and they are especially low for Scotland (see Jenkins et al, 2008). Nonetheless, CDD have been increasing, as the UK climate has warmed, although these increases have been modest. Increases in Scotland have been low (with a 3% increase in CDD for West Scotland, see Jenkins et al 2009, period 1961-2006). Baseline levels of CDD in Scotland are almost two orders of magnitude lower than current heating degree days.

There are projections of the increase in CDD with climate change. These show increases for the UK[21], but the projected increase is reduced with increasing latitude, and the increases over Scotland (HRW, 2012) are low at 25 to 50 CDD by the 2080s, which would make the levels similar to southern England today. There is, however, the additional factor of the urban heat island to consider for Glasgow city. A report by ClimateXChange (2015) looked briefly at CDD in Scotland. They report very low current levels. For the future (2015–2090), they project an increase in CDD, reporting that the maximum CDD in any year (across ensemble projections) was approximately 80 CDD. The Jacobs report (2015) also assessed cooling degree days for Glasgow and reported an additional 2.3 CDD per year by the 2050s for the medium UKCP09 scenario.

No previous studies (as identified by this review) have assessed the impact of climate change on cooling demand in Scotland (only CDD). However, it is possible to make some analysis of the changes by looking at the available information. As with heating, future demand is dependent on many factors, though income is particularly important. There is the issue of the capital purchase of air conditioning units

20 An annual measure of the extent to which temperatures suggest that buildings may require some form of cooling (e.g. air conditioning), based on the daily temperature being above a specified threshold of 22°C. There are two ways of calculating CDD – a simple summation of the number of degrees Celsius the mean temperature is above a 22°C for each day and a weighted summation.

21 UKCP09 reports average CDD over southern England for the1961-1990 ensemble mean are simulated to be approximately 25 to 50, whereas by the 2080s they increase to between 125 and 175.

(from a very low current baseline) and the fact that cooling is predominantly powered by electricity, thus it is expensive to deliver. Alongside the direct costs, it is noted that increases in cooling and electricity demand will increase GHG emissions and air pollution (depending on the electricity supply mix), thus also adding to economic costs.

This study has undertaken some initial scoping analysis. For the medium scenarios (2050s), the potential economic costs of cooling demand in the Glasgow region are considered to be extremely low and would not have significant economic costs. In the long-term, i.e. by the 2080s, there could be some cooling demand. At the moment, cooling demand represents only 4% of total electricity demand in the UK (14.8TWh), though London has an estimated annual demand (2004) of around 4.5 TWh (Day et al, 2008) for domestic and non-residential sectors (total). By the end of the century, most projections show CDD levels rise in Glasgow could be similar to the south of England today. This would mean some (albeit modest) electricity demand for cooling will arise. Based on the available data, it is estimated that cooling demand could have a cost of >£10 million/year in the region by the end of the century (based on current retail prices). This number is only indicative. Nevertheless, it demonstrates that this is much smaller (over an order of magnitude) than the benefits of reduced winter heating demand. Despite this, some further consideration of cooling demand is warranted, not least because of the nature of the regions building stock (which is designed to reduce winter heating) and because of potentially higher CDD increases in the city, due to the urban heat island. There could also be some potential risks for some buildings, notably hospitals during extreme heat episodes, where high building temperatures could pose health risks.

Parks and Recreation

- **BE5 Increased maintenance of green space due to rising temperatures and severe weather**

The issue of increasing vegetation growth was outlined in the earlier road and rail sections. There will be an increase in maintenance costs associated with vegetation control and management of green spaces. The current study has not been able to source current maintenance costs, but if there were available, some indicative analysis of potential future climate change impacts would be possible.

- **BE9: Potential for improved physical and mental health from increased use of parks and green space due to warmer weather**

There will be additional recreational benefits (economic benefits) from the increased recreational activities possible with longer summer seasons and warmer weather. However, there are likely to be additional summer related costs associated with higher maintenance and staffing to meet this demand.

- **BE10: Opportunities for local food growing from warmer temperatures and increased growing season**

There are some potential benefits from improved community gardens, though these benefits have not been considered in this analysis, due to a lack of data on current production. The potential economic benefits are considered to be low.

Renewable Electricity

- **BE12: Increased viability of renewable electricity and heat from changing weather conditions**

Potential impacts on renewable generation, notably hydro, was discussed in theme 1.

THEME 3 – SOCIETY AND HEALTH

This section focuses on society and health. This provides additional challenges, because the impacts are generally more difficult to value than for other sectors, as there are no observed market prices. However, it is possible to derive monetary values by considering the total effect on society's welfare. This requires analysis of three components which each capture different parts of the total effect:

- The resource costs i.e. medical treatment costs;
- The opportunity costs, in terms of lost productivity; and
- Dis-utility i.e. pain or suffering, concern and inconvenience to family and others.

The first two components can be captured relatively easily. Techniques are also available to capture the third component, by assessing the 'willingness to pay' or the 'willingness to accept compensation' for a particular health outcome. These are derived using survey-based "stated" preference methods and/or "revealed" preferences methods that are based on observed expenditures such as on consumer safety.

Flood related impacts

- **SH1: Risks to people and communities from flooding**

The analysis of people flooded was included in the estimates of residential flooding in the infrastructure theme. There are, however, three additional issues which are relevant here. First, the distributional effects of flooding. Second, the health impacts of flooding. And third, the impacts of flooding on community infrastructure.

The Mapping Flood Disadvantage report (Kazmierczak, 2015) identifies Glasgow as having extremely high flood disadvantage. It identifies that West Dunbartonshire has the highest flooding risk of all city regions for coastal flooding, i.e. with a high proportion of residential properties at risk. It also identifies that one-third of the acutely/extremely disadvantaged data zones in relation to surface water flooding are in Glasgow. A further report by Sayers et al (2017) for the Joseph Rowntree Foundation also looked at flood disadvantage. This finds socially vulnerable neighbourhoods are over-represented in areas prone to flooding (all sources), but most significantly in areas prone to coastal (and tidal) flooding. Glasgow is identified as one of the ten local authorities (in the UK) where the most vulnerable neighbourhoods are located, i.e. it is one of the ten most flood disadvantaged local authorities in UK. In Glasgow, those living in the floodplain are almost twice as likely to experience frequent flooding than the UK average.

A key finding is therefore that there are large distributional differences in flooding in the region, i.e. the impacts of flooding are higher for deprived neighbourhoods, and these groups have lower resilience to flooding, because of lower income levels and lower access to insurance. Those living in flood prone areas in Scotland experience the highest equivalent annual damage per person (on average, £113 per person), which is over double that of England (on average, £50 per person). By the 2080s, for a high climate change scenario (+4°C), the EAD per person in Scotland increases to £183 per person (compared to £95 per person in England) with the risk in socially vulnerable neighbourhoods increasing twice as quickly as elsewhere.

Flooding is also associated with increased rates of anxiety and depression, and extreme flood events can also lead to injuries. The methods for assessing these impacts was set out in Chapter 2, in relation to the impacts on mental health and wellbeing from the 2015 flood. This reported the estimated maximum health costs, based on the number of properties at risk in each authority, shown below.

Table 34.. Maximum possible economic costs from flooding on mental health and injuries for a 1 in 100 year event. Current risks.

Local Authority	Total Health costs river flooding (1 in 100)	Total Health costs surface flooding (1 in 100)
East Dunbartonshire	580,000	960,000
East Renfrewshire	860,000	1,420,000
Glasgow City	2,360,000	3,900,000
Inverclyde	380,000	620,000
Renfrewshire	2,070,000	3,420,000
West Dunbartonshire	1,580,000	2,610,000
North Lanarkshire	1,410,000	2,320,000
South Lanarkshire	1,850,000	3,060,000

The uplifts presented in the previous section (on property flooding under climate change) indicate that the risk of river flooding (in terms of the additional number of properties flooded) could increase by just over 40% by the 2080s, and by 80% for coastal flooding, due to climate change. These would increase the health impacts of floods by the same proportion. This therefore indicate that the increase in health-related flood impacts is important in economic terms, but that it would be low relative to direct property damage costs.

The FRM strategy also highlights that a number of educational buildings and healthcare facilities are at risk of river flooding (<10) and educational buildings at risk of surface water flooding (60). There is also a series of studies that have been undertaken on the health facilities in Scotland, with the NHS (including NHS Greater Glasgow and Clyde) (JBA, 2016) and for specific NHS councils (e.g. for North and South Lanarkshire (JBA, 2015). These identify the potential risks to health infrastructure.

- **SH5: Risks to the viability of coastal communities from sea level rise**

The discussion of coastal flooding on property was reported in the earlier theme. The viability of coastal communities to sea level rise relates to cases where sea level rise and inundation (the frequency of flooding), or erosion, lead to the potential abandonment of coastal communities. This can happen when either erosion or erosion risk affects the safety of the area, or where the frequency of flooding becomes so high as to make insurance unviable. However, these outcomes assume that adaptation measures are not implemented.

It is highlighted that there are clusters of existing and proposed housing and commercial development around Greenock and Gourock as well as particular individual other sites in Renfrewshire and West Dunbartonshire, that could be at potential risk of coastal impacts. However, more research is needed to better characterise the impacts from sea level rise on coastal communities, thresholds for viability, and what steps should be taken to engage and support affected communities.

Heat related effects

- **SH2: Increase in summer temperatures and heatwaves leading to increased morbidity and mortality**

The main health risk of higher summer temperatures and heatwaves is associated with premature (excess) deaths (mortality). Numerous studies show that daily mortality increases above a temperature threshold, though the threshold and rate of increase varying between regions.

Several studies have quantified these impacts in the UK, though the focus has been on England and Wales. However, the CCRA1 (HRW, 2012/ Hames and Vardoulakis, 2011) estimated additional morbidity impacts by region, and the estimates of numbers of premature mortality cases from climate change in Scotland have been used in this study. In practice, estimates vary strongly according to the functions used, and whether future acclimatization is included (natural adaptation). There are also important issues of future population growth and the proportion of older people (who are more vulnerable) which increases future impacts.

The additional premature fatalities – specifically the change in the risk of a fatality – can be valued in monetary terms. The valuation of the change in the risk of fatalities is routinely included in Government appraisal, in the road transport sector with respect to accidents. The current values from DfT (2017) for the average value of prevention of a fatality is £1,888,675 (2017 prices), which comprises the total from lost output, human costs and medical costs.

However, there is an important question of whether these values should be transferred to the heat context, as heat predominantly affects those who are old and/or have exiting health conditions. Previous studies have therefore used an alternative approach as a sensitivity, based on the Value of a Life Year (VOLY) Lost (which is derived from the full Value of Statistical Life, i.e. the VPF) mirroring the approach used in air pollution valuation by Defra. This adjusts down the economic costs based on the estimated period of life lost. For this analysis, we use both values. The VOLY numbers are based on Interdepartmental Group on Costs and Benefits (Defra, 2007), with values updated to 2017 prices, and assuming 6 months of life is lost on average for each fatality.

Table 35. Estimate of the number of additional mortality cases/year for the Glasgow City Region (based on HRW, 2012) including population growth.

Numbers fatalities /year			
	2020s	2050s	2080s
Low	12	27	43
Central	28	57	94
High	50	108	185

Table 36. Monetary valuation of heat related mortality – Glasgow City Region (VOLY approach), £M/year.

Valuation £million/year)			
	2020s	2050s	2080s
Low	0.4	0.9	1.5
Central	0.9	1.9	3.2
High	1.7	3.6	6.2

Table 37. Monetary valuation of heat related mortality – Glasgow City Region (VSL approach), £M/year.

Valuation £million/year)			
	2020s	2050s	2080s
Low	22.5	50.3	81.7
Central	52.4	107.1	177.5
High	94.6	204.0	349.7

This shows that the choice of valuation metric makes a very large difference to the results. Indeed, with a full Value of a Prevented Fatality, the impacts become one of the most important economic costs for the region from climate change.

There is also a strong distributional factor with these impacts. The health impacts are disproportionately higher for vulnerable groups (the elderly, those with existing health conditions, socially deprived), due to a combination of exposure, sensitivity and capacity (including support networks).

Importantly, these results do not fully include the effects of heat waves, and they do not factor in the higher risks of the urban heat island effect, which would increase the values above. However, they do not include natural acclimatisation (to changing temperatures over time), which would significantly reduce the values.

The CCRA1 estimates were updated in a later study (Hajat et al, 2014). This reported that climate change in Scotland could potentially result in a 520% increase in heat related deaths by the 2080s under a medium emissions scenario – though this is small in real terms (rising from 0.7 per 100,000 population to 4.4 per 100,000 population). These estimates of premature mortality cases per year for Scotland are in line with the CCRA estimates in the table. This study also reported that heat mortality risks increased with age group, with the greatest risks by far occurring in those above 75 and especially above 85 years. They also report that the relative decline in cold days will be lower than the increase in hot days, which is important for the later comparison of cold related mortality.

In addition to these fatalities, heat (and extreme heat) is linked with a range of other health impacts (morbidity). Previous studies (e.g. CCRA, HRW, 2012/ Hames and Vardoulakis, 2011) have estimated these additional morbidity impacts by correlating with heat related mortality. This looks at the increase in hospital patient days (hospital admissions as a result of heat related illnesses), though these should only be considered as indicative. This approach is used here, relating additional morbidity to the mortality cases. These cases of morbidity are valued using the Interdepartmental Group on Costs and Benefits values (derived in the context of air quality) for the economic costs of hospital admissions, updated to 2017 prices. The values are shown below.

Table 38. Estimate of increased health morbidity (patient days) related to heat for Glasgow City Region (based on HRW, 2012) including population growth.

Numbers of patient days from heat/year			
	2020s	2050s	2080s
Low	1216	2718	4414
Central	2827	5782	9585
High	5107	11017	18884

Table 39. Monetary valuation of heat related morbidity – Glasgow City Region, £million/year.

Valuation £million/year)			
	2020s	2050s	2080s
Low	0.9	1.9	3.1
Central	2.0	4.0	6.7
High	3.6	7.7	13.2

These show that these costs could be significant. They will also be implications for health and social care during hotter periods. As with mortality, these health impacts are disproportionately high for vulnerable groups (the elderly, those with existing health conditions, socially deprived).

It is noted that unlike England and Wales, Scotland is not currently part of the heat health watch system (HHW), although it is covered by the broader National Severe Weather Warnings (NSWWS)[22].

There is also a link between heat, health and wellbeing. Above certain thresholds, heat can reduce comfort levels in buildings. This is partially covered by the potential increase in cooling (as an autonomous adaptation) but given the low levels of cooling degree days in Scotland, this is more likely to be represented as periods of hotter weather with higher internal building temperatures.

Finally, there are some additional areas that could arise, but which have not been considered:

- There is a link with extreme heat waves and mental health;
- Warmer weather impacts on broader well-being, with a wide range of positive effects, including health benefits (well-being, exercise levels, outdoor recreation, etc.), although these are often negated during extreme heat events.

Cold Weather and Other Extremes

- **SH9: Potential benefits to health and wellbeing from reduced cold**

Cold-related deaths and illness are a large existing public health problem in the UK, and in terms of baseline levels, there are far more col-related than heat-related impacts currently.

With reducing winter and cold temperatures under climate change, there will also be reduced cold-related mortality and morbidity, which is a benefit. This will result in lower numbers of fatalities and hospital admissions. These are more difficult to attribute due to the greater number of winter related factors (i.e. infectious diseases), though there are some estimates available.

22 https://www.metoffice.gov.uk/public/weather/heat-health/#?tab=heatHealth

The CCRA (e.g. CCRA, HRW, 2012/ Hames and Vardoulakis, 2011) assessed the potential decrease in cold related mortality and estimated these additional morbidity impacts by correlating to mortality and morbidity from earlier studies. They reported that the economic benefits of cold related mortality from climate change were much larger than the increase in heat related mortality.

An update from Hajat et al, (2014) assessed the changes in mortality from climate change and found the frequency of hot days was projected to rise steeply, with over a threefold increase by the 2080s, whereas the number of cold days was projected to decline at a less dramatic pace. The effect of this was that there were more marginal (additional) deaths relative to the baseline from heat related mortality than reduced cold related mortality by the end of the century. This would imply that the marginal economic cold related mortality benefits were lower than the heat related mortality impacts from the 2050s onwards (although because of current baseline levels, there would still be more cold-related than heat related deaths in all periods).

The study provided estimates for Scotland. This modelling suggests that the rate of deaths will reduce from 55 per 100,000 in the 2000's to 31.2 per 100,000 population in Scotland by the 2080s. This would lead to high economic benefits, which are much higher than the additional cold related mortality impacts estimated in earlier in this chapter.

- **SH3: Risks to business continuity of health and social care from extreme weather**
- **SH4: Increased patient demand on NHS services from high winds, snow and ice, floods, cold weather**

There a range of effects from extreme heat on health and social care. The most apparent is the extra incidence of mortality and morbidity, which was assessed above. The resource costs of these impacts on the health services are included in the values presented earlier.

There are, however, some additional costs. The NHS Glasgow studies (JBA, 2015:2016) identified potential health and social care impacts from climate change and heat. NHS Greater Glasgow and Clyde have identified that 5 of the 23 hospitals are at very high or high risks of a 1 in 200 year surface water or river flooding in the 2080s. Similar data has not yet been obtained for NHS Lanarkshire. SEPA's assessment of flood risk to community buildings identifies that over 60 community facilities (which includes healthcare and emergency facilities) are at potential risk.

Cold, snow and ice make it difficult for patients and staff to access health facilities and for care staff to get to people's homes. Ambulance response times are longer during the very cold weather. (medium confidence) (LWEC, 2015). There are also emergency hospital admissions for falls (associated with snow and ice) and ambulance response times both increase during harsh winters. (medium confidence). Cold, snow and ice-related disruptions are likely to decrease from climate change, i.e. a benefit, although severe cold spells will still occur.

Current patient demand on NHS services does arise from extremes (high winds, snow and ice, floods, cold weather). The relative change in all of these events will determine the potential size of changing demand under climate change, noting some will lead to increases and others decreases. Injuries and admittances from floods, and potentially high winds, are likely to increase, whereas those from ice and snow (including trips and falls) and cold weather (see earlier) will decrease.

The economic benefits of the various impacts and benefits above have not been quantified, as there is a lack of quantified studies.

Other health impacts

- **SH6: Risks to health from changes in air quality**

Climate change will have some effects by changing the concentrations of ozone and potentially particular matter, affecting the health impacts of air pollution. These impacts have been assessed in European and UK studies (e.g. Vautard et al, 2016). For ozone, models indicate an increase in ozone in most of Europe in the summer, but in winter the uncertainty on the sign of change is high. For particulate matter, changes due to climate change are uncertain, as the models do not agree on the sign of the change, though impacts/benefits could potentially be important. Air pollution episodes can be a particular problem during heat waves, thus the potential increase in heat events could exacerbate current impacts. However, it is noted that the decreases in air pollution from air pollution and mitigation policy will strongly reduce baseline air pollution impacts in the future, thus the marginal impact of climate change on future air pollution levels will be low.

A further risk from climate change is the impacts on aeroallergens and hay fever, eczema and asthma episodes. Climate change is likely to trigger changes in pollen concentration, volume and distribution, with an associated increase in the prevalence and severity of allergic diseases in many parts of Europe, notably where plant productivity increases (which is likely in Scotland due to the warmer temperatures). There are no estimates of these impacts and thus no valuation is possible. This could be a potentially important impact and represents a gap.

- **SH7: Risks to health from vector-borne pathogens**

Vector-borne diseases (VBDs) refer to infections transmitted by the bite of blood-sucking arthropods such as mosquitoes or ticks. These species are sensitive to climatic factors, and climate change has the potential to change prevalence (range) and occurrence. In Europe, tick borne diseases are most important currently (Tick-borne encephalitis (TBE) and Lyme disease), that latter of which is prevalent in the UK (TBE is not currently a risk).

Currently the incidence of Lyme disease is low in Scotland though there is evidence numbers are increasing (though this will be due to many factors). The number of cases of Lyme borreliosis in Scotland remained low from 1996 (n=27) until 2003 (n=52) but then rose steadily to a peak of 440 cases in 2010 (Mavin et al, 2015). It is likely that the range of the ticks will increase in Scotland with climate change, and thus the incidence is likely to increase though there are no quantified estimates of the potential increase.

There are risks of mosquito borne disease emerging in Europe, notably malaria, dengue fever, west Nile virus and Chikungunya, but these risks are considered low because of effective vector control measures already in place. However, in the longer-term, there is the potential for climate change to facilitate the expansion of either vectors or current parasites responsible for disease into Europe. Given Scotland's geographical position, the risks of these changes are considered low.

- **SH8: Risks to Sport and leisure activities from severe weather, higher temperatures and increased precipitation**

There are potential positive as well as negative impacts from changes in weather extremes and climate on sport and leisure activities. There is currently a lack of information in the literature on these, but they are likely to be low relative to other categories.

Other health risks

There are a number of other health impacts that are not considered in the Climate Ready Clyde list.

Salmonellosis is an important cause of food borne illness in Europe and is sensitive to ambient temperature: increases in incidence are therefore expected with climate change. However, cases of Salmonella are decreasing, because of improved food hygiene. There are some other food borne diseases, but none of these are considered a high risk (from climate induced change).

The impacts of water borne disease primarily arise from extremes (floods and droughts) affecting water quality and availability. They are highly site specific and follow complex indirect pathways, thus are not well assessed. There are country studies of climate related impacts: these do not find high health impacts, but they do highlight that the costs of additional water treatment could be high.

THEME 4 – NATURAL ENVIRONMENT

Agriculture and Forestry

- **NE1: Risks from changes in agricultural productivity and land suitability**
- **NE2: Risks to soils from increased seasonal aridity and wetness**
- **NE3: Risks from changes in forest productivity and land suitability**
- **NE8: Risks of land management practices exacerbating flood risk**
- **NE9: Risks to agriculture, forestry, landscapes and wildlife from pests, pathogens and invasive species**
- **NE10: Risks to agriculture, forestry, landscapes and heritage from changes in frequency and/or magnitude of extreme weather and wildfire events**
- **NE13: Opportunities from changes in agricultural productivity and land suitability**
- **NE14: Opportunities from changes in forest productivity and land suitability**

Although the primary focus of this study is on urban issues, the Glasgow region also encompasses rural areas for which some additional impacts arise. In particular, agriculture and forestry dominate non-urban land use, with farming occupying around 200k hectares and forestry a further 57k ha (most of which is dedicated woodland, but some on farmland and some within urban areas).

The combination of soils, topography and climate mean that the region is best suited to livestock production rather than cropping, and this is reflected in both the dominance of grassland and rough grazing but also in the types of farming systems present: of around 3100 farm holdings, over 2400 are for cattle and sheep and a further 110 for dairying but only around 100 for crop or horticultural production. Total agricultural employment is around 2700 Full Time Equivalents (FTEs), total output is around £118m and Gross Value Added (GVA) perhaps £40m[23]. Less detail is available for regional forestry activities, but simple pro-rata area estimation from national figures[24] would suggest employment of around 200 and GVA of around £11m (CJC, 2015).

The costs and benefits of climate change and adaptation activities in Scottish agriculture and forestry have yet to be quantified, but potential effects have been identified qualitatively.[25] In particular, it is apparent that moderate warming will benefit biological-based production systems by extending the growing season and potentially raising yields, plus possibly increasing the range of crop and tree species that can be grown. This suggests that adaptation actions involving changing the seasonal timing of management activities will be

23 Agricultural GVA is not reported at the LA-level, but pro-rata from national figures gives a crude indication.

24 NB. pro-rata applied to sub-set of categories, to exclude wider supply-chain (as for agriculture).

25 e.g. https://www.adaptationscotland.org.uk/why-adapt/impacts-scotland; https://www.forestry.gov.uk/fr/climatechangescotland. See also: Reidsma et al. (2010)

Table 40. Agricultural and Forestry Land Areas (hectares). (Source: pers. comm, (2018) Scottish Government and Forestry Commission Scotland).

Local Authority	Farmland Area	Crops	Grasslan	Rough Grazing	Total Forestry	Of which on farm
East Dunbartonshire	10309	661	4050	3415	2791	*1553*
East Renfrewshire	11927	92	7301	3713	2030	*584*
Glasgow City	1311	0	551	9	1627	*704*
Inverclyde	11369	57	4379	6108	2014	*586*
North Lanarkshire	28223	1882	15370	4742	10038	*3875*
Renfrewshire	15026	1089	9290	3121	3263	*1448*
South Lanarkshire	131475	5987	59606	5378	31729	*8509*
West Dunbartonshire	8962	180	4660	2944	3553	*921*
Grand Total	**218601**	**9949**	**105207**	**77834**	**57045**	***18180***

required, possibly extending to introduction of new activities, but with anticipated positive impacts on employment and production.

However, whilst moderate warming may be welcome, more extreme increases in temperature – either in general or during specific heatwaves – will lead to heat stress which reduces plant and animal growth rates. This is particularly the case if water availability is reduced, for example during drought periods – although these risks are considered low for the region (compared to other parts of the UK). Nonetheless, adaptation may need to include selection of crop and tree species and livestock breeds with greater tolerance of heat stress and/or construction of (especially) on-farm water storage and distribution systems.

Climate change is also anticipated to increase the incidence of various pests and diseases affecting agriculture and forestry. This is a potentially important risk. As such, prudent adaptive responses include increased capacity for monitoring/surveillance of risks plus adoption of measures to alleviate or avoid damage. For example, more regular screening of fields/plantations/herds and identification of appropriate controls. The latter may, again, involve selection of different plant and livestock varieties with less susceptibility to increased pest and diseases risks.

Beyond the effects of climate change on commodity production, consideration also needs to be given to the range of broader ecosystem services associated with agriculture and forestry. For example, land management influences landscapes in terms of cultural enjoyment and ecological processes, and climate change will affect these as well as food and timber production. In particular, warmer temperatures will shift the geographical range of plant and animal species and may do so too rapidly for natural migration to occur.

In this case, adaptive responses to either protect existing habitats and/or improve habitat connectivity to facilitate migration may be feasible. For example, using trees to provide shade, providing supplementary feed crops and maintaining habitat corridors. The study region contains some international and domestic statutory environmental designations, plus encompasses a number of Local Nature Reserves and as Country Parks, and hence adaptation measures directed at biodiversity, habitats and landscapes are relevant.

Impacts on agricultural and forestry can also affect urban areas in other ways. For example, natural flood management involving changes to rural land use can delay and/or reduce surface water peak flows. Equally, renewable energy in the form of wind and hydro power plus biofuel feedstocks is typically located on agricultural or forestry sites. Rumble et al. (2015) estimate that urban trees deliver ecosystem services worth £4.5m/year within Glasgow.

Encouraging appropriate adaptations in agriculture and forestry is dependent upon the capacity of private land managers in terms of their awareness of likely challenges and opportunities plus their ability to respond, which may be constrained by a lack of relevant skills and/or access to funding. This suggests a policy role for advisory and training services plus grant-aid.

In addition, agriculture is currently influenced strongly by support under the Common Agricultural Policy. The Scottish Land Strategy[26] already exits to encourage discussion of priorities and trade-offs between different land uses and may have a role to play in helping to progress agricultural and forestry adaptations.

The potential risks and opportunities were outlined in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA). However, given the estimated agricultural and forest GVA for the region, climate change is unlikely to have very high economic cost, certainly when compared to the urban impacts documented elsewhere in this report. Nevertheless, they could still be important local impacts or benefits.

- **NE6: Risks to agriculture and wildlife from water scarcity and flooding**

The FRM strategy (2015) identified the agriculture land at risk of flooding and estimated annual damage. This found for Clyde and Loch Lomond Local Plan District:

- For river flooding, 92 km2 of agricultural land at risk, with average annual damages to agriculture of £180,000;
- For coastal flooding, 9 km2 of agricultural land at risk, with average annual damages to agriculture of £16,000.

26 See www.gov.scot/Topics/Environment/Countryside/Landusestrategy

The increased risk of flooding from climate change would affect these land areas, increasing them by around 40% and 80% respectively. However, the marginal economic costs from climate change would be low relative to property damage, and the benefits to agricultural production (e.g. longer growing seasons, reduced frost days) would also compensate for these increases.

As highlighted earlier, the region is expected to have a water supply surplus, so water scarcity is not considered an issue.

The risks from land management on flooding is an issue for Scotland, but given the agricultural land in the region is of relatively low value, this is not considered a major economic impact.

Natural Environment including Marine and Coastal

- **NE4: Risks to species and habitats due to inability to respond to changing climatic conditions**
- **NE5: Risks to natural carbon stores and carbon sequestration**
- **NE7: Risks to freshwater fish species from higher water temperature, phenology and changes to hydrological regimes**
- **NE15: Opportunities from new species colonisations**
- **NE11: Risks to the natural environment from sea level rise**
- **NE12: Risks and opportunities for marine species, fisheries and marine heritage from ocean acidification and higher water temperatures**

Climate change poses very large risks to terrestrial, aquatic and marine biodiversity and the ecosystem services they provide (provisioning, regulating, cultural and supporting services). It will shift geographic ranges, seasonal activities, migration patterns, reproduction, growth, abundance and species interactions, and will increase the rate of species extinction, especially in the second half of the 21st century (Settele et al., 2014). As well as terrestrial ecosystems, there are potentially large impacts on marine ecosystems, including nutrient cycling, carbon storage and phytoplankton stocks, from ocean acidification, ocean warming and sea-level rise, as well as impacts on freshwater ecosystems (rivers and lakes). Geological features may also be at climate-induced risk from flooding, sea-level rise and erosion.

The potential risks and opportunities were outlined in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA).

However, this remains one of the most challenging areas for economic analysis. As noted by others (e.g. Suggitt et al., 2015), there remains a lack of quantitative studies on the physical impacts of climate change on biodiversity and ecosystem services, making it difficult to undertake subsequent economic costings. In particular, data on current conditions are often incomplete whilst qualitative descriptions of likely changes are rarely accompanied by quantification of either the magnitude of change or the pace with which it might occur. This hinders attempts to estimate economic implications and represents a research gap that needs to be addressed.

Where information on biophysical impacts does exist, economic analysis is often made difficult by a lack of relevant price data to represent the economic significance of any biophysical changes. This reflects the fact that most ecosystem services are generally not captured by market prices, which makes valuation challenging. Non-market measures of the willingness to pay (to avoid impacts) can be used, though these are highly specific and are difficult and resource intensive to obtain, though the valuation literature has been advanced under The Economics of Ecosystems and Biodiversity initiative (TEEB, 2009: TEEB 2010). There are also challenges for valuation given the risk that climate change may lead to non-marginal changes.

At the aggregate level, previous work has generated estimates of the current monetary value of ecosystem functions for Scotland to derive a current annual ecosystem service value of approximately £17 billion (Williams et al., 2003). However, this is primarily delivered through rural and coastal areas, and urban areas will not be as rich in biodiversity and ecosystem services, thus this value cannot be directly downscaled to the Glasgow city region context. Nevertheless, the potential value of urban and coastal ecosystem services in the area could be potentially large.

There has also been some qualitative analysis of the monetary valuation of climate change impacts on the natural environment (terrestrial, freshwater and marine) for Scotland as part of CCRA1 (PWA, 2012).

This highlighted high uncertainty, but indicated that for Scotland overall, these impacts could be significant in monetary terms. However, these costs were mostly associated with the rural environment, and therefore the relative impacts in the Glasgow region would be low. The analysis did provide quantified estimates of the economic costs for forestry, but again, for the GCR, these will translate into low local costs, given the small area of land under forestry.

One example for which some economic analysis has been conducted is the case of peatlands. These play an important role in climate regulation through their store of carbon, but also deliver a range of other ecosystem services including water regulation and recreation, plus they provide habitats for a range of plant and animal species. Unfortunately, degradation due to a range of land management practices such as burning, draining and over-grazing has impaired service delivery from many peatlands, and placed them at risk of further degradation from climate change (Smyth et al., 2015). Recognition of the degraded state of many peatlands and of the benefits lost as a result has prompted UK-wide efforts to restore peatlands and has prompted economic analysis of the costs and benefits of doing so, including in Scotland.

Glenk & Martin-Ortega (2018) report use of an online stated-preference survey of 2000 people to value carbon, water and wildlife benefits arising from restoration activities under Peatland Action in Scotland. Estimated valuations ranged between £127/ha/year and £414/ha/year, depending on the type and location of restoration considered. If the upper-bound is interpreted as applying to more degraded sites and the lower-bound to mildly degraded sites, then the difference in valuation (£287/ha/yr) indicates the magnitude of damage costs arising from further degradation. By extension, given that climate change is anticipated to accelerate degradation of unrestored sites, the valuation difference may be interpreted as a crude indicator of the damage costs likely to arise from climate change if restoration is not undertaken.[27]

Combining these valuations with estimates of the extent of peatlands within the Glasgow City Region of between around 25k ha and 36k ha, implies aggregate restoration benefits of the order of £3.2 million to £14.9 million and an estimate of future climate-induced damage costs of £7.5million/yr to £10.3 million/yr. More refined estimates would require more detailed information on current site conditions and degradation time-paths but, although somewhat crude, such figures do give an indication of the order of magnitude of possible damage costs.

27 Functioning peatlands can self-adapt to climate change through adjustments to the mix of (e.g.) sphagnum species present. Degraded peatlands lack this capacity and hence are susceptible to further, and likely accelerating, degradation through climate-change effects.

THEME 5 – BUSINESS AND INDUSTRY

The next theme relates to the effects of climate change on business and industry. This is a particular focus because Glasgow City Region is a key engine of economic growth for both the Scottish and UK economies, generating around 33% of Scotland's Gross Value Added, 33% of Scottish jobs and is home to over 29% of all businesses in Scotland (GCR, 2016).

- **BI1: Risk to new and existing business sites from river, surface water and coastal flooding.**

This risk is captured in Theme 2, as this includes non-residential properties. It is highlighted that these potential risks are the most important risk of climate change for the business and industrial activities in the city region. There are large economic costs – as expressed as annual average damage – currently for non-residential properties in the city and these are projected to increase with future climate change. The analysis was detailed under theme 2 and summarised below. Note that the estimates of current AAD and future risks will be revised in the near future with the forthcoming revised National Flood Risk Assessment (NFRA).

- **BI2: Risks to business operations from water scarcity**

As highlighted in Theme 1, there is an anticipated water surplus for the region. There are therefore not significant risks to business operations from water scarcity.

- **BI3: Risks to business from reduced employee productivity due to infrastructure disruption and higher temperatures in working environments**

There are a number of potential effects here, discussed in turn below. The first is associated with outdoor working, and the occupational health impacts from either reduced productivity at higher temperatures, or else interruptions to work due to exceedance of occupational standards.

There is an existing literature on the relationship between heat and humidity and daily labour productivity (Kjellstrom et al., 2009). Analysis at the European scale identifies important economic costs for Southern Europe (Kovats et al, 2012), but negligible effects for Northern Europe and thus Scotland. In term of indoor working, there are existing occupational standards for heat, but these are unlikely to be exceeded in Scotland.

At less extreme high temperature, there may be issues with comfort levels, which will either result in increased cooling demand (see earlier) or reduced productivity. Earlier work linked productivity levels to external temperature (CEBR, 2003) and found that productivity falls by 8% at 26°C and by 29% at 32°C. However, for Glasgow, there are only an additional 2 days over 25°C per year by the 2020s and 15 days by the 2080s (medium scenario) and no days above 30C. The level of productivity losses from higher temperatures are therefore considered to be low. Indeed, there are likely to be greater productivity benefits from reduced frost, snow and ice.

- **BI4: Risks to business from disruption to supply chains and distribution networks**

There is an emerging theme of disruption to supply chains and distribution networks, and this is a particular issue from flood related events. The main issues are likely to arise from transport related disruption (see theme 1) from the flood risks to transport.

There are also some impacts that may arise outside the region, in Scotland, that subsequently affect businesses based in the GCR, such as impacts to the Whisky (food and drink) industry.

Table 41. Estimated current and indicative future AAD under climate change (2080s) for business properties. Current damage from FRM Strategy (SEPA, 2015) plus future climate increase (estimates this study).

Category	River Flooding £Million/yr		Coastal Flooding £Million/yr		Surface Flooding £Million/yr	
	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)
Non-residential	6.4	10.3 (3.9)	11	20.3 (9.3)	8.8	11.9 (3.1)

- **BI5: Opportunities for products and services to support adaptation to climate change**

The potential opportunities have been considered in a parallel study by K-Matrix.

- **BI6: Increased tourism revenue from increased temperatures**

The primary benefit of increased temperatures on tourist demand occurs with beach tourism, as a key factor in tourism comfort index (TCI). This is not relevant for Glasgow. The impact of temperature on broader city and cultural tourism is less apparent. The reduction in cold weather and snow, as well as warmer summer temperatures, would have some potential benefits, though these are considered low, i.e. the climate is not a particularly important factor in visiting Glasgow. There are, however, potentially wider tourism benefits for Scotland from climate change that would have benefits for tourism in the Glasgow region as a tourism hub.

THEME 6 – INTERNATIONAL AND CROSS-CUTTING

- **It1: Risks from weather-related shocks to international food production and trade**
- **It2: Imported food safety risks**
- **It3: Risks and opportunities from long-term, climate-related changes in global food production**
- **It4: Risks to the UK from climate-related international human displacements**
- **It5: Risks to the UK from international violent conflict**
- **It6: Risks to international law and governance**
- **It7: Opportunities from changes in international trade routes**

There are a range of potential impacts that could arise internationally that would affect Scotland and the Glasgow region. The table below – adapted from Watkiss and Hunt (2012) – summarises a range of climate change risks that could impact on the UK and therefore on Glasgow City Region, though they originate in other countries. Column 3 identifies where risks in the draft Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA) coincide with the risks identified for the UK. It also identifies sectors that are either a significant employer currently, or that are highlighted as future growth sector in the new Glasgow Economic Strategy.

The table finds that while there are some issues identified, these do not appear to raise very high economic costs, given the nature of the Glasgow economy and primary sectors.

Table 42. Overview of International Climate Change Impacts and Effects on the UK and Glasgow.

Climatic variable(s) leading to climate impact	Potential Sectoral Climatic Impact(s) Identified – UK	Relevance of UK risks to Glasgow region (main employment and growth sectors)	Cross-Sectoral linkages	Key Uncertainties
Agriculture and forestry				
Higher global mean temperatures	Permanent changes in global crop production patterns leading to: a) changes in UK trading patterns with primary product suppliers; b) higher food prices faced by UK consumers	It3: Risks and opportunities from long-term, climate-related changes in global food production. Wholesale and Retail trade	Water resources; Ecosystem services	Pattern of climatic change (extent and timing) and impacts interaction with socio-economic change e.g. technological changes in production
Extreme weather events: precipitation or temperature	Temporary changes in food output for domestic population leading to food poverty and associated population movements and/ or conflict. Migration pressures and security concerns for UK	It1: Risks from weather-related shocks to international food production and trade.	Water resources; Ecosystem services.	As previous.
Fisheries				
Higher global mean temperatures	Permanent changes in global patterns of fish stocks leading to changing relative prices of fish in UK	It1: Risks from weather-related shocks to international food production and trade. Wholesale and Retail trade	Tourism; General economic development.	Impacts may be dominated by fish resource pressure, and attendant regulatory regimes, not associated with climate change
Energy				
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to energy infrastructures and their operation internationally that prevent energy transmission to UK. Damage to energy infrastructure assets owned by UK companies.		General economic development.	Technological change and geo-political changes may over-ride climate considerations.

Climatic variable(s) leading to climate impact	Potential Sectoral Climatic Impact(s) Identified – UK	Relevance of UK risks to Glasgow region (main employment and growth sectors)	Cross-Sectoral linkages	Key Uncertainties
Transport Infrastructure				
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to transport infrastructures and their operation internationally that impact adversely on product supply chains to UK or to UK-owned businesses operating abroad.	It1: Risks from weather-related shocks to international food production and trade. Wholesale and Retail trade Business and professional services	General economic development.	Socio-economic change, including shifting patterns of consumer demand, may over-ride climate considerations.
Tourism				
Higher global mean temperatures	Changes in regional and global patterns of tourist movements intra-annually.	Tourism	General economic development.	Socio-economic change, including changes in income levels may dominate climatic factors.
Industry				
Higher global mean temperatures; changes in precipitation	For UK-owned industry: Adverse impacts on labour force productivity in hot weather. Availability & quality of raw materials for manufacturing may decline	It7: Opportunities from changes in international trade routes. Wholesale and Retail trade Business and professional services	General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan. Consumer demand patterns dominate.
Extreme weather events: precipitation, wind or temperature; storm surge.	Damage or disruption to industrial infrastructures and their operation internationally that impact adversely on product supply chains to UK or to UK-owned businesses operating abroad.	Wholesale and Retail trade Business and professional services	General economic development.	Socio-economic change, including shifting patterns of consumer demand, may over-ride climate considerations.
Financial Services				
Higher global mean temperatures; changes in precipitation	Adverse impacts on financial services sector are indirect and are determined by the extent that physical assets and business operations overseas are effectively owned by banks through their lending policy to UK-owned companies.	Business and professional services	Construction; Planning; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan.
Extreme weather events: precipitation, wind or temperature; storm surge.	Adverse impacts on financial services sector are indirect and are determined by the extent that physical assets and business operations overseas are given insurance coverage.	Business and professional services	Construction; Planning; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan.

Climatic variable(s) leading to climate impact	Potential Sectoral Climatic Impact(s) Identified – UK	Relevance of UK risks to Glasgow region (main employment and growth sectors)	Cross-Sectoral linkages	Key Uncertainties
Health				
Higher global mean temperatures; changes in precipitation	Decline in agricultural productivity and/or supply of water resources may lead to fall in public health in some regions leading to increased need for international development assistance.		Water resources; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan, exacerbated by uncertainties in socio-economic change.
Extreme weather events: precipitation, wind or temperature; storm surge.	Extreme events may lead to malnutrition, starvation, and associated need for emergency aid.		Agriculture; General economic development.	Pattern of climatic change (extent and timing) uncertain so difficult to plan, exacerbated by uncertainties in socio-economic change.
Ecosystem Services				
Higher global mean temperatures; changes in precipitation	Provisioning services of ecosystems e.g. as supplier of raw materials and waste management processes overseas may decline and affect UK-owned business operating in these areas or that make use of such resources. Support functions may deteriorate leading to migration or resource conflict and associated impacts on UK.	It4: Risks to the UK from climate-related international human displacements. It5: Risks to the UK from international violent conflict.	Water resources; General economic development.	Socio-economic change, including population growth and technological change, may result in increased demand for ecosystem services that dominate climate factors.
Water resources				
Higher global mean temperatures; changes in precipitation	Declines in water availability lead to changes in a number of sectors, as indicated in other parts of the table, and including many aspects of human livelihood.	It4: Risks to the UK from climate-related international human displacements. It5: Risks to the UK from international violent conflict.	Ecosystem services; General economic development.	Socio-economic change, including population growth and technological change, likely to exacerbate climate factors.
Sea-Level Rise				
Higher global mean temperatures; storm surges	Sea-water inundation may lead to loss of land and associated socio-economic activity, with pressures to relocate/migrate away from coast. Associated impacts on UK.	It4: Risks to the UK from climate-related international human displacements. It5: Risks to the UK from international violent conflict.	General economic development.	Socio-economic change, including population growth, likely to exacerbate climate factors.

Summary of Economic Costs and Benefits

The previous chapters provide an overview of the economic costs and benefits from climate change for the 60 or so risks and opportunities in Glasgow City Region Climate Risk and Opportunity Assessment. The results are brought together and presented in the figure below. This shows a synthesis of the <u>total</u> possible impacts of current economic costs from weather and climate variability and the additional costs of climate change (combined). Details on the marginal impact of climate change are presented in the previous chapter.

It is stressed that in many cases, quantified information does not exist on the impacts of climate change, which makes valuation extremely challenging. In these cases, indicative estimates of the order of magnitude have been made using the available information and expert judgement. However, for some categories, the lack of information has made even these estimates difficult, and in these cases, gaps are included: this was a particular issue for the natural environment theme.

It is highlighted that value for river, surface and coastal flooding will be updated in the forthcoming second National Flood Risk Assessment (NFRA).

The study has also made an initial mapping of the potential international risks to the region (theme 6). While there are some issues identified, these do not appear to raise very high economic costs, given the nature of the Glasgow economy and primary sectors.

Figure 6 Total Economic Costs of Current Climate Extremes and Future Climate Change for the Glasgow City Region.

IMPACT			BENEFIT		
N	Negligble				
-L	Low	<£0.5 million/yr	+L	Low	<£0.5 million/yr
-M	Medium	£0.5 - 5 million/yr	+M	Medium	£0.5 - 5 million/yr
-H	High	£5 - 25 million/yr	+H	High	£5 - 25 million/yr
-VH	Very high	>£25 million/yr	+VH	Very high	>£25 million/yr

min Ext risk = Extreme event with minor impacts
Maj Ext risk = Extreme event with major ($/HH) impacts

	CURRENT		2020s	2050s	2080s
THEME 1 - INFRASTRUCTURE					
In1: Risks of cascading failures from interdependent infrastructure networks	Uncertain	*Maj Ext risk	Uncertain		
In2: Risks to infrastructure services from river, surface water and groundwater flooding	-M	*Maj Ext risk	-M	-M	-H
In3: Risks to infrastructure services from coastal flooding and erosion	-M	*Maj Ext risk	-M	-M	-M
In4: Risks of sewer flooding due to heavy rainfall	Uncertain	*Maj Ext risk	Uncertain but potenitally high		
In5: Risks to bridges and pipelines from high river flows and bank erosion	-L	*min Ext risk	-L	-L	-L
In6: Risks to transport networks from slope and embankment failure	-L	*Maj Ext risk	-L	-L	-L
In7: Risks to subterranean and surface infrastructure from subsidence	Uncertain		-L	-L	-L
In8: Risks to energy, transport and ICT infrastructure from storms and high waves	-M	*Maj Ext risk	-M	-M	-M
In9: Risks to transport, digital and energy infrastructure from extreme heat		*min Ext risk		-L	-L
In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season	-M		-M	-M	-M
In11: Risks to infrastructure from wildfires				-L	-L
In12: Risks to water-based transport and trade infrastructure (ports, canals, harbours, etc.) from SLR	Uncertain				
In13: Potential benefits to water, transport, digital, energy infrastructure from reduced extreme cold	Uncertain				
THEME 2 - BUILT ENVIRONMENT					
BE1. Risks to homes from flooding	-VH	*Maj Ext risk	-VH	-VH	-VH
BE2. Risks to building fabric from moisture, wind, storms and driving rain	-L	*Maj Ext risk	-L	-L	-L
BE3. Risks to significant heritage properties from landslides, flooding or coastal erosion	Uncertain				
BE4. Risks to traditional and historic buildings from moisture, wind and driving rain	Uncertain				
BE5. Increased maintenance of green space due to rising temperatures and severe weather	Uncertain				
BE6. Increased cooling demand in buildings as a result of rising temperatures	-L		-L	-L	-H
BE7. Risks to homes from sea level rise	captured in flooding above				
BE8. Risk of overheating of buildings from increased energy efficiency/insulation					
BE9. Potential for improved physical and mental health from increased use of parks and green space			+L	+L	+L
BE10. Opportunities for local food growing from warmer temperatures and increased growing season			+L	+L	+L
BE11. Reduced heating demand to buildings from rising temperatures	+VH		+VH	+VH	+VH
BE12. Increased viability of renewable electricity and heat from changing weather conditions			-L	-L	-L

	CURRENT		2020s	2050s	2080s
THEME 3 - COMMUNITIES AND HEALTH					
CH1: Risks to people and communities from flooding	-L		-L	-M	-M
CH2: Increase in summer temperatures and heatwaves leading to increased morbidity and mortality	-L	*Maj Ext risk	-M	-M	-M
CH3: Risks to business continuity of health and social care from extreme weather	Uncertain		Uncertain but potenitally high		
CH4: Increased patient demand on NHS services from high winds, snow and ice, floods, cold weather			-L	-L	-L
CH5: Risks to the viability of coastal communities from sea level rise	partly captured in flooding				
CH6: Risks to health from changes in air quality	-L		-L	-L	-L
Risks to health from changes in air quality (aero-allergens)	Not quantified				
CH7: Risks to health from vector-borne pathogens	-L		Uncertain		
CH8: Risks to Sport and leisure activities from severe weather, higher temp and increased prec			-L	-L	-L
CH9: Potential benefits to health and wellbeing from reduced cold			+VH	+VH	+VH
THEME 4 - NATURAL ENVIRONMENT					
NE1: Risks from changes in agricultural productivity and land suitability	Not quantified				
NE2: Risks to soils from increased seasonal aridity and wetness	Not quantified				
NE3: Risks from changes in forest productivity and land suitability	-L		-L	-L	-L
NE4: Risks to species and habitats due to inability to respond to changing climatic conditions	Not quantified				
NE5: Risks to natural carbon stores and carbon sequestration	Not quantified				
NE6: Risks to agriculture and wildlife from water scarcity and flooding	-L		-L	-L	-L
NE7: Risks to freshwater fish species from higher water temperature, phenology	Not quantified				
NE8: Risks of land management practices exacerbating flood risk	Not quantified				
NE9: Risks to agriculture, forestry, landscapes and wildlife from pests, pathogens and invasive sp	Not quantified				
NE10: Risks to agriculture, forestry, landscapes and heritage from changes in extremes and wildfire	Not quantified				
NE11: Risks to the natural environment from sea level rise	Not quantified				
NE12: Risks and opportunities for marine species, fisheries and heritage from ocean acidification	Not quantified				
NE13: Opportunities from changes in agricultural productivity and land suitability	Not quantified				
NE14: Opportunities from changes in forest productivity and land suitability	Not quantified				
NE15: Opportunities from new species colonisations	Not quantified				
THEME 5 - BUSINESS AND INDUSTRY					
BI1: Risk to new and existing business sites from river, surface water and coastal flooding.	-VH	*Maj Ext risk	-VH	-VH	-VH
BI2: Risks to business operations from water scarcity	N		N	-L	-L
BI3: Risks to business from reduced employee productivity	-L		-L	-L	-L
BI4: Risks to business from disruption to supply chains and distribution networks	Uncertain		Uncertain but potenitally high		
BI5: Opportunities for products and services to support adaptation to climate change	This will be covered in the K-Matrix report				
BI6: Increased tourism revenue from increased temperatures			+L	+L	+L

Analysis and discussion of key risks and opportunities

The analysis has found that the future economic costs of climate change are likely to be dominated by a small number of risk categories. These are:

- River, surface and coastal floods leading to property damage for residential houses;
- River, surface and coastal floods leading to property damage for business and industry;
- And to a lesser extent, flood related disruption to transport (road and rail), including damage to infrastructure and impacts on travel time.

These impacts will all lead to large financial as well as economic costs. It is stressed that many of these economic impacts will disproportionally affect socially deprived and vulnerable groups. There are also strong geographical patterns for the distribution of risks across different authorities, reflecting differentiated flood risks. There are also potentially significant economic costs (non-market) from increasing heat extremes (health related mortality and morbidity) in the longer term.

It is highlighted that there is a lack of quantifiable estimates for some categories, notably the natural environment theme. While the direct contribution of agriculture, forestry and the natural environment to the economy is low in Glasgow City Region (due to the predominately urban land area), the potential impact on ecosystem services (non-market) could be potentially large.

The results also show, however, that there will be large economic benefits for the Glasgow region. Again, these are dominated by a small number of categories, notably:

- Large financial and economic benefits in terms of reduced winter energy use for heating, for both the residential sector and business/industry;
- Large economic benefits from reduced cold related health impacts;
- And to a lesser extent, financial and economic benefits from reduced cold weather-related expenditure and disruption for infrastructure and transport.

These benefits will also fall disproportionally to socially deprived and vulnerable groups, however, they are more evenly spread across all geographical areas of the City Region.

Wider economic impacts

As highlighted in the previous chapter, the economic impacts of extreme weather events – whether experienced today or in terms of increased risks from climate change – will include both direct and indirect effects.

The increases in extreme events from climate change will therefore have larger impacts than the values presented in the table above, in cases where there are large scale events that impact on the regional economy. Similarly, the changes in household income, such as from reduced heating demand, could have important induced effects on the regional economy.

Multipliers do exist for the Glasgow area, disaggregated on a sectoral basis. Most recently, these have been estimated by Hermannson (2016). These indicate a multiplier of around 1.5, which means for a very large-scale climate event, the economic costs could be 50% greater than the direct cost (e.g. as borne by households) alone. This would therefore feed through and impact regional GVA figures.

Aggregate impacts

Given the partial coverage of risks, it is difficult to aggregate all the 60 or so risks (and opportunities) and provide a headline economic cost of climate change for the Glasgow region. Nevertheless, it is possible to provide some insights into the potential scale of aggregate impact.

As outlined in the Glasgow City Region Economic Strategy 2017 – 2035 (GCR, 2016), Glasgow generates around one third of Scotland's Gross Value Added (GVA), estimated at over £40 billion. The results indicate that the annual economic costs of climate extremes and climate change by mid-century (2050s) in Glasgow City Region could be several hundred £million/year by the 2050s (for the combined impact of current extremes and future climate change). While this is high, it is modest when compared to the regional economy (i.e. around 1% of current GVA). Nonetheless, as these are annual damages, they will reduce regional growth. Furthermore, as highlighted above, many of these impacts will fall on disadvantaged and vulnerable groups.

The study also estimates that climate change will lead to large aggregate annual economic benefits for the region, primarily from the reduction in winter heating (reducing costs) and the reduction winter related mortality and morbidity (economic benefits). These economic benefits are likely to be of a similar order of magnitude to the economic impacts.

However, the consideration of annual costs only masks a very important finding. The result reveal that climate change will increase the likelihood (frequency) of large economic shocks from major extreme weather events. These will have very large one-off impacts in particular years, which are not adequately captured when presenting average annual impacts.

River, coastal and surface water floods, and to a lesser extent windstorms, are all projected to increase in the Glasgow City region due to climate change, and there is a greater likelihood of large events with vary large direct costs. As outlined above, these events are also likely to lead to large indirect costs (potentially increasing costs by 50%). Such events could have major impacts on infrastructure investment (such as the City Deal) and could have important implications for public budgets, because of the very large costs that fall in a particular year. They can also lead to extremely large costs for those affected, whether individuals or businesses.

Finally, the results reinforce the need to accelerate work on mitigation. The analysis of different mitigation and adaptation scenarios shows that the potential economic costs (overall and for extremes) would be significantly reduced under low emission pathway, i.e. consistent with 2°C of warming. They could also be significantly reduced with cost-effective adaptation.

Recommendations and Next Steps

This phase 1 study has assessed the potential economic costs and benefits of the risks and opportunities from climate change in the Glasgow City Region. It finds that climate change could have a material impact on the region. A number of recommendations are made in light of these findings:

- To consider future climate impacts as part of any refresh of the Regional Economy Strategy and Action plan;
- To consider future climate risks (climate risk screening), including the analysis of economic costs, in individual decisions on future investments in the City Region – notably within the City Deal – and to assess potential adaptation measures to reduce these costs;
- To consider the economic costs and benefits for the City Region adaptation strategy and other relevant plans, strategies and activities;
- To explore the potential for developing new finance mechanisms for adaptation.

The next phase of this study – phase 2 – will progress a number of these areas, investigating the potential economic case for adaptation. It will build on the information in this report to identify and assess strategic adaptation options for Glasgow City Region. It will also provide some headline estimates of the potential costs and benefits of adaptation, then undertake case studies to explore adaptation options using an iterative risk management approach.

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ABOUT CLIMATE READY CLYDE

Climate Ready Clyde is a cross-sector initiative funded by public and private member organisations and Scottish Government to create a shared vision, strategy and action plan for an adapting Glasgow City Region.

The Climate Ready Clyde programme is managed and delivered by Scottish sustainability charity Sniffer

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