Economic Implications of Climate Change for Glasgow City Region

Part 2 - Adaptation Report

Report by

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То

Climate Ready Clyde

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ABOUT CLIMATE READY CLYDE

Climate Ready Clyde is a cross-sector initiative funded by the Scottish Government and 15 member organisations to create a shared vision, strategy and action plan for an adapting Glasgow City Region.

Climate Ready Clyde is governed and steered by a board comprising senior representatives from each of the funding organisations. The board is supported by a small secretariat who lead the implementation on their behalf. The Climate Ready Clyde secretariat is managed and delivered by Scottish sustainability charity Sniffer.



EXECUTIVE SUMMARY

This report presents the second 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 overall study is to address the current gap on the economic impacts of climate change for Glasgow City Region.

The first phase of the study identified that climate change is an important economic and financial risk for Glasgow City Region. The aim of the second phase of the study is to provide information on the economic benefits of managing these risks and adapting successfully. This initial assessment can be used by CRC and partners to support the development of more detailed business cases in priority adaptation areas.

The report presents a draft Climate Change Adaptation Framework, to help structure early resilience measures for Glasgow City Region. This sets out how to assess where early action is needed – and identifies three early priorities. The paper then presents case study applications for each of these, drawing on international best practice to showcase these approaches for the Glasgow City Region.

Overall framework for adaptation

The study first developed a framework for adaptation. This focuses on early adaptation decisions, which might be introduced over the next five or so years, to address short, medium and long-term climate risks. The framework is designed to help identify those options that have a strong economic justification. It focuses on three different types of priorities:

- Addressing the existing adaptation gap by implementing 'no-regret' or 'low-regret' actions to reduce risks from current climate variability as well as building future climate resilience.
- Intervening early to ensure that adaptation is considered in decisions that have long lifetimes, such as major infrastructure developments, in order to avoid 'lock-in'.
- Fast-tracking early adaptation steps for decisions that have long lead times or involve major future change, using an adaptation pathways approach.

These approaches are complementary and together form an integrated approach for early adaptation. The framework builds on the approach used in the UK Climate Change Risk Assessment (CCRA) and the adaptation literature. It also aligns to national and regional public policy and project appraisal, but uses an extended cost-benefits analysis approach, recognising the additional challenges involved in adaptation.

Case study applications

The study has undertaken three case study applications, to demonstrate each of the areas above and to recommend ways forward for key aspects of managing Glasgow City Region's climate risks:

- 1. **Early no and low-regret adaptation -** An aggregate analysis that follows on from the phase 1 study (on the future economic costs of climate change in the region), assessing the potential costs and benefits of early adaptation for a number of the most important economic risks.
- 2. Climate Risk Management in long-term investment decisions and financing A high-level climate risk screening and enhanced resilience approach for major infrastructure developments

in the Glasgow City Region City Deal, which is also relevant to a much wider cross-section of public and private sector investment.

3. Long-term adaptation pathway planning - An adaptation pathway analysis for the Clyde Corridor, looking at an iterative framework and an adaptation route-map to address long-term risks from coastal flooding and sea level rise.

<u>Case study 1. No and low-regrets adaptation: costs and benefits including detailed analysis</u> The phase 1 study assessed the future economic costs of climate change in Glasgow City Region (the climate risks and opportunities in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA)). The first case study looked at these economic costs, and assessed the potential costs and benefits of reducing these impacts focusing on some of the largest economic risks.

For the built environment, the analysis has focused on flooding. The findings of the study are:

- While future economic costs of flooding (coastal, river and surface flooding) are projected to increase significantly with climate change in Glasgow City Region, there are adaptation measures that can reduce these impacts.
- There are a set of interventions that reduce the probability of flooding. These measures are estimated to significantly reduce future flood risk, but not remove it entirely. These have good benefit to cost ratios (typically 3:1), but would mean a large increase in flood defence expenditure in Glasgow City Region in future. Importantly, costs will rise as risk levels are reduced, so there is a trade-off between levels of risk and flood defence expenditure, which warrants early discussion (on the appropriate level of risk) with stakeholders.
- There are also household level options, for enhancing resilience and resistance. These are more cost-effective when fitted in new buildings. Analysis of the costs and benefits of these options suggests that resistance measures (that stop entry of water) could be cost-effective in all new build properties; some resilience measures (that reduce recovery time, so that the building can quickly be returned to use after the flooding) are cost-effective, but these depend on flood frequency. It is highlighted that there are barriers to the uptake of these measures, as they place the emphasis on properties, and would require more support to help the industry promote and 'sell' such measures to developers.
- Complementing these options, there is a role for enhanced early warning for floods, as these can deliver very high benefit to cost ratios. However, to be most effective, to ensure that users receive timely warnings but also know how to react to reduce losses.
- It is also stressed that for new housing and non-residential development, an important factor will be to ensure future flood risks are taken into account in siting and design.

For people and communities, the task has focused down on heat, as the findings highlight that:

- While current heat related health impacts in Glasgow City Region are low, these are projected to rise with climate change. The recent UKCP18 projections show an increase in (relative) heat waves in Scotland, and this could be a particular issue in Glasgow city due to the urban heat island. These would translate into economic costs from the increases in health-related mortality and morbidity, and the knock-on effects on the public health and social care systems.
- An analysis has been made of possible options to reduce these impacts, focusing on the potential for a Heat Health Watch System for Scotland and Glasgow City Region. The analysis has estimated the potential benefits of a scheme, and assessed the additional costs for the

health system in Glasgow City Region from its implementation. The analysis finds that such a scheme would be likely to have a high benefit to cost ratio. This has relevance for NHS Greater Glasgow and Clyde and NHS Lanarkshire health boards.

- It is highlighted that heat-related effects are most prevalent in the elderly, and a key early action should be to consider heat in the design of new hospitals and care homes to ensure these consider over-heating risks.
- Finally, given heat is a new issue for Glasgow City Region, it is highlighted that there is a need for more monitoring and research, to improve understanding of heat extremes in Glasgow City Region, and Glasgow city in particular.

The task has also looked at building overheating risk. It is stressed that building overheating is context and building specific, and thus it is difficult to generalise about future risks and adaptation. Nonetheless, it is obvious that buildings in the city region have – to date – been optimised to address cold rather than heat. The study has reviewed the literature on adaptation options to address heat. While measures are available, these do involve costs, and an initial economic analysis (cost-benefit analysis) highlights that it is difficult to justify these measures for all buildings in Glasgow City Region (currently) because of low levels of current risk. There is a slightly better case for considering overheating in new public building and residential housing stock in Glasgow due to the urban heat island effect, but even here, the dominant economic issue is to address cold. This might indicate a need to focus on ensuring buildings are built to ensure they do not increase the risk of over-heating, and perhaps the introduction of low-cost measures that can reduce overheating risks, as well as looking at measures that could provide heating savings as well as cooling (noting these have to be considered carefully to provide both benefits and minimise trade-offs).

The task has also reviewed the potential adaptation options for the themes of business and industry, as well as international risks. For all of these areas, businesses will take adaptation actions when the benefits of doing so outweigh their (private) costs. However, the complexity of business risks and supply chains multi-staged process, coupled with the uncertainty around climate change impacts, suggest that the private sector might struggle to take the appropriate actions. Glasgow City Region could therefore play a role in removing some of the barriers to enable and encourage private sector adaptation, notably by providing information and raising awareness.

<u>Case study 2.</u> Climate Risk Management in long-term investment decisions and financing There is growing awareness of the potential risks of climate change on infrastructure and urban development investments (climate risk assessment), across Government, developers and infrastructure providers, as well as the financial markets. There is also a recognition that failure to account for climate risks in investment decisions could lead to economic and financial impacts, either from weather related damage of assets, or from climate change affecting operating costs, performance and anticipated benefits. This reflects the fact that these investments have a long lifetime and so will be exposed to future climate change, but also because they are often difficult or costly to retrofit later, so it is useful to consider climate resilience in their design. This is sometimes called climate proofing.

As a result, climate risks are being factored into project safeguards and financial risk management. Indeed, many lending organisations – notably the most forward-thinking public investment and development banks - have already introduced climate risk management systems (CRMs) as part of their safeguard (due diligence) process. These systems assess project investments and assess their

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

level of climate risk, and if needed, they then assess and include adaptation (resilience) measures in the design. It is highlighted that Climate Ready Clyde has developed similar methods and processes with its toolkit to support the incorporation of climate adaptation infrastructure and built environment projects.

The second case study investigates the potential application of such a climate risk management and climate resilience (adaptation) approach to the Glasgow City Region, looking at the potential relevance and application for Glasgow City Region City Deal. The case study has been undertaken to develop a position paper on the potential need and opportunities for enhancing climate resilience in the City Deal process and portfolio. This builds on the existing initiatives on climate risk screening methods that are being used in investment appraisal by the public investment banks. These climate risk screening and adaptation assessments usually proceed through a two-step process.

The first step is an initial climate risk screening, which assesses whether a project is a low, medium or high climate risk. Projects that are assessed as medium and high risk are then investigated with a more detailed climate risk and adaptation assessment. The case study has undertaken a high- level climate risk screening of the projects included in the Glasgow City Region City Deal portfolio, assessing their level of potential risk. This finds that:

- All the existing infrastructure projects are a medium or high climate risk, i.e. if these projects went through a typical investment bank CRM, they would require a more detailed climate risk and adaptation assessment.
- In contrast, the skills and employment projects in City Deal were all screened as being low climate risk, and would not require further analysis.

The identification of medium and high risks does not necessarily mean that major threats exist or that costly adaptation is needed, but rather that there is need for further investigation. It is also stressed that some (possibly many) of these risks will have been addressed already as part of the design work (notably for projects that require planning permission, which are assessed for flood risk). The main cause of the medium and high ranking is the level of current and future flood risk in the Glasgow City Region.

The second step involves a more detailed climate risk and adaptation assessment. This involves a detailed project by project analysis of the climate risks, followed by the identification of possible climate resilience (adaptation) measures, with analysis of their costs and benefits. Within this short scoping study, it is not possible to undertake this level of analysis for all City Deal project due to the available resources. However, the analysis has looked at the main project investments in the infrastructure portfolio, focusing on road projects, coastal area development, and urban built environment, and investigated relevant issues. This has focused on:

- How important climate change could be for each project. This is influenced by the life-time and level of lock-in (the level or irreversibility in the investment decision);
- The importance of climate change on the economic and financial performance of projects; and
- Promising adaptation options.

The analysis also identified those projects in the City Deal portfolio that have longer life-times and greater lock-in should be priorities for adaptation, because of the higher risks and the greater need (but also the greater opportunity) to include resilience during their design. These include:

- Bridges (long life-time and lock-in). There are several projects with Bridge components;
- Siting decisions (new roads, siting of new rail stations, siting of park and ride, etc.), as these lockin development areas. These are involved in several projects.
- Long lived components of road projects, which includes culverts, tunnels. These will be relevant for most projects, although they may be a small part of the overall project.
- Coastline development and riverside investments.

The study has reviewed the potential economic and financial risks of climate change, at a general level for the various types of project investments in the City Deal portfolio. This assesses the potential risk on assets, operating costs and performance, benefits and revenues, and ultimately on the potential for projects to deliver the anticipated economic growth. This reflects a greater focus on these aspects in the financial markets, and by risk rating agencies. For all major infrastructure investments, there are potential risks to the economic objectives of City Deal projects, although it is difficult without more detailed analysis to assess how material these are. In some cases, these risks will have been addressed already, as part of the design standards and practice included for climate risks in infrastructure design in the UK. However, as the City Deal portfolio did not undertake a systematic review of climate risks, residual risks are likely to remain. This informs the later recommendations.

The final part of the analysis identified examples of climate resilience (adaptation) options that could address the potential climate risks in infrastructure projects, focusing on some of the key City Deal investments. It has also considered the potential costs and benefits of this action. The analysis finds the choice of climate resilient options in infrastructure investments needs to be carefully considered, because there are potential high costs. This means that the simple over-design of all infrastructure projects in City Deal is unlikely to be economic (in cost benefit terms).

To address these issues, the main investment banks have been piloting different approaches, that look at whether to make projects climate smart during their design, or whether to use alternatives that may be more cost-effective. The latter can include more focus on non-technical options, but also the introduction of flexibility in projects, so that they can be upgraded more easily later on. Complementing this, they are also making sure that current risks are adequately addressed with no and low-regret options, and introducing adaptive management, i.e. a process of monitoring and reviewing risks, that can inform future investment rounds. The introduction of this type of iterative risk management might be useful for Glasgow City Region. The exact options depend on the context, and would be considered as part of detailed project design and feasibility. However, there are a number of key areas which could be prioritised in design and delivery of City Deal projects.

Case Study 3. Long-term Adaptation Pathway planning

The final case study focuses on adaptation pathways, developing an adaptation pathway for coastal flooding for the Clyde Corridor. The case study started with a literature review to identify the various types of adaptation pathways, identifying four broad approaches:

- 1. Adaptation pathway frameworks or roadmaps;
- 2. Adaptive (iterative) management;
- 3. Adaptation tipping points and route maps (dynamic pathways); and
- 4. Adaptation landscapes.

While all of these consider the sequencing of adaptation over time, they vary in terms of iterative feedbacks and monitoring (adaptive management), the use of climate thresholds (route-maps), and the consideration of socio-institutional aspects (landscapes). They also have different applicability. The general frameworks can be applied at a strategic level or during a scoping phase, whereas adaptive management and dynamic route-maps are a form of decision making under uncertainty and thus align to a project level analysis (appraisal). The case study developed an illustrative application for the Clyde Corridor, looking at coastal flood risks.

The case study explored the potential for a medium-term planning approach (from the current to the 2050s) using an adaptation pathways framework, providing an example of a strategic approach for sequencing adaptation over time and identifying early priorities. This type of approach is considered particularly useful for Climate Ready Clyde.

The case study identifies possible tipping points, thresholds and policy options using a dynamic adaptation route map approach. This is focuses on long-term planning. It uses a more detailed method to look at long-term climate risks and adaptation responses under uncertainty. The case study has developed an illustrative adaptation route-map for coastal flooding in the Clyde Corridor, based on thresholds (unacceptable levels of properties at risk/annual damage), and showing different pathways linked to a monitoring programme.

This case study has provided some useful insights on the adaptation route-maps approach. It identifies the potential role of these methods for communicating an iterative approach, and that climate uncertainty is not a barrier to action. However, the case study has shown that these methods have high analytical complexity, require detailed modelling, are technical in nature, and require considerable time and resources, meaning such approaches should be applied proportionately.

Study Recommendations

Overall, the paper finds that the development of an adaptation framework, and the identification of early adaptation priorities (the three building blocks) would be extremely beneficial for the development of the regional Adaptation Strategy and Action Plan. This would help to identify the (urgent) actions that could be prioritised in the next plan cycle (i.e. next five years or so) and provide a strong economic rationale to ensure value for money.

Recommendations

- To consider the economic costs and benefits for the Glasgow City Region adaptation strategy and other relevant plans, strategies and activities, using the framework presented here to frame the analysis;
- To explore the potential for developing new finance mechanisms for adaptation.

Moving to the three applications, these demonstrate new adaptation thinking and apply this to the Glasgow City Region, with some recommendations for next steps in each area.

Early low and no-regret adaptation. There are early, low-regret options that can be introduced to help address current risks, which will also help build resilience to future climate change. The analysis identified a number of promising options and used detailed review, and initial economic analysis, to identify options with high benefits and low costs, i.e. options that could be introduced as

early quick wins in the forthcoming Adaptation Action Plan. This focused on additional options to address flood risks, as well as new measures to start preparing for the anticipated increase in heat (and heat-waves). The application demonstrated the use of economic analysis to help select promising options and build the case to justify action. Further work would be beneficial to develop these early priorities into business cases, to put forward as concrete actions in the emerging adaptation plan.

Recommendations

- To consider future climate impacts as part of any refresh of the Regional Economy Strategy and Action plan;
- To consider more detailed business cases for a number of the early priorities, notably around flooding, heat alerts and information (awareness raising).

Climate Change Risk Management in long-term investment decisions and financing. Addressing climate risks could be an important factor in the success of the City Deal project and subsequent similar infrastructure investments. It is highlighted that many of the risks identified will have been addressed in the existing design and feasibility studies for the existing City Deal project. However, the case study suggests that a more structured climate risk approach for City Deal might be useful going forward, particularly for the Gateway projects. It is therefore recommended that climate risk screening and potential fuller climate risk and adaptation assessment requirements are embedded into the City Deal assurance framework. These approaches would also be useful for subsequent investment projects in the Glasgow City Region.

Recommendations:

- To consider future climate risks (climate risk screening), including the analysis of economic costs, in individual decisions on future investments in Glasgow City Region notably within the future projects of the City Deal and to assess potential adaptation measures to reduce these costs;
- To consider the role for a screening framework as part of the new Regional Spatial Strategy and in Local Development Plans as well as in other relevant plans and strategies.

Long-term adaptation pathway planning. There is a valuable role for these methods in structuring and communicating a long-term and iterative approach, and to demonstrate that climate uncertainty is not a barrier to action. The application concluded that this type of long-term approach would be particularly useful for Climate Ready Clyde, as well as for other stakeholders, for developing a longer-term adaptation plan, aligned to broader land use planning and regional development. This could develop the concepts for the Clyde Corridor, including for the River Clyde Corridor SDF and any aspirations for future inclusion on the next National Planning Framework. Underpinning this, there is also a benefit in starting a monitoring programme for some of the key threats for the region, and to start discussions in regional government and with stakeholders on long-term objectives and governance arrangements.

Recommendation

• To consider the development of an iterative adaptation pathway for managing risks from flooding, erosion and sea level rise for the Clyde Corridor which could inform relevant regional plans and strategies.

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

Overall, the three applications of the framework find that these approaches could be valuable for Glasgow City Region, and would support the region in managing future climate risks. The adoption of such approaches would have large economic and financial benefits, and would also demonstrate that Glasgow City Region are managing risks to external stakeholders. Taking such action, and communicating progress, would give the region an important first mover advantage in this new landscape.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	I
INTRODUCTION	1
A FRAMEWORK FOR ADAPTATION IN GLASGOW CITY REGION	2
CASE STUDY 1: COSTS AND BENEFITS OF ADAPTATION	4
INFRASTRUCTURE Built Environment Communities and health Natural Environment Business and Industry, International and Cross Cutting Discussion	
CASE STUDY 2: CLIMATE RESILIENCE IN GLASGOW CITY REGION CITY DEAL	23
PROJECT INVESTMENT APPRAISAL AND CLIMATE RESILIENCE GLASGOW CITY REGION CITY DEAL METHODS FOR SCREENING AND RISK ASSESSMENT PRELIMINARY CLIMATE RISK SCREENING OF CITY DEAL LIGHT-TOUCH CLIMATE RISK AND ADAPTATION ASSESSMENT OF CITY DEAL PROJECT ADAPTATION PRIORITIES FOR FURTHER EXPLORATION IN GLASGOW CITY REGION CITY DEAL DISCUSSION	23 25 27 29 35 42 45
CASE STUDY 3: ADAPTATION PATHWAYS FOR THE CLYDE CORRIDOR	46
REVIEW OF ADAPTATION PATHWAYS LITERATURE	
REFERENCES	77
APPENDIX 1. ADAPTATION PATHWAYS AND DECISION MAKING UNDER UNCERTAINTY	86

INTRODUCTION

This report presents the phase 2 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 (adaptation) successfully for Glasgow City Region and Climate Ready Clyde.

The study is broken into two phases.

Phase 1 of the study had 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 2 of the study. It starts with the presentation of an overall integrated framework for adaptation, and then undertakes three case studies.

A FRAMEWORK FOR ADAPTATION IN GLASGOW CITY REGION

The starting point for the phase 2 analysis has been to develop a framework for adaptation for the Glasgow City Region. This is needed to address the large number of diverse risks, and to capture the challenges involved in adaptation, namely the long time-frames involved (which are much longer than traditional policy cycles) and the high uncertainty associated with future climate change.

The focus of the framework is on <u>early adaptation priorities</u>, to help identify adaptation decisions that might be introduced over the next five to ten years, to address short, medium and long-term climate risks. The framework is based on the approach used in the UK Climate Change Risk Assessment (CCRA) and the adaptation literature. It also aligns to national and regional public policy and project appraisal, but with an extended cost-benefits analysis approach, recognising the additional challenges involved in adaptation.

This framework categories early adaptation into three types of priorities for:

- Addressing the existing adaptation deficit by implementing 'no-regret' or 'low-regret' actions (i.e. that have early economic benefits) to reduce risks associated with current climate variability as well as building future climate resilience.
- 2. Intervening early to ensure that adaptation is considered in decisions that have long lifetimes, such as major infrastructure developments, in order to avoid 'lock-in'. This includes the use of concepts which support decision-making under uncertainty (i.e. flexibility, robustness).
- 3. Fast-tracking early adaptation steps for decisions that have long lead times or involve major future change, e.g. monitoring and research, with learning, to improve future decisions.



These are shown below.

Figure 1 Early priorities for adaptation. Source: CCRA3

For the purposes of developing a holistic adaptation strategy for Glasgow City Region, a portfolio comprising all three types of adaptation response may be needed (they are not mutually exclusive). They start with a broad framework and then focus down on investment resilience (project level) and long-term corridor risks (adaptation route-maps). As such, they reflect different scale and

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

aggregation issues, and different adaptation decisions, from regional wide planning down to specific project investments.

The study has undertaken three case studies, which demonstrate each of the areas above:

- An aggregate analysis that follows on from the phase 1 study (on the future economic costs of climate change in the region), assessing the potential costs and benefits of early adaptation for a number of the most important economic risks.
- A position paper on climate risk screening and enhanced resilience in the Glasgow City Region City Deal, for major infrastructure developments, which is also relevant to a much wider crosssection of public and private sector investment.
- An adaptation pathway analysis for the Clyde Corridor, looking at an iterative framework and an adaptation route-map to address long-term risks.

CASE STUDY 1: COSTS AND BENEFITS OF ADAPTATION

This phase of the study follows on from the phase 1 study and its forward-looking analysis of the economic costs of climate change in the Glasgow City Region.

The phase 1 study assessed the future economic costs of climate change in the Glasgow region, considering each of the 60 or so climate risks and opportunities identified in the Glasgow City Region Climate Risk and Opportunity Assessment (GCRCROA). The analysis set out 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 and it values both market and non-market impacts, i.e. it 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 Book¹

The headline estimates of economic costs are shown in the figure below. The total estimates could be very large, as annual costs, especially once future growth and development in the region is taken into account.

The results of the analysis found that the future economic costs of climate change were dominated by a small number of risk categories:

- 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;
- Flood related disruption to transport (road and rail), including damage to infrastructure and impacts on travel time;
- Heat extremes leading to health-related mortality and morbidity (in the longer-term)

Many of these economic impacts will disproportionally affect socially deprived and vulnerable groups and that there were strong geographical patterns across local authorities. The study also found a number of very large economic benefits (opportunities) from climate change, notably related to reduced demand for heating in buildings, but also from the effects of warmer temperatures on health, noting that many of these benefits would happen autonomously.

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

Figure 2 Economic Costs of Current Climate and Future Climate Change for Glasgow City Region.

	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	-Н
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 poten	itally 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 flood	ing 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
THEME 3 - COMMUNITIES AND HEALTH					
CH1: Risks to people and communities from flooding	-L		-1	-M	-M
CH2: Increase in summer temperatures and heatwayes leading to increased morbidity and mortality	-1	*Mai Ext risk	-M/VH	-M/VH	-M/VE
CH3: Risks to business continuity of health and social care from extreme weather	Uncertain	maj exertisk	Uncertair	n hut noter	nitally hig
CH4: Increased nations domained on NHS services from high winds snow and ice floods cold weather	oncertain		-I	-I	-1
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	linecoung	-1	-1	-1
Risks to health from changes in air quality (aero-allergens)	Not quantified		-	-	-
CH7: Risks to health from vector-horne nathogens	-l		Uncertair	n	
CH8: Risks to Sport and leisure activities from severe weather, higher temp and increased prec			-l		
CH9: Potential benefits to health and wellbeing from reduced cold			+VH	+VH	+VH
				-	
THERE & NATION CONSTRAINT					
THEME 4 - NATURAL ENVIRONMENT NF1: Risks from changes in agricultural productivity and land suitability	Not quantified				
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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 ri	sk =	Extreme event with ma	jor (\$/HH)	impacts	

The first case study in phase 2 analysis follows on from this aggregate analysis. The analysis has investigated the potential costs and benefits of adaptation for the GCRCROA. The aim is to look at the aggregate or macro-scale level, and assess how adaptation could reduce the overall costs of climate change for the region (the benefits), and what might be the possible costs of implementing such measures.

These headline numbers provide useful information to support the case for adaptation in the region. In doing this, we explore a number of aspects for this adaptation analysis. The study has assessed the possible costs and benefits of reducing the areas of highest potential future cost, as identified in the phase 1 report. It has also looked to prioritise early adaptation actions, drawing on the approaches used for risk assessment in the 3rd Climate Change Risk Assessment (for the UK and Devolved Administrations).

Infrastructure

As highlighted in the phase 1 report, 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.

The infrastructure analysis has been undertaken in a more detailed case study (case study 2) looking at the potential risks of climate change on the Glasgow City Region City Deal. This has included discussion of the potential adaptation options for infrastructure.

Built Environment

The theme of the built environment includes a large number of risks, however, the largest economic costs to Glasgow City Region are from flooding. Flooding is currently a major risk for the Glasgow City Region, and the evidence on current risks and economic costs are well developed. Annual average damages are around £26 million (river floods), £19 million (coastal floods) and £20 million (surface water floods) (SEPA, 2015). Future economic costs were estimated in the phase 1 report as increasing to approximately £100 million/year by 2080s (high scenario), based on the SEPA baseline analysis, assuming the current economy². It is stressed that SEPA's updated National Flood Risk Assessment (NFRA) provides new estimates of current flood risks (and annual average damages) and the future risks under climate change.

However, these estimates do not take into account socio-economic change (population, value at risk). When population and economic growth (as captured by GDP/capita) are included, this significantly increase the future economic costs. This is because there are a larger number of people and a higher value of assets at risks, even without climate change. The estimated costs of climate change on flooding with and without economic growth, are shown below, building on the phase 1 economics report. Note that new socio-economic data will be produced by country and region as part of the UK CCRA3 research studies.

² Note that an alternative 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), and these were also considered in the Phase 1 report. This reports a lower baseline (current) average annual damage for the Clyde and Loch Lomond region from flooding, and it estimates an increase in costs of 54% and 140% under climate change for 2°C and 4°C scenarios by the 2080s (respectively).

Table 1 Annual average damage (£) from Flooding in Glasgow City Region – Effects of climate, socio-economic change. Source Phase 1 Economic study with additional analysis of socio-economic data.

Scenario	Current	2030	2050	2080
Current	£60 million/yr			
Climate change (CC) only	£60 million/yr			£100 million/yr
Socio-economic (SE) change only	£60 million/yr	£94 million/yr	£135 million/yr	£195 million/yr
CC and SE together	£60 million/yr	£105 million/yr	£170 million/yr	£290 million/yr

Current estimates and future CC only are based on the values from SEPA (2015). CC scenario is UKCP09 high. SE scenario = SSP2 = Middle of the Road scenario, based on the IIASA SSP data. Samir et al 2017., Cuaresma, 2017. This takes UK data and scales for Glasgow City Region.

Including socio-economic change has the effect of dramatically increasing future flood damages. This means that even without climate change, there will be more incentive for Glasgow City Region to increase protection, as more people and assets become exposed.

The SEPA Clyde and Loch Lomond Local Plan District: Local Flood Risk Management Plan (SEPA, 2016) and the SEPA Flood Risk Management Strategy: Clyde and Loch Lomond (SEPA, 2018), set out the immediate flood risk management priorities (i.e. adaptation) for the region. These are discussed in more detail in the Task 2 of the study. However, these do not consider the long-term costs and benefits of adaptation, i.e. after 2030 through to the end of the century. The need to address these is explored in the later case study on adaptation pathways.

There are other studies which have undertaken such analysis. The Sayers et al. (2015) report for CCRA2 did look at adaptation options to address long-term risks. The study considered different adaptation approaches:

- Manage the probability of flooding.
- Manage exposure to flooding.
- Manage the vulnerability of those exposed to flooding, i.e. property level, early warning.

And it considered seven individual adaptation measures:

- Construction and maintenance of river and coastal defences;
- Working with natural processes at the coast and in estuaries managed realignment;
- Natural flood management practices in rural catchments;
- Urban flood management practices;
- Spatial planning;
- Receptor Level Protection Measures (e.g. household level);
- Forecasting, warning and community response.

At the national level, Sayers et al. study estimates 180,000 residential properties and 42,000 nonresidential properties are currently at risk in Scotland, and 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). It also projected high increases for Scotland under climate change (presented in the phase 1 report), e.g. under a 4°C scenario in the 2080s, these could rise to £120 million for residential (direct), £270 million non-residential (direct) and £670 million for the total costs (direct and indirect costs). These estimates were provided in the phase 1 report. However, these are based on a static economy, and do not include socio-economic change. The same type of risk multipliers would arise for these estimates. Adaptation has large benefits in reducing these costs. The Sayers study finds that current levels of adaptation can offset a large proportion of the projected increase in risk, but not all of the increases, especially under a 4°C scenario.

It found that the most effective adaptation measures (of those assessed) are those that act to reduce the <u>probability of flooding</u> (PFA), i.e. improving defences, managed realignment on the coast, catchment management and urban runoff management through sustainable drainage systems (SUDS). Options that focus on reducing exposure and vulnerability are less effective. Options that reduce <u>vulnerability</u> are effective, but limited because the estimated flood risk is dominated by the vulnerability of the existing stock of properties. It found that <u>exposure</u>-based measures, such as spatial planning and building codes, were least effective, because it only targets new areas rather than the existing stock. The increase in climate change costs, and the role of adaptation, is shown in the figure below. Standard adaptation can reduce around 30-50% of the risks, but enhanced adaptation as much as 70% of the additional risks.



Figure 3 Disaggregation of the drivers of future risk (climate only) and the ability of adaptation to offset that risk for Scotland. Sayers et al, 2005.

Key to adaptation: Baseline adaptation: Continuation of Current Level of Adaptation (CLA). Enhanced 'whole system' adaptation (EWS). Reduced 'whole system' adaptation (RWS). Probability focused adaptation (PFA). Exposure focused adaptation (EFA). Vulnerability focused adaptation (VFA).

For the Glasgow City Region, this would suggest that adaptation could reduce 50% of future climate risks with a current adaptation approach focused on probability focused adaptation and 75% of future climate risks with an enhanced (whole system) adaptation approach. This would reduce the increase from climate change (£40 million annual average damage/year) down to £20 million AAD/year (probability focused) and £10 million AAD/year (enhanced). However, the Sayers study does not assess the costs of adaptation, and the comparison costs and benefits.

There are studies that do look at the costs and benefits of adaptation to flooding. Many of these are centred on general flood risk management options, i.e. managing the risk of flooding.

A number of studies have looked at the costs and benefits of coastal adaptation (Brown et al., 2011: Hinkel et al., 2014; Brown et al., 2015). These studies show that adaptation is an extremely costeffective response, with hard (e.g. dike building) significantly reducing coastal flooding costs down to very low levels. The values above, these fall dramatically with adaptation, by one to three orders of magnitude (RISES-AM, 2017). These show it is economically robust to invest in protection where coastal population densities are high, i.e. urban areas. In rural areas with lower population, however, protection measures generally have benefit-cost ratios lower than one (Brown et al, 2015: RISES-AM 2017), which suggests that it will be difficult to mobilize resources. These studies would therefore suggest a high benefit to cost ratio for coastal flood protection. However, this adaptation involves up-front costs (for uncertain returns) and hard coastal adaptation options involve possible conflicts with other coastal stakeholders, as well as natural environments (coastal squeeze). These hard measures are expected to become difficult to sustain under high-end climate scenarios, and thus ecosystem-based adaptation and/or coastal realignment options may be favoured, although this is highly site specific. It is also highlighted that at the city scale, costs maybe higher when moving to more engineered protection (rather than just barriers or dikes).

There is also a study by Hallegate et al (2013) that estimates present and future flood losses from coastal impacts, and adaptation costs and benefits, for the 136 largest coastal cities globally: this includes Glasgow city region. This estimates that current mean annual losses from coastal flooding in the city are currently low (estimated at \$4 million/year with the current 1 in 200 year level of protection – though this is lower than the SEPA estimates), 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 (per capita GDP) and thus rising exposure and asset values. The study also investigated adaptation, considering a baseline of no upgrade, i.e. continue with current existing protection and maintaining this over time, as well as options that maintain standards at constant levels (i.e. the 1 in 200 year level), or maintain the level or relative risk (in \$), the latter involving higher levels of protection. For both 20 and 40 cm scenarios, the study estimated that losses could be reduced down to \$4 -5 million/year with adaptation. However, the paper highlights that if the defences were overtopped, there would be very high damages in the future, thus higher adaptation levels of protection may be justified.

Similarly, there are other studies of the benefits of adaptation on <u>river</u> flooding. Roudier et al. (IMPACT2C, 2015) estimated the damage from river floods in Europe, including the UK, and found adaptation could reduce damages significantly (by a factor of five). Ward et al., (2017) analyzed the cost-benefit analysis of adaptation for river floods from climate change, reporting high benefit to cost ratios, but notes these vary according to the objective, i.e. whether this considers the optimal response (maximize NPV), or adapts with constant absolute or constant relative risks, for example the benefit-cost ratio (BCR) for optimized responses was >4, but this ratio falls if risks are kept constant in relative terms, and especially if risks are kept constant in absolute terms, because of rising costs of protection. These findings are relevant for Glasgow City Region: it is likely that climate related flood impacts can be reduced significantly, but the level of decrease will depend on the objectives set and therefore the costs incurred.

A recent European review (ECONADPT, 2016) containing 110 observations on investments/projects from 32 studies and databases in 16 European countries found mean BCR of 6 (but median of 3): this

also found Hard flood control (4:1) had higher BCR than soft flood control (1.6:1) – however, other studies find the reverse (i.e. soft BCRs > hard). This highlights site and context specificity.



Figure 4 Frequency distribution of BCRs of DRM investments in Europe (the distribution is only shown for BCR's between 0 and 10, larger BCR's are not shown because they would negatively affect the readability of the graph). Source ECONADAPT, 2016.

An alternative aspect is to look at the <u>costs and benefits of household measures</u>, i.e. to manage the vulnerability of those exposed to flooding. There have been a number of studies that have assessed the potential costs of <u>household measures</u> (EA, 2015, ASC, 2015: 2019). These include <u>resilience</u> measures and <u>resistance</u> techniques:

- Resilience measures are those that are undertaken inside a property to reduce damage caused by floodwaters. Flood resilience, or wet proofing, accepts that floodwater will enter the building and allows for this situation through careful internal design such as raising electrical sockets and fitting tiled floors so that the building can quickly be returned to use after the flood.
- Flood resistance, or dry proofing, techniques prevent floodwater from entering a building. This approach includes, for example, using flood barriers across doorways, airbricks and raised floor levels, to prevent floodwaters from entering a building structure.

There is some information on the costs and benefits of these measures. For resilience measures, costs include survey costs (EA, 2015), installation costs (EA, 2015; Wood Plc, 2019) and maintenance costs (EA, 2015). Generally, this literature reports that these measures are more expensive if retrofitted rather than installed in new builds. This is shown in the table below. The analysis shows that the costs of some resilience measures are much lower (and for some individual measures, involve no additional costs) for new builds. For resistance measures, the difference between costs of retrofitting vs. incorporating into new builds are more modest. However, the applicability of each of these measures depends on the type of flooding (recurrence and depth), as this alters the relative cost-effectiveness (and benefit to cost ratio). Recent work for ASC (Wood Plc 2019) found that a number of flood resilience and resistance measures could be considered no-regret adaptation measures (i.e. a benefit to cost ratio of greater than one in cases where there is a greater than 1% chance of Annual Exceedance Probability (AEP).

Table 2 Unit costs of flood resistance and resistance measures. Source Wood 2019.

Category	Adaptation Measure	Unit costs (£ per property, one-off)							
		<70m² semi- or terrcd	<70m² flat	70 -110m² semi- or terrcd	70 -110m² flat	70 -110m ^a dtchd	>110m ² dtchd		
Flood resistance	Flood resistance package (fit seals; Repointing of external	t &forget) Demour walls up to 1m ab	table door guar ove ground leve	ds; Manual airb I with water res	rick covers; Sewe istant mortar	erage bungs	/ toilet pan		
	Discretionary	£1,685	£1,903	£1,059	£1,145	£2,813	£3,115		
	Repair	£1,421	£1,639	£795	£882	£2,549	£2,851		
	New Build	£1,231	£1,341	£786	£868	£2,014	£2,178		
Flood resistance	Flood resistance package (m sewer pipe; Repointing of ex	anual activation) D ternal walls up to	emountable do 1m above groun	or guards; Sma Id level with wa	rt airbricks; Non- ter resistant mor	return valve tar	on main		
	Discretionary	£1,228	£1,504	£601	£722	£2,387	£2,672		
	Repair	£1,228	£1,504	£601	£722	£2,387	£2,672		
	New Build	£1,047	£1,220	£601	£722	£1,871	£2,027		
		Category A	daptation Mea	isure	Unit costs (£ per prope	erty, one-off)	– discretior	nary retrofit
					Three-Bedro Semi-Detach House	oom Fou ned Bed Det Hou	r- Tw room Be ached Gr ise Flo	vo- edroom ound oor Flat	Two- Bedroom Terrace House

		House	Detached House	Ground Floor Flat	Terrace House	Bungalow
Flood	Install dense screed	821	997	721	633	1,184
floors	Replace chipboard flooring with treated timber floorboards	1,143	1,378	997	879	1,641
	Install a new floor with treated timber joists	4,244	5,129	3,763	3,324	5,944
	Install a solid concrete floor	10,845	12,779	9,848	8,910	14,655
	Raise the floor above likely flood level	37,869	42,675	36,344	33,062	52,406
Flood resilience -	Use closed cell cavity insulation to prevent water wicking in walls.	821	956	780	727	1,049
Walls	Use water resistant plaster	7,972	8,998	7,709	7,328	9,614
	Install a chemical damp-proof course	7,673	9,262	6,753	5,962	10,868
	Install water resistant doors and windows	12,275	15,042	12,791	9,508	17,598
Flood	Install a wall-mounted boiler	1,172	1,172	1,172	1,172	1,172
interiors	Move washing machine to first floor	703	703	N/A	703	N/A
	Specify a raised, built-under oven	762	821	762	762	879
	Move electrics above flood level	938	1,055	821	821	1,290
	Move service meters above flood level	1,759	1,759	1,759	1,759	1,759
	Specify plastic kitchen / bathroom units	3,986	9,262	6,753	5,962	10,868
Category	Adaptation Measure	Unit cos	sts (£ per prop	erty, one-off)-	on repair (end o	f life)
		Three-Bedroom Semi-Detached House	Four- Bedroom Detached House	Two- Bedroom Ground Floor Flat	Two- Bedroom Terrace House	Three- Bedroom Bungalow
Flood	Install dense screed	135	170	123	106	199
floors	Replace chipboard flooring with treated timber floorboards	592	709	516	457	850
	Install a new floor with treated timber joists	610	733	539	475	856

Three-

Source: Davis Langdon (2011) updated to current prices in WOOD (2019).

An indicative CBA analysis of household resilience and resistance – based on the CCC analysis indicates that there are some very low-cost <u>resilience</u> measures which are effective in reducing damage from flooding. These could be considered as no-regret for all new houses built in areas at risk. This means more should be done to help the industry promote and 'sell' such measures to developers and architects. However, a 'complete' package of all resilience measures is expensive, even when built in new houses, and fails to pass a CBA test for low risk areas (but could be viable for high risk areas > 2% annual flooding risk). <u>Resistance</u> measures for new houses have a reasonable cost per property (below £1,500), and the analysis shows that are able to deliver high BCRs under all future climate scenarios. It would be possible to apply these estimates to the proposed new build in Glasgow City Region, noting the need to differentiate by flood risk level.

Finally, there is existing flood risk warning in Glasgow City Region, but there is a strong economic case for strengthening this. Early warning systems have high benefit to cost ratios (Clements et al, 2013). The benefits of these increase under future climate change, with increasing events, although costs and residual damage increase as well. However, to deliver benefits, there needs to be investment along whole weather chain (i.e. from supply to users) not just meteorological infrastructure and warnings. This includes the uptake and use of the information, i.e. so that people who receive warnings have plans and know what to do to reduce damage and losses.

Overall, on flooding, the findings are:

- While future economic costs of flooding (coastal, river and surface flooding) is projected to increase significantly with climate change in Glasgow City Region, there are adaptation measures that can reduce these impacts.
- There are a set of interventions that reduce the probability of flooding. These measures are estimated to significantly reduce future flood risk, but not remove it entirely. These have good benefit to cost ratios (typically 3:1), but would still mean a major increase in flood defence expenditure in Glasgow City Region in future years. Importantly, costs will rise as risk levels are reduced, so there is a trade-off between levels of risk and flood defence expenditure. Discussion on the appropriate level of risk are therefore important, and should be started with stakeholders.
- There are also household level options, for enhancing resilience and resistance. These are more cost-effective when fitted in new buildings. Analysis of the costs and benefits of these options suggests that resistance measures (that stop entry of water) could be cost-effective in all new build properties in areas of flood risk; some resilience measures (that reduce recovery time, so that the building can quickly be returned to use after the flooding) are cost-effective measures, but these depend on flood frequency. It is highlighted that there are barriers to the uptake of these measures, as they place the emphasis on properties, and would require more support to help the private sector promote and 'sell' such measures to developers and home owners. This might mean potential opportunities for local planning policy and local plans.
- Complementing these options, there is a role for enhanced early warning for floods, as these can deliver very high benefit to cost ratios. However, to be most effective, these need to invest in the uptake and use of the information, i.e. to ensure that users receive timely warnings but also know how to react to reduce losses.
- It is also stressed that for new housing and non-residential development, an important factor will be to ensure future flood risks are taken in account in siting and design. This is discussed further in the Task 2 study.

• There is also a recommendation to consider future flood risks with an adaptation pathway. This is also considered in the Task 2 study.

Communities and health

The theme of communities and health involves a number of risks. The flood risks are captured in the analysis above and thus the focus of this analysis has been on heat.

Analysis of heat and health

The main health risk of higher summer temperatures and heatwaves is associated with premature (excess) deaths (mortality) and morbidity: the former dominates the economic costs while the latter dominates the physical number of cases. Numerous studies show that daily mortality increases above a temperature threshold, though the threshold and rate of increase varying between regions.

The Phase 1 report reported on the estimated current numbers of heat related mortality and morbidity in Glasgow City Region (which are low) and the estimated the future numbers and economic costs of additional heat related impacts. These are presented in the phase 1 report.

The current levels of heat related mortality is low: the Adaptation Committee of the Committee on Climate Change (Hajat et al, 2014) assessed current and potential future heat related mortality in Scotland and estimated these might rise from 0.7 per 100,000 population to 4.4 per 100,000 population by the 2080s. For the Glasgow City Region, this equates to an approximate increase from 13 deaths per year to 80 deaths per year. It is stressed that heat mortality risks increase with age group, with the greatest risks by far occurring in those above 75 years.

The Phase 1 study used the CCRA1 results to look in more detail at the potential changes over time and under difference scenarios, and assessed heat related morbidity for the region³. These estimates were assessed in economic terms, using standard UK Government appraisal methods for valuing the change in fatality risks. Note that the choice of valuation metric makes a very large difference to the results, in particular whether a full Value of a Prevented Fatality or a Value of a Life Year Lost approach is considered. When using the full VFP, the estimated economic costs for Glasgow City Region are large, potentially as much as £100 million by the 2050s, but this falls by an order of magnitude if the VOLY approach is used.

The analysis also looked at the potential number of additional morbidity cases and hospital admissions that might occur. This estimated a central estimate of 5,700 extra cases a year from heat by the 2050s. The economic costs were estimated at an additional £4 million a year (capturing the treatment costs, productivity costs and the pain and suffering involved).

This task has considered the potential costs and benefits of adaptation to address these heat and health risks. There are a large number of potential adaptation options to address these heat related risks, but they generally fall under two main themes:

- Health related interventions, including awareness and behavioural change; and
- Building and spatial planning related interventions.

A list of potential adaptation options is shown below.

³ It is noted that the projected 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. However, they do not include natural acclimatisation (to changing temperatures over time), which would significantly reduce the values.

Table 3 potential adaptation options for heat.

1				
Health options			Bui	lding and spatial options
	-	Health education	-	Air conditioning, residential (retrofit,
	-	Awareness raising		new build)
	-	Training of health service staff for heat extremes	-	Health system infrastructure (new)
	-	Improvement of morbidity and mortality records / systems	-	Building insulation
	-	Research on physiological adaptation and socioeconomics	-	Natural (passive) ventilation new build
	-	Research into physical / mental stressors in old age & climate		(design / building codes)
	-	Heat alert systems	-	Active-cooling systems low energy/low
	-	Enhanced heat alert system		carbon
	-	Register of vulnerable and partner / carer systems	-	Natural (passive) ventilation retrofit
	-	Structural improvements to care homes (e.g. cool room)	-	Green roofs
	-	Air conditioning care homes (all) (retrofit)	-	Shade trees
	-	Natural (passive) ventilation care homes (retrofit)	-	Green urban areas
	-	Structural improvements to hospitals (cool room)	-	Spatial planning (property,
	-	Air conditioning health service (retrofit)		development) - new
	-	Natural (passive) ventilation health service (retrofit)	-	Zoning and transportation (new)
	-	Adjust working hours (outside work) during extremes	-	Spatial planning / zoning (property,
	-	Behavioural change clothing, drink, scheduling daily work		development) – retrofit

There is also a need to adopt an adaptive management approach for this risk, because current risks are low, and so there is more need to think how to start with low cost options and increase adaptation over time, while noting that for some aspects (urban built environment), there is a large degree of lock-in, which might necessitate early consideration. These effects are likely to be most pronounced for Glasgow City, because of the urban heat island effects.

In terms of the short-term (next five years or so), we highlight potential early actions as:

- Low-regret actions to consider the potential for heat alert systems and raising awareness to vulnerable populations (social care/care homes for the elderly, especially in the Glasgow city area, where urban heat island effects are highest).
- Long lifetimes / lock-in to consider the design for new hospitals and care homes to ensure these take account of over-heating risks.
- To enhance research in better understanding of heat extremes in Glasgow City Region, and Glasgow city in particular, especially in relation to heat extremes, urban heat island, to improve monitoring and recording of heat extremes and their health effects, and research to identify high heat risk building types in the built environment.

The most obvious early adaptation is to introduce a heat alert system. 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)⁴. There is evidence from previous studies on the cost and benefits of these schemes, with analysis of the benefits and costs of heat alert systems in the US and France (Ebi, 2004; Fouillet et al 2008) and the potential benefits under climate change (Hunt et al., 2016; Bouwer et al., 2018). For example, the estimated benefits on setup of a warning system, real-time surveillance of health data, and emergency plans for vulnerable people with visits and care offer, have been estimated to be 65% effective and have high benefit to cost ratios (Chiabai

⁴ https://www.metoffice.gov.uk/public/weather/heat-health/#?tab=heatHealth

et al., 2018). Note however that the future annual costs of heat alert schemes are projected to rise, as the systems are triggered more frequently with climate change.

Assuming a 65% effectiveness in reducing heat related fatalities, a heat alert system would have large economic benefits, with current annual benefits of £15.6 million for the Glasgow City Region (full value of prevented fatality). A sensitivity analysis using the Value of a Life Year Lost, and assuming 6 months of life lost on average, would reduce this to £277,700. These benefits would rise rapidly in future years, e.g. with annual benefits rising £ 69.6 million for the central projection in the 2050s for Glasgow City Region (with a sensitivity value of £1.2 million for the VOLY). These benefits can be compared against the potential costs of the scheme. To estimate this, the information on future heat wave events is needed. The previous studies (see phase 1 report) reported on future heat wave frequency.

Some new work (Undorf et al, 2018) has considered the new UKCP18 data for Glasgow. UKCP18 does appear to show 'hotter' projections than UKCP08, and this indicates a higher heat wave frequency, below. This indicates a heat wave on average of approximately 1 in 2 years by the 2050s.



Figure 5 Projected frequency of heat wave days. Source: Undorf et al, 2019.

A hot day defined as one in which both daily minimum temperature exceed 15°C and daily maximum temperature exceed 28°C when bias-corrected and averaged over the southern half of Scotland. Heatwave day defined as a hot day that is preceded by four other hot days.

In order to estimate costs, the study has built on previous analysis (Hunt et al., 2016). In the UK Heat Health Watch System (HWWS), the UK Meteorological Office issues heat-wave weather warnings

when there is an expectation of significantly higher than average temperatures in one or more regions of England (and which we assume here is extended to Scotland). The HHWS comprises four levels of response based upon threshold maximum daytime and minimum night-time temperatures. These thresholds vary by English region, though an average threshold temperature is 30 °C by day and 15 °C overnight. We assume that the same type HHWS could be introduced for Glasgow City Region, but with a lower threshold, consistent with that currently used in the North of England.

Box 1. The Health Watch System

There are four levels of response:

- Level 1 Awareness the minimum state of vigilance during the summer.
- Level 2 Alert triggered as soon as the risk is 60% or above for threshold temperatures being reached on at least two consecutive days to have significant effects on health. This will normally occur 2 to 3 days before the event is expected.
- Level 3 Heatwave triggered as soon as the Meteorological Office confirms threshold temperatures will be reached in one or more regions.
- Level 4 Emergency reached when a heatwave is so severe and/or prolonged that its effects extend outside the health and social care system.

The roles of these health professionals and the associated resource implications of these roles that we assume in this analysis is set out below.

Alert Level	Role of Health Professionals	Resource Implications
Level 1 –	Planning at beginning of heat-wave season to	One hour per Health Professional,
Awareness	protect vulnerable people:	annually.
	- Be familiar with the principles and core elements	
	of the Heatwave Plan	Other fixed costs components
	- Be familiar with the client heat-wave advice leaflet	incurred at Level 1 include:
	and give copies to clients as appropriate.	- Weather Office contract fee;
	- Consider clients' vulnerability to adverse weather	 Printing, distribution and
	conditions and add to at-risk list	storage of information leaflets
		& documentation.
Level 2 – Alert	 Identify list of those from existing caseload who 	One and a half hours per Health
	will require daily contact in the event of a heat-	Professional, each time Level 2 is
	wave;	reached.
	 Avoid duplicate contact /visits from multiple 	
	agencies;	
	- Determine what non-essential activities could	
	cease.	
Level 3 –	- Stop nonessential activities;	Four hours/day per Health
Heatwave	 Commence daily contact with clients at risk; 	Professional, for duration of heat-
	- Make daily situation reports	wave.
Level 4 –	 Continue to do best for caseload; 	Four hours/day per Health
Emergency	- Provide situation reports upwards, as requested,	Professional, for duration of heat-
	and raise any concerns they may have;	wave.

Sources: Roles and resources based on Department of Health (2010).

The three warning systems are formulated principally to require action by health professionals, notably Advanced Nurse Practitioners, (ANPs), who are primarily involved in the care of the local population in their homes, rather than in hospitals. We assume that the co-ordinating action of nurse team leaders is included in the time that is allocated to nurses.

The warning systems are evaluated on the basis of the costs and benefits associated with their implementation. The HWWS is considered over a 50-year time period, from 2021 to 2070. The current and future costs of the warning systems are calculated according to a series of stages:

- The total number, (full-time equivalents), of ANPs currently working in Greater Glasgow are reported to be 122, as of September 2018.
- The employment totals are projected over the 50 year time period under the IIASA SSP2 population scenario. It is assumed that the population-HP ratio is kept constant at today's levels over this time period.
- The annual cost of employing an ANP is calculated from cost information identified from previous analysis (Hunt et al, 2016)for the UK. Cost information includes: salary, on-costs, non-capital overheads, capital overheads. These are divided by 220 (annual working days) to give costs of £147/day (Glasgow City Region)⁵.

The total HP costs for Glasgow are calculated for the four different warning levels.

- For Level 1, as identified in the Table, it is assumed that each ANP typically spends one hour of time per year meeting its requirements. This day-fraction, (0.125), is first multiplied by the day resource cost identified above. This ANP unit cost is then multiplied by the total numbers of ANPs in Glasgow. In addition to these costs, the costs associated with the weather office annual contract fee, plus the costs of printing, distribution and storage of information leaflets and documentation are derived to give a total annual fixed cost of the warning system. This is estimated to be €200,000 for the UK Meteorological Office.
- For Level 2, the ANP unit cost is estimated in the same way as for Level 1. The incidence costs of a level 2 event are estimated on the basis of those incurred in the Summer 2003 event. The probability of an equivalent event occurring is derived from the climate model projections adopted. These probabilities are multiplied by the unit cost; the resulting expected annual ANP unit cost is then multiplied by the total numbers of HPs deployed in each year to produce a Level 2 total annual variable cost.
- For Level 3, the total annual variable cost is estimated in the same way as for level 2. The weather event is assumed to last for five days.
- For Level 4, using the Summer 2003 experience as an analogue, there are assumed to be no additional HP costs to those associated with Level 3. This is a conservative assumption: a more severe event – of the type experienced by Paris in 2003 - is estimated to justify an increase in ANP costs of 25-50%.

The results are shown below. The Table presents the un-discounted costs over the next 30 years for the baseline case where no climate change is included, the mean climate change case and the high climate change case. It shows the annual average costs for Glasgow, disaggregated by the implementation level of the HWWS.

Level 1 costs are the highest associated with the levels, reflecting the high annual fixed costs associated with having a heat health warning system. Level 3 costs are higher than Level 2 costs, reflecting the fact that in the event of a heat event of this magnitude occurring, the time incurred in providing the care to the population will be substantial.

⁵ Curtis, L. (2010) Unit Costs of Health and Social Care 2010. At: <u>http://www.pssru.ac.uk/pdf/uc/uc2010/uc2010.pdf</u>

HWWS Alert Level	No climate change	Mean climate change	High climate change
Level 1	6,335,384	6,335,384	6,335,384
Level 2	2,708	7,435	13,864
Level 3	27,077	74,353	138,636
Level 4	27,077	74,353	138,636
Total	6,365,168	6,417,172	6,487,883

Table 4. Expected Warning System Costs, annualized (£, 2018, un-discounted)

These costs can be compared to the anticipated benefits of the scheme, as estimated by the avoided fatalities and hospital admissions above. The analysis finds that when the higher estimates of valuation are used, the scheme has a very high benefit to cost ratio, for example anticipated benefits of £70 million per year as compared to the costs above. When the lower values for fatalities and the morbidity benefits are included, the benefits are lower, but are still broadly equal to costs.

Overall, on heat and health, the findings are:

- While current heat related health impacts in Glasgow City Region are low, these are projected to rise with climate change. The recent UKCP18 projections show an increase in (relative) heat waves in Scotland, and this could be a particular issue in Glasgow city due to the urban heat island.
- An analysis has been made of possible options to reduce these impacts, focusing on the potential for a Heat Health Watch System (HWWS) for Scotland and Glasgow. The analysis estimates the benefits of the scheme, but has assessed the additional costs for the health care system in Glasgow City Region from its implementation and responses to heat waves. The analysis finds that such a scheme would be likely to have a high benefit to cost ratio.
- It is also highlighted that heat related effects are most prevalent in the elderly, and a key early action should be to consider heat in the design of new hospitals and care homes to ensure these take account of over-heating risks.
- Finally, given heat is a new issue for Glasgow City Region, it is highlighted that there is a need for more monitoring and research, to improve understanding of heat extremes in GCR, and Glasgow city in particular.

The task has also looked at building overheating risk. It is stressed that building overheating is context and building specific, and thus it is difficult to generalise about future risks and adaptation. Nonetheless, it is obvious that building in the region have – to date – been optimised to address cold rather than heat. The study has reviewed the literature on adaptation options to address heat. There are some studies of the costs of measures to address building overheating.

One option is to introduce mechanical cooling – air conditioning – but this increases energy costs and increases GHG emissions. The main focus has therefore been on reducing overheating by passive design measures. These are primarily changes to the building envelope and include:

- Insulation. Insulation is common as a retrofit, specifically for wintertime benefits, but it can also reduce thermal transmittance into the building.
- Increase thermal mass (new builds)

- Excluding/ reducing solar gain (solar control). Minimising the effect of direct solar radiation is done by limiting solar gain through enhanced glazing, surface materials or shading elements. This minimises incident solar gain on the building fabric and limits the resultant heat gain
- Ventilation, e.g. night ventilation and window rules

Defra (2013) reports that costs are relatively moderate but can vary considerably. They report it is possible to reduce overheating by 80% at £3,000 for 3-bed semi-detached and by 97% at £10,000 cost, with reduction in winter heating too (10% and 30% respectively). The costs of adaptation increase significantly for daytime occupancy. There is a diminishing return in both heating and cooling performance as costs go up. The effectiveness of measures will vary between new build and existing stock. They can be much more effective in new builds as they are included in the design rather than being bolted on as retrofits (Defra, 2013). However, when this is applied to the whole housing stock, costs are significant. A recent study commissioned by the ASC and carried out by Wood Plc (2019) has also estimated low regret measures for different types of dwellings.

For the Glasgow City Region, the projected warming does not justify extensive uptake of these measures, especially as retrofit. There is perhaps a better case for new builds - especially in Glasgow City itself (due to the urban heat island effect) - but even here, the economic justification is low. This indicates a focus on ensuring design does not increase the risk of over-heating, as well as looking at measures that could provide heating savings as well as cooling (primarily insulation), while noting these have to be considered carefully to provide both benefits and minimise trade-offs (especially given winter heating benefits and reducing cold are more important in economic terms) as some passive measures are potentially maladaptive, e.g. internal insulation (walls and floors) can let heat in and prevents it getting out, increasing the overheating risk in some properties. Other options, such as behavioural change, are also an option and would reduce these risks.

Natural Environment

As highlighted in the phase 1 report, the estimated economic costs of climate change in the Glasgow on the natural environment are potentially large, but challenging to value in monetary terms.

One example for which some economic analysis has been conducted is the case of peatlands. The phase 1 study estimated the future climate-induced damage costs of £7.5million/yr to £10.3 million/yr, based on the extent of peatlands within the Glasgow City Region of between around 25,000 ha and 36,000 ha.

Restoration of degraded peatlands represents both a mitigation response and an adaptation response. In terms of mitigation, restoration can reduce existing intense emissions from actively eroding sites, and reduce the risk of less degraded sites becoming more intense sources due to further degradation. However, because climate change is anticipated to further increase the emissions from degraded peatlands, restoration is also an adaptation response in that it will help to protect the carbon store against future pressures – ideally by allowing the peatland itself to adapt (e.g. shifts between plant species), but at least by making it more resistant to climate change pressures. In addition, restoration of peatland provides other ecosystem services and adaptation benefits. Restoration has early short-term benefits as well as building longer-term resilience to climate change.

Restoration typically requires removal of damaging pressures, most notably unsympathetic management practices, but also often remedial structural action. The latter includes blocking of drainage to raise the water table, but can also involve stabilisation and revegetation of bare peat plus reprofiling of gulleys – all of which entail capital investments upfront. Management practices also need to change in order to encourage recovery to occur once structural improvements have been made. This may take the form of changes to land use, such as with cessation of peat extraction, and/or intensity of land use, such as with reductions in livestock numbers.

Comparison of the costs and benefits of restoration needs to account for relative magnitudes but also timing. In particular, capital investment costs are incurred upfront whilst benefits accumulate more slowly over time (as do any opportunity costs). This makes the choice regarding both the time period over which comparisons are made, and the discount rate by which future costs and benefits are translated to an equivalent Present Value, important. In particular, shorter time horizons and higher discount rates will diminish the apparent value of durable ecosystem services derived from a functioning peatland capable of withstanding climate change.

Restoring the peatlands of 25k ha and 36k ha is estimated to provide restoration benefits of the order of £3.2 million to £14.9 million. Cost-benefit analysis indicate that restoration is generally worthwhile in most (but not all) cases. For example, reported cost-benefit ratios for different sites range between 1.3:1 and 12:1, depending on the time-horizons and benefits considered. Importantly, the merits of restoration increase if more ecosystem services are included. They also increase the longer the time-period considered and the greater the assumed pace and extent of climate change: climate change strengthens the case for restoration.

Business and Industry, International and Cross Cutting

As highlighted in the phase 1 report, the estimated economic costs of climate change in the Glasgow on the business and industry sectors are dominated by flooding from river, surface water and coastal flooding. These are captured in the earlier analysis.

There are some additional risks from disruption to supply chains and distribution networks, both within Glasgow City Region and in terms of wider national and international linkages. These impacts include:

- Changing conditions affecting the extraction and/or production of inputs.
- Damage to facilities, buildings, equipment and products involved in the production process.
- Disruption to the transportation of raw materials, labour, capital or finished goods and services;
- Negative impacts on prices from effects in domestic and global markets.

It is also noted that the impact of climate change to the food supply chain in Scotland are likely to manifest themselves in the price levels of food products rather than their physical availability. Given the highly inter-dependent nature of domestic and international food supply chains, it is likely that whilst there will be short-terms price hikes as a result of national or international extreme weather events, these hikes will be of short duration but result in greater price volatility with associated costs both for the consumer (in periods of higher prices) and producers.

There are range of adaptation options that might be effective in reducing these risks. It is highlighted that these adaptation options may be undertaken by a range of actors, both within the regional, nationally and internationally. Examples are provided below.

Climate change impact on food supply chain	Adaptation option/measure	Adaptation actor (public/private)
Changing conditions affecting the extraction and/or production of raw materials to be used in food and manufacturing processes	Development and adoption of climate resilient varieties; Adoption of farm-level climate- sensitive measures, e.g. water efficient irrigation systems; enhanced insurance coverage; More diversified supplier network. Information/advice services, including development of longer- term weather forecasting services for producers	Public and collective industry investments Private producers Private producers Public and collective industry
Damage to facilities, buildings, equipment and products involved in the food production process	Flood resistant property design; Enhanced insurance coverage	Private
Disruption to the transportation of raw materials, labour, capital or finished goods and services	Diversified supplier network; Climate-resilient design, e.g. higher sea port coastal defences; Food storage facilities.	Private and public infrastructure investment
Negative impacts on food prices from effects on production in domestic and global food markets	Food storage facilities; Price regulation; Expanded/efficient trade provision; Food commodity hedging markets	Private Public Public/private Private

Note that was also an analysis of the value of current adaptation services in the report by K Matrix for CRC

For all of these areas, businesses will take adaptation actions when the benefits of doing so outweigh their (private) costs. However, the great complexity of business risks and supply chains multi-staged process, coupled with the uncertainty around climate change impacts, suggest that the private sector might struggle to take the appropriate actions. Glasgow City Region could therefore play a role in removing some of the barriers to enable and encourage private sector adaptation as well as ensuring a higher level of resilience along supply chains e.g. for infrastructure: this could be through the provision of information and awareness raising initially.

Discussion

This case study has looked at some of the potential costs and benefits of adaptation to address the risks and opportunities from climate change in the Glasgow City Region. While the phase 1 study highlighted that climate change could lead to large future economic costs, this analysis finds that these can be reduced cost-effectively by adaptation.

The review of costs and benefits for priority risks in the City Region has highlighted the potential justification for adaptation for flooding, heat alerts and information (awareness raising). However, it is noted that the estimates above are primarily based on similar studies in other areas, and there are important caveats (ECONADAPT, 2017) of transfering these estimates to the local context (in this case the Glasgow City Region. There is therefore a need to undertake further analysis, using local information. There is therefore a recommendation that more detailed business cases should be developed for these early priorites. These should be advanced with more specific local information.

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

Finally, 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 more detailed business cases for a number of the early priorities, notably around flooding, heat alerts and information (awareness raising);
- 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

CASE STUDY 2: CLIMATE RESILIENCE IN GLASGOW CITY REGION CITY DEAL

There is growing awareness of the potential risks of climate change on infrastructure and urban development investments (climate risk assessment), across Government, developers and infrastructure providers, and the financial markets. This reflects the fact that these investments have a long lifetime and will be exposed to future climate change, but also because they are often difficult or costly to retrofit later, so it is useful to consider building climate resilience into their design. This is sometimes called climate proofing.

There is also a recognition that failure to account for climate risks in investment decisions could lead to economic and financial impacts, either from weather related damage on assets, or from climate change lead to impacts on operating costs, performance and anticipated benefits. As a result, these climate risks are being seen less as an environmental problem, and more as a due diligence issue that is factored in project development safeguards and financial risk management. In recognition of this, many lending organisations (such as the public investment and development banks), have implemented climate risk management systems (CRMs) as part of their safeguard (due diligence) process. These assess project investments and assess their level of climate risk, and if needed, then include adaptation (resilience) measures in their design to manage these. For example, they have been used in assessing climate risks for city investment projects as part of European Investment Bank loans, including in the UK.

This case study investigates the potential application of such a climate risk management and climate resilience (adaptation) approach to the Glasgow City Region, looking at the potential relevance and application for Glasgow City Region City Deal. The case study has been undertaken to develop a position paper on the potential need and opportunities for enhancing climate resilience in the City Deal process and portfolio. This builds on the existing initiatives on climate risk screening methods that are being used in investment appraisal by the public investment banks.

Project Investment Appraisal and Climate Resilience

The Government (HMG, 2018) 25 Year Environmental Plan (25 YEP) sets out the goal taking 'all possible action to mitigate climate change, while adapting to reduce its impact', and for the latter, it set a target of 'making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century'.

The Treasury Green Book (HMT, 2018) presents the recommended framework and guidance for the <u>development and appraisal</u> of all policies, programmes and projects in UK Government. The Green Book sets out the key stages in the development of a proposal, from the articulation of the rationale for intervention and the setting of objectives, through to options appraisal and, eventually, implementation and evaluation. The Green Book emphasises that economic principles that should be applied during this appraisal process, from the economic justification for public intervention, and through to the economic appraisal of alternative ways of delivering objectives. This includes the identification of options that could meet the stated objectives, which are subject to an appraisal which assess their costs and benefits (from a societal perspective).

These principles are also used in public sector investment projects, such as with city regions and local authorities, and form the basis for the <u>business case</u> for proposed investments. They are also

used in the developing of European funding proposals, for example the economic appraisal of investment projects undertaken by the European Investment Bank (EIB, 2013) and the appraisal of EU funds (e.g. structural funds.

At the same time, it is increasingly recognised that large public sector investment projects – such as City Deal – could be affected by future climate change. Weather related disasters already have major impacts on infrastructure and weather-related losses in recent years are among the highest on record (Munich Re, 2018). Looking ahead, climate change will alter the frequency, intensity, extent, duration, and timing of extreme weather and climate events, and is likely to result in unprecedented extremes (IPCC, 2012). There is already evidence that human-induced global warming has increased the frequency and intensity of heavy precipitation events globally, as well as increasing risks of other extremes in some regions (IPCC, 2018). Climate change will also alter trends and induce shifts in the long-term average climate that will have major impacts within the Region.

These climate change risks are particularly relevant for large infrastructure and urban development projects that involve land-use development (Warren et al. 2016) for a number of reasons.

- Infrastructure has a <u>long life-time</u>, and thus will be exposed to future climate change. This may
 result in climate change affecting the operating costs, performance or anticipated service or
 benefits of the infrastructure, and in turn the rate of return. It could also result in changing
 patterns of extreme events from climate change exceeding the design criteria of infrastructure,
 causing damage or failure. A key issue is that it is often easier and cheaper to build resilience
 (adaptation) into these projects at the design stage, rather than retrofitting later, because
 retrofitting is often more expensive, or in some cases, not possible
- Furthermore, many public investment projects involve <u>lock-in</u>, or irreversibility, in that they alter patterns of exposure or vulnerability to future climate change. As an example, the siting of new infrastructure or land-use change such as a new housing development has to be carefully considered, because current patterns of climate risks will change in the future. What might be an area at low risk of flooding today could become high risk (i.e. fall within the flood plain) due to higher peak flows or more frequent return periods under climate change. The key issue here is that once infrastructure has been built, or land-use change has happened, it is very difficult to change it later, e.g. land-use change usually fixes patterns of development for decades, making relocation extremely expensive, and locking in areas to the need for flood protection or abandonment (i.e. stranded assets). By identifying risks at the outset, it is possible to avoid locating infrastructure in areas that are exposed to future climate risks.

In recognition of these issues, the large multi-lateral development banks (MDBs) and investment banks/international financial institutions (e.g. European Bank for Reconstruction and Development (EBRD), European Investment Bank (EIB)), as well as EU funding programmes, have implemented climate risk management systems (CRMs) as part of their safeguard process (due diligence) (EUFIWACC, 2016). These assess project investments and assess their level of climate risk during the project appraisal cycle, and if needed, include adaptation (resilience) measures in their design to manage these. These climate risk screening processes are undertaken as part of the routine project investment appraisal cycle and it has become part of mainstreaming investment financing: in 2017 the MDBs spent \$7.4 billion on such climate resilient investments, mostly for infrastructure (MDB, 2018).

These systems use a process cycle of <u>climate risk screening</u> that is applied to all potential project investments. These identify the potential climate risks, preferably during the early project development and appraisal stage. If these are judged to be significant, then these are assessed in detail and resilience measures included in the main design phase of the project development.

This process of climate risk screening and adaptation is sometimes called 'climate proofing', but we do not recommend this term, because it is often not possible, and certainly not normally economically efficient, to complete climate-proof infrastructure against all risks over all time periods. A preferred term is making investments <u>climate resilient</u> or climate-smart.

The climate risk screening steps therefore forms part of standard project safeguard assessment (i.e. of the due diligence). Similar aspects have long been considered as part of environmental impact assessment, but there is a recognition that the severity of climate risk warrants a separate analysis. Furthermore, experience of EIA finds that is normally too late to be influential for climate resilience because (OECD, 2015) the analysis of climate risks and design changes needs to occur early in the project cycle, such as at the concept or design stage. These climate risk management systems normally have a two-stage process.

- The first stage is usually a simple climate risks screening to assess potential risks. As an example, the African Development Bank (AfDB, 2011) has introduced a Climate Safeguard System that includes a traffic light system or scorecard to identify which projects may be highly vulnerable to climate risk. These projects require a more detailed evaluation to consider integration of climate aspects into design and implementation.
- The second stage is usually a more detailed climate risk and adaptation analysis, such as used by the Asian Development Bank in its climate risk management system (ADB, 2014). A similar climate risk management system is currently under development in the European Investment Bank. These include a more detailed analysis, which includes the identification of possible adaptation options, and their costs and benefits (ADB, 2015), for inclusion into project design.

Recognising these issues, Climate Ready Clyde (in partnership with Adaptation Scotland) has also produced a toolkit which incorporates these approaches to support the incorporation of climate adaptation in projects in the built environment (Climate Ready Clyde and Adaptation Scotland, 2019).

This case study has applied these climate risk management concepts to the City Deal programme. The objective is to set out the rationale for including such approaches in future rounds of City Deal or other large-scale public sector investment, and to set out what such an approach might involve, as well as the benefits it would provide.

Glasgow City Region City Deal

The Glasgow and Clyde Valley City Deal is an agreement between the UK Government; the Scottish Government: and the eight local authorities across Glasgow and Clyde Valley. It involves £1 billion of Scottish Government and UK Government capital funding to support the proposed infrastructure investment programme for the area, complemented by a minimum of £130 million of investment from Glasgow and Clyde Valley local authorities. The programme aims to lever in a further estimated £3.3 billion of private sector investment. The City Deal established a £1.13 billion Glasgow and Clyde Valley Infrastructure Fund, which will fund investments over a 20 year period. Work commenced in 2015/16, with the funding will be used to enhance transport infrastructure; unlock new sites for housing and employment; and improve public transport over the next 10-20 years.
In the first five years the UK and Scottish Governments will each provide Glasgow and Clyde Valley with total capital grant of £75 million (2015/16 to 2019/20), totalling investment of £150 million The formal process for agreeing the release of future grant will be a series of 5-yearly Gateway Reviews. In total there will be three Gateway Reviews. The first Gateway Review is scheduled to take place soon and if successfully passed will unlock £250 million of payments for 2020/21 – 2024/25.

The Fund will invest in 20 projects in total. For their selection, 40 projects were modelled individually against a counterfactual (baseline), and the top performing projects (in terms of GVA per £1 of whole life costs) were assembled into a 'programme' or 'package' of investments. This prioritization process was carried out using both a Strathclyde Integrated Transport and Land Use Model (SITLUM) and a productivity model developed by KPMG⁶ and used in a high-level economic business case. However, the City Deal Economic Case (2015) did not include climate change risk as a specific part of the analysis. This is not surprising as it is focused on delivering economic growth and employment.

It is also highlighted that during the project selection process, an Infrastructure Assurance Framework was applied. This was created to set the principles for deciding which projects would be funded, and provided templates and guidelines for individual projects business cases. Projects proponents were required to assess the combined economic, transport and environmental impact of their project; identify risks and interdependencies; lay out project finances, and timescale. However, the framework does not make specific reference to climate change risk.

Project	Net nominal
FIOJECI	
Incngreen	9.4
A8/M8 Corridor Access Improvements	9.0
Collegelands Calton Barras Action Plan	27.0
Clyde Waterfront & Renfrew Riverside	78.3
Stewartfield Way	62.2
Camlachie Burn/GMDS	45.8
Greenhills Road/A726 Dual Carriageway	23.1
City Centre Public Realm	199.2
Glasgow Airport Economic Investment Areas	51.4
M77 Strategic Corridor	44.0
Govan and Clyde Waterfront Regeneration	113.9
Inverkip	3.8
Gartcosh Community Growth Area	43.8
Ocean Terminal	14.2
Community Growth Areas (CGAs)	62.3
Pan Lanarkshire Orbital Transport Corridor	119.7
Cathkin Bypass	21.6
Exxon Site	27.9
	£957m
Pan-regional projects	
Glasgow Airport Rail Link	144.3
Strathclyde Bus Investment Programme (reduced scope)	30.0
	£1.13bn

Table 5. List of projects contained within Glasgow City Region City Deal

⁶ The authorities commissioned work to further develop the existing Strathclyde Integrated Transport and Land Use Model (SITLUM). SITLUM analyses the employment impacts of projects, together with a productivity model developed by KPMG.

Nearly all these projects are either major infrastructure investments, or involved urban land-use development. They therefore could involve potential climate risks, due to the long life-times and lock-in. It is stressed, however, that any project that requires Planning Permission will have to be assessed for flood risk. While it is too late to include a wider climate risk screening process in existing projects, there is still the opportunity to do some retrospective screening, to check if there are any potential risks to the current portfolio. It would also be possible to introduce climate risk screening in future gateway reviews and future project design phases. There would a number of benefits from undertaking this type of climate risk screening and resilience building activities:

- It would identify if there are any potential major risks to current projects, including the assets (capital investment), planned operation, and anticipated returns. This is important because City Deal is a capital grant, and future blocks are subject to agreed outputs and outcomes⁷.
- For new projects, it would be possible to include climate risk screening during the design phase, and include adaptation measures to ensure the climate resilience of the investments.

Methods for screening and risk assessment

As highlighted above, most climate risk screening methods for project investments (for infrastructure and major projects) have a two-stage approach. The first phase undertakes an initial screening to assess the potential risk level. If a medium or high risk to the project is identified, this then proceeds to a more detailed assessment, which includes analysis of risks, but also adaptation options that can address these risks. Note that these approaches use a number of common terms around risk, vulnerability, exposure, hazard and impacts, presented in box 1.

The initial <u>climate risk screening</u> step is often quite quick, and usually involves a simple analysis that relates to a combination of:

- Sector. The climate sensitivity of the investment type, i.e. what type of hazards it is vulnerable to (e.g. heat, heavy rainfall, etc.).
- Country or region. The climate risk of the areas usually geographically specific to the project area, although this is often at a very course aggregation level (i.e. not that specific)'. This often draws on historical risks in the location.

Many organisations use simple matrices to implement these early climate risk screening steps, with a scoring system to identify the level of risk (low, medium, high). A number of private sector companies offer this type of climate risk screening, sometimes with automated software, though these often lose the site and context specificity. Projects that have a medium or high risk, which will include many infrastructure projects, are then subject to a more detailed analysis.

Once a project has been identified as being at potential risk, a more rigorous assessment is undertaken which assesses the climate risks, then looks at the potential adaptation options, i.e. a form of <u>climate risk and adaptation assessment</u>. There are different approaches for undertaking these assessments. There some organizations that apply a general process and set of guidance for this (e.g. ADB, 2014; NYC MORR, 2018). There are other organizations that produce much more specific sector guidance (e.g. Ray and Brown, ADB, 2012; 2014; Mott MacDonald, 2018).

⁷ Funding provided by the UK and Scottish Governments will be paid over a twenty year period and unlocked in five-year blocks, subject to the City Deal delivering agreed outputs and outcomes, assessed through a Gateway Review mechanism. The UK and Scottish Governments will each give the city region £500 million in grant funding, and the local authorities will borrow a further £130 million. http://www.glasgowcityregion.co.uk/article/7621/How-will-the-City-Deal-work

Box 1 - Terminology and definitions

Climate risk screening involves certain core terms and definitions. These are usually based on the IPCC core concepts and definitions, with respect to risk. This framing is used here.



Figure 6 Core concepts. IPCC, AR5 (2014)

The key terms are:

- **Exposure** The presence (of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets) in places and settings that could be adversely affected.
- **Hazard** The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- Vulnerability The propensity or predisposition to be adversely affected. Vulnerability encompasses a
 variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope
 and adapt.
- **Risk** The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
- Incremental adaptation. Adaptation that maintains the essence and integrity of a system or process at a given scale. In some cases, incremental adaptation can accrue to result in transformational adaptation.
- **Transformational adaptation** -. Adaptation that changes the fundamental attributes of a socioecological system in anticipation of climate change and its impacts.
- **Resilience** The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation.

For projects that face major risks, these climate risk assessments involve considerable time and resources to complete, not least because they may have important cost implications for the overall project (and thus may need to assess the economic costs and benefits of adaptation). It is not possible to apply this level of detail for all the City Deal projects in this short scoping study, because of the level of resources that would be needed, but it is possible to identify some of the potentially important risks in the context of specific locations of projects, and identify the broad types of adaptation decisions that could be considered.

Preliminary Climate Risk Screening of City Deal

Climate risk screening methods take account of the broad geographical profile of risks for the location on the investment or development projects, as well as the type of sector and the broad categories of climate risk these are vulnerable to.

The profile of climate risks includes categories such as:

- Temperature including heat, hot days, warm nights, heat spell duration, heatwaves.
- Precipitation, including dry spells, duration, droughts.
- Storm and wind, i.e. cyclone (hurricane/typhoon), winter storm (extra-tropical storm), local windstorm (orographic storm), tornado, severe wind.
- Sea -level rise, including storminess and wave heights, but also salt-water intrusion, acidification.
- Cold, cold spells, cold days freeze-frost cycles.
- Solar radiation, cloudiness.
- Etc.

These are sometimes extended to additional hazards caused by these, e.g. wildfire.

The sectors are usually based around typically categories, e.g.

- Transport, separated by mode (road, rail, air, etc.)
- Ports, etc.
- Energy generation, e.g. separated into coal, wind, hydro, etc.
- Electricity transmission and distribution, etc.
- Telecommunications.
- Agriculture and forestry,
- Etc.

This can be used in a matrix structure, e.g. for road transport, often with existing templates. An example is shown below for the road sector (based on ADB, 2014).

Some organisations also include an analysis of capacity, i.e. the ability to adapt, but this is usually used to differentiate between countries, e.g. allocating lower capacity levels to developing countries. Further work to explore and understand capacity in Glasgow City Region would be useful.

Table 6 Example of matrix showing potential climate risk and impact on road infrastructure. SourceAdapted from ADB (2011), Climate Change and US Transportation (2008).

Potential Climate Risk	Impacts on Road Transport Infrastructure
Increases in very hot days	Deterioration of pavement integrity, such as softening, traffic-related rutting,
and heat waves	and migration of liquid asphalt due to increase in temperature (sustained air
	temperature over 32°C is identified as a significant threshold)
	Thermal expansion of bridge expansion joints and paved surfaces
Increases in very hot days	Corrosion of steel reinforcements in concrete structures due increase in surface
and heat waves and	salt levels in some locations
decreased precipitation	
Increases in temperature in	Changes in road subsidence and weakening of bridge supports due to thawing of
very cold areas	permafrost
	Reduced ice loading on structures such as bridges*
Sea level rise and storm	Damage to highways, roads, underground tunnels, and bridges due to flooding,
surges	inundation in coastal areas, and coastal erosion
	Damage to infrastructure from land subsidence and landslides
	More frequent flooding of underground tunnels and low-lying infrastructure
	Erosion of road base and bridge supports
	Reduced clearance under bridges
	Decreased expected lifetime of highways exposed to storm surges
	Increased salinity levels will reduce the structural strength of pavements and
	lead to precipitated rusting of the reinforcement in concrete structures
Increase in intense	Damage to roads, subterranean tunnels, and drainage systems due to flooding
precipitation events	Increase in scouring of roads, bridges, and support structures
	Damage to road infrastructure due to landslides Overloading of drainage
	systems
	Deterioration of structural integrity of roads, bridges, and tunnels due to
	increase in soil moisture levels
	Changes in precipitation and water levels, including from flooding, will impact
	road foundations.
Increases in drought	Damage to infrastructure due to increased susceptibility to wildfires
conditions for some regions	Damage to infrastructure from mudslides in areas deforested by wildfires
Increase of storm intensity	Damage to road infrastructure and increased probability of infrastructure
	failures
	Increased threat to stability of bridge decks
	Increased damage to signs, lighting fixtures, and supports
Increase in wind speed	Suspension bridges, signs, and tall structures at risk from increasing wind speeds

The second risk screening component is focused on the geographical profile of risks in the area of the project investment. This often looks at the <u>profile of hazards</u> for the location. This is used particularly for sites in coastal locations for sea level rise risk (obviously) but also areas that have profiles of high hazards for extremes, e.g. for flood risk, high windstorms, etc.

The resolution of these initial hazard mapping is quite aggregated, i.e. it would not be down to the resolution of specific project sites, or even local authorities, and this would mean that hazard data would generally be applied at the City-region scale (see later maps).

The combination of sector risk, hazard information, sector location (exposure), and the vulnerability can be combined in tables to give risk scoring estimates, e.g. as below.

Investment	Category	Hazard	Exposure	Vulnerability	Risk
					level
Road	River	High	High	Medium	High
	Flood				
	Etc				

And can even be applied at the individual project scale.

Project name	Heavy	Sea level rise	Heat, heat	Rainfall	Wind-	Cold	Other
	rainfall and	and coastal	waves	average	storm		
	flood (river	flood and	and	and dry			
	and surface)	surge)	extreme	spell			
Road project 1	High	None	Low	Low	Low	Medium	
						(benefit)	

An indicative risk screening of the current City Deal portfolio identifies that <u>most of the existing</u> <u>infrastructure projects would be identified as at medium or high risk</u>, e.g. if these projects went through the typical procedures at one of the international investment banks, they would be identified as potentially at risk, and would need to go to the second more detailed climate risk and adaptation assessment.

It is stressed that this does not necessarily mean that major threats exist or costly adaptation is needed, but instead it just flags up that there is a need to investigate further. Further, in many cases, these risks may have already been assessed and mitigated as part of the detailed design work. It is also highlighted that new projections for the UK (UKCP18) are also now available: these provide updated climate information that may be valuable to consider.

It is stressed that the skills and employment projects would be screened as low risk, and would not require further analysis.

The main reason for the high risk ranking for City Deal projects is the high level of flood risk in the Glasgow City Region. The types of detail applied at the climate risk screening stage is relatively aggregate, and it is based on the importance of existing hazards, as well as future risks. Glasgow City Region has high baseline levels of coastal, river and surface water. All infrastructure projects in the Glasgow City Region would therefore likely to be identified as at risk.

Some projects would also flag up risks for other specific climate risks, e.g. coastal development projects would obviously rank highest for sea level rise and storm surge, while river developments to river flooding. It is noted that several projects are already been identified as having high risks to coastal flooding.



Figure 7 Potentially Vulnerable Areas identified. Source SEPA, 2015.



Figure 8 Location of Glasgow and Clyde Valley City Deal Infrastructure Projects. Source ClydePlan

An initial mapping has been undertaken at a more disaggregated site level. This draws on work already undertaken by CRC.

Table 7 Description and Initial Risk Ranking for City Deal Projects.

Project name	Project type	Description	Relevant climate risks
East Renfrewshire			
M77 Strategic Corridor	Park	Investment will support the	Medium – High. Surface and
	development,	development of a country park, new	river flooding. Vegetation
	road, rail, mixed	business infrastructure and	growth (enhanced)
		development, an enhanced road	Multiple risks for road / rail
		network and a new rail station.	(see table 6).
Glasgow City	Mined		Madium high Cunface flagd
	wixed	project industries cluster new	Multiple ricks for road (see
Galeway		leisure and recreation facilities and	table 6)
		site remediation for development	
		Road and bridge connections to city.	
City Centre Enabling	Mixed	Public improvements; resurfacing of	High. Coastal, river, surface
Infrastructure Public		streets and pavements; 'smart'	flood. Other risks for
Realm		infrastructure; creation of avenues of	infrastructure development.
		trees; segregated cycle lanes;	Potential issue of City urban
		underground facilities.	heat island and heat effects.
Clyde Waterfront &	Mixed	Unlocking of vacant and derelict sites	High. Coastal, river, surface
West End Innovation	development	for employment and housing.	flood. Multiple risks for
Quarter			building.
Collegelands Calton	Mixed	Improving infrastructure, quality of	Medium -high. Surface flood.
Barras	development and	land and travel connections	Multiple risks for road / rail
	transport		(see table 6).
	(Deil read)		
Motropolitan Glasgow	(Kall, road).	Drainago infrastructuro	High (rick/bonofit) Coastal
Strategic Drainage	drainage	Diamage initiastructure	river surface floods Other
Partnershin	infrastructure		risks on infrastructure
Inverclyde			
,	h		
Inverkip	Road	Infrastructure and development	High. Coastal flood. Multiple
Inverkip	Road	Infrastructure and development project which addresses the	High. Coastal flood. Multiple hazards for road project (see
Inverkip	Road	Infrastructure and development project which addresses the restricted network and junction	High. Coastal flood. Multiple hazards for road project (see table 6).
Inverkip	Road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at	High. Coastal flood. Multiple hazards for road project (see table 6).
Inverkip	Road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip.	High. Coastal flood. Multiple hazards for road project (see table 6).
Inverkip Ocean Terminal	Road Port	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm
Inverkip Ocean Terminal	Road Port	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks.
Inverkip Ocean Terminal	Road Port	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks.
Inverkip Ocean Terminal	Road Port	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships.	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at lochgreen	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire	Road Port Mixed	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access	Road Port Mixed Road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements	Road Port Mixed Road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements	Road Port Mixed Road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA	Road Port Mixed Road Road, park and	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA	Road Port Mixed Road Road, park and ride, nature	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA	Road Port Mixed Road Road, park and ride, nature	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal and storm surge. Other coastal risks.
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA Pan Lanarkshire Orbital Transport Corridor	Road Port Mixed Road Road, park and ride, nature Transport	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve Transport Corridor, and transport	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see table 6).
Inverkip Ocean Terminal Inchgreen North Lanarkshire A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA Pan Lanarkshire Orbital Transport Corridor	Road Port Mixed Road Road, park and ride, nature Transport	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve Transport Corridor, and transport and public transport improvements in Motherwell town centre	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see table 6).
Inverkip Ocean Terminal Inchgreen Inchgreen A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA Pan Lanarkshire Orbital Transport Corridor	Road Port Mixed Road Road, park and ride, nature Transport	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve Transport Corridor, and transport and public transport improvements in Motherwell town centre.	 High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see table 6).
Inverkip Ocean Terminal Inchgreen Inchgreen A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA Pan Lanarkshire Orbital Transport Corridor Renfrewshire Clyde Waterfront and	Road Port Mixed Road Road, park and ride, nature Transport	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve Transport Corridor, and transport and public transport improvements in Motherwell town centre.	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see table 6). High. Coastal and river flood.
Inverkip Ocean Terminal Inchgreen Inchgreen A8 M8 Corridor Access Improvements Gartcosh/Glenboig CGA Pan Lanarkshire Orbital Transport Corridor Renfrewshire Clyde Waterfront and Renfrew Riverside	Road Port Mixed Road Road, park and ride, nature Transport Bridge, road	Infrastructure and development project which addresses the restricted network and junction capacity on the A78 trunk road at four locations in and around Inverkip. Expansion of the quayside and new visitor centre to further expand Greenock Ocean Terminal for cruise ships. Partnership project to promote, make market ready and secure key sector investment at Inchgreen. redevelopment of a brownfield site, development of quay assets and the Inchgreen dry dock to offer a dedicated on shore marine hub Road infrastructure, plus park and ride - seven miles of new motorway between Baillieston and Newhouse New strategic road infrastructure and park and ride investment plus Gartcosh Local Nature Reserve Transport Corridor, and transport and public transport improvements in Motherwell town centre.	High. Coastal flood. Multiple hazards for road project (see table 6). High. Coastal flood and storm surge. Other coastal risks. High. Coastal and storm surge. Other coastal and storm surge. Other coastal risks. Medium-High. River and surface flooding. Multiple hazards for road project (see table 6). High. Coastal and river flood. Multiple risks for road / bridge

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

During the second	Ducto at these	Description	Delevent ellevete stelle
Project name	Project type	Description	Relevant climate risks
Glasgow Airport	Bridges, road	Two new bridges, a 'Gateway Route'	Medium – high. River and
Investment Area		between Paisley and the airport, and	surface flood. Multiple risks
		improved travel infrastructure	for road / bridge (see table 6).
South Lanarkshire			
Cathkin Relief Road	Road	Road, junction upgrade and tree and	Medium – high. River and
		shrub planting.	surface flood. Multiple risks
Greenhills Road A726	Road	Upgrade to duel carriageway.	for road / bridge (see table 6).
Stewartfield Way	Road	Road widening and junction upgrade	
Community Growth	Buildings and	Four community growth areas to	Medium-high. River and
Area - Newton	transport	deliver education, transport and	surface flooding. Multiple risks
CGA- Hamilton		community infrastructure projects	for road / buildings (see
CGA- Larkhall			earlier).
CGA- East Kilbride			
West Dunbartonshire			
Exxon Site	Mixed	Site development near Bowling with	High. Coastal and river flood.
Development Project		a major industrial and commercial	Other development risks.
		development, plus new road link for	
		West Dunbartonshire.	
Regional Projects			
Airport Access	Tram	Direct link between Glasgow Central	Medium – high. River and
(Regional Project)		Station and Glasgow Airport	surface flood. Multiple risks on
			rail.
SPT- Strathclyde Bus	Transport		Multiple risks.
Investment Programme			
INNOVATION PROGRAMM	ME		
Stratified Medicine:	Built environment	Imaging Centre (ICE) of Excellence at	Medium-high. Building design
Imaging Centre of		the new Queen Elizabeth II Hospital	and heating and cooling.
Excellence (ICE)		Campus	
MediCity	Built environment	Medical technology incubation	Medium. Building design and
		facility.	heating and cooling. Surface
			flooding.
Tontine (IGI)	Services. Some	Project to provide support service for	Low - Medium. Services low,
	built environment	high-growth companies in the	but some linkages to built
		enabling technology, advanced	environment through
		design and manufacturing, and	promotion of office
		creative economy sectors.	workspaces.
SKILLS & EMPLOYMENT P	ROGRAMME	,	
In-Work Progression		Three labour market projects help to	Low. Not considered to be at
Working Matters (ESA)		address local employment	risk from climate change.
Youth Gateway		challenges.	
Guarantee		ž	

Note low, medium and high rating based on results of the Phase 1 study on climate risks and economic costs, analysis of site location in the city and potential hazards, and expert judgement.

Light-touch Climate Risk and Adaptation Assessment of City Deal Project

For those projects that are identified at medium or high risk, the next set of steps is to move to a more detailed risk assessment and to identify any potential adaptation options.

There are a variety of methods that can be used for these assessments. Some organisations provide formalised guidance, with step by step guidance, often including additional sector guidance (e.g. ADB, 2014: 2015: Jaspers, 2017). Others use a more ad-hoc approach, using competitive tenders and delivering through consultants. However, many detailed climate risk studies get somewhat lost in the climate change model projections, and focus less on the key considerations for the project, and on the primary objective which is to try and enhance the climate resilience of the project.

This section looks at a number of key aspects for climate risk assessments, and applies these in general terms to City Deal projects. In particular, it identifies:

- How important climate change is for a project, which is influenced by the life-time and level of lock-in.
- The importance of climate change on the actual economic and financial performance of the project.
- The selection of early promising adaptation options for infrastructure projects.

Lifetime and lock-in

As highlighted earlier, the need to include early adaptation does depend on the life-time of the project, and the degree of lock-in (irreversibility). Those projects in the City Deal portfolio that have higher life-time and greater lock-in will be priorities for adaptation, because of the higher risks and the greater opportunity to include resilience during design.

This can be illustrated with a number of examples from the road sector.

- Road surfaces are vulnerable to extreme heat. However, the likely exceedance of heat thresholds in Glasgow is very low currently, and these events are only likely to occur in the 2040s. At the same time, the lifetime of road surfaces is short, and they will be replaced in the next 15 years. The life-time is short, and there is little lock-in or irreversibility involved.
- Bridges are large infrastructure investments, that are heavily engineered, and they typically have a very long life-time. It can be very difficult or costly to retrofit major changes in response to changing climate risks. Their life-time is long and they have a degree of irreversibility.
- Roads are at risk of flooding today (coastal, surface, river) and these risks are projected to increase with climate change. The siting of a road needs to consider both current risks, but also the potential increase in flood hazard, otherwise there is a risk of siting the road in an area that will get repeatedly flooded in the near future due to climate change increasing flood risk area or frequency. The decision on where to site the road is a one-off decision and is irreversible and locks-in the road to future hazard patterns, i.e. either the risk of flooding or expensive adaptation measures later to increase the flood protection for the road.

It is therefore much more important to focus on climate resilient design for a bridge, and for the siting of a road, than it is to build in adaptation to heat for a road surface.

Road sector

A large number of the City Deal projects are focused on the road sector and transport infrastructure. Looking at the road sector in more detail, the highways agency has identified the lifetime of different investments, shown in the figure below. Culverts, bridges tunnels and retaining walls have the longest- lifetime.



Figure 9 Design life of different road transport components and priorities for adaptation. Source: Highways Agency (2011).

Therefore, it is more important to consider City Deal projects that involve these longer-lived investments (e.g. bridges) or the longer-lived components of main road projects (e.g. culverts).

Looking at the City Deal projects, the most relevant aspects for climate resilience will involve:

- Bridges (long life-time and lock-in). There are several projects with Bridge components;
- Siting decisions (new roads, siting of new rail stations, siting of park and ride, etc.), as these lockin development areas. These are involved in several projects.
- Long lived components of road projects, see list in figure above, which includes culverts, tunnels. These will be relevant for most projects, although they may be a small part of the overall project.

Port and Coastal Infrastructure Investments

There are a number of the City Deal projects that involve development along the Firth of Clyde. These could be affected by future coastal flooding risks. In many cases, these investments involve siting decision and land use change, that have a long life-time and degree of lock-in.

These include investments that will be subject to the potential risk of coastal and river flooding. In particular, this involves the Inverkip, Ocean Terminal and Inchgreen projects, the Exxon site, as well as the Clyde Waterfront & West End Innovation Quarter, especially the projects on quay walls and extension into the river. These investments all have a long life-time, and they involve high lock-in because they are changing land-use patterns.

Port infrastructure has been a focus of much of the early climate resilience work. A number of investment banks have looked at climate resilience for the port sector (EBRD, 2016; IFC, 2011) and are building resilience into these investments. Most recently, there has been a The World Association for Waterborne Transport Infrastructure (PIANC) Working Group (178) Guidance on climate change adaptation for ports and inland waterways.

These studies highlight key issues around siting and elevation of sites (and future exposure to coastal flooding over time with sea level rise, and potential change in storminess). Importantly, they also highlight the importance of transport connectivity (access roads) and the need to make sure these are sited with similar considerations, and long-term resilience in mind.

Built Environment

All new buildings will have a fairly long life-time, which means they need to be aware of the future climate, and they involve siting decisions with respect to current and future flood risks. There are a number of projects that involve new buildings or new facilities, such as the three innovation projects. As highlighted in the earlier studies, heat extremes are unlikely to be a major issue for Glasgow City Region, but there are opportunities when designing new buildings to ensure they reduce the risk of over-heating in the future (BRE, 2017).

Table 8 Indicative Analysis of Potential Life-time, Lock-in and Level of Precaution

Project name	Lifetime	Lock-in	Level precaution	Potential issues
M77 Strategic Corridor	Medium / High	Medium – High	Low - Medium	Site choice
	(see figure 9)	Land-use change.		Siting of rail station
Canal and North	Medium / High	Medium - High	Low - Medium	Site choice
Gateway		(land use)		Bridge connections.
City Centre Enabling	Medium / High	Medium - High	Low - Medium	Underground
Infrastructure Public		(land use)		Tree selection
Realm				
Clyde Waterfront &	High	High (water front	Medium - high	Siting important,
West End Innovation		development)	asset risk	especially
Quarter		Bridges & land-use		-Quay Walls
		change		-Bridges
Collegelands Calton	Medium / High	Medium	Low - Medium	Siting of rail station
Barras	(see Figure 9)	(road development) –		
		new or existing		
Metropolitan Glasgow	High	High	High – Critical	Site choice
Strategic Drainage Part.			infra-structure	
Inverkip	Medium / High	Medium - High	Low - Medium	
	(see Figure 9)			
Ocean Terminal	High	High (land use)	Medium	Siting of terminal
Inchgreen	High	High (land use)	Low	
A8 M8 Corridor Access	Medium / High	Medium	Low – Medium	Siting of Park and
Improvements	(see Figure 9)			ride
Gartcosh/Glenboig CGA	Medium / High	Medium – high	Low – Medium	Siting of nature
	(see Figure 9)	Land use change		reserve
Pan Lanarkshire Orbital	Medium / High	Medium	Low – Medium	
Transport Corridor	(see Figure 9)			
Clyde Waterfront and	High - bridges	Medium - high	Low – Medium	Bridge
Renfrew Riverside				
Glasgow Airport Investment	High - bridges	Medium - high	Low – Medium	Bridges
Cathkin Relief Road	Medium / High	Medium - High	Low - Medium	
Greenhills Road A726	(see Figure 9)	Weddull - High		
Stewartfield Way	(300 1 1601 0 3)			
Community Growth Area	Low - medium	Medium	Low	
CGA- Hamilton	Low - mealam	Wedialli		
CGA- Larkhall				
CGA- East Kilbride				
Exxon Site Development	High	High	Medium	
Project	ייאיי ואיי	1.1.2		
Airport Access (Regional	Medium / High	Medium	Low - Medium	
Project)	(see Figure 9)			
SPT- Strathclyde Bus	Medium / High	Medium	Low - Medium	
Investment Programme	(see Figure 9)			

<u>Key</u>

Lifetime. Medium – over 30 years. High – likely to be more than 50 years.

Lock-in – potential for increased future risk from decision now and/or level or irreversibility. Level of precaution. Critical infrastructure or cascading failure risks - high. Service disruption (cascading risk – transport) -medium.

Economic and financial risks

While climate change is often thought of as an environmental risk, a key issue is that the impacts could affect the economic and financial performance of projects. In the context of City Deal, this could affect the delivery of the anticipated benefits, and it could thus affect the viability of the project and the economic growth achieved.

To put these in context, there has been a growing focus on the importance of climate risk, making sure that financial and capital markets start to consider these. This is being advanced with the Task Force on Climate-related Financial Disclosure (TCFD)⁸. While the initial focus has been on the risk of stranded assets because of mitigation policy and carbon taxation, there is an increasing recognition of the need to assess and disclose physical climate impact risks. It is also being recognised that changing risk profiles from climate change could alter asset values and operational costs. This applies to local public budgets and private companies. This is important as many City Deal investments are leveraging other funding, including private funding. As an example, properly accounting for physical climate risk could - on average – reduce company values by 2-3% due to the risk costs of insuring assets, and more in some sectors⁹. As a result, the ratings agencies, as well as investment risk analysts, are starting to include these factors in everything from country basis points through to individual company assessments.

It is therefore useful to map the pathways by which climate change could affect the economic and financial performance of projects. A general list of categories is shown below (Watkiss and Wilby, 2018).

Category	Current weather and extremes	Future climate change
Asset /Capital Cost	Current weather extremes (e.g.	Slow onset change – average
Operating and Maintenance	shocks such as floods)	trends
(O&M) / O&M costs	Current climate variability	Changes in the intensity or
Revenues / benefit stream	Possible threshold levels	frequency of extreme events
Access to finance/ insurance		Changes in variability.
Socio-economic effects		Exceedance of thresholds
(economic)		

Table 9 Economic and Financial Risks from Climate Change on Investment Projects.

Source Watkiss and Wilby (2018).

The potential economic and financial risks for a number of the main City Deal infrastructure project investment types are summarised below.

Road projects

Road projects include both new and upgrade projects. As highlighted above, several elements will need to be taken into account to prevent locking in future vulnerabilities, notably the choice of location to avoid exposure to floods. Upgrade projects could present the opportunity of incorporating new climate evidence into investment decisions. The potential pathways by which climate could affect the economic and financial performance are:

⁸ See https://www.fsb-tcfd.org, established by the G20's Financial Stability Board.

⁹ https://www.economist.com/business/2019/02/23/business-and-the-effects-of-global-warming

- Assets/Capital cost: Climate change could lead to a faster depreciation of assets, whose lifespan might be reduced if repair, downtime, and damage costs become too frequent and financially unsustainable. Road infrastructure in coastal areas is sensitive to more frequent and permanent flooding from sea level rise and storm surges, with floods risks for roads located in flood risk areas (now or under future climate change). Landslides and wash-outs could occur more frequently. Extreme events could delay construction works, with implications for the financials of the projects (e.g. penalties, interest during construction etc).
- **O&M**: More frequent and heavier rainfall could put the infrastructure under stress, possibly requiring more frequent maintenance and repairs. Higher than estimated (design) temperatures can cause pavement to soften and expand, although this is unlikely to be a major issue for GLD. There are potentially high risks from tree fall during storms, and more frequent maintenance of the vegetation along the road network might be required. More frequent flood events lead to increasing repair and reconstruction costs. Flooding events would weaken or wash out the soil and culverts that support roads, and tunnels. Insurance costs might increase. Certain projects may experience cost savings and improved mobility from reduced freezing and freeze-thaw and less-frequent winter storms since warmer winters may lead to reductions in snow and ice removal, as well as salting requirements.
- **Revenues**: Revenues flows could be delayed as a result of delay in construction works, typically caused by more frequent and heavier rainfall.
- **Socio-economic**: Climate-induced events affect the safety and availability of roads. Travel disruptions have domino effects (increasing costs) for businesses and households.

Bridges

Bridges are key infrastructure nodes in transportation networks. Their building and operation have implications for the traffic on all connected transport infrastructure. The potential pathways by which climate could affect the economic and financial performance are:

- Assets/Capital cost: Possible delays in construction due to heavier and more frequent rainfall, windstorms etc. which could increase capital costs. Climate change could expose bridges to more frequent and heavier rainfall and increasingly higher temperature, both possibly leading to a faster deterioration of the assets. For waterway bridges, increase in scouring of support structures might compromise the stability of the asset, and /or freeboard height may be reduced in the future, reducing the asset value (e.g. if navigation underneath the bridge is reduced). Extreme events (wind storms) might lead to damage and reconstruction costs. Decisions on over-design or phased adaptation to changing climate conditions would need to be incorporated into capital investment decisions upfront.
- **O&M:** Increased threat to stability of bridge decks, and suspension bridges, signs, and tall structures are at risk from increasing wind speeds/ As a result, more frequent maintenance works can be required to stabilise and secure the infrastructure. Increasing temperatures and extreme heat can lead to thermal expansion of bridge joints and paved surfaces.
- **Revenues**: Delayed construction due to climate-related events (e.g. windstorms, heavy precipitation and floods). Bridge infrastructure in coastal areas could be sensitive to sea level rise and storm surges.
- **Socio-economic**: Bridge closure/disruptions have domino effects (increasing costs) for businesses and households. Closure of bridges increases travel time.

Ports and coastal development

Ports and coastal developments have a strong risk exposure to weather hazards and climate change, particularly from the potential risks of sea level rise and storm. Some of the key linkages are below.

- Assets. Frequent disruption and damage to port infrastructure from coastal storms and storm surges could lead to a decrease in tangible asset value, as well as the a port's brand and reputation and service ratings by vessel operators and other customers/clients. These risks could be increased from sea level rise. SLR may also lead to inundation of areas or increases in erosion affecting assets.
- **O&M:** Changes in precipitation including storms, heavy precipitation might increase costs due to more frequent use of anticipatory safety measures for equipment (e.g., cranes) from impending severe weather events impact port availability. Contingency and recovery costs may increase and/or become more frequent, and penalties may be payable if operating standards under concession are exceeded. Port facilities may be damaged by flooding and require more frequent and costly recovery costs. These effects could be exacerbated by sea level rise, which could increase the frequency or intensity of floods and storms. High temperatures could affect ongoing costs and or maintenance, but this is not considered to be a high risk.
- **Revenues**. Flooding may close access roads and shipping channels, disrupting traffic to/from ports. Increased runoff from severe weather events may increase accumulation of debris and silt, making port access channels shallower and thus disrupting port traffic. Ports are also vulnerable to disruptions to water, electricity and fuel supplies due to severe weather and flooding that may affect ports' ability to offer services. Revenues may be temporarily affected until normal port operations resume. Storms could lead to service disruption and disrupt traffic to/from ports and port operations. Revenues may be temporarily affected until normal port operations. Revenues may be temporarily affected until normal port operations.
- Socio-economic. The effects above could have knock on effects on the value chains associated with ports. Access roads which are critical linkages for moving goods to/from port facilities may be vulnerable to both acute precipitation/flooding and (in some areas) chronic nuisance flooding which impact normal port operations. Sea-level rise could submerge patio and other infrastructure, rendering port facilities inoperable. To the extent that sea-level rise impacts inland waterways, bridge clearance may affect traffic and thus port revenues.

Urban Built Environment

This sector includes a range of infrastructure and assets: new public buildings, urban transport, urban water supply and wastewater treatment, waste management, etc. Each of these sub-sectors could be impacted by climate change in different ways. The high degree and complexity of the interdependencies between them make the estimation of the climate change risks on the urban sector particularly challenging. Some of the key linkages are below.

 Assets/Capital cost: Assets value depreciation rate might be higher than originally planned. Reputation and brand of service suppliers might be damaged by frequent service disruptions. More frequent floods and storms could damage critical infrastructure such as water supply, electricity supply, roads and telecommunications, hospitals and sewage systems. Restoring systems, rebuilding damaged houses, restoring contaminated water sources and restoring access to livelihoods would need to be part of cities reconstruction and recovery plans - for which sufficient financial resources would need to be set aside.

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

- **O&M**: More frequent and costly maintenance works might be required to guarantee services supply in the face of a changing climate. Heavier rainfalls, higher temperatures, and wind storms would most likely require more frequent maintenance interventions to maintain supply of urban services at certain level. Heavy rainfalls and floods for example could cause damage to rails, substations, basements and under-level equipment, tunnels, etc. which would need to be repaired to minimise the risk of disruptions. Accelerated maintenance of the drainage infrastructure will be necessary to remove blockages, repair leaks and breaks, and ensure that vital pumping stations have sufficient power to keep operating. Increasing temperatures and heat waves could have a range of effects on a wide number of services, from transport to waste management, although it would also have benefits from reduced cold related maintenance costs.
- **Revenues**: Climate change could result in urban assets being more frequently disrupted than originally planned, and hence less profitable. Heavy rainfalls can lead to substation power outages, and overhead lines (OHL) loosening; and traction voltage disturbances can occur due to freezing, and stop service. However, cold and freeze related damage would be reduced. These compromise services supply, and the profitability of the infrastructure projects.
- Socio-economic: The vulnerability of the urban built environment to climate change has a direct impact on those who live and work in cities: disrupted transport services would have direct implications on travel time, and travel preferences. Discomfort in the built environment during the summer or heat-waves could have impact on productivity levels of workers (office buildings), and severe health consequences particularly for the most vulnerable people (children and the elderly in hospitals and schools).

For all major infrastructure investments, there are potential risks to the economic objectives of City Deal projects, although it is difficult without more detailed analysis to assess how material these are. In some cases, these risks will have been addressed already, notably as part of the greater mainstreaming of climate risks – including in standards and engineering design practice - in the UK. However, as the City Deal portfolio did not undertake a systematic review of climate risks, residual risks are likely to remain. This informs the later recommendations.

Adaptation priorities for further exploration in Glasgow City Region City Deal

In developing adaptation for infrastructure investment projects, there is a particular need to consider the potential costs and benefits of added resilience.

There are costs are associated with the additional (marginal) costs of the additional resilience measures or activities and some options can involve high up-front costs. For example, the World Bank (2006) estimated that accounting for future climate in high-risk projects today could potentially increase project costs by 5 - 15%. Further implementation experience from climate resilience in the road sector in ADB, has found the additional costs to deliver resilience varies from 0.5 - 10% of the total project investment cost (ADB, 2014b).

To put these in context, thesel benchmark costs (0.5-10%) would imply quite large adaptation costs for the Glasgow City Region City Deal portfolio of between £5.7 million and £113 million.

It is important to consider whether these costs can be justified. There are two components to this. First, whether the anticipated benefits are greater than the costs (if they are not, then it may be better to look at alternatives, such as insurance). This decision also needs to take account of the profile of costs and benefits, using discount rates, to express costs and benefits in equivalent net present values (HMT, 2018), as the effect of discounting will make it more difficult to justify benefits that only occur in the long-term.

Second, the challenge of uncertainty (see also the Adaptation Pathways case study). This includes scenario uncertainty (i.e. are we on a 2 or 4°C path?) but also climate model uncertainty (for a given scenario), noting the latter can be larger than the former. As design changes need to be considered now, this make it difficult to know exactly what changes to make. For example, it is easy to design infrastructure for one future scenario (e.g. an increase in run-off) or another (e.g. a decrease in run-off), but more difficult to produce designs that works equally well in both cases. One answer is to over-design to cope with the worst case, but this involves much higher costs, noting also that this will protect to an outcome (the most extreme) that is actually unlikely to occur. This is therefore not an efficient approach.

This means that the choice of these future orientated options in investment projects has to be made carefully, to avoid misallocation of resources, whether this be due to the high costs of additional upfront capital investment, or the early opportunity costs from actions that prevent short-term economic benefits (e.g. land planning constraints). This has led to a focus on decision making under uncertainty. The main investment banks have been looking at ways to take account of this uncertainty, and enhance the economic appraisal of climate resilience for infrastructure. Further, many of these are using the decision making under uncertainty approaches outlined. For example, the ADB has produced specific guidance on the economic appraisal of climate proofing (ADB, 2015). This recommends the potential for building flexibility in project design, to allow upgrade later if climate risks emerge, as well as adaptive management approaches that monitor over time. The EBRD (2015) has been applying similar concepts, as well as looking at approaches that minimise regrets. The World Bank has been advancing robust decision making for urban projects (Lempert et al, 2013) as well as Climate Risk Informed Decision Analysis (UNESCO, 2018).

In short, these look at whether to invest in climate proofing projects during design, or whether to use decision making uncertainty concepts to advance robust adaptation (which will work well across all future scenarios), to build in flexibility (so a project can be upgraded later if needed), to look at alternative approaches to address risk, to design to minimise large downsides. However, all approaches have a focus on making sure current risks are adequately addressed with no and low-regret options, as well as a greater focus on adaptive management, i.e. to assess climate risk over time.

These can be used as part of wider options analysis for projects, as part of the process of identifying options. An example is shown below from recent work in ADB (Watkiss and Wilby, 2018).

Table 10 Adaptation Options for Investment Projects.

Adaptation type and timing	Examples of the adaptation type
Design and engineering at time of	Change the site or location
design	Change the design (engineering) - includes dimensions, materials, technology, structural (defences), etc.
Design and engineering (later)	Flexibility built into the design
	Modular or iterative design to enable later change
Maintenance and operations	Change maintenance regime or infrastructure operations (on-site, system)
Non-technical and non-engineering	Institutional and capacity building
options	Includes information, research and behavioural change
Alternatives to design changes	Non-technical options or measures
as addressing risks	Financial and market based (including insurance)
	Policy and legislative
Do nothing	No adaptation (live with the risks)
Reconsider the project	

Source Watkiss and Wilby, 2018.

The exact options depend on the context, and would be considered as part of detailed project design and feasibility. However, there are a number of key areas which could be prioritised in design and delivery of City Deal projects. Some examples of the types of options are outlined below:

- Review project location for current and future flood risk For all road and urban projects, there are obvious benefits in the siting of projects, to avoid high flood risk areas, or to locate critical parts of the road network (e.g. junctions) away from risks. A critical issue here is that these assessments need to consider future flood hazards, rather than historic. There are also sub-project siting choices, notably around critical components, or those that have a longer life-time, where are a greater degree of climate proofing can be applied (Se NYCMMC, 2018).
- Evaluate the overdesign of key components Reviews of road projects in the development banks (ADB, 2014b) often show that it is relatively low cost to overdesign key components of road projects, such as culverts and drainage, and it may be simpler to include these in design. Indeed, some of this is already factored into the engineering design standards used in the UK for road projects.
- **Continue to develop no-regret options** For all these projects, there are no-regret options for improving weather and climate information to better help manage risks, and for individual projects, to have emergency plans in place for climate hazards.

The same siting issues applies to port, coastal and riverside development, but there is obviously a trade-off between location and function, i.e. while it might be useful to set-back infrastructure from the water hazard, this is usually like to affect functionality. In these cases, there is the option to look at raising sites, either immediately, or building in the flexibility to do this later. Enhanced weather and climate information, and emergency response, is also a major part of many climate resilient port

development projects (e.g. EBRD, 2016). As highlighted earlier, recent guidance has been produced on adaptation measures for ports, which focus on low and no-regret options (PIANC, 2019).

Discussion

This case study has undertaken a review of climate resilience in the City Deal, and will use the results to help in developing a position paper. The case study has undertaken a high-level climate risk screening of the projects included in the City Deal portfolio, assessing their level of potential risk. This estimates that all the existing infrastructure projects are a medium or high climate risk, i.e. if these projects went through a typical investment bank CRM, they would require a more detailed climate risk and adaptation assessment. In contrast, the skills and employment projects in City Deal were all screened as being low climate risk, and would not require further analysis. It is also highlighted that many of the climate risks identified have probably been picked up in the existing design and feasibility studies. The main cause of the medium and high ranking is the level of flood risk in Glasgow City Region.

The analysis has also considered what would be involved in a subsequent detailed climate risk and adaptation assessment. It is not possible within this scoping project to undertake this level of analysis for all City Deal projects. However, the analysis has looked at the main project investments in the infrastructure portfolio, focusing on road projects, coastal area development, and urban built environment, and investigated the potential risks to the project, in terms of the life-time and level of lock-in (the level or irreversibility in the investment decision), the importance of climate change on the economic and financial performance of the project and early promising adaptation options.

The case study does suggest that a more structured climate risk approach for City Deal might be useful, particularly for the gateway projects (undertaking an initial climate risk screening of new projects), as well as new large public-funded infrastructure projects in GCR. This would identify climate risks more systematically, and ensure climate resilience was considered in their design and feasibility studies. For the existing GCR City Deal projects it is recognised that these have already been through an extensive assessment and identified as having large economic and social benefits. Nonetheless, there may be an opportunity at future Gateway Reviews to put them through an additional climate screening process – this would make the proposed projects even more valuable and cost-effective.

It is therefore recommended that climate risk screening and potential fuller risk and vulnerability assessment requirements are embedded into the City Deal assurance framework. To deliver this, it would be useful to draw on the existing CRC toolkit, as well as existing practice in public investment banks. These approaches would be useful for subsequent investment projects in Glasgow City Region.

The approach explored here also has wider potential applications, including in relation to the emerging Scottish National Investment Bank. The bank's objects, as set out in the Bill (Scottish Parliament, 2019), include investing in inclusive and sustainable economic growth, creating and shaping markets through the provision of patient capital, and contributing to the achievement of the Scottish Government's economic policy objectives. Avoidance of climate change risk is a key supporting aspect in achieving these goals. Similarly, climate risk could be incorporated into the main ethical, social and governance (ESG) criteria used to ensure that investments are resilient to future climate change.

CASE STUDY 3: ADAPTATION PATHWAYS FOR THE CLYDE CORRIDOR

The task focuses down on the use of adaptation pathways, which were identified to be of interest in GCR and Adaptation Scotland. To progress this, a pathways case study was developed focusing on the Clyde Corridor.

Review of adaptation pathways literature

The study undertook a detailed of the adaptation pathways literature, and relevant information. This identified the following types of adaptation pathway approaches:

- <u>Adaptation pathway frameworks or roadmaps</u>, i.e. the general use of portfolios of adaptation that change over time in response to varying risks (Downing, 2012). These are used to sequence adaptation, and to identify early adaptation priorities which are an immediate priority. This type of approach was used in early pathways work (SEI, 2008), as well as the UK Economics of Climate Resilience (Watkiss et al, 2011; Frontier et al, 2013).
- <u>Adaptive management</u> (also sometimes called iterative risk management). This is an iterative cycle of monitoring, research, evaluation and learning, i.e. a process, that is used to improve future management strategies (IPCC, 2012). This approach is particularly relevant for adaptation given the high uncertainty. The method usually develops adaptation pathways, but an important difference is that it uses an iterative framework that allows changes to be made through a process of review and learning, i.e. it is more strongly linked to practical implementation, monitoring and review.
- A variation on iterative adaptive management is to include risk thresholds that trigger changes in the adaptation pathway. This brings together adaptive management and decision making under uncertainty. It is more focused on decisions (and decision support) for projects. These methods identify thresholds that act as <u>adaptation tipping points</u> or turning points (Werner et al, 2013), i.e. thresholds where biophysical tolerance levels or policy objectives are exceeded, which require a change in adaptation. Alternative options or combinations of options can be considered at these points. These are often presented as <u>adaptation route maps</u> (also called adaptation pathways): these route maps usually show a number of alternative pathways and options, which in collaboration with stakeholders, allows consideration of preferences and a preferred route to be chosen. These maps are accompanied by a monitoring programme, to measure the threshold indicator, and can be used as part of adaptive management to bring forward or delay future action as needed. A good example of this was the Thames Estuary 2100 study, (EA, 2011: Reeder and Ranger, 2011). This approach was also developed in the Netherlands, notably with the Dynamic adaptation policy pathways, Haasnoot et al 2013.
- There have been extensions of the approaches above to consider socio-institutional issues, with literature on <u>transformational change</u> (e.g. Wise et al, 2013) including <u>adaptation landscapes</u>. This has a stronger focus on societal change and values, as well as institutional and governance dimensions, because of their role in constraining traditional pathway approaches. This literature is particularly relevant for longer-term transformational adaptation (beyond incremental). Related to this, there is a recognition of the barriers to adaptation, i.e. policy, institutional, governance, behavioural, market and financial (Cimato and Watkiss, 2017) and there is work (Brown et al, 2017) identifying climate change <u>adaptation windows</u>, i.e. individual or collective decisions that either narrow or enhance decisions / action to facilitate planned adaptation.

Current study and method

The starting point for the case study was to decide on the type of adaptation pathway and the methods to be applied. To help progress this, the literature review considered current adaptation pathways guidance (e.g. Bosomworth et al, 2015: RAMSES, 2017a: b; UNESCO/CRIDA, 2018) and it reviewed previous coastal applications (EA, 2011; Ranger et al, 2013; Ramm et al, 2017; NYC MORR, 2018). Following this, the study focused on three key activities:

- 1) Developing a <u>high-level adaptation pathway for the Clyde Corridor</u>, i.e. applying ASC/CCCRA2 framework (Warren et al, 2016) to identify early priorities for adaptation, alongside the sequencing of adaptation options over time.
- 2) Developing a more in-depth <u>adaptation route-map</u>, with an increased emphasis on iterative adaptation pathways including decision making under uncertainty. This includes the identification of adaptation turning points/thresholds, a route-map, and adaptive management (review and monitoring). To do this properly would require considerable analysis, with detailed flood risk mapping, but it was possible to undertake initial analysis of thresholds and a route-map approach to explore the extent to which it offered a viable approach for future risk management for the City Region.
- 3) Climate Risk Screening for major infrastructure investments or projects. For such investments, it is possible to apply a detailed climate risk screening and decision making under uncertainty, using an adaptation pathway, to provide very specific project recommendations. This is particularly important for investment decisions with a long life-time such as the City Deal. Therefore, the third part of the case study focused on project level climate resilience.

The overall methodology to undertake these case studies starts with a series of common steps:

- Set the objectives in discussion with stakeholder consultation, as well as inputs from existing legislation and produce the overall process cycle (from objectives to evaluation);
- Assess current risks, using available data;
- Assess future risks, including climate and socio-economic change, for different scenarios, with consideration of uncertainty;
- Identify potential issues of lifetime and lock-in (relevant for adaptation frameworks);
- Identify possible thresholds, considering biophysical risks and tipping points and critical thresholds and adaptation turning points (relevant for adaptation route-maps) for the overall corridor but also for specific developments. Discuss and agree these with stakeholders;
- Identify potential adaptation options;
- Identify the potential benefits (risk reduction) of adaptation options and assess the costs and benefits (as well as other criteria of interest to stakeholders) for options and portfolios.

There is then a set of steps related to the three specific methods.

- Apply an initial adaptation pathway framework to identify early priorities and sequence adaptation options over time;
- Develop an adaptation route-map, with key thresholds and turning points, linked to packages of options over time. Discuss potential routes (and understand risk preferences) with stakeholders, and agree on priorities;
- Apply a climate risk screening and adaptation pathways approach to an individual project development.

It is stressed that undertaking adaptation case studies does involve considerable time and resources, and as this is a scoping study, the case study has not undertaken new modelling analysis. Instead it draws on existing assessments, notably:

- The SEPA National Flood Risk Assessment analysis and Flood Risk Management (SEPA, 2015: 2018);
- The UK ASC coastal risk assessment (Sayers et al, 2015);
- Clyde plan, and the Clyde plan risk of flooding information;
- The National Coastal Change Assessment and Dynamic Coast Change study (Rennie et al, 2017);
- The Scottish Natural Heritage sea level rise study (Hansom et al, 2017).

The Clyde Corridor

The focus of the case study is on coastal flooding in the Clyde Corridor, from the city centre through to the terminal areas around Greenock/Gourock.



Figure 10 Clyde Corridor. Source Google maps.

Note that there is a narrower definition of the Clyde Corridor as it relates to the regeneration strategy¹⁰, which covers the area from the City Centre up to Renfrew. These development areas are a priority for early adaptation, because of the potential risks of lock-in. Many of these potential projects are now being advanced in the City Deal.

Objectives

The starting point for the approach is to identify objectives. These should be discussed and agreed with stakeholders, and this was progressed with an adaptation pathways workshop (see Box). The key climate objective agreed was 'to ensure the Clyde Corridor was flood resilient and future proofed'. However, there was also agreement that this climate objective needed to be seen in the context of the wider objectives for the development of the Clyde Corridor.

¹⁰ https://www.williemiller.com/clyde-corridor-regeneration-strategy.htm

There are also some specific objectives on climate risks as set out in existing flood risk management policy in Scotland. The Flood Risk Management Strategies (SEPA, 2015) set out short to long term ambitions for flood risk management in Scotland. The strategies state the objectives, as agreed by responsible authorities, for tackling floods in high risk areas. Actions that will then deliver these objectives are described and prioritised in six-year planning cycles. For this process, SEPA (2015) uses 'risk of flooding' metrics, which refer to likelihood of flooding. These are shown below. SEPA uses the 1 in 200 chance of flooding in any given year as a medium 'risk of flooding'. This is applied to properties. The chances of low and high risk are also shown.

Chance / likelihood of flooding		
High	1 in 10 year (10%)	
Medium	1 in 200 year (0.5%)	
Low	1 in 1,000 year (0.1%)	

Adaptation Pathways Workshop

To progress the case study, an initial adaptation pathways workshop was held on the 31st July 2018 in Glasgow. This included participants from Climate Ready Clyde, ClydePlan, SEPA, City Deal, Clyde Marine Planning Partnership, GCV Green Network Partnership, Glasgow City Council, University of Glasgow and University of Strathclyde and the COACCH project.

The workshop confirmed an interest in developing a high-level adaptation pathway for the Clyde Corridor, looking at how rising levels of climate change (primarily sea level-rise) would lead to increasing climate risks (to people, assets, natural habitats, etc), and building an adaptation pathway of possible responses over time. However, a clear focus was to support multiple objectives, rather than just climate change. There was a broad discussion of the potential long-term vision for the Clyde Corridor at the workshop, that captured multiple aspects, including the role in economic development, connectivity, recreation and amenity, public space, re-engaging with the river, green, a safe environment, as well as positive distributional benefits (community focused). This included more transformational long-term visions, including how adaptation could also be part of a transformational approach for the Clyde. There were also some more specific objectives as part of the regeneration strategy and City Deal.

Focusing down on climate, possible case study objectives were discussed on how adaptation could be mainstreamed into the broader Clyde vision (i.e. to ensure the vision and objectives will still be met, in the face of climate change). At the workshop, this was outlined as an <u>objective to ensure the Clyde</u> <u>Corridor was flood resilient and future proofed</u>. The specific climate risk objectives were not discussed, but as discussed below, there are existing goals in the Scottish Flood Risk Management Assessment.

The workshop also discussed what would be unacceptable (the starting point for adaptation turning points and thresholds). Possible unacceptable aspects identified were:

- A major impact or flooding critical infrastructure;
- Impact on city deal repayment, private development;
- Unacceptable costs.
- Failure of a new housing project.
- Increases in flood disadvantage.

Importantly, the National Flood Risk Assessment (NFRA) uses different likelihoods of flooding, for different receptors, to define what a nationally significant risk is. For properties, the medium likelihood is used (i.e. 1 in 200). For utilities, the low likelihood is used (1 in 1000), reflecting the role

of critical infrastructure. For transport and agriculture, the high likelihood (1 in 10) is used. This means that a higher level of protection is warranted for utilities, followed by houses, and much lower levels for other receptors.

There are also some general objectives and actions in the Clyde and Loch Lomond Local Plan District Flood Risk Management Strategy (SEPA, 2015), which looks at future flood risk areas and designates them in terms of whether to: Avoid an overall increase in flood risk or Reduce overall flood risk. However, even these relatively simple objectives become challenging under climate change, because they involve choices.

Much of the adaptation literature has presented alternative choices for future flood adaptation based on the level of protection from an economic perspective (Sayers et al, 2015; Hallegate et al., 2013; Ward et al, 2017), with choice of:

- Maintaining existing protection of infrastructure (no additional action);
- An optimized response [which maximizes net present value], where the costs and benefits of further protection are considered and the optimal response introduced;
- A constant relative risk [with future expected annual damage [EAD] constant as a % of GDP]);
- A constant absolute risk [with future EAD constant], which leads to much higher levels of protection, given rising risks and asset values.

Adaptation cost rise as one goes down the list. Adaptation benefits also increase, but the benefit to cost ratio (BCR) generally falls. Therefore, the highest benefit to cost ratio (highest NPVs) are achieved under the `optimize' objective. The same issues apply if flood policy is set using acceptable levels of risk and associated standards of protection, i.e. protecting property against a 1 in 200 year event. There is a choice between protecting to the level consistent with a current 1 in 200 year event, or protecting for the 1 in 200 year event under climate change. The latter involves much higher levels of protection, because the frequency and intensity of extreme events will increase under climate change, e.g. what was a 1 in 200 year event could become a 1 in 100 year or even 1 in 50 year event. Previous work by the Met Office has quantified some of these changes for selected places, and work is currently underway to produce similar work for Scotland in light of the 2018 UK Climate Projections. This then leads to the question of whether it is judged appropriate to increase costs and maintain the same risk of flooding, or accept a higher level of risk.

Current and Future Risk Levels

The second task is focused on the analysis of climate risks. This involves three steps: i) to assess current risks, ii) to assess future risks over time, from climate and socio-economic change, for different scenarios with consideration of uncertainty and iii) to look at the lifetime and lock-in of specific plans and actions. It is stressed that the application of adaptation pathways to the Clyde Corridor is complicated, because it involves multiple risk pathways, i.e. coastal, river flooding, surface flooding and erosion. Most adaptation pathways studies have focused on one risk (usually sea level rise and storm surge). For this case study, we focus on <u>sea level rise increase and coastal flooding</u>, but note that there are river and surface flood risk for most of the same locations. Further, from the perspective of managing flood risks, it is clearly critical to consider all risks together, alongside economic development, inward investment and land use planning to provide a holistic approach.

Current risks

The starting point for the analysis is the level of current risks. The current risks of flooding are set out in the phase 1 economics report, with the SEPA (2015) Flood Risk Management Strategy (Flood Risk Management Strategy: Clyde and Loch Lomond Local Plan District) and the UK CCRA2 analysis (Sayers et al, 2015).

It is stressed that SEPA has recently undertaken a new National Flood Risk Assessment (NFRA) (2018), that provides updated estimates of the flood risks. However, this was produced after this analysis, and thus in this study we use the previous 2015 report.

The SEPA analysis estimated <u>current</u> annual average damages across the region are be £67 million. The Annual Average Damages caused by river flooding are £27 million, those caused by coastal flooding are £19 million and those caused by surface water flooding are £20 million. The coastal flooding risks are shown below.





Figure 11 Areas of coastal flooding (top) and Annual Average Damages from coastal flooding (bottom) (SEPA, 2015).

More detailed analysis of locations along the firth of Clyde and the river are shown in the subsequent figures. This shows for most sites, the risks of flooding are a combination of coastal, river and surface water flooding, though the relative importance of each of these varies with location.



Figure 12 Areas at risk and current estimates of risk of flooding and Annual Average Damage. Source Clyde and Loch Lomond Local Plan District (SEPA, 2015). NOTE, individual maps are not to the same scale.



Figure 13 People at risk of flooding. Source Clyde and Loch Lomond Local Plan District (SEPA, 2015). NOTE, individual maps are not to same scale.

The SEPA (2015) Flood Risk Management Strategy: Clyde and Loch Lomond Local Plan District estimates there are approximately 3,600 residential properties and approximately 1,300 non-residential at risk of coastal flooding currently.

	Residential and non-residential	Annual Average
	properties at risk of coastal flooding	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

 Table 11 Flood Risk Management Clyde and Loch Lomond Local Plan District (SEPA, 2015).

The Annual Average Damages caused by coastal flooding within the catchment are just under £20 million/year. The damages are distributed as follows:

- 59% non-residential properties (£11 million)
- 27% residential properties (£5.2 million)
- 5% emergency services (£1.0 million)
- 5% roads (£940,000)
- 3% vehicles (£540,000)
- 1% agriculture (£16,000).

The focus of this case study is on properties, but it is highlighted that overall risks (the list above, plus educational and health facilities, cultural heritage sites, environmental designated areas, etc.) should be considered when developing flood response policy.

Future climate change risks

The next step is to consider future climate risks. In a full study, the analysis would be interested in:

- Relative sea level rise the local change of sea level relative to the land;
- Surges the temporary change in sea level resulting from meteorological (wind and atmospheric pressure) forcing of the ocean surface;
- Waves the wind induced disturbance of the sea that propagates across the surface;
- Coastal morphology and sediment supply change in the form of the seabed, shoreline and adjacent coastal land, and estuaries;
- Socio-economic change changes to population, demographics and asset value will affect the impact of flooding as well as the population's ability to recover.

However, as noted above, the main focus of the case study has been on sea level rise and flooding.

The SEPA (2015) Flood Risk Management Strategy: Clyde and Loch Lomond Local Plan District, sets out the future potential risks of climate change. Reporting on the UKCP09 high emissions scenario

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

for 2080¹¹, it identifies the projected average sea level increase for the area is approximately 0.47 metres by 2080. This also corresponds to the sea level rise (in m) for the Firth of Clyde estimated in SNH study (Hansom et al, 2017), but this was more specific and reported this for UKCP09 High Emissions scenario at 95% confidence. This takes account of landmass isostatic movements. It also projected that future changes in storm surge were very small (millimetres) compared to those of sea-level rise (tens of centimetres), i.e. that climate change will not alter storm surges.

The SEPA FRM Strategy estimates that an increase of 0.47m of sea level rise 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. Moreover, it only takes account of the impact of a changing climate on the magnitude of flooding; they do not take into account any potential increase due to socio-economic change (i.e. population change, development pressures or urban creep). They also they do they take into account any mitigation as a result of actions contained in the FRM or future Flood Risk Management Strategies.

There are also now estimates from the SEPA NFRA analysis (SEPA, 2018). This also uses UKCP09 projections for future flood risk, looking at a 2080s high scenario, and provide estimates for this one future scenario. This uses a slightly different approach, and thus has different estimates of properties at risk and AAD. These are not yet available on a catchment basis, but only through access to the SEPA National Flood Risk Assessment 2018: Data Explorer Tool.

Both the first and second National Flood Risk Assessments do not provide sufficient information for an adaptation pathway, because they do not present scenarios over time, or consider alternative scenarios. We have therefore looked at other data sources to generate this information. The UKCP09 estimates have been updated in the UKCP18 climate marine projections (Palmer et al, 2018). This reports the following global values. Note that UKCP18 is still working on developing a new High ++ for UKCP18.

	UKCP18	IPCC AR5*
RCP2.6	0.29 - 0.66	0.27 - 0.61
RCP4.5	0.38 - 0.79	0.36 - 0.71
RCP8.5	0.56 - 1.12	0.53 - 0.98

Table 12 Global mean sea level rise at 2100 (m). Source UKCP18 (Palmer et al, 2018).

*Note that the IPCC AR5 values have been adjusted to the 1981-2000 baseline used in UKCP18.

Importantly, UKCP18 projections show that mean sea level change around the UK will vary substantially by climate change scenario and geographic location. For UK capital cities, the UKCP18 projections at 2100 range from approximately 0.1 - 0.5m (Edinburgh and Belfast under RCP2.6) to 0.5 - 1.1m (London and Cardiff under RCP8.5). The data for the nearest cell to Glasgow has been downloaded from the new UKCP18 marine projections¹². These are shown below for the three RCP

¹¹ The report highlights an individual year, 2080, but in general, the UKCP09 projections were for the 2080s, i.e. the thirty year average period from 2071-2100. We assume this is for the 2080s. Note that for SLR, values are often expressed in specific years, but normally with reference to the year 2100 for the period of the 2080s. We interpret the coastal value for 2080 as the 2080s.

¹² https://www.metoffice.gov.uk/research/collaboration/ukcp/download-data

scenarios, RCP2.6, 4.5 and 8.5 (see RCP box), with the central projections (50th) and the range (5th to 95th percentile). It is noted that the rise under the RCP2.6 scenarios is slow and linear: in contrast, the SLR for the RCP8.5 increases strongly after 2050, at a higher rate of change.

Representative Concentration Pathways (RCPs)

For the IPCC 5th Assessment Report, a new family of scenarios was defined, the Representative Concentration Pathways (the RCPs). These include a set of four new climate (forcing) pathways, which cover futures consistent with the 2°C goal through to high-end (>4°C) scenarios. The four RCPs span a range of possible future emission trajectories over the next century, with each corresponding to a level of total radiative forcing (W/m²) in the year 2100. The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6 W/m² (RCP2.6), only marginally higher compared to today (2.29 W/m², IPCC, 2013). It is a "peak-and-decline" scenario and is representative of scenarios that lead to very low greenhouse gas concentration levels. This scenario has a good chance of achieving the 2°C goal. There is also new RCP 2.0 pathway being constructed for a 1.5°C pathway. There are also two stabilization scenarios (RCP4.5 and RCP6). RCP4.5 is a medium-low emission scenario in which forcing is stabilised by 2100. It is similar to the A1B scenario from the SRES. Even in this scenario, annual emissions (of CO₂) will need to sharply reduce in the second half of the century, which will require significant climate policy (mitigation). Finally, there is one rising (non-stabilisation) scenario (RCP8.5), representative of a nonclimate policy scenario, in which GHGs carry on increasing over the century, leading to very high concentrations by 2100.

There are also a set of exploratory SLR scenarios out to the year 2300. These are also included below. Importantly, this shows that SLR continues to rise in future years, even under lower scenarios. This so-called 'commitment to sea-level rise' reflects the strong thermal inertia of the oceans, which means that sea-level rise is the least responsive climate parameter to climate mitigation. However, it is also important to note that these present a high degree of uncertainty as to the exact extent of mean sea level rise, with estimates varying from no significant change, to nearly 3.5 metres by 2300.

The risk of coastal flood events will rise in line with the projections of increase in time-mean sea level. However, the actual flood risk will vary with the level of storm surge. The impact of climate change on storm surges is uncertain, but the Met Office suggests a best estimate of no significant additional increase (in the statistics of extreme water levels associated with atmospheric storminess). There is also considerable uncertainty over the change in wave height and extreme waves. Note however that the effects of storm surges will be greater in the future, because they occur on top of higher mean sea levels. It is stressed, however, that the effects of storminess are locally influenced, and are lower in more sheltered coastal regions, such as the Clyde.

Work is still underway on an extreme sea level scenario (a High ++ scenario), reflecting the fact that the scenarios above do not fully take into account all processes or uncertainty (including major ice-sheet melt). However, there are other literature sources that have produced information on high-end scenarios. A recent source is the RISES-AM project RISES study (AM-RISES, 2017), which provided new estimates of extreme high sea level rise scenarios (i.e. above even current IPCC estimates). These show upper projections of 180 cm (1.8 m) of SLR by 2100, due to the consideration of Greenland and Antarctica ice sheet melting. These can be compared to the global values reported in UKCP18, which has high range value for RCP8.5 of 1.12 metres, i.e. the upper values from AM-RISES are 60% higher than UKCP18. Based on the analysis of the Firth of Clyde and global sea level rise (mean), the high-level AM-RISES scenario would translate into a high-level sea level rise of

approximately 1.5 metres by 2100 for the firth of Clyde. This highlights that even using the 95th percentile from UKCP may not cover the full range of possible outcomes.



Figure 14 Regional sea level projections for Firth of Clyde Source. Source UKCP18. Top 50th percentile. Centre 5 and 95th Percentile. Bottom exploratory long-term (to 2300).

Note that the Local Flood Risk Management Strategies also use the UKCP09 high emissions scenario for 2080 to look at river flooding, and reports that by this period, the average peak river flows for the Clyde, Firth of Forth and River Leven basins (for this high scenario) may all increase by 44%. It

estimates that this would potentially increase the risk of river flooding. These increases were reported in the phase 1 economic report.

Indirect effects of flooding

The focus of the analysis here is on risk of flooding to property and on annual damages, but it also is important to think about some of the wider consequences of increased flooding. These include impacts on infrastructure and utilities, and designated environmental areas and designated cultural and historic importance, as well as erosion risk. The SNH study (Hansom et al 2017) on climate change and the Firth of Clyde identified several areas of designated habitats, coastal communities and infrastructure (such as road and rail links) that are currently at risk of sea-level rise induced flooding as well as adjacent areas that will be at risk in the future. The study was not clear how saltmarsh and mudflat habitats will be impacted by sea-level rise. However, it reported that a lack of sediment delivery from both marine and fluvial sources will impact negatively on the ability of these habitats to keep pace with rising sea-level and so, with a few very localised exceptions, the present trend of erosion along the saltmarsh edges will continue and likely accelerate, thus increasing the risks to the Inner Clyde Special Protection Area (SPA). Looking at erosion risk, the National Coastal Change Assessment (Dynamic Coast 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. The first is located at the shore to the east of Ardmore Point. The second area is around Cardross. The final section at risk of coastal erosion is Dumbarton Castle Bay.

There are also some further issues that could be important in the medium term, and that might have some large implications for insurance, with impacts on property value (which are different to annual average damages). Significant increases in flood risk, if not accompanied by flood protection, has the potential to increase insurance premiums. In the longer-term, depending on the market, it could have major implications for the insurability of properties. This in turn has major implications for mortgages, and residential and non-residential property prices. Rising flood risks could therefore lead to much higher economic impacts, not just in terms of higher insurance payments, but the loss of value of the residential and non-residential properties. Flood Re – a joint initiative between the Government and insurers - a reinsurance company, enables insurance companies to insure themselves against losses because of flooding. This has helped the insurance industry meet the market demand for insurance cover in flood-prone areas. Unlike other reinsurance companies it is a not-for-profit fund, owned and managed by the insurance industry. However, in 2039 the Flood Re Scheme will end and there will be a free market for flood risk insurance. After 2039, those exposed to high levels of flood risk may be asked to contribute the full costs of insurance cover.

A further important issue is that future climate risks are likely to inform public and private sector investment decisions (private sector), and this could have very large impacts on the financial investment in Glasgow City Region. New global data sets are compiling risk information and using this to inform investors. As an example, Glasgow has been identified in one of these recent sets which has focused on the impacts of climate change on real estate investment trusts (REITs) (Four Twenty Seven & GeoPhy, 2018), even though it is identified as having a low risk compared to many other global cities. This information is part of a broader set of initiative in financial disclosure for climate related risks and it is likely to provide a stronger message for investors on identifying and disclosing risks. This will change risk and investment appetite and there will be increasing pressure on cities to reduce these risks to help secure future investment, economic development and growth. This will be further compounded by plans from the Prudential Regulation Authority for Banks. Building societies and insurance companies will be required to report and disclose the financial risks associated with the physical risks of climate change (Prudential Regulation Authority, 2018).

Socio-economic change

As well as the impact of future climate change, it is important to look at the influence of socioeconomic development because this could increase the future areas and assets at risk of flooding. As well as the existing areas, a particularly important issue for adaptation pathways is around new development, because of the lifetime of decisions and potential lock-in involved.

Glasgow and City Valley Strategic Development Planning Authority (Clydeplan) published a Strategic Development Plan (the latest plan published as Clydeplan, 2017). There are estimates of population and housing growth presented in the Strategic Development Plan (2017). This estimates the population of the city region in 2030 will be 1,849,600 (an increase of ~60,000 from 1,789,500 in 2012) and the number of households will be 895,100 (compared to 814,900 in 2012). This equates to an additional 80,200 households. The Strategic Development Plan sets out Housing Supply Targets and Housing Land Requirement, based on these population and migration estimates, but with adjustments to give housing supply estimates. The latest figures estimate an additional 91,860 houses are required (from 2012 – to 2029, central figure), equivalent to 5400 per year. These supply targets have been mapped to Local Authorities and potential sites identified. Figures from National Records of Scotland show the population rising from 1,817,860 (2016) to 1,877,535 (2030) and on to 1,893,460 (2040). However, not all areas are growing equally, and some areas (including coastal areas such as Inverclyde) are currently projected to see declines in population.

There is an issue on the siting of these new houses, so as to avoid <u>lock-in</u> to risk to current and future flood risks. Decisions made now on siting and design will influence the patterns of exposure or vulnerability to future climate change over many future years, and a key issue is whether locations are sited in areas that will become at risk of flood risk in the future (from coastal, surface and river flooding). What might be an area at low risk of flooding today could become high risk (and fall within the flood plain) due to more frequent return periods or more intense events under climate change.

This is important as such analysis is not yet formalised in planning guidance, although Clydeplan's Strategic Flood Risk Assessment has provided an analysis of the potential flood risks for new areas, classifying into extreme, moderate (10-50%) or minimum (0-10%) categories. There is also a further issue of whether new build house include property level measures to help enhance resilience and resistance to flooding, in relation to building codes and design standards, noting these are set nationally. These issues of lock-in could be quite important in the attractiveness of new investments. An application for a multi-use development including housing in Govan docks (former a dry dock) was recently rejected, on the grounds it was in a flood risk area. This is a useful example where flood risk has already influenced planning decisions.

Clydeplan also set outs a planned Development Corridor, which runs west to east through the city region running parallel to the River Clyde and the M8 corridor. This is focused on the Clyde Corridor and is relevant for the case study. It includes transformational mixed-use projects and spatial priorities including: Community Growth Areas; Clyde Gateway; Clyde Waterfront; Forth and Clyde Canal; Glasgow and the Clyde Valley Green Network; Glasgow City Centre; Ravenscraig; and River Clyde. A large number of these investments are part of Glasgow City Region City Deal.

Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

Again, a key issue is that any new projects or development areas will have a long life-time and will be exposed to climate change over their expected design lifetime. This is particularly important for longer lived investments (e.g. large infrastructure) and where land-use patterns change (as this tend to lock-in development patterns for decades). This lock-in, or irreversibility, occurs when the siting decision is made. Clearly the Clyde Waterfront and Renfrew riverside projects are a priority for any future adaptation pathway in terms of these sorts of lock-in risks. Clyde Waterfront is a large-scale mixed-use community regeneration and restructuring development opportunity requiring long term commitment (and therefore lock-in), given the focus on reconnecting with the river. A particular issue is highlighted for City Deal investments in city quay walls, especially as many of these extend into the river. The overall focus on the River Clyde – as part of the Spatial Development Strategy – is also important. There are also highly relevant projects at Greenock and Inchgreen and West Dunbartonshire (Exxon site).



Figure 15 Current Glasgow and Clyde Valley City Deal Infrastructure Projects that are in the Spatial Development Strategy). Source Clydeplan (2017). 1. Clyde waterfront 2. Glasgow city centre. 3. Clyde Gateway. 4. Ravenscraig.

Finally, it is highlighted that for critical infrastructure, or infrastructure with the potential to have large economic impacts if affected, then higher standards of protection are currently required. This is an important issue when considering individual projects or developments, and highlights different risk tolerance levels.

Thresholds

The next step is to look at potential thresholds. These are particularly relevant for adaptive management approaches, notably for techniques such as adaptation route-maps and decision scaling. These thresholds can be derived for the overall corridor but also for specific developments.

These thresholds act as triggers for a review of options, and can be linked to points in time when different alternative options (and routes) are needed. A review of studies shows that sea level rise can be associated with the exceedance of risk or damage levels, such as thresholds for the number of people or the level of economic damage that occurs (i.e. thresholds for acceptable levels). A similar set of thresholds could be based on ensuring acceptable standards of protection (i.e. exceedance of flood probability thresholds under climate change, so as not to exceed a 1 in 200 year

level). More specific thresholds could be associated to critical infrastructure / or new development sites, protected sites or natural habitats. These thresholds, or tipping points, are then used as trigger points when additional adaptation should be considered or implemented.

These thresholds need to be discussed and agreed by stakeholders, and would ideally be based on detailed flood risk mapping along the corridor. Nonetheless, it is possible to identify illustrative thresholds for the case study. A simple threshold approach is to look at the rising levels of the number of people at risk of floods, and the annual economic damage, and set unacceptable future levels. This is the approach that was used by Ramm et al (2017) for a coastal adaptation pathway, although this was a theoretical case study. This set unacceptable future levels for both safety (number of people exposed) and property damage, as being twice the current baseline level.

For the purpose of exploring the usefulness of <u>adaptation route-maps</u>, we use this approach to set a high-level threshold for the Clyde Corridor for coastal flooding. Analysis of the SEPA (2015) flood risk identifies that for coastal flooding, climate change is likely to increase the number of households at risk of flooding from 3700 now to 7500 by 2080 (high UKCP09). This is associated with 0.47m by the 2080s. This is approximately <u>two times current risks for population at risk and annual average</u> damage, and provides a useful long-term threshold, though it is stressed this does not take account of future population or socio-economic change). Current annual average damages from coastal flooding are £18.7 million, and assuming the same uplift (for the purposes of illustration), this would equate to an increase to £36 million by 2080. These thresholds can be plotted onto the UKCP18 SLR scenarios above. For this study, we have used the RCP2.6, 4.5 and 8.5 central (50th) values, as well as the RCP8.5 upper 95th percentile. The analysis in Figure 7 shows this level of damage (x2) (top horizontal line) does not occur at all under the central RCP2.6 or 4.5 scenarios. But it could occur for the RCP8.5 scenario around 2090 and for the RCP8.5 high (95th) scenario around 2070.

To make the pathway more informative, we also identify an intermediate threshold of x1.5 population at risk/annual average damage from current baseline levels. This assumes a linear response to rising sea level and damage and uses the mid-point SLR from the UKCP09 projection of 0.23m. This is shown on the figure (bottom horizontal dashed line) and shows that this threshold level would be reached around 2100 under the RCP2.6 scenario, but as potentially as early as 2045 under a RCP8.5 95th scenario.

This information is then plotted in an adaptation network map diagram. The levels of 0.23 and 0.47 metres as tipping (turning) points for x1.5 and x2 number of people at risk of flooding/annual average damage are shown, and how these align to time periods for different scenarios.

When these thresholds are hit depends on the scenario and the dates. Under a RCP2.6 and 4.5 scenario, even the x1.5 threshold is not exceeded until late century. In contrast, with a RCP8.5 (95th), the 1.5 threshold could be exceeded in as little as 25 years' time.

As highlighted above, this only includes current houses and a further number of factors will affect when these thresholds are reached. In a detailed case study, it would be useful to include the additional houses, as well as rising asset values, to properly assess the future number of households at risk/annual damage. Including these socio-economic changes would mean the thresholds above would be exceeded earlier. The population and number of households is expected to increase over time (though the increases are modest) and there is likely to be a greater increase in the value at risk (this is likely to increase the annual average damage more than the increase in people flooded). At
the same time, these numbers do not include the planned next round of flood protection measures, which these would reduce the estimates.



Figure 16 Possible points in time – related to different Sea Level Rise scenarios – when x2 and x1.5 number of households at risk / annual average damage could be exceeded for the Clyde (coastal flooding).



Figure 17 Turning points for further action (x1.5/x2) for the Clyde for coastal flooding and possible time periods when exceeded.

It is also possible, and somewhat easier, to look at thresholds at a detailed site or investment project level. This can be used to help in the climate resilient design of new developments or infrastructure. These can relate to siting issues, e.g. with respect to threats such as changing coastal or river flooding, or engineering design criteria, such as heat tolerance levels.

Adaptation options

The next stage is to identify adaptation options, then to proceed to see how these could be used to reduce the levels of risk set out above. There are a large number of potential adaptation options, which include a large number of different approaches. Adaptation typologies have been developed (in the IPCC 3rd and 4th assessment reports), as illustrated in the figure below.



Figure 18 Classification of Adaptation Options, Source Smit et al (2001)

In the flood context, adaptation often focus three types of approaches – protect, accommodate or retreat. It can also be framed around three types of options (Sayers et al, 2015), noting these can be applied individually or in combination.

- 1. Manage the probability of flooding, i.e. traditional flood defences, managing flood flows (such as rural and urban storage and run-off management) or realigning the coast to improve the Standard of Protection (SoP) afforded by a defence.
- 2. Manage exposure to flooding, e.g. by limiting the impact of new development on flood risk.
- 3. Manage the vulnerability of those exposed to flooding, e.g. by encouraging individuals and organisations to improve the flood resistance and resilience of their properties/assets or improving forecasting and warning to enable more effective action to be taken.

There are also a further set of variations for each of these. For example,

- Technical options can include technical or engineered design, but can include green and ecosystem-based adaptation.
- Non-technical options can include:
 - o Institutional and capacity building;
 - Information, research and behavioral change;
 - Non-technical options or measures;
 - Financial and market-based options (including insurance);
 - Policy and legislative.

It is also highlighted that the starting point for adaptation is to consider existing risk reduction and protection measures. In terms of current options and plans, the NFRM (SEPA, 2015) outlines the following options matrix. 'Self-help' includes steps to reduce damage and disruption to homes and businesses should flooding happen: including preparing a flood plan and flood kit, installing property level protection, signing up to Floodline, and ensuring that properties and businesses are insured.

This is part of the counterfactual scenario to assess what measures are already in place, or planned, and therefore what additional measures are needed. For the coastal domain, SEPA already has 15 coastal flood warning areas within the Local Plan District (SEPA 2015).

Flood protection scheme/works	Natural flood management works	New flood warning	Community flood action groups	Property level protection scheme	Site protection plans
Flood protection study	Natural flood management study	Maintain flood warning	Awareness raising	Surface water plan / study	Emergency plans / response
Maintain flood protection scheme	Strategic mapping and modelling	Flood forecasting	Self- help	Maintenance	Planning policies

	Table 13.	Flood	measures matr	ix (SEPA,	2015).
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These are shown below. However, the percentage of properties that have signed up to receive flood warnings is quite low, ranging from 10% to 36% across different areas. An early priority for adaptation would be to enhance this uptake. There are already existing flood defences – though these are taken into account in the risk of flooding numbers above. The location and type of existing coastal defences in this coastal area are shown below. Note that even if protection is in place, it will not deliver the same level of protection in the future under climate change, even if maintained.



Figure 19 Coastal flood warning areas (left) and Coastal protection (right) (SEPA, 2015)

Medium term approach (2050s) using adaptation pathways frameworks / roadmaps

The first case study application is focused on the sequencing of adaptation and the identification of early adaptation priorities, using <u>adaptation pathway frameworks</u>. These are focused on actions for the next five years and have high relevance for the forthcoming City Region adaptation strategy. For this analysis, we use the CCRA2 priorities for early adaptation:

- To address the existing adaptation deficit by implementing 'low-regret' actions to reduce risks associated with current climate variability. This might include non-technical information (weather information to users) as well as low cost interventions.
- To intervene early to ensure that adaptation is considered in decisions that have long lifetimes, such as major infrastructure developments, housing, in order to avoid 'lock-in' of future risk.
- To fast-track early adaptation steps for decisions that have long lead times or where information, monitoring, research and pilots could help inform future decisions.

It is also possible to look at additional options that might be needed over time and look at the potential sequencing and timing of these, in a broad adaptation pathway or roadmap.

Early low regret options.

A literature review has been undertaken to help identify promising options, shown in the table. The first set of early adaptation priorities is to identify the early low regret options. These include:

- No regret measures, or win-win options, e.g. that provide economic benefits even without climate change, or lead to large co-benefits;
- Low regret measures, i.e. which have low costs, or are cost-effective;
- Capacity building, i.e. awareness raising, information, early warning (including within government, but also residents, private sector, etc.);
- Risk preparedness, i.e. emergency planning and response;
- Risk spreading, e.g. which effectively transfer or pool risks.

Option	Evidence
Investments that enhance preparedness to disasters, e.g. evacuation plans	 High benefit to cost ratios with studies reporting the highest (~10:1) of all DRR interventions (ECONDAPT, 2016). Benefits delivered through reduction in damages. Focused on current, but provides additional benefits for future increases in trends from climate change. However, not sufficient to reduce all damages on its own (residual damages), so should be part of wider package of interventions.
Early warning systems (EWS), e.g. flood warning	 Good evidence of high BCRs (see Shreve and Kelman, 2014: Mechler, 2016; Desbartes, 2012: Clements et al, 2013). Benefits arise from the use of information to improve decisions (value of information/quasi-option value), i.e. to take action to avoid losses. Benefits increase under future climate change, with increasing events, although costs and residual damage increase as well. However, investment needs to be along whole EWS chain (i.e. from forecasting to users) to deliver benefits, and require capacity and government ownership. Further, not sufficient to reduce all damages on its own (residual damages) so should be part of wider package of interventions.
Flood prevention and protection (coastal and river) using hard measures (e.g. dikes) and soft measures (e.g. ecosystem based)	 A systematic review (Mechler, 2016) of flood risk management appraisal (27 studies, mix ex ante and ex post) found BCR of 5 to 1 for flood related risks. Further European review (ECONADAPT, 2016) containing 110 observations on investments/projects from 32 studies and databases in 16 European countries found mean BCR of 6 (but median of 3): this also found Hard flood control (4:1) had higher BCR than soft flood control (1.6:1) – however, other studies find the reverse (i.e. soft BCRs > hard). This highlights site and context specificity. Studies highlight higher benefits from portfolios that combine hard and soft options. Climate impacts modelling literature finds high BCR for future climate change, for sea level rise (AM-RISES, 2017) and urban floods (Ward et al, 2017), but positive BCRs only in some areas (i.e. only urban coasts, and not all urban cities).
Household resilience	 Encouraging individuals and organisations (household level). This includes i) water entry or resilience strategy measures and ii) water exclusion or resistance measures, noting that the latter are preferred. UK Studies on the benefits and costs of household measures (Royal Haskoning DHV, 2012; EA, 2015) find that property level protection measures are only likely to be cost-effective where flood frequencies are high, as relatively high cost of such measures and inability to prevent large amounts of damage when a property scale resistance measure is overtopped. There is also the question of whether to retrofit these measures, as compared to including in new properties. It is more cost effective to build into new properties.

Many of these options are already included in the Clyde and Loch Lomond Local Plan, i.e.: Flood Forecasting (Scottish Flood Forecasting Service);

- Self-help (household);
- Raising public awareness of flood risk;
- Maintenance of flood protection (schedules of clearance and repair works);
- Emergency plans and response;
- Planning Policy and accompanying Planning Advice Notes.

Early decision with long lifetimes or lock-in

The second set of early priorities are associated with longer lived decisions that need to be taken in the short-term, such as infrastructure development. These include options such as:

- Changing the location to reduce future risks (siting decisions);
- Planning controls / enhanced planning review on at risk sites;

And for infrastructure design, to use decision making under uncertainty to enhance resilience, e.g.:

- No-regret design (see above);
- Flexible design to allow later upgrade more easily;
- Iterative design to monitor and learn upgrade later if needed;
- Robust design (now) to perform well over a range of future uncertainty, such as climate and socio-economic change;
- Shorten the design lifetime so it can include climate in future cycles;
- Precautionary over-design if reason (critical infrastructure).

Note that a precondition for these is to enhance climate risk screening and resilient decision and appraisal, i.e. the supporting process-based steps. This has already been started with the Climate Ready Clyde and Adaptation Scotland screening guide: A changing climate for development providing some of the tools and concepts needed for the City Region to adopt this approach (2019).

Early planning (for long decisions or major risks)

The third set of early priorities refer to the early steps as part of an iterative long-term adaptive management programme. These include:

- Monitoring;
- Research;
- Long-term planning, i.e. to draw together a detailed plan of what actions could meet future risks, with analysis of future options.

Subsequent adaptation options and sequencing

Alongside these early priorities, there is a need to look at additional activities over time that can cope with rising risks. This is likely to involve more focus on future flood defences, and more costly measures, especially on a higher emission (and thus Sea Level Rise) pathway. This would need to consider options such as:

- Hard coastal flood defences;
- Green or ecosystem-based adaptation (green-grey infrastructure, flood buffer zones, etc.);
- Realigning the coast (including managed realignment);
- Relocation; and
- Major barrages.



The overall set of measures as a high-level adaptation pathway / roadmap is shown below.

Figure 20 High-level adaptation pathway/roadmap showing early priorities for coastal adaptation.

There is evidence on the costs and benefits of various flood adaptation measures in the longer-term, as identified in CCRA2 (Sayers et al, 2015). This found that the most effective adaptation measures are those that act to reduce the probability of flooding, i.e. improving defences, managed realignment on the coast, catchment management and urban runoff management through sustainable drainage systems (SUDS), and that reducing exposure and vulnerability are less effective. However, all options were needed – in a combined portfolio - to reduce future risk levels down to current levels of risk and damage. While it was for England only, the recent analysis of coastal measures by the Adaptation Sub Committee also provides economic analysis (Jacobs, 2018), which analyses Shoreline Management Plans (SMPs) through to 2100 with sea-level rise. This found at the national level, the benefits of implementing SMP policies outweigh the costs, with a net benefit of nearly £2 billion over 100 years. The Jacobs report also highlighted the lead-in time for implementing such measures will be lengthy, and this can be reflected in the adaptation pathways.

Identifying thresholds, tipping points and options using adaptation route-maps

The next part of the case study has been to demonstrate a dynamic <u>adaptation route-map</u> – linked to the adaptation thresholds and turning points discussed earlier. As highlighted above, a first (illustrative) tipping point could occur when flood damages rise to x1.5 current levels (an additional 1900 residential properties at risk of flooding and indicatively an extra £8.7 million AAD) and a

second tipping point when flood damages rise to x2 current levels (a cumulative total of 3700 properties at risk of flooding and indicatively a cumulative total of £17 million AAD).

At the first x1.5 tipping point, associated with 0.23 m of SLR, a major investment in new flood protection would be triggered – noting that in practice monitoring data would inform when this level was approaching. This first tipping point could occur at any time after 2045 (RCP8.5 high) to sometime in the next century, thus it may only be reached under certain futures. A number of adaptation packages could respond to this first threshold. The first package (option mix 1) protects only those houses that are affected by the higher risk of flooding, using a cost-effective approach. An alternative (option mix 2) introduces a very comprehensive set of measures, that protects the whole Clyde Corridor with a very high level of protection. At the second x2 tipping point, associated with 0.47 m of SLR, a second threshold level is triggered. This impacts on a set of additional houses, which then require additional protection, shown with the additional adaptation option 3 (noting these are added on top of option 1). However, there is no need for additional protection under the option 2 pathway, because this has already overprotected for both tipping points. It is also possible that at the x2 tipping point, instead of going to option 3, one could move to the more comprehensive option 1 pathway (shown by the dotted line).



Figure 21 Illustrative Adaptation Route Map for Coastal Flooding for the Clyde Corridor

Options 1 and 3 could be comprised of the current types of flood protection measures, combined with household level resilience, and planning measures (noting the latter affects new development). Some of the current high-risk coastal areas in the Flood Risk Management Strategy for current Clyde and Loch Lomond Local Plan District (SEPA, 2015) were shown earlier, with the table showing the planned measures (noting these include actions for coastal, river and surface flooding).

	Flood protection scheme/ works	Natural flood management works	New flood warning	Flood protection study	Natural flood management study	Surface water plan/study	Strategic mapping and modelling	Maintain flood protection scheme*	Maintain flood warning*	Flood forecasting	Property level protection scheme	Community flood action groups	Self help	Awareness raising	Maintenance	Site protection plans	Emergency plans/ response	Planning policies
Loch Lomond and Vale of Leven	~	 ✓ 	 ✓ 	 ✓ 	~	✓	~	~	~	✓			√	~	~		~	~
Helensburgh to Loch Long	~			~		~	~	N/A	~	~			√	 ✓ 	 Image: A start of the start of		~	~
Yoker catchment				\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark			\checkmark	\checkmark	\checkmark		\checkmark	\checkmark
Isle of Bute				\checkmark			\checkmark	\checkmark	\checkmark	\checkmark			✓	\checkmark	✓		\checkmark	\checkmark
Dunoon				\checkmark		\checkmark	\checkmark	✓	✓	\checkmark			√	\checkmark	 ✓ 		\checkmark	 ✓
Greenock to Gourock	 ✓ 					\checkmark	\checkmark	✓	✓	\checkmark	\checkmark		√	\checkmark	 ✓ 		\checkmark	 ✓
Clyde south	\checkmark					~	>	N/A	N/A	\checkmark			\checkmark	\checkmark	\checkmark		\checkmark	>
White Cart Water	\checkmark			\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark		\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark
Glasgow City centre	\checkmark					\checkmark	\checkmark	\checkmark	\checkmark	\checkmark			\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark

Table 15 Actions to manage flood risk in the Local Plan District. SEPA (2016).

Options 1 and 3 would be likely to comprise of existing types of measures from the matrix. However, it is noted that there are gaps on natural flood management. This could include Integrated Green Grey Infrastructure, i.e. bioengineering solutions that could be utilised to enhance the habitat potential of the existing or future hard engineering structures (Hansom et al, 2017). There is also an increasing interest in the use of natural (eco-system based) adaptation, either individually or in combination with conventional protection, e.g. as assessed in New York (Aerts et al., 2013: Aerts et al., 2014). Natural based systems are being favoured because of their wider economic benefits (recreational, environmental, etc.), however, on their own they may not provide the protection levels of hard adaptation.

Option 2 could involve more transformative options. One option would be a moveable barrier structure for the inlet or estuary. This has been considered here as a long-term option, and plotted on the route-map below, though we highlight that the economic case for such a structure is low. This is because the annual damages, and the level or risks, would not seem to justify the costs. The costs of these measures are extremely high. The Thames Barrier in London cost £0.5 billion when built, which is equivalent to over £1.5 billion in current prices, and the Modulo Sperimentale Elettromeccanico barrier in Venice has a capital cost of €4.7 billion (Brown et al, 2011, updated). Current coastal annual average damages in the Glasgow region are £19 million/year, and even with a doubling of damages under climate change, it is difficult to justify barrrier investment for the Clyde Corridor. It is also noted that North Sea cities face higher risks from storm surges. For Glasgow, the need for such a structure would only be likely to relevant in the long-term (after 2100) and only under exceptionally high SLR. There has, however, been some discussion around a fixed link between Inverclyde and Argyll and Bute (Cowal Fixed Link working group). While this is currently focused on bridge or tunnel options, it might be possible to include barrier structures. Such a structure might be justified because of the wider economic benefits from enhanced connectivity.



Figure 22 Illustrative Adaptation Route Map for Coastal Flooding

In practice, the decisions are unlikely to be as discrete as above, i.e. they will involve quite complex portfolios of options. Nevertheless, these maps could help stakeholders discuss options and identify preferences, e.g. to provide a preferred path as illustrated below.



Figure 23 Illustration of a preferred pathway for coastal flooding.

This simple example shows the approach. and the role that route maps can have in communicating the high-level need for an iterative approach, and can highlight that early actions are needed and there are important sequencing issues. Perhaps most importantly, they show that climate uncertainty is not a barrier to action. However, it also highlights the analytical complexity and the detailed modelling needed to develop detailed route-maps. If a more detailed analysis was undertaken, it would lead to a very complicated pathway. And yet, at the same time, the information presented in this route-map is an oversimplification. It is also misleading as it does not communicate the nature and trade-offs involved. Further, this map does not easily align to the existing planning approach, the five- year cycles of the NFRM, and the impact of successive rounds.

The identification of thresholds is also challenging. Indeed, this is one of the most difficult aspects of the route-maps approach. For this example, we have chosen illustrative thresholds associated with unacceptable levels of future risk and damage. Going forward, stakeholders would need to consider and identify appropriate thresholds. The pathways approach also clashes somewhat against standard project appraisal methods, which first assess the various costs and benefits of options, then see what is possible (with the resources available).

Perhaps most importantly, the route-map above is only focused on coastal flood risk. Ideally routemaps would be needed for surface and river flooding as well (some of these are now emerging, e.g. for urban drainage). While these could - in theory - be combined into a on overall master pathway that captured all risks and tipping points, these would be extremely complicated. Moreover, flood risk reduction / management should ideally be undertaken as part of an integrated and holistic approach, which considers multiple objectives (economic objectives, social cohesion, etc.) rather than individual pathways that focus primarily on only one issue – climate change.

Developing Adaptation Pathways at a Project Level

A detailed adaptation pathways approach can also be applied at the project level. The final part of this pathways case study has therefore been focused on a more detailed application. The case study focuses on potential new investments (though could also be applied retrospectively to existing projects, or project refurbishment). It centres on large infrastructure or development investments that are being developed in the short-term, and there is a risk of lock-in. Such investments are one of the priorities for early adaptation (see earlier adaptation framework, i.e. the second priority area), because they will be exposed to future climate change. This has led to a focus on climate risk screening and climate resilience, sometimes called climate proofing.

The key issue is that when designing and constructing new infrastructure or developments, there is a choice on whether to make these investments climate resilient now, to include flexibility or monitoring to make them resilient later, or to do nothing. This decision is not straightforward. First, because of uncertainty, it is it more difficult to know how much adaptation to build into a project when designing it today, because the future risks of climate change are uncertain. Second, there are economic and financial barriers to early adaptation. The economic benefits of building resilience will generally arise in the longer-term (e.g. in the 2040s), thus they are low in present value terms, when compared to resilience (adaptation) costs incurred during project construction. This case is further weakened by uncertainty, e.g. there is a risk that investing in adaptation turns out not to be needed. Therefore, while it is possible to simply over-design a project to all possible future climate risks (noting even this can be difficult when even the direction of change is not known), this is unlikely to pass a cost-benefit test, because it is spending money for futures that are highly unlikely to arise.

As a consequence, the adaptation literature has started to use appraisal approaches which focus on decision making under uncertainty. This can include adaptation pathway approaches, although there are a number of alternative approaches. The table below shows the various adaptation choices for an illustrative infrastructure investment project and their economic rationale (from Watkiss and Wilby, 2018). Only the options highlighted in red involve adaptation pathway thinking. The other options seek to address these problems through other characteristics, whether these are spreading risks with insurance, looking to build more robust options in design, etc. Focusing down on these two pathway options, there is a choice between:

- Building in flexibility to the project so it can be upgraded easily later; or
- Wait, collect information and data, and upgrade the project later if needed.

	Examples of the extent time	Provide wetten alle fan alle tra of a dawtetten
Adaptation	Examples of the adaptation	Economic rationale for choice of adaptation
type and timing	type	
Design and	Change the site or location	No regret/ win-win - benefits without CC
engineering NOW		Low regret – low costs or cost-effective
	Change the design (engineering) Includes dimensions, materials, technology, structural (defences), etc.	<u>Shorten design lifetime</u> to include CC in future cycles <u>Robust</u> - perform well over range of uncertainty <u>Precautionary over-design</u> (critical infrastructure)
Design and	Flexibility built into the design	Flexible design to allow later upgrade more easily
engineering for	Modular or iterative design to enable	Iterative design to monitor and learn - upgrade
LATER (pathways)	later change	later if needed
Maintenance and operations	Change maintenance regime or infrastructure operations	No-regret or win-win or low regret
Non-technical and	Institutional and capacity building	No-regret or win-win or low regret
non-engineering options	Information, research and behavioural change / Non-technical	
design changes.	Financial and market based (including insurance)	
	Policy and legislative	
Do nothing	No adaptation (live with the risks)	If risks and benefits are low, or costs of adaptation
		very high
Reconsider project		If risks unacceptable and no suitable adaptation

Table 16 Investment Adaptation Options, Timing and Economics for an infrastructure investment(Source: Watkiss and Wilby, 2018).

The relevance of these two adaptation pathways options will depend on the characteristics of the project, and the balance of costs and benefits on resilience costs, costs of flexibility, the costs of retrofit later, etc. (for detail, see ADB, 2015). Nevertheless, there are some types of investments that will be more relevant for an adaptation pathway approach (Watkiss and Wilby, 2018), i.e.:

- Those with a long lifetime. If the investment lifetime is short, then the focus is more on current risks and these pathway approaches are not so relevant;
- Those with high up-front resilience costs. If the costs of resilience are low, it will generally be more effective to include in design, especially because retrofit costs are often high;
- If there is a degree of lock-in or irreversibility, that makes it difficult to change later;

As examples, this will include investments that have a long life-time and are difficult or costly to upgrade later, e.g. a large bridge project. It will also include investments that lock-in land patterns, such as housing.

For this case study, we have selected some hypothetical examples to illustrate the development of project level adaptation pathways. The starting point is the current risks of coastal flooding. These are based on the elevation, level of protection and site location. Detailed flood maps have been developed by SEPA and some examples of areas of high risk are shown in the earlier figure. Ideally, projects would be assessed in terms of their detailed location with analysis of different coastal flood return periods (including storm surge). These would then be complemented with future climate risk analysis, considering uncertainty.

The next step is to consider thresholds. At this investment or project level, these are easier to identify, as they can be based on key performance characteristics. These could be engineering tolerance levels (e.g. maximum temperature for safe operation of infrastructure), engineering design standards (e.g. required protection against define levels of flood return, expressed as capacity for peak flows and drainage), or an acceptable level of risk/standard of protection, i.e. 1 in 200 (0.5% AEP) (household) or 1 in 1,000 (0.1% AEP) (critical infrastructure).

A set of adaptation options can then be identified. For infrastructure or development that is near the coastal flood zone, and could be affected in later years, the protection options could be:

- Protect now with a high level of coastal flood protection (built during construction);
- Protect to a low level of protection now (construction), but build flexibility to increase later at low cost, e.g. building a coastal protection wall that can be increased in height later;
- Monitor now, and build protection as levels approach risk thresholds.

A number of examples are presented to illustrate this. One approach is to build sea defences (walls) with larger foundations, so these can more easily be upgraded in the future. The same can apply to coastal infrastructure. As an example, a recent project in the Cooke islands (ADB, 2014) has included flexible design in port investments. As part of a major port project, the wharf was replaced with a structure that included flexibility in design. This involved strengthening the pilings during construction to increase the load bearing capacity, so that the wharf can be raised more easily in the future, if this is required because of faster rising sea levels. Port investments have also been considered for resilience in IFC (2011) and EBRD (2016). There is also forthcoming guidance on climate change adaptation for ports and inland waterways (PIANC Working Group 178).

A further set of examples are given in the New York City Climate Resiliency Design Guidelines (NYC MORR, 2018). These provide instructions on such a site-specific approach, focused on iterative design. It provides a useful example of detailed project level analysis, in this case for City capital projects. The main focus is on flexibility, providing extra protection against hazards in the initial decades while also leaving open design alternatives for updating resiliency measures as new data is provided or new risk assessments are completed. The guidance also highlights the need to identify critical versus non-critical components, with critical components (essential to the facility's functionality) protected to a higher standard of protection. As an example, the guidelines look at an emergency generator with a life of 25 years located outside a building that has a much longer life-time (75 years). It recommends the generator is built on an elevated concrete slab that matches the future year design flood elevation, and that when replaced (after 25 years), the concrete slab is

elevated, to reflect the increased levels of risks. In order to enable this future upgrade, the foundations are built to support the additional future load from a higher concrete slab. These concepts are illustrated below.



Figure 24 Illustration of Project level adaptation pathway choices.

While this simple example illustrates the potential benefits of this pathways approach, in practice, the potential applicability depends strongly on costs and benefits. There are likely to be a large number of low regret options that could enhance resilience, which would be an alternative for modest climate change risks. Thus in economic terms, flexible options may not be the most cost-effective. There are also additional costs and governance (post design) issues with monitoring and upgrades, i.e. it can be difficult to implement very long project pathways, because it requires a monitoring, governance and upgrade programme over decades. Many investment projects are fit and forget projects, or transfer assets over to others, and this can make it very challenging to actually implement these project level pathways in practice. This does highlight the potential benefit (as a public good) from city level monitoring and capacity support for projects. Further consideration of the project level is included in the final case study on Glasgow City Region City Deal.

Discussion

This case study has identified the various types of adaptation pathways, identifying four broad approaches:

- Adaptation pathway frameworks or roadmaps;
- Adaptive (iterative) management;
- Adaptation tipping points and route maps (dynamic pathways);
- Adaptation landscapes.

While all of these consider the sequencing of adaptation over time, they vary in terms of iterative feedbacks and monitoring (adaptive management), the use of thresholds (route-maps), and the consideration of broader socio-institutional aspects (landscapes). These methods also have different applicability. The general frameworks can be applied at an aggregate scale or at a scoping level, whereas adaptive management and route-maps are a form of decision making under uncertainty and thus align more strongly to a project level analysis (appraisal). The case study has developed

illustrative applications of the first three methods for the Clyde Corridor, looking at coastal flood risks.

The application of broad <u>adaptation pathway frameworks</u> provides an example of an approach for sequencing adaptation over time and identifying early priorities. This focuses on three early action areas. First, low-regret adaptation priorities. Second, early decisions where there are long life-times or lock-in, which are important for investment projects such as the Strategic Development Plan and future land use plans, and the Glasgow City Region City Deal. Third, early activities to start monitoring for longer-term risks and preparing iterative plans. This type of approach is considered particularly useful for Climate Ready Clyde, and it is recommended that such an approach is adopted to frame the first Adaptation Strategy and Action Plan for Glasgow City Region.

The second case study looks at the longer-term adaptation planning, demonstrating an adaptation <u>route-map</u>. This is a complementary approach to the general framework above, focusing on the third priority of long-term planning. It uses a more detailed method to look at long-term climate risks and adaptation responses under uncertainty. The case study has developed an illustrative adaptation route-map for coastal flooding in the Clyde Corridor, based on unacceptable levels of properties at risk/annual damage, and shows different pathways linked to a monitoring programme. This case study has provided some useful insights on the adaptation route-maps approach. These can have a useful role in communicating an iterative approach, and they show that monitoring and sequenced actions are needed. Perhaps most usefully, they show that climate uncertainty is not a barrier to action.

However, the case study has shown that these methods have high analytical complexity, require detailed modelling, are technical in nature, and require considerable time and resources. It is also noted that sea level rise is the easiest risk to address with route-maps, because the direction of change is known, it is slow, and the main issue is around timing. Applying the approach for more complex and uncertain risks, such as precipitation, or more complex thresholds which involves multiple metrics (natural systems and interactions with the built environment) would be much more challenging. We also stress that focusing on coastal flooding alone is only part of the story: additional pathways would be needed for surface and river flooding. It is possible that river, coastal and surface water analysis could be combined into one overall pathway that captured all risks and tipping points, but this would be extremely complicated, and further, considering risks one at a time is less likely to lead to an integrated and holistic approach. The route-maps themselves also tend to be over-simplifications, and may make it difficult to consider the inherent trade-offs involved, including barriers as well as non-technical and governance / capacity building actions. We therefore consider the route-map approach is not a substitute for a detailed adaptation plan that involves the allocation of resources to real problems, but it may be a useful way to present existing information and analysis, to help communicate the need for iterative approaches and long-term thinking.

The final application of adaptation pathways has been at the <u>project level</u>. This is one of several approaches for building resilience in new investments (infrastructure, housing development, etc.) that have a long life-time and a risk of locking in vulnerability to future climate change risks. The key pathways application is centred on building flexibility during project design and construction, combined with a monitoring programme, to allow the later upgrade (at low cost) of resilience as and when risk levels change. This does have potential application to strategic investments in Glasgow City Region, such as Glasgow City Region City Deal. However, this does involve additional costs, which would need to be considered in more detailed cost-benefit analysis. Furthermore, there are

additional costs and governance issues with monitoring and upgrading projects over decades, which may actually make it difficult to implement these pathway approaches. The role for co-ordinated monitoring and information provision is therefore highlighted as an important central (government) public good to help inform long-term planning.

It is stressed that the three approaches are complementary. They start with a broad framework and then focus down on investment resilience (project level) and long-term corridor risks (adaptation route-maps). As such, they can be seen as components of a wider nested hierarchy, related to different scale and aggregation issues, and different adaptation decisions (related to regional wide planning down to specific project investments).

Finally, the case study has considered the lessons and insights from the analysis to highlight possible <u>next steps</u>. As outlined above, we recommend that Climate Ready Clyde structure the development of the City Region's first adaptation strategy and action plan around a general adaptation pathways framework, and the identification of early adaptation priorities (the three building blocks). This would help to identify the (urgent) actions that could be prioritised in the next plan cycle (i.e. for the next five years or so) by major risk category, as well as setting a direction for others to work within.

Following on from this, one set of specific early actions could be to consider the potential to investigate resilience in near-term Glasgow City Region investments that involve lock-in. This would include the identification of possible resilience investments as part of the current or next Strategic Development Plan and the next set of City Deal projects planned for delivery, as well as other strategic initiatives, such as the City Development Plan Strategic Development Frameworks (SDFs) which include a spatial framework (which are part of the delivery of the Glasgow City Development Plan under the Sustainable Spatial Strategy (SG2). All of these investments involve long lived infrastructure and land-use change. The primary aim would be to apply climate risk screening to these investments, and consider possible resilience measures for any major risks identified (to consider whether to make these investments climate smart), though it is stressed that this does not need a pathways approach. Complementing this it would be useful to consider similar risk screening for critical infrastructure investment (including new utility investments).

It is also recommended that Climate Ready Clyde work with other key stakeholders to o consider some elements of the iterative and adaptation pathways thinking and start developing a longer-term adaptation plan (e.g. this could be similar to the Thames 2100 plan). This could develop the concepts for the Clyde Corridor, and consider an iterative monitoring framework and the sequencing of adaptation, but it need not use the detailed route-map approach (given the findings above). This could be particularly relevant for River Clyde Corridor SDF, especially as each SDF is supported by an iterative action plan. It would also be useful for Climate Ready Clyde to consider asking SEPA to consider uncertainty in the long-term flood risk analysis, rather than the current use of only one future (high) scenario. Underpinning this, there is also a need for partners to identify and develop a monitoring programme around some of the key threats for the region, to discuss some of the key objectives and thresholds with stakeholders, and to consider possible long-term governance arrangements for an iterative based approach.

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APPENDIX 1. ADAPTATION PATHWAYS AND DECISION MAKING UNDER UNCERTAINTY LITERATURE REVIEW

Planned, pro-active adaptation¹³ involves complex temporal dimensions, as it has to address risks that vary dynamically and non-linearly over time. It also involves a mix of technical and non-technical options, for a range of decisions, at different scales. This, in turn, leads to a number of key challenges for the identification and prioritisation of planned adaptation.

First, future climate change is uncertain, and this requires a different approach for decision analysis (Wilby and Dessai 2009ⁱ). This includes scenario uncertainty (i.e. are we on a 2 or 4°C path?) and also climate model uncertainty (for a given scenario), noting the latter can be larger than the former, especially in the period to mid-century. For decisions that need to be taken now (e.g. designing infrastructure), this makes adaptation difficult: it is easy to design for one future scenario (e.g. an increase in run-off) or another (e.g. a decrease in run-off), but difficult to produce designs that works equally well in all cases. It also stressed that over-design (for the most extreme outcomes) is unlikely to be an economically efficient response.

Second, it is difficult to identify early efficient and effective adaptation interventions (i.e. in economic present value terms) because of discounting and uncertainty (OECD, 2015ⁱⁱ). The onset of climate change is gradual, and the really large impacts of climate change will emerge after the year 2030. The full benefits of adapting to these future impacts also arise in the longer-term, thus benefits are low in present value terms when compared to up-front adaptation costs.

Alongside this, there is an issue of the 'adaptation deficit'.¹⁴ This is the existing impact of current climate variability and weather extremes, including floods and droughts. All countries have some adaptation deficit, and many adaptation options will therefore have potential benefits in reducing the deficit as well as reducing early climate change risks.

The combination of uncertainty and economics has led to the development and application of frameworks and approaches for identifying and prioritising early adaptation (i.e. interventions for the next five years or so), often termed '<u>early and/or low-regret adaptation'</u> (e.g. DFID, 2014ⁱⁱⁱ), as well as methods for <u>decision making under uncertainty (DMUU)</u> (e.g. Mediation, 2014^{iv}). However, it is critical to recognise that these operate at two different levels and potential steps in the policy or project cycle for adaptation decision making:

- <u>Frameworks for adaptation</u>, such as low regret frameworks or adaptation pathways, which help in framing adaptation, and also can be applied to help prioritise and sequence adaptation over time in policies, programmes or projects over time;
- <u>Decision support tools</u> for adaptation, including formal DMUU methods. These can be applied as part of policy or programme applications, but are most relevant and applicable for project appraisal, i.e. in helping to assess and prioritise adaptation options.

Adaptation frameworks have high relevance at the strategic or policy level, but can also be used in the early scoping of adaptation options, both identifying promising options and help the phasing and

¹³ Adaptation can be reactive, responding to changes that have been already experienced, or it can be proactive (or planned), preparing for the future impacts of climate change.

¹⁴ Defined in the IPCC AR5 Glossary as The gap between the current state of a system and a state that minimizes adverse impacts from existing climate conditions and variability. Note that this definition is contested by some authors, as it implies that the aim should be to minimise impacts, whereas from an economic perspective, they should be managed down to a point where the benefits of action are greater than the costs, which implies some level of residual damage is optimal.

sequencing of adaptation options over time to increasing risks. These general frameworks can be used to produce adaptation pathways.

Decision making under uncertainty approaches involve a set of more formalised methodologies. They provide decision support to help identify and prioritise options, using principles such as robustness, diversity, flexibility, learning, and choice editing: several of these are economic methods and all of them can include economic analysis as part of appraisal (Watkiss et al, 2014^v), see box. These include more detailed adaptation pathways methods, discussed in the next section. However, these formal methods are more difficult to apply at a policy, sector or programmatic level, because they require quite specific inputs, as well as time and resource constraints.

Box 1 Decision making under Uncertainty approaches

A number of DMUU methods are aligned to adaptation pathways or adaptive management, which are discussed in the next section, but there are also other approaches, summarised below.

<u>Real option analysis (ROA)</u> (Dixit and Pindyck, 1994^{vi}) quantifies the investment risk with uncertain future outcomes. This is useful when considering the value of flexibility with respect to the timing of capital investment, or adjustment of the investment over time in a number of stages, in response to unfolding events. This allows for the consideration of flexibility, learning and future information (option values). In the adaptation context, it can be used to assess whether there is a value to waiting for (climate) uncertainties to be resolved to avoid negative outcomes, and to assess whether investing in more flexible adaptation solutions that can be changed later, are preferable, trading off the additional cost involved. It involves formal economic quantitative analysis (based around an extended cost-benefit analysis) and is applicable at the project level.

<u>Robust Decision Making (RDM)</u> is a decision-support method premised on robustness rather than optimality (Groves and Lempert, 2007^{vii}). RDM involves testing strategies across a large number of plausible futures, and identifying those options or strategies which perform well over a wide range of scenario futures, i.e. that are robust. It can be used in cases of deep uncertainty, i.e. to help make robust decisions today, where little or no probabilistic information about the future is available. Some studies only apply the concept of the technique to the analysis of climate change futures, but more formally the approach has been used in a structured application using computing power to examine large numbers of futures (e.g. Lempert and Groves, 2010^{viii}). The approach does not involve economic analysis per se, but most studies include costs, and some extend to cost-benefit analysis.

<u>Decision scaling</u> is an approach for climate risk assessment that links bottom-up vulnerability assessment with multiple sources of climate information (Brown 2011: Ray and Brown, 2015^{ix}). It typically uses a series of steps, identifying and defining Performance Indicators (PIs) and acceptable thresholds (for decision or investment. It then assesses performance of the PIs to current climate (and climate variability) and develops climate response functions. Finally, it analyses risks to PIs from the full ensemble of future climate models, to stress test performance. The method aims to make the best use of uncertain but potentially useful climate information. The approach has been advanced for hydro power investments.

Portfolio Analysis (PA) provides a quantitative means to maximise the return on investments using a portfolio. The principle is that spreading investments over a range of asset types (diversification) spreads risks, rather than managing assets individually. The PA technique highlights the trade-off between the returns on an investment and the riskiness, and can maximise the expected rate of return and minimise the total portfolio variance, for given risk preferences (Markowitz, 1952^x). In the adaptation context, PA helps in selecting combinations of options that, together, are effective over the range of possible projected future climates, rather than a single option best suited to one possible future. It is primarily a quantitative analysis method and predominantly uses an extended cost-benefit analysis framework. The economic information is presented against variance in an efficiency frontier, which provides the investor or decision maker with a choice of alternative (efficient) portfolios, which they can choose from, based on their risk-return preferences.

There are also <u>rule based decision support</u> criteria. These include (Metroeconomica, 2004^{xi}): Minimax regret rules, which minimise the maximum regret; maximax rules, in which the decision maker should opt for highest outcome; and maximin rules, which maximise the minimum outcome.

Decision making support me	ethods	7
Cost benefit analysis with sensitivity	Analysis of project benefits versus project costs, with sensitivity testing (or switching values) for key parameters	
Cost effectiveness analysis	Analysis of benefits (non monetary) using a common metric, expressed per unit cost, to allow least cost analysis	 Standard Appraisal
Multi-criteria analysis	Analysis of project using wide range of criteria (monetary and non-monetary) to rank projects	
ecision making under unce	rtainty	
Iterative Risk Management (IRM)	Uses iterative framework of monitoring, research, evaluation and learning to improve future strategies.	Learning,
Real Options Analysis (ROA)	Allows economic analysis of future option value and economic benefit of waiting / future information / flexibility.	flexibility
Robust Decision Making (RDM)	Identifies robust (rather than optimal) decisions under deep uncertainty, by testing large numbers of scenarios.	Robustness
Decision scaling	Identifies key performance indicators and stress tests many future scenario, to identify options that robust	
Portfolio Analysis (PA)	Economic analysis of optimal portfolio of options by trade-off between return (NPV) and uncertainty (variance).	Hedging / diversification
Rule based decision support	Minimax: minimise the maximum regret; Maximax: opt for highest outcome: Maximin maximise minimum outcome	Minimising/ - maximising regrets / choices

Updated from Watkiss et al, 2014.

The frameworks and decision support tools that are related to adaptation pathways are discussed in more detail below.

Adaptation Pathway Frameworks (sequencing and prioritising early adaptation)

The earlier climate impacts literature generally applied a science-first approach (Ranger et al, 2013^{xii}), in which adaptation was considered at the end of a sequence of analysis from climate models, to impact models, to adaptation, and which tended to adopt if-then frameworks to assess technical adaptation in future time periods (i.e. 2050s to 2080s). As highlighted by many authors, such assessments do not provide the information for real adaptation Füssel and Klein, 2006^{xiii}; OECD, 2015^{xiv}) because these do not focus on short-term and real-world early adaptation, they tend to focus on technical options, they do not consider existing policy and other drivers (climate and non-climate) and they do not consider the adaptation process (and capacity) or governance issues.

As a result, there was a move towards policy-first frameworks (decision centric), which focus on informing adaptation decisions, and thus tend to focus on identifying early adaptation (noting that this may still be to address long-term as well as short-term risks) (Wilby, 2012^{xv}).

There are a set of <u>adaptation pathway frameworks</u> that use approaches to help in the identification and prioritisation of this type of practical adaptation (i.e. applied, policy first and decision orientated adaptation), and in particular, to identify portfolios of adaptation interventions that can be sequenced over time to respond to changing risks (Downing, 2012^{xvi}). The focus is to prioritise early adaptation that might be introduced in a current policy round (e.g. such as a National Adaptation Programme phase, or a short-term local adaptation plan), as well as to identify the timing and sequencing of adaptation subsequently over time to increasing risk levels.

This adaptation pathway framework approach has been advanced in the UK, to help inform the prioritisation of early adaptation, including in national analysis. The frameworks developed build on earlier studies (Fankhauser et al^{xvii}, Hallegatte (2009^{xviii}), Ranger et al (2010^{xix}), Watkiss et al^{xx}) and were adopted in early Adaptation Sub-Committee (ASC) frameworks.

This approach was also adopted in the UK CCRA 2 method (Warren et al, 2016: Warren et al, 2018^{xxi}), which identified a typology of three early adaptation interventions that were the priority for the next five year NAP cycle:

- 1. To address existing adaptation deficit in the UK by implementing '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, such as major infrastructure developments or land-use change, in order to avoid 'lock-in'.
- 3. To fast-track early adaptation steps for decisions that have long lead times and to initiate early activities that provide information to improve adaptation decisions in the future (e.g. by enabling research, monitoring and piloting to enhance learning).

Note that these three types of intervention are complementary (i.e. a portfolio is needed). It is also highlighted that for points 2 and 3, the application of decision making under uncertainty (DMUU) tools and techniques are highly relevant: for example, if an investment has a long life-time and some early action is needed in design, then it is possible to use robustness, flexibility, etc to ensure the investment takes account of uncertainty.

This <u>adaptation pathway framework</u> approach was developed and applied in the UK Economics of Climate Resilience (which followed CCRA1). The method for the UK Economics of Climate Resilient (Watkiss and Hunt, 2011^{xxii}) developed and recommended this type of approach. This was subsequently applied in the Economics of Climate Resilience study (HMG, 2013^{xxiii}: Frontier, 2013^{xxiv}).



An example of a simple adaptation pathway that results from this framework is presented below, showing the potential sequencing of adaptation over time, as well as early priorities.

Figure 26 Simple Adaptation Pathway showing sequencing of options to rising risk over time. Source Watkiss and Hunt, 2010.

This was explicit linked to the CCRA cycle in the ECR. An example of an adaptation pathway is shown below. However, this also provided some lessons. The pathways in the ECR were often developed at the sector level (e.g. for agriculture) and this proved extremely challenging. A key lesson is that it is easier to develop adaptation pathways for specific risks, and ideally for specific risks and locations.

Furthermore, to do this prioritisation and sequencing well, it is necessary to consider the adaptation problem, as well as the types of adaptation decision, i.e. it is not just about identifying a set of options that can meet increasing risks (probability and magnitude) over time. This is because it requires some identification of what investments or decision involve longer life-times or involve lock-in, noting these will vary by sector and investment (Ranger et al, 2014^{xxv}).



Figure 27 Policy Adaptation Pathway (Economics of Climate Resilience). Frontier et al, 2013.

An early example of this more applied approach – considering elements such as lifetime - can be seen in the Highways Agency climate risk assessment (HA, 2011^{xxvi}). As well as looking at the climate risks of relevance for the national road network, it also considered the design lifetime of the investments it was making – highlighting that in some cases, even if a risk receives a low-ranking based on the risk appraisal scoring, it would still be sensible to undertake early adaptation for reasons associated with the nature of the adaptation strategy, e.g. when i) there was a long lead-time needed to plan adaptation, ii) because of the need to smooth the investment programme over time, and iii) where adaptation is concerned with a long-life, expensive asset where there may be benefits from future-proofing new designs now. It therefore identified early priorities that were 'early adaptation advisable'.

A more specific project-based example is the climate risk management and climate proofing guidance for investment projects in the Asian Development Bank (ADB, 2015^{xxvii}). This uses a framework and analysis to characterise infrastructure investments in terms of the risks that faced, but also what adaptation options make sense, to subsequently identify which of the following three options to take for adaptation: (i) climate proof now; (ii) make the project climate-ready; or (iii) wait, collect information and data, and revise if needed

Adaptive Management (Iterative adaptation pathways)

There is a strong focus on the use of <u>adaptive management</u> approaches for adaptation. Adaptive management is an established approach that uses an iterative process of monitoring, research, evaluation and learning process (as a cycle) to improve future management strategies. Its potential application to adaptation has long been recognised (Tompkins and Adger, 2004^{xxviii}) and an adaptive management approach – also described as <u>iterative risk management</u> - was highlighted in the IPCC SREX report (IPCC, 2012^{xxix}).

The approach is also present in the literature on management and resolution of complex problems (Snowden and Boone, 2007^{xxx}; Andrews et al. 2012^{xxxi}) and organisational learning (notably the 'double loop learning theory' developed by Argyris and Schon, 1978^{xxxii}).

The common feature of an iterative approach are 'feed-back loops', which encourage information to be gathered, lessons to be evaluated, or research to be conducted, that is used to inform subsequent decisions.

These adaptive management and iterative approaches are a form of adaptation pathway, where the pathway over time shows the evaluation cycle and the use of information to adjust strategies.

Adaptation pathways including thresholds tipping points and route maps

The concepts of iterative pathways have been developed further to capture thresholds levels. This has been advanced with the literature on <u>adaptation tipping points (or turning points)</u> (Werner et al, 2013^{xxxiii}). These bring together adaptive management and decision making under uncertainty and so moves towards decision making and decision support, and thus into appraisal of plans and projects, with analysis of options.

The concept of adaptation tipping points (often termed turning points to avoid confusion with the large-scale global tipping points literature) refers to a specific situation (the turning point) where climate change induces policy failure and alternative strategies have to be considered.

It has been used to address climate uncertainty over time, looking at when specific thresholds could be exceeded, and then to frame iterative adaptation responses into a pathway over time that considers the uncertainty.

The methodological steps involves defining the policy or project objectives, but also considering what is an unacceptable change (the threshold or tipping points). This involves the analysis of targets and thresholds (i.e. critical threshold that represent an unacceptable level of performance or reliability that stakeholders want to avoid), along with analysis of when these thresholds might be reached (including analysis of uncertainty). This can be set out in an adaptation pathway (see below), that show how adaptation interventions change over time in response to threshold exceedances.



Figure 28 Adaptation Turning Points: example for sea level. Source Werners et al 2013.

Early examples include the application of adaptation tipping points and associated pathways to longterm water management in the Netherlands (Kwadijk et al., 2010^{xxxiv}). This study looked at the threshold situation where current management strategy could no longer meet the policy objectives, the 'adaptation tipping point'.

While these studies can look at policy conditions (and unacceptable levels of change), they can also be used in more specific project- based analysis, using more practical thresholds associated with biophysical levels (such as sea level rise), and thus linked explicitly to an iterative process with monitoring. One of the most frequently cited applications of such an approach is the Thames Estuary 2100 project (EA, 2011^{xxxv}). This developed a tidal flood risk management plan for London, developing a short-, medium- and long-term programme to address sea level rise. The study findings were presented as 'Adaptation Pathways', also known as 'route-maps'. This approach helps the decision maker to identify the timing and sequencing of possible pathways of adaptation over time under different scenarios – in this case, each pathway incorporates a package of individual measures. The project included a monitoring and evaluation strategy, with established decision points. If monitoring reveals SLR is happening more quickly (or slowly), options can be brought forward (or put back).

The method involves the following steps (Reeder and Ranger, 2011^{xxxvi}). First, an understanding of the current climate variability and any existing adaptation deficit are made, followed by the identification of major future risks from climate change. Future risk scenarios are then constructed and the analysis investigates and identifies vulnerability/impact thresholds that could trigger risks when coping capacity is exceeded, as well as effective indicators. The analysis then moves to adaptation, identifying possible adaptation options or portfolios that could be implemented in response to different threshold levels, and develops a pathway of options. Finally, the analysis considers options against economic and other criteria and recommends a feasible, preferred route or pathway, as well as key monitoring variables. A key element of the approach is the link to ongoing monitoring and a cycle of review, which allows learning and revision of the strategy over time. This iterative cycle incorporates learning, so that rather than taking an irreversible decision now—which may or may not be needed - decisions evolve over time. This helps ensure that appropriate decisions are taken at the right time, ideally with reference to the risk preferences for the given context. Using the route-map, it is possible to define 'decision points' (for example, in terms of

observations of mean sea level), where one would either take additional action or switch to an alternative pathway (Ranger et al, 2013).



Figure 29 Adaptation pathway for TE2100 Ranger et al, 2013^{xxxvii}.

High-level options and pathways developed by TE2100 (on the y-axis) shown relative to threshold levels increase in extreme water level (on the x-axis). For example, the blue line illustrates a possible 'route' where a decision maker would initially follow HLO2 then switch to HLO4 if sea level was found to increase faster than predicted. The sea level rise shown incorporates all components of sea level rise, not just mean sea level.

The adaptation tipping points literature has advanced in particular in the Netherlands, with the early work from Kwadijk et al., 2010 leading to the concepts of <u>Dynamic adaptation policy pathways</u> (Haasnoot et al 2013^{xxxviii}), which also use <u>adaptation route maps (or adaptation pathways maps)</u>. These bring together decision making under uncertainty with adaptation pathways, i.e. to stimulate planners to include adaptation over time in their plans and to explicitly think about decision lifetime and taking short-term actions, while keeping options open and avoiding lock-in. These have been presented using route maps.



Figure 30 Adaptation pathways map for fresh water supply from the IJsselmeer area. Haasnoot et al 2013.

Adaptation Pathways map. In the map, the grey line shows current policy, and once a tipping point is hit, there are alternative options (shown in different colours). Some of these routes meet policy objectives through to 2100, but others hit new tipping points over time, in which case a shift to one of the other options is needed.

There has also been some literature in the Netherlands on dynamic cost-benefit analysis for adaptation (Eijgenraam et al, 2014^{xxxix}; Kind 2014^{xl}), although this involves different concepts.

The main disadvantage of these adaptation route-map studies is the difficulty in identifying risk / impact thresholds. As a result, the main application to date has been for sea level rise, which is directionally bounded, and gradual. It is much more complicated to develop these thresholds when the risk is more uncertain (e.g. for rainfall projections in areas where the models are unclear even on the direction of change), where there are multiple climate variables that affect the overall risk threshold, or where there are more complex socio-economic and or policy response (that have multiple objectives, or many ancillary costs and benefits, rather than just a climate focus alone). These problems are compounded with scale and geographical aggregation, i.e. it is much easier to do this with a project application that for a programme. Application can also be challenging due to the dependencies between options within a pathway.

Transformational Change

Finally, there is a further literature that talks about adaptation pathways using a broader conceptualisation (Wise et al 2014^{xli}), that draws on 'pathways thinking' in the sustainable development domain to consider the implications of path dependency, interactions between adaptation plans, vested interests and global change, and situations where values, interests, or institutions constrain societal responses to change. This is contrasted with existing adaptation pathways that focuses on robust decision making within adaptive processes in the face of uncertainty and inter-temporal complexity, and does not address the complex governance issues

involved. The key addition is a strong focus on societal dimensions. These are sometimes set out in <u>adaptative landscapes</u>.



Figure 31 Decision-making actor's adaptation pathways through an adaptive landscape. Source Wise et al, 2013.

The boundaries between adaptive and maladaptive responses are changing over time, due to biophysical changes, but also due to changes in social and institutional context, including the actions of other decisionmakers who may perceive different adaptation pathways. Circle arrows represent decision points, dark blue arrows represent pathways that are contemporaneously adaptive, grey arrows lead to maladaptive dead-ends; dashed blue arrows represent more-or-less transformative pathway segments, and the green arrows show antecedent pathways prior to the current decision cycle (a) faced by the decision-maker of concern. Boxes A–D highlight differences to adaptation pathways.

Adaptation pathways guidance

There is some guidance on adaptation pathways available. The study has reviewed this to help with the methodological development and applications.

There is guidance on adaptation transitions from the EC funded RAMSES project, which is presented as an adaptation pathway. The RAMSES Transition Handbook (2017^{×lii}) embeds the key RAMSES findings in a process management cycle, alongside a training package, targeted towards city stakeholders, to support cities in the definition of their transition towards successful adaptation. There is consideration of adaptation pathways for the planning stage, with the sequencing of options over time and the identification of tipping points. It also recommends several adaptation pathways are developed. The performance of each adaptation pathway is then assessed (to what extent do the different pathways reduce risk, how much they cost etc.). However, there is little explicit guidance on how to do this. There are also applications in the project, in Antwerp^{xliii}, though these are more focused on heat strategies.



Adaptation Pathway approach (Source RAMSES D8.2, Mendizabal, M. et al., 2016^{xliv})

There is also guidance in the Climate Risk Informed Decision Analysis (CRIDA) Manuel (UNESCO, 2018^{xlv}). This provides useful guidance on how to assess thresholds, which is one of the more difficult aspects of this approach. It highlights that adaptation pathways approach often seek to identify critical thresholds, i.e. an unacceptable chronic level of performance or reliability that stakeholders want to avoid. This can often be derived from legal guidance, by-laws, decrees, court precedents, policy documents, and resource management guidelines. Examples include flood risk standards, regulatory frameworks, other design standards (e.g., minimum power generation), water supply resource management concerns, private sector management scope, and energy service levels. They can also be based on stakeholders' experience, who are often best positioned to discuss tolerance to failure and management-related values. Stakeholders may refer to "breaking points" that require translation of tolerance into terms relevant to climate conditions. Some evidence for thresholds can be taken from past critical events. These indicators might relate to loss of life, total economic losses, social losses, irreversible or irreplaceable losses, etc.

Ramm et al, 2017^{xlvi} provides a proof of concept for a combined robust decision making (RDM) and dynamic adaptive policy pathways (DAPP) approach in coastal flood risk management. It applies the dynamic adaptation pathways of Dutch studies (Haasnoot et al, 2013) uses a theoretical case study on sea level rise to demonstrate adaptation tipping points which may inform the development of technical signpost indicators. The case study selected objectives based on the number of people exposed to extreme flooding and the level of property damage, as tipping points, and looked at the point in time policies no longer keep impacts below these tolerable levels (where tolerable levels were considered to be more than double current levels). These used the change in frequency of a 1.1m flood event. Even a small amount of SLR (0.2-0.3m) could increase the return period of such an event to an intolerable level. It looked at a number of options to address this and build pathways, including planned retreat, barrier protection, building design and land-use change. It is also useful as an example of the use of multiple criteria to assess the pathway options.

It does add that in some examples, it found limitations in what appeared to be robust adaptation policies, where historical path dependencies or long lead times constrained the rate of adaptation and the extent to which future coastal flood impacts can be successfully managed, and because of this it moved to extend the approach to investigate socially-oriented signpost indicators.


(a) Possible adaptation pathways for Lakes Entrance



Adaptation Pathways	Relative \$ cost to community	Scenery	Natural environment	Safety	Proximity to water	Lifestyle	Short-term political risk ^{Note 3}	Rate of implementation Note 4
· -O-	\$	~	-	+	~	~	L	$\Theta \oplus \Theta$
² - O - O -	\$\$	-	-	+	~	~	L	•
· -O-	\$	-	-	+	~	~	L/M	G
4 	\$\$			+	~	~	L/M	Ġ
5 -O-	\$	~	~	+		-	м	66
- O - O -	\$\$	-	-	+	-	-	м	© ©
-0-0-	\$\$	+	+	++		-	м/н	G
- O-O	\$\$\$	-	-	++		-	м	ĠĠ
• -O-	\$\$\$	+	+	++		-	м/н	G

Note 1: Lived values based upon Granam et al (2014). Refer to Appendix B of the online supplementary ma Note 2: '--' large relative loss; '-' relative loss; '-' no change; '+' relative gain; '+ +' large relative gain Note 3: Based upon 'outrage potential' discussed in Gibbs (2016)

Note 4: Assumes no large scale redevelopment of existing property stock following a shock event

Figure 32 Possible adaptation pathways for Lakes Entrance. Source Ramm et al, 2017.

Top. Conditions the lead to adaptation tipping points for policy options (assessed individually) are shown along with the median use-by year for individual policies across the top axis. A simple qualitative scorecard showing possible trade-offs to lived values from adaptation pathways are shown in the bottom panel.

Bosomworth et al (2015)^{xlvii} published an Adaptation Pathways playbook for developing options for climate change adaptation in Natural Resource Management. This outlines that pathways planning involves five activities set (define objectives, understand current situation, analysis possible futures, develop adaptation pathways, monitor evaluate and learn), although this is effectively a standard adaptation appraisal cycle, with the options appraisal stage replaced with adaptation pathways.

More usefully, it identifies six sub-steps in identifying adaptation pathways for a particular objective: 1. Identify options to address existing drivers of vulnerabilities under current conditions; 2. Identify tipping points (biophysical thresholds), turning points (social–political threshold) and trigger points (the necessary lead time for action before a turning point is reached);

3. Identify alternate and additional options that could help address objectives under the range of potential futures;

- 4. Sequence potential actions into draft pathways (and document)
- 5. Analyse and evaluate the pathways;

6. Finalise and document or map pathways.

It highlights that tipping points are the kinds of conditions under which:

- an existing or potential future action may no longer be effective;
- a system or asset threshold might be reached; and

• an asset or system might change (these changes may be directly driven by climate change, or driven by changes in surrounding land use).

The New York City Climate Resiliency Design Guidelines (NYC MORR, 2018^{xlviii}) provide step-by-step instructions on how to supplement historic climate data with specific, regional, forward-looking climate change data in the design of City facilities. The guidance recommends flexible adaptation pathways (although these are more an application of decision making under uncertainty), as these provide a useful, iterative approach for managing uncertainty and designing resilient facilities, particularly those with a useful life that extends over 50 years. It highlights that a facility can be engineered with an adaptable protection level which reduces the hazard risk to acceptable levels for part of its useful life and that can be re-evaluated as risk levels change. An example is shown below. The main focus is on flexibility, providing extra protection against hazards in the initial decades while also leaving open design alternatives for updating resiliency measures as new data is provided or new risk assessments are completed.

For sea level rise risks, the guidance does highlight the need to consider critical versus non-critical component. Critical components essential to the facility's functionality should be protected to the higher standard for criticality, even if the facility itself is non-critical. Examples include electrical distribution and switching areas, motorcontrol centers, communications systems, monitoring and safety equipment, HVAC units, fire alarms and suppression equipment, furnaces, emergency fuel supplies, emergency generators and hazardous material storage. Importantly, it considers not only facilities sited in the current flood plain (e.g. at 1 in 100 risk, i.e. 1% annual chance) but also those that might become part of this flood plain with SLR. The guidance also sets out design options and also how to estimate benefits of resilience, with for large project (>\$50 million) to undertake quantitative analysis and benefit cost analysis.





Economic Implications of Climate Change for Glasgow City Region: Adaptation Report

The example shows an emergency generator with an approximate useful life of 25 years located outside a building. In order to incorporate the Guidelines into design, it is recommended that the foundation of the generator structure is designed to match the useful life of the building, which can vary between 50-70 years, that the generator serves. Assuming the generator is subject to flooding risk from sea level rise and coastal surge, it should be built on an elevated concrete slab that matches the future year design flood elevation (DFE) scenario corresponding to the end of the generator's useful life. The generator must be replaced when it reaches the end of its useful life, which is typically far less than that of the building. When the replacement generator is installed, the concrete slab is further elevated to accommodate the future DFE. The foundation of the generator and the columns are designed to support the additional future load from the concrete slab. Thereby, the initial investment into the foundation can be used to adapt in the future, allowing for future flexibility and avoided costs.

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