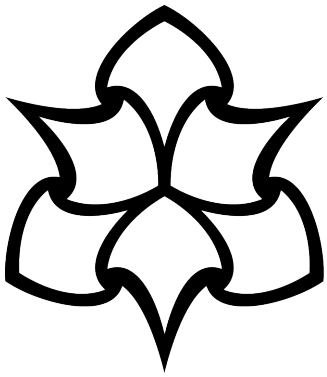

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MANCHESTER CLIMATE RISK: A FRAMEWORK FOR UNDERSTANDING HAZARDS & VULNERABILITY

DR PAUL O'HARE
APRIL 2021

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Author: Dr Paul O'Hare, Manchester Metropolitan University

Produced for the Manchester Climate Change Agency

This work was funded by the UK Climate Resilience Programme

To cite this document:

O'Hare, P. (2021) *Manchester's climate risk: a framework for understanding hazards & vulnerability*. Manchester, Manchester Climate Change Agency.

Version 1. Published April 2021

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EXECUTIVE SUMMARY

The *Manchester Climate Change Framework 2020-25* outlines the city's plan to ensure Manchester is a thriving, zero carbon, climate resilient city. The framework is partly about ensuring Manchester plays its full part in mitigating climate change - keeping global heating to below 2°C. But whilst mitigation is vital, ***adaptation to climate change is increasingly urgent***.

To this end, the Climate Change Framework has the following high-level objective: ***"To adapt the city's buildings, infrastructure and natural environment to the changing climate and to increase the climate resilience of our residents and organisations."*** However, there is an acknowledgement that the adaptation and resilience dimension of Manchester's climate change work requires further development before the city's policy commitments and action reach parity with mitigation.

This document establishes an evidence base for ***a more detailed climate change risk assessment*** for Manchester. It identifies ***weather related hazards*** in the city and projects ***how climate change will affect these hazards***. It also establishes ***a framework to support the comprehensive assessment of the city's vulnerabilities to climate change*** and to evaluate our capacity – or lack thereof – to respond to these threats.

Key points

- Like everywhere else across the UK, Manchester is exposed to a range of weather hazards. These will be exacerbated by climate change, potentially creating significant future challenges for the city.
- In terms of hazards, flooding is Manchester's most prominent extreme weather and climate change threat. Floods in February 2020 and January 2021 are just the latest examples of the damage and disruption that these events can cause.
- Although currently relatively uncommon, droughts, heatwaves and wildfires represent future risks. Of particular concern is the impact that hotter summers will have on the city and its inhabitants.
- Many aspects of the city are exposed to the direct and indirect impacts of weather hazards, including society, economy, buildings, infrastructure, and natural assets. These impacts will be exacerbated by climate change.

- More research and evaluation is required to fully appreciate the extent of the risk of climate change for Manchester, both in terms of exposure and vulnerability. However, a framework for understanding vulnerability is proposed in this document.
- Manchester should consider developing an evidence-based climate risk assessment. There are several options for this, of varying degrees of complexity and resource requirement. Other cities have already developed, or are in the process of developing, a detailed climate risk assessment.

There are several benefits to be derived from a comprehensive climate risk assessment:

- It will demonstrate we have an informed comprehension of its climate risk, particularly its most critical economic, societal and infrastructure vulnerabilities.
- It will be beneficial in developing a coherent and robust resilience and adaptation plan. In particular, it will provide a baseline for understanding the impact of adaptation and resilience interventions.
- The clear articulation of the impacts of climate change will raise the profile of the climate challenge, informing policy makers, political leaders, investors, business and commerce, service providers and the public.
- It is increasingly likely to be an element of standard climate policy and practice disclosure. Further details on this may come from the recently launched *Race to Resilience* initiative.
- It will provide confidence in – and a reference point for – stakeholders across the city who will increasingly be obliged to pay regard to climate change risk in various disclosures, investment plans, corporate strategies and asset and business continuity documents.

The city risk assessment should be conducted according to the latest international best practice, in line with Manchester's commitment to be a world-class city. We therefore await the development of the *Race to Resilience* initiative which will provide further information regarding metrics for assessing city-wide climate vulnerability, and adaptation and resilience.

INTRODUCTION

The *Manchester Climate Change Framework 2020-25* outlines the city's strategy for making Manchester a thriving, zero carbon, climate resilient city. The framework is partly about ensuring Manchester plays its full part in mitigating climate change - keeping global heating to below 2°C. But whilst mitigation is vital, ***adaptation to climate change is increasingly urgent***.

The Framework has this strategic objective regarding climate change resilience and adaptation:

"TO ADAPT THE CITY'S BUILDINGS, INFRASTRUCTURE AND NATURAL ENVIRONMENT TO THE CHANGING CLIMATE AND TO INCREASE THE CLIMATE RESILIENCE OF OUR RESIDENTS AND ORGANISATIONS."

Beyond assisting Manchester in dealing with the consequences of severe weather, effort now will make an important cumulative contribution toward national and global efforts of climate change action. Any action requires careful planning, and ideally the development of a smart objective that can drive coherent intervention. There is also a need to establish a monitoring framework to assess our progress toward achieving climate resilience and adaptation.

Against this context, this document establishes the groundwork for ***a more detailed climate change risk assessment*** for Manchester. It identifies weather related hazards in the city and projects how climate change will affect these hazards. It also establishes a method to support the comprehensive assessment of the city's vulnerabilities to climate change and beyond to evaluate our capacity – or lack thereof – to respond to these threats.

To this end, the document can be used as a reference point and to inform the risk management activities of many sectors across the city. We also hope it will be useful in informing those wishing to develop their own bespoke risk assessments.

NEXT STEPS – SOME RECOMMENDATIONS

A critical recommendation emerging from this work is that Manchester should consider ***developing an evidence-based climate risk assessment***.

Such an assessment will require an investment of resources, time and expertise, but will bring multiple benefits:

- A detailed assessment of risk (and possibly also opportunities) will demonstrate that the city has a robust, and informed comprehension of its climate risk, particularly in terms of its most critical economic, societal and infrastructure vulnerabilities. This is vital to underwrite an effective, coherent plan for climate adaptation and climate resilience.
- A risk assessment will have value in supporting Manchester in its various climate risk reporting obligations. It will also provide confidence in – and a reference point for – others across the city who will be increasingly obliged to pay regard to climate change risk in various disclosures, investment plans, corporate strategies and asset and business continuity documentation.
- The clear articulation of the impacts of climate change will raise the profile of the climate challenge and help identify its implications for the entire city. It will inform policy makers, political leaders, investors, business and commerce, service providers and the public. This is necessary to support concerted climate adaptation and resilience action. It will have the added benefit of publicly demonstrating the city's ambition to meet its climate change adaptation and resilience objectives.
- It will provide a baseline understanding of the full implications of climate risk. This can be used to assess progress in our development and pursuit of strategic adaptation and resilience strategies.
- It will underwrite the city's ability to make informed decisions regarding adaptation and resilience. More particularly, it will help prioritise adaptation actions, ensuring investment is targeted and cost-effective. It could have the added benefit of attracting future investment in climate change action measures for the city, and bolstering investor, business, and institutional confidence.

Appendix 1 provides some recommendations regarding what a city-wide risk assessment might look like, including reference to examples from other cities.

STRUCTURE & CONTENT

The report provides an overarching framework for assessing climate risk and climate vulnerability for the city of Manchester. It is worth noting that risk is composed of interrelated yet distinct dimensions: hazard, exposure, vulnerability and capacity to respond. Each of these elements need to be understood to fully appreciate the risk that climate change poses to the city (see Table 1).

HAZARD	An event or scenario that is a potential source of harm.
EXPOSURE	People, places or assets that could be affected by a hazard.
VULNERABILITY	The extent to which entities (units or systems) could be harmed by a hazard.
CAPACITY TO RESPOND	The ability (or inability) of entities to respond to a hazard.

Table 1: Dimensions of risk

In terms of content, the report:

- Draws on pre-existing research and secondary sources to identify Manchester's main weather hazards and climate risks and indicates how these could evolve in the future.
- Provides a framework for understanding the city's vulnerability to climate change. This is outlined through six sections. See Table 2, below, for a summary. This is expanded later in the report.
- Evaluates sources to identify gaps in knowledge and to identify where further work might be required.

Further information regarding how the document was developed is outlined in Appendix 2.

PEOPLE & SOCIETY	The health, wealth and well-being of everyone in society are fundamental indicators of the success and vitality of a city. Manchester is a complex and diverse city, composed of many intersecting communities with contrasting characteristics. Communities and individuals will be affected by climate change in different ways. Some people will have greater capacity to respond than others.
ECONOMIC ACTIVITY	Manchester faces considerable economic challenges. Moreover, wealth and economic opportunity is not shared across the city or its people. Climate change will bring both threats and opportunities to the economic sustainability and the competitiveness of the city. It has the potential to have significant implications for social justice and inclusive growth.
PLACE & THE BUILT ENVIRONMENT	The places that we inhabit, and more specifically our built environment, is a key element of our exposure to the impacts to climate change. We need to consider how our urban spaces, public places and parks and green spaces are vulnerable to the impacts of climate change.

INFRASTRUCTURE	The effective functioning of our infrastructure is vital for economic and social well-being of all those that live and work in the city. Climate change threatens to both exacerbate long-standing vulnerabilities and introduce new vulnerabilities to the city's infrastructure networks.
NATURAL ENVIRONMENT, BIODIVERSITY AND GREEN & BLUE INFRASTRUCTURE	Manchester has a vast range of green and blue space and biodiversity. However, these spaces are of varying quality, and will come under increasing pressure from future development and fragmentation. Some of these spaces and their biodiversity and quality will themselves be impacted by climate change.
CROSS-CUTTING THEMES	There are several cross-cutting factors that should be considered when assessing Manchester's sensitivity and vulnerability to climate change. These include interdependencies that will frame any efforts to adapt to climate change such as the management of risk across the city's boundaries, and evaluating the understanding of climate risk, resilience and adaptation.

Table 2: Summary of framework for understanding Manchester's vulnerability to climate change

MANCHESTER – GEOGRAPHY, CLIMATE & WEATHER

MANCHESTER'S GEOGRAPHY & CLIMATE

Manchester is a metropolitan borough in North West England. According to the Office of National Statistics (ONS), in mid-2019 the city had a population of 552,900[i]. The city is one of ten local authorities that form Greater Manchester urban region, itself the third largest conurbation in the UK.

The city is bordered by the Cheshire Plain to the south. It is bounded by the foothills and moors of the Pennines to the north and east. This results in Manchester possessing a significant water catchment area that both catalysed the city's historic economic development, but that also creates challenges for managing the impacts of climate change, particularly in terms of flood risk.

Manchester is regarded as one of the first industrial cities, becoming a hub of textile manufacturing by capitalising on its humid climate, water supply and rivers and proximity to significant coal fields. At one time, the city hosted the world's largest marketplace for cotton goods, becoming known as 'Cottonopolis'. The industrial era has left a significant built environment legacy for the city. Much of the infrastructure still in existence and still used in the city today was planned and constructed at this time, including canals, railways, warehouses, street and road layouts and drainage infrastructure.

Like much of the UK, Manchester has a temperate oceanic climate, with generally warm summers and cool winters. The British Isles are subject to weather carried by the Atlantic jet stream; bands of westerly winds conveying powerful weather systems. Fluctuations in its relative intensity and position can bring variable weather conditions to Manchester.

Despite Manchester's reputation, the city has below average rainfall for the UK. Between 1981 and 2015 Manchester had an average 867mm of rainfall in Manchester per annum[ii]. Lying snow is infrequent due to the urban and quite low-lying profile of the city, being around 40 metres above sea level. However, snowfalls do occur in the surrounding moorlands to the north west (the South Pennine moors) the north east (the South Pennines) and the west (the Peak District). This can cause disruption to rail and road networks beyond the city boundaries.

The lowest temperature recorded in Manchester was −17.6 °C on 7th January 2010. Manchester's hottest temperature on record was 33.7°C recorded in August 1976. The most recent highest temperature recorded was almost 32.8°C on 25th July 2019.

The city has four main river courses, the largest of which is the River Irwell which rises in moorland near Bacup. The Irwell flows to the west of Manchester city centre and is canalised in its lower reaches, eventually becoming the Manchester Ship Canal. The Irwell catchment area is wetter than the UK average. It is considered 'flashy', responding very quickly to rainfall given the rapid runoff from steep and narrow valleys, moorland that has lost water retention functionality since the industrial era, and intense urbanisation across Greater Manchester over several centuries.

The Irwell confluences with the much smaller rivers Irk and Medlock in the city centre. These two tributaries, and other subordinate tributaries and brooks, are heavily modified in their lower reaches, in many places being fully culverted. The River Mersey skirts the south of the city.

RECENT SIGNIFICANT WEATHER EVENTS IN THE CITY

There have been a series of recent significant weather events across the city. We cannot assume any of these events are a direct consequence of a changing climate. Nevertheless, these are *possible* indicators of the future weather extremes that the city may face more frequently in the future.

WEATHER EVENTS	DESCRIPTION	REFERENCES & MEDIA REPORTS
FLOODS	In the past decade, Manchester has experienced several notable floods, or 'near misses'. Storm Christoph in January 2021 threatened flooding in Didsbury and Northenden. The Mersey at Northenden reached 3.27 metres on 21 January (the minor flood level is 1.8 metres). Over 2,000 properties were evacuated, demonstrating the significant disruption that can be caused when flood warnings are issued in an urban area. There have been reports that the flood defences in the area were close to over-topping in places. Significant flooding occurred across Greater Manchester on 26th December 2015. Across the city region 2,225 properties were internally flooded. In Manchester, 37 properties were internally flooded in Cheetham and Hendham Vale. In August 2015 a sinkhole appeared in the Mancunian Way closing part of the road for several weeks. The closure generated significant congestion on nearby roads. The road only fully reopened on 15 June 2016.	Manchester Evening News article *Flood Investigation Report: Greater Manchester, 26 December 2015* Manchester Evening News article
HEATWAVES/ DROUGHTS	In 2018 Manchester, like many other parts of the UK, experienced a prolonged period of dry, warm weather. Throughout the summer, moorlands across several parts of the country suffered a series of wildfires. Two such wildfires were on Saddleworth Moor in Greater Manchester, said to be one of the largest in living memory, and on Winter Hill in Lancashire. The fires were not extinguished for three weeks, burning deep into the peatland. The Saddleworth Moor fire was believed to have caused a significant decline in air quality across GM, including in Manchester. In Manchester, smoke, ash, particle pollution and reduced visibility were reported across the city. Moreover, air pollution might be exacerbated by climate conditions, for instance being trapped by hot still air masses.	*The Guardian* article BBC News article

	Previous heatwaves/ extremely hot days were also recorded in 2013 and 2006.	
SNOWSTORMS/ LYING SNOW	Over the past 15 years, the city has experienced several major snowfall and cold weather events. The most notable of these were in December 2009/ January 2011; November / December 2010; March 2013; and most recently, the so-called *Beast from the East* in February/ March 2018. Although the impact of these weather events in Manchester varied, they did bring extended periods of wintry weather, very cold winds and, in some instances, heavy snowfalls. On occasion, temperatures have fallen well below freezing for several consecutive days, sometimes remaining below freezing even during daylight hours. At various times, transport networks and mobility across the city, the city-region and beyond was severely disrupted.	Manchester Evening News article
STORMS AND HIGH WINDS	In February 2014, the Met Office issued a red warning for wind in Manchester - the highest level possible. Although the event did not, in the end, cause much damage, people were advised to avoid travelling for several hours and to remain indoors. Many premises closed and employees were sent home early.	Manchester Evening News article

UNDERSTANDING THE CITY'S CLIMATE RISK

MANCHESTER'S CLIMATE AND WEATHER HAZARDS

Effort to identify future climate hazards is characterised by uncertainty. This uncertainty increases as climate change projections stretch further into the future or as we attempt to isolate hazards for a particular spatial location, such as a city.

There is, however, an emerging consensus that as the planet warms, Manchester – like the rest of the United Kingdom - will experience long-term, persistent climate change as well as climate instability and variability. These forces will drive potentially significant ***climate stresses and climate shocks*** for the city.

In short, weather events once considered to be outliers in terms of their extremity or rarity *could* become our new normal, underlining the necessity of work to embolden the city's climate change adaptation and resilience policy and practice.

Table 3 outlines the distinction between climate change, climate variability and climate shock.

CLIMATE VARIABILITY	Deviations or anomalies in the mean state and other statistics of the climate across temporal and spatial scales. These extend beyond individual weather events and might include a series of extremes in quite close succession. It is a rather broad term. Climate variability might refer to changes across a series of seasons or a handful of years. But beyond this, it also includes long-term – potentially generational - variations in the climate. Whilst some of the variability may seem random, and perhaps may not have apparent systematic drivers, other aspects *might* be indicative of new and emergent climatic patterns.
CLIMATE CHANGE	Statistically significant variation in the mean state of the climate across an extended period, usually 20-30 years, or longer. This might include the observation of persistent changes in climate variability, and climate anomalies, including how extreme weather events might become more or less frequent over time.

	Article 1 of the 1994 *United Nations Framework Convention on Climate Change (UNFCCC)* defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".
CLIMATE SHOCKS	Short term but potentially high-impact weather events that can cause significant disruption to social and economic functions at various spatial scales, from neighbourhoods and local communities to entire regions. Although sometimes discrete, some 'shocks' might also be indicative of longer-term climate variability and climate change.

Table 3: Defining climate change, shocks and variability (partially sourced from World Metrological Office, 2021)

UNITED KINGDOM CLIMATE PROJECTIONS 2018

The UK Climate Projections (UKCP) 2018 provides one of the most recent scientific assessments of how the UK's climate could change in the future. As with all climate projections, they are based on various emissions scenarios ranging from low to high.

Although laden with assumptions, there is an emerging consensus that nationally there is an "…increased chance of warmer, wetter winters and hotter, drier summers along with an increase in the frequency and intensity of extremes" (Met Office, 2019: 5). With time, these trends are predicted to become more pronounced.

Beyond this, UKCP 2018 states "There is also the potential for future changes in the time spent experiencing different types of weather regimes." (Met Office, 2018, 4)

MANCHESTER'S FUTURE CLIMATE IS EXPECTED TO REFLECT THE BROADER AND LONGER-TERM PROJECTIONS FOR CLIMATE CHANGE AND CLIMATE VARIABILITY.

THE CITY WILL ALSO FACE MEDIUM-TERM VARIATIONS IN CLIMATE PATTERNS AND ANOMALIES THAT LIE OUTSIDE THE HEADLINE CLIMATE CHANGE TRENDS.

UKCP state that we must take greater account not only of these longer-term trends, but also of medium-term variations in climate patterns and in anomalies that lie outside the headline climate change trends. As the UKCP 2018 report states, climate change trends do not completely preclude that "natural variations mean that some cold winters, some dry winters, some cool summers and some wet summers will still occur and users may need to factor this into decision-making" (Met Office, 2018: 4). These variations will pose critical challenges to the management of weather hazards, particularly when they are unanticipated.

CLIMATE CHANGE IN MANCHESTER

There is evidence to suggest that we have already started to experience the effects of climate change in Manchester. Meteorological observations demonstrate that there has been an overall warming in the city's year-round climate.

As we progress through the century, Manchester, like everywhere else in the UK, is projected to see a gradual creeping upwards in temperature, though this is not expected to be to the same extent as in southern regions of the UK. This warming will be more pronounced in summer than in winter.

In terms of headline weather hazards, flooding is Manchester's most prominent extreme weather and climate change risk. Although currently relatively rare, droughts, heatwaves and wildfires will also occur more frequently and will need to be given much more attention. Storms and high winds will also present a further risk.

Table 4 identifies and summarises the range of hazards that the city might face in the future and indicates how climate change might influence these.

CLIMATIC & WEATHER HAZARD	POTENTIAL IMPACT OF CLIMATE CHANGE ON HAZARDS
SHORT-MEDIUM TERM HEAT WAVES	Climate projections suggest that Manchester will face warmer summers in the future. There is an associated increased likelihood that we will face intense very hot spells (heatwaves). Some summer days could potentially be extremely hot. Higher night-time temperatures will be a particular problem in cities where buildings retain heat overnight. Increased frequency and intensity of intense convectional rainfall.
LONG-TERM PERIODS OF DRY/ HOT WEATHER	Summers are, generally, expected to be drier in the future. Prolonged dry and warm periods may lead to drought conditions, exacerbated by increased demands on dwindling water supplies. Some projections suggest that this hazard is more extreme than any of the historical events referred to above.
SUMMER STORMS	Although it is anticipated that, generally, the climate will be drier in Summer in the future, data from UKCP 2018 also indicates future increases in short-lived heavy rainfall events. There is an increased likelihood that there will be greater intensity in hourly precipitation extremes. More particularly, the impacts of increased convectional rainfall events could be exacerbated by significant surface water run-off with precipitation falling on very dry ground.

AUTUMNAL AND WINTER STORMS/ WINTER PRECIPITATION	Winters are likely to be wetter. In particular, successive mid-Atlantic lows have the potential to bring considerable amounts of rain to the region. Groundwater levels and soil saturation could remain high all winter, particularly in the hills and moorlands around Manchester that feed rivers. It is worth noting that UKCP 2018 warns "Users may wish to take the precautionary approach of considering the implications of a very large winter precipitation increase being more likely than the probabilistic projections suggest" (Met Office, 2019: 8).
COLD SNAPS/ LYING SNOW	Climate projections indicate winters will generally be warmer. UKCP 2018 suggest that by the end of the century there will be very few, if any, incidents of snowfall lying on the ground, except for on higher ground. This does not, however, entirely preclude periods of relatively prolonged cold snaps and accumulations of ground-lying snow in the short to medium term.

Table 4: Identifying Manchester's main climate hazards

EXPOSURE TO CLIMATE CHANGE – THE DIRECT IMPACTS

The warmer global climate and associated increases in mean surface air temperatures has implications for weather patterns and climate variability. These in turn will have significant consequences for society, the environment and infrastructure. Table 5 outlines the main primary impacts that climate hazards are likely to have.

WEATHER HAZARD	DIRECT IMPACTS – PRIMARY EXPOSURE & VULNERABILITY
SHORT-MEDIUM TERM HEAT WAVES	Significant human health implications. Increased death rates for the old, the very young and those with underlying conditions. Negative impact on the thermal comfort of inhabitants. Consequences for the ability of people to rest and sleep, again with implications for human health and productivity. Increased use of air conditioning, paradoxically producing further climate changing emissions. Pressure on urban infrastructure including railways and airport capacity and efficiency. IT servers may struggle to cope with very hot weather.
LONG TERM PERIODS OF DRY WEATHER, OR DROUGHT CONDITIONS	Increased demands on water resource at a time when reservoirs may not be replenished. Potential subsidence and pipe fracturing. Increased likelihood of moorland fires around the city with implications for air quality and human health.
SUMMER STORMS/ INTENSE	Fluvial flooding for communities and properties - both residential and commercial – and infrastructure. Significant economic damage, as well as potentially severe, long-term social and psychological impacts for communities.

CONVECTIONAL PRECIPITATION	High river levels may accelerate riverbank erosion, cause silting and potentially alter the course of channels. Overwhelming of urban drainage infrastructure. Pluvial flooding of communities, businesses and infrastructure nodes. Overtopping or undermining of reservoirs or water storage. Treatment works can overspill into a river during times of excess flow causing pollution. Land instability, landslips, subsidence or sinkholes. Possible (though likely to be isolated) damage from lightning strikes during intense convectional thunderstorms. Disruption to – and potential closure of – infrastructure and transport networks. Dangerous winds with the potential for fallen trees (in full-leaf), infrastructure disruption, and damage to buildings.
AUTUMNAL & WINTER STORMS/ WINTER PRECIPITATION	Fluvial flooding to communities and properties - both residential and commercial – and infrastructure. Significant economic damage, as well as social and psychological impacts for communities. High river levels may accelerate riverbank erosion, causing silting and altering the course of channels. Overwhelming of urban drainage infrastructure, pluvial flooding of residential property, businesses, and key parts of infrastructure and sinkholes. Treatment works can overspill into a river during times of excess flow causing pollution. Land instability, landslides and subsidence. Overtopping or undermining of reservoirs or water storage Disruption to – potential closure of – infrastructure and transport networks. Dangerous winds with the potential for fallen trees, infrastructure disruption, and damage to buildings.
COLD SNAPS/ LYING SNOW	Threat to human health, particularly for vulnerable people including the elderly, people in fuel poverty and the homeless. Pressure on infrastructure including disruption to transport networks, the fracturing of water and drainage pipes, snow and ice on power lines. Disruption to transport services, including airport and road closures. Disruption to public and human health services, including school closures, health services, and council services. Economic impacts given business and infrastructure disruption.

Table 5: The main primary impacts of future climate hazards

In addition to these primary hazards, the UK is exposed to indirect – or cascading - effects of climate change overseas. These systemic risks may be more severe than the direct UK impacts (UK Climate Risk, 2020). These could include, for instance, climate-related disruptions to global food and supply

systems. Climate change may also increase migratory pressures with implications for social cohesion and the provision and delivery of local public services.

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VULNERABILITY TO CLIMATE CHANGE

Understanding climate hazards is the vital first step in assessing how climate change will affect Manchester. However, we must consider our ***vulnerability*** to climate change if we are to gain a full appreciation of risk in the most holistic sense of the word.

The remainder of the document outlines a framework that could guide future assessments of Manchester's vulnerability to climate change.

DEFINING VULNERABILITY

Vulnerability refers to the extent to which entities (units or systems) are at risk of being harmed by a hazard. The term is very broad, referring to physical assets (such as infrastructure networks, buildings or systems), the delivery of services, and governmental, economic, cultural and societal factors.

FACING A CLIMATE HAZARD, PEOPLE AND INFRASTRUCTURES ARE EXPOSED TO THE SAME POTENTIAL LOSSES BUT ARE NOT VULNERABLE IN THE SAME WAY. VULNERABILITY DEPENDS ON PHYSICAL, SOCIO-ECONOMIC, THE AVAILABILITY OF SERVICES, GOVERNMENTAL AND CULTURAL FACTORS AND CAN BE QUANTIFIED BY THE DEGREE OF LOSS RESULTING FROM A HAZARD, AND THE CAPACITY TO RECOVER FROM AN EVENT.

(C40 Cities, 2018: 2)

UNDERSTANDING THE VULNERABILITY OF THE CITY

There are challenges to assessing the extent of our vulnerability to future climate change, not least given the range of complex, intersecting factors that vulnerability is contingent upon:

> "There is poor evidence on the range of possible future scenarios for vulnerability and exposure, which will be dictated by socioeconomic trends as well as changes in climate hazards." (UK Climate Risk, 2020: 3)

A comprehensive risk assessment requires interaction with stakeholders not only in the city but also those that lie across the city boundaries. Doing so will provide a more sensitive understanding of the impacts of hazards and sectoral and cross-sectoral vulnerabilities. Ultimately this will also provide a more accurate baseline for approaching and assessing adaptation. There is also a need to evaluate how attitudes toward climate change and its impacts frame individuals and organisational perceptions of vulnerability.

Identifying and mapping vulnerability is challenging. Different sectors do not necessarily share the same sensitivity to climate change or may not be vulnerable in the same way. Moreover, vulnerability is dynamic, altering across time and due to the changing conditions and circumstances of each facet of the city system, many of which are outlined below.

Consequently, efforts to identify and articulate a risk assessment for the city will forever be a work in progress; something that will evolve as engagement with partners across the city intensifies and as the nature and extent of risk evolves and develops.

ASSESSING VULNERABILITY

The remainder of this section provides a framework for understanding vulnerability. In particular, it summarises the key considerations for assessing how various dimensions of the city will be impacted by the direct and indirect implications of a changing climate.

The categories outlined are not comprehensive, but they do provide an initial structure and reference point for a fuller climate risk assessment.

PEOPLE & SOCIETY

The health, economic security, and physical and mental well-being of all members of our society are fundamental indicators of the success and vitality of the city. Manchester is immensely diverse; a complex mosaic that is composed of many different individuals and communities that themselves have distinct needs and priorities. These communities will be affected by climate change in different ways – both tangible and intangible - that we must be taken account of in any full assessment of climate risk.

PEOPLE & SOCIETY	
GEOGRAPHICAL EXPOSURE TO CLIMATE RISK	Certain communities will be at greater risk to climate change given their physical proximity and exposure to climate hazards. An obvious example of this is how communities living in close proximity to an undefended river or in a place with inadequate drainage networks are at greater risk of periodic – and often recurrent – flooding. Climate change and other factors such as urbanisation and infrastructure failure is likely to change the future hazard profile of communities. Households and communities not currently considered to be at high risk of weather hazards might be in the future. The distribution of exposure to climate change has a further dimension in terms of how a hazard (or multiple hazards) might affect multiple locations at the same time. For example, several incidents of flooding across the city occurring simultaneously or perhaps occurring during a heatwave, will have a cumulative effect, exacerbating the disruptive impact for people and services, and placing greater strain on those managing events and first responders.
SOCIO-ECONOMIC VULNERABILITIES	Some individuals and communities are at greater vulnerability to climate change. Beyond this, some may have less capacity to respond to climate change. Additionally, climate change will exacerbate existing social and economic conditions, as well as introducing new societal challenges and inequalities. For instance, previous research in Greater Manchester has acknowledged

that people face significant deprivation in certain parts of the city-region with a bearing on the vulnerability of some residents to the changing climate (RESIN, 2016).[iii]

Socio-economic vulnerability depends on many factors, including:

- People on low incomes, at serious socio-economic disadvantage, or living in poverty.
- The elderly or very young.
- Black and minority ethnic communities.
- Households unable to access transport.
- Those with fewer educational qualifications.
- People in ill-health.
- People with physical or cognitive impairments.
- Households with a low disposable income and/ or in fuel poverty.
- People in social housing or rental housing.
- The homeless.
- People living in social isolation or with limited friend and family networks.
- People in poor quality housing or in areas with broader challenges including deprivation, disadvantage or high crime rates.
- Those with communication difficulties or with limited proficiency in English.

There are also other characteristics that intersect these variables, such as access to cooling systems, home insurance or having the ability and permission to adapt a property to climate change.

These factors can intersect, creating multiple dimensions to vulnerability. That said, the possession of any one of these characteristics, or a combination of them, by no means *necessarily* means that particular individuals or communities are inherently vulnerable. They are, rather, *indicators of potential* climate disadvantage and must, therefore, be treated with caution. Moreover, we must also be aware that much climate disadvantage mapping relies on aggregations. Communities that might, as an aggregate, appear to be well placed to avoid the worst impacts of climate change may have individuals or households that are extremely exposed to one or multiple hazards given their personal or household characteristics or circumstances (O'Hare & White, 2018).

It is also important to take account of what the future demographic profile of the city will be and of demographic projections. For instance, it is projected that Manchester will have an ageing population in the future, potentially exacerbating the city's inhabitants' vulnerability to climate change (see Bagnall, 2018).

	In some limited circumstances, climate change might have a positive impact on some of these variables. For instance, warmer winters might lift some people out of fuel poverty. However, warmer summers and the increased likelihood of heatwaves will put increased demand for potentially cost prohibitive cooling systems. This will include increased use of air-conditioning which, paradoxically, might increase carbon emissions.
CIVIL SOCIETY AND THE VOLUNTARY SECTOR	Civil society organisations and the voluntary and community sector play a significant role in supporting and providing vital services to communities and individuals, some of whom are the most socially and economically precarious in the city. Civil society is a very broad term, encompassing a vast range of organisations involved in a huge variety of missions. Some of organisations, as well as the people and the services that rely on them, are vulnerable to a changing climate. This vulnerability is twofold, first in terms of direct impacts on staff, service delivery, and facilities and buildings that they are responsible for and second, given how climate change may alter and potentially intensify the demand for services.
HUMAN HEALTH	The adverse direct impacts of climate change – particularly from flooding and higher summer temperatures/ heatwaves - on human health could be considerable. They will involve both exacerbating existing health inequalities and the introduction of new health risks for people. Notably, Greater Manchester is referred to as a 'Marmot city-region'; a place necessitating innovative cross sectoral governance responses to address significant health in-equalities (Codling & Allen, 2020). Health inequalities and the impacts on recovery from shocks were further demonstrated by recent work by Public Health England (2020) outlining disparities in the risk and outcomes from COVID19 across a range of population characteristics (see also Marmot et al, 2020). The human health impacts of climate change may disproportionately affect those who are already vulnerable, for example, older people, very young people, people living in socio-economic deprivation and those with underlying health conditions. Demonstrating this, heatwaves and air pollution exacerbated by climate conditions or moorland fires can cause death and serious illness, particularly in the elderly, children and those with pre-existing respiratory illness and cardio-vascular disease. Flood water poses a (relatively small) risk of drowning and may harbour disease. Households that flood, but for whatever reason are unable to relocate either during the flood event or the process of reconstruction, report ill-health from living in damp homes.

	Experience of hazards can generate severe mental health and emotional impacts that may outlast the immediate impacts of events. For instance, communities that have suffered from flooding often report impacts in mental health several years after specific flood events. In the longer-term, climate change could increase the risk of new pathogens and diseases borne by invasive insect species. It is possible that warmer summers and milder winters will encourage greater use of the outdoors and greenspace, potentially bringing benefits to physical and mental health.
HUMAN HEALTH & SOCIAL CARE SERVICES	Climate change will have likely impacts on the delivery of functional human health and social care services. There are two key dimensions to this: 1. How climate change will directly impact staff, facilities and the effective delivery of essential human health and social care services. This might include disruption to buildings through flooding or other weather related damage, staff shortages during extreme weather events, or disruption caused by outages to critical infrastructure such as road and public transport networks, power and water supply and/ or IT and communication systems. 2. How climate change will drive further/ or a new demand for services. For instance, heatwaves may put pressure on acute medical services. Dislocation from floods and storms might increase pressure on social services and GP services. There may also be longer term stresses on services given that climate change is likely to increase chronic physical and mental health challenges.

ECONOMIC ACTIVITY

Manchester's economy is a powerhouse for the Greater Manchester city region. In 2018 Manchester's GVA was estimated to be £22,500 million (Manchester City Council, 2021). In March 2020, according to the UK Business Count 2020 (ONS), there were 22,850 enterprises in Manchester. However, the city faces considerable economic challenges in terms of its long-term adjustment to post-industrial economic growth, in incubating sustainable and stable economic growth and in terms of the city's economic recovery from the Covid-19 pandemic. Moreover, there are concerns regarding social justice. Wealth and economic opportunity is not distributed equally, whilst the city has some of the poorest communities of any place in the UK.

Climate change will bring both threats and opportunities to the economic sustainability and competitiveness of the city. In particular, it will both exacerbate some long-standing challenges, and will also introduce new threats to economic equality and inclusive growth.

ECONOMIC ACTIVITY	
DISRUPTION OF BUSINESS CONTINUITY	Weather hazards have the potential to bring considerable disruption to businesses operating across the city. In particular, disruption to buildings and building services, the ability of employees to gain access to sites and to conduct their jobs, and the ability of customers and clients to use business services could severely and directly undermine economic activity. For instance, hazards such as severe heatwaves, water shortages due to droughts, or floods and storm damage could prevent some businesses from operating for a period of time or undermine productivity. For instance, water rationing due to drought conditions may have a considerable impact on water reliant industry. Often businesses are insured for public liability and for damage to premises, but are severely under-insured for losses due to business continuity interruption or disruption to supply chains. Small and medium sized enterprises may be most vulnerable to the impacts of climate change, yet be the least agile in terms of responding.

DISRUPTION TO SUPPLY CHAINS	Businesses and service providers are not discrete entities. They rely on supplies, raw materials and access to markets that might be vulnerable to the impacts of climate change. Importantly, these supply chains will often extend beyond the administrative boundaries of the city. Similarly, employees, staff and service and business users might live beyond the city boundaries. Consequently, there is a need to consider this connectivity and these complex relationships in a comprehensive and holistic sense.
IMPACTS ON BUILDINGS	*See next section.*
ENSURING INCLUSIVE, SOCIALLY JUST ECONOMIC DEVELOPMENT	As noted earlier, climate change will have particular impacts for areas, for communities, and individuals already suffering from economic disadvantage. Sustainable economic development against the context of climate change should go hand-in-hand with socially just and socially inclusive economic development. There might be business and employment opportunities in addressing vulnerability to climate change. For instance, efforts to adapt or retrofit Manchester's buildings and infrastructure to a changing climate will provide employment for qualified and skilled trades people and professionals.

PLACE & THE BUILT ENVIRONMENT

The places that we inhabit, and more specifically our built environment, is a key element of our exposure to the impacts of climate change. Our buildings must be constructed, managed and maintained in a way that ensures they are fit for purpose in a changing climate. We must also consider how our urban spaces, public places and parks and green spaces are vulnerable to the impacts of climate change. Beyond this, there is a need to assess how buildings, open spaces and other places might be used to provide shelter or alternative accommodation for communities and businesses in the aftermath of severe impacts from weather hazards.

PLACE AND THE BUILT ENVIRONMENT	
BUILDINGS	Manchester has a wide range of types, uses and ages of buildings. Each building type, and each individual building bring their own challenges for living in a changing climate. There is a need to understand how the urban fabric that we have inherited is – or alternatively, is not - resilient to current and future climate hazards. Most of the buildings that we will live and work in over the next 50+ years have already been constructed. Existing building stock will need to be adapted and retrofitted to ensure they are resilient to our future climate. Specific attention must be paid to ensure buildings with vulnerable occupants are carefully considered in risk profiling and adaptation and resilience projects. Of particular concern are buildings that are vulnerable to fluvial and pluvial flooding, not just now but in the future as flood risk exposure profiles change over time. A further concern for Manchester are buildings that are prone to overheating, causing ill-health or exacerbating underlying health conditions for occupants and that, more broadly, undermine the thermal comfort of occupants. Poorly insulated or hard to heat homes might affect the health and wellbeing of occupants during periods of cold weather.

BUILT AND CULTURAL HERITAGE	The city has a wealth of historic and heritage buildings that are integral to the urban fabric. These are often much loved by residents, visitors and investors, and provide Manchester with significant architectural interest and heritage value. But these older buildings bring their own vulnerabilities to climate change. Their fabric might be constructed of materials or in a style that might make them more exposed to the elements. They might not be easily adapted or retrofitted. They might be close to rivers, have inadequate drainage and sewerage systems, or might be densely packed together. In terms of retrofitting, some buildings might be listed or have preservation orders complicating or even prohibiting options for adapting them for climate resilience.
SPATIAL PLANNING AND BUILDING STANDARDS	Across Manchester, there are significant pressures for land for development and urban infill. In some instances, these pressures threaten green space that might already be providing climate change mitigation and adaptation services. In addition, a general intensification of urbanisation without taking account of climate impacts poses a considerable challenge for the future development of the city. Care must be taken to ensure new vulnerabilities are not introduced through the construction of buildings in places that are exposed to a changing climate, or because buildings are constructed or retrofitted without considering climate resilience. We must also ensure there are not unintended consequences of mitigation and adaptation initiatives. The design and construction of new build properties or retrofitting of existing buildings must not exacerbate pre-existing exposure and vulnerabilities to climate change.
PUBLIC SPACES	Urban public space (e.g. civic squares) and urban green space and features (e.g. parks, gardens and urban trees) are not only an asset to the conviviality and liveability of the city, but may also be an asset for climate change mitigation and adaptation. These spaces should be assessed for their vulnerability to the adverse affects of climate change. For instance, are planting schemes and tree species able to withstand the future climate of the city, including drought tolerance and ability to withstand warmer summer temperatures. Beyond this, public spaces should be assessed for their ability to assist the city in adapting to climate change. Can, for instance, parks be retrofitted to provide sustainable urban drainage or to provide an urban cooling function? Will urban spaces and urban parks be able to accommodate a possible increase in user numbers, including tourists, in warmer summers and on very hot days?
SUPPORTING OTHER AMBITIONS OF THE CITY	Consideration should be given to how spatial planning, development control, construction methods and materials and the use of buildings and public space can be used to realise a more genuinely resilient urban future. For example, are there instances where rainwater harvesting could be used to store water in times of excess and to reduce the impacts of potential droughts? Can urban trees be used to reduce pollution and to reduce urban cooling? Are there examples of urban space that could be used for local food growing?

INFRASTRUCTURE

The effective functioning of our infrastructure is vital for the economic and social well-being of all those that live and work in the city. Infrastructure failure does not just have an economic impact on the city, but can damage the city's reputation for liveability and as an investment prospect. Climate change threatens to both exacerbate long-standing vulnerabilities and introduce new vulnerabilities to the city's infrastructure networks (GMCA, 2020). Demonstrating this, work by the National Infrastructure Commission (2020) has detailed the potential impacts that climate change, as well as other hazards, might have for infrastructure across the country. There is also a need to understand how the impacts of climate change on infrastructure can cascade throughout the city.

INFRASTRUCTURE	
DEFINING THE CRITICALITY OF INFRASTRUCTURE	Infrastructure can be delineated according to how critical it is to the functioning of the city, how dependent we are on it for sustaining and supporting our lives, and according to the impacts that disruption to one site or network will have for the wider city. For instance, disruption to water, energy and certain parts of transport infrastructure might have very severe widespread impacts for many other sectors across the city. In other instances, impacts might still be considerable but at a local or more discrete scale. The UK Government defines critical national infrastructure as: "Those critical elements of infrastructure (namely assets, facilities, systems, networks or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in: A. Major detrimental impact on the availability, integrity or delivery of essential services – including those services whose integrity, if compromised, could result in significant loss of life or casualties – taking into account significant economic or social impacts; and/or

	B. Significant impact on national security, national defence, or the functioning of the state.' (CPNI, 2021) In the UK, there are 13 national infrastructure sectors: Chemicals, Civil Nuclear, Communications, Defence, Emergency Services, Energy, Finance, Food, Government, Health, Space, Transport and Water. Several sectors have defined 'sub-sectors'; Emergency Services for example can be split into Police, Ambulance, Fire Services. Recent work at the Greater Manchester scale identified five infrastructure sectors at significant risk from the impacts of climate change: energy, road; water supply and treatment, green infrastructure and social infrastructure (RESIN, 2018). Social infrastructure refers to facilities such as schools and education, health service centres and community facilities. Notably, there is a lack of spatial data that might be used to develop a comprehensive assessment of risk to infrastructure (RESIN, 2018). The GM Mapping tool could serve as an open-source host for such spatial information in the future, though concerns regarding security might prohibit the publishing of some material and data.
DIRECT IMPACTS OF CLIMATE HAZARDS	Extreme weather could cause significant disruption for the whole range of infrastructure that the city's economic and social activity depends upon. Road and rail networks may suffer from reduced capacity or complete closure due to high temperatures, flooding or storms. In heatwaves, vehicles such as buses may be unbearably hot. In extreme circumstances, wildfires may reduce visibility on roads. Droughts and a decrease in groundwater and soil moisture may fracture pipes or cause subsidence. It is likely that climate change will mean that cold weather events will become less severe or less frequent in the future.
IMPACTS ON HAZARD MANAGEMENT INFRASTRUCTURE	Some places are already afforded some form of protection against the impacts of climate change. For instance, some parts of rivers have embankments and flood basins. Yet these structures are themselves vulnerable to climate change. Damage might be caused to them by extreme weather events. Some may now be reaching the end of their life expectancy or may have been built with capacities or thresholds that are now inadequate given the scale of future climate change.
CASCADING IMPACTS OF INFRASTRUCTURE FAILURE	Infrastructure networks are highly complex interconnected and interdependent systems. The cascading impacts of extreme weather on one element or network of infrastructure may have implications for other sectors (RESIN, 2018). The failure of one element of infrastructure such as a road or a bridge, might also compromise other services such as a sewers or drains, gas pipelines, electricity cables or fibre optics. Moreover, weather events may not be isolated incidents. For instance, severe weather might affect different parts of the city at the same time.

DRIVERS OF RISK BEYOND HAZARD EXPOSURE	Climate change and other factors such as urbanisation and infrastructure failure or deterioration will change the hazard profile of infrastructure. Consequently, elements and networks of infrastructure that are not currently exposed to hazards might be in the future. For instance, an increase in the frequency and severity of the risk of pluvial flooding poses a specific challenge in urban areas such as Manchester. This risk is likely to be exacerbated not only by climate change, but also through increased urbanisation and reliance on an ageing and inadequate drainage infrastructure system.

THE NATURAL ENVIRONMENT, BIODIVERSITY AND GREEN & BLUE INFRASTRUCTURE

Manchester has a range of green and blue space and biodiversity. These can be vital to the economic prosperity and the social and health well-being of the city. They can also have significant functionality for climate change mitigation and resilience. However, these spaces are of varying quality, and will come under increasing pressure from future development and fragmentation. The quality and functionality of these spaces are also vulnerable to climate change. Each element of the environment will face particular, often complex, challenges that need to be understood.

THE NATURAL ENVIRONMENT, BIODIVERSITY AND GREEN AND BLUE INFRASTRUCTURE	
URBAN GREEN SPACE, WOODLANDS AND FORESTS	Green space (parks, gardens, trees and urban planting) are an asset for climate change mitigation and adaptation. These spaces should be assessed for their vulnerability to the adverse effects of climate change. Specific attention should be paid to spaces of particular importance for biodiversity and heritage or that hold social, health or well-being value. There may also be implications for the viability of land use for local, sustainable food production. Many spaces will need to accommodate more intense future use as warmer summers attract people to urban green space for relaxation, socialising and to benefit from their urban cooling capacity.
CANALS, RIVERS, LAKES AND PONDS	Warmer water temperatures will undermine the suitability of these as habitats. They may also become more conducive to invasive species.
SOIL QUALITY	Soil quality and stability might be compromised through erosion, water logging and subsidence. This will have implications for the viability of land to grow trees, plants and food, which may undermine biodiversity and impact air and water quality.

DIRECT IMPACTS OF CLIMATE HAZARDS	Extreme weather could cause direct damage to green and blue infrastructure, forestry, agriculture. There may also be implications for wildlife exposed to damage to their habitats. Climate change could mean that cold weather events will become less severe or less frequent in the future.
BIODIVERSITY	Warmer year-round temperatures and shifting rainfall patterns will alter flora and fauna habitats. Some species will grow differently, others may be inappropriate for the future climate particularly in terms of their capacity for drought tolerance and ability to withstand warmer summer temperatures.
INVASIVE SPECIES	Invasive species, in particular those that thrive in warmer temperatures, may flourish in an altered climate. There is a risk of the possible introduction of new vector-borne-diseases, for instance, from disease carrying mosquitos in warmer, wetter weather.

CROSS-CUTTING THEMES

There are several generic factors that should be considered when assessing Manchester's sensitivity and vulnerability to climate change. These include complex interdependent issues that will frame – both positively and negatively - any effort to adapt to the impacts of climate change.

CROSS-CUTTING THEMES	
RISK BEYOND THE CITY BOUNDARIES	The drivers and consequences of climate change hazards cross local authority boundaries to regional, national and global scales. For instance, supply chains are – more often than not - dependent upon infrastructure networks, businesses and service suppliers in other places. Employees, business customers, and service users may live in other places outside Manchester, or may travel through Manchester to reach destinations. The city's rivers convey water from other parts of the city region and beyond meaning that flood water is both imported from other local authorities and, in turn, is exported elsewhere. Manchester may also be impacted by the international affects of climate change including potential disruption to continental and global food supplies, trading, human migration and the introduction of invasive species. Consequently, consideration should be given to how climate change mitigation, adaptation and resilience elsewhere might have consequences for Manchester's vulnerability.
KNOWLEDGE AND UNDERSTANDING OF CLIMATE RISK, RESILIENCE AND ADAPTATION	In recent years, there has been an increase in societal understanding of the implications of climate change and the need to pursue mitigation strategies. However, there might be less understanding amongst the public and other stakeholders regarding specific actions that can be taken to increase resilience to climate change. Perceptions will vary between individuals and across differing communities and areas of expertise.

ADAPTIVE CAPACITY OF THE CITY	There are several other factors that might affect the vulnerability of the city. Cities already have an inherent resilience to weather hazards. However, these might come under increasing pressure from climate change, pushing the thresholds or our adaptive capacity and potentially edging us toward 'tipping points'. For instance, there are increasing concerns that long-standing flood defences might be weakened by future climate hazards.
BROADER SOCIO-ECONOMIC RESILIENCE OF THE CITY	Manchester, like all cities, faces multiple social, economic and political vulnerabilities that will be exacerbated by climate change. Effort should be placed in understanding how these vulnerabilities intersect. These variables include, but are by no means limited to: - Socio-economic vulnerabilities; - Human health; - Social care and well-being; - Air quality; - Greenhouse gas emissions. Any effort to reduce climate change vulnerabilities should, where possible, take account of potential complementarities. They must, for instance, ensure that any efforts to address vulnerability does not have any maladaptive or unintended consequences. There is also a need to consider how climate risk intersects with other possible shocks and stressors. How might, for instance, climate change be compounded by broader socio-economic declines, or how might vulnerability and response to climate change face further challenges during the time of a public health emergency.

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APPENDIX 1: WHAT MIGHT A CITY-WIDE RISK ASSESSMENT LOOK LIKE?

It is recommended that a full climate risk assessment is conducted for Manchester.

A city level risk assessment ***should be as comprehensive as possible***. It should draw upon qualitative, quantitative data regarding risk to measure vulnerability and exposure. It should also, as far as is possible given data availability, spatially map risk, particularly in terms of asset and population vulnerability. To this end, ***the assessment should be expert led, but informed by the city's stakeholders and public***.

A number of approaches to producing a risk assessment could be taken, varying in detail and intensity. That being said, each further step or layer of detail, though instructive for risk assessing and useful in providing a context for taking climate action, would require more resource.

The most straightforward approach would entail a collation and review of all easily accessible current climate risk data for the city. A further step could involve engagement with key partners across the city through workshops and seminars to discuss risk, to identify the main hazards and vulnerabilities from their perspective and to access 'grey' and unpublished data and information. This unpublished information could include organisational or corporate risk registers or, where they exist, detailed climate risk assessments that have already been conducted. Beyond this, a more resource intensive option would be to commission technical expertise to produce detailed climate risk assessments, including quantification and spatial analysis, across the city.

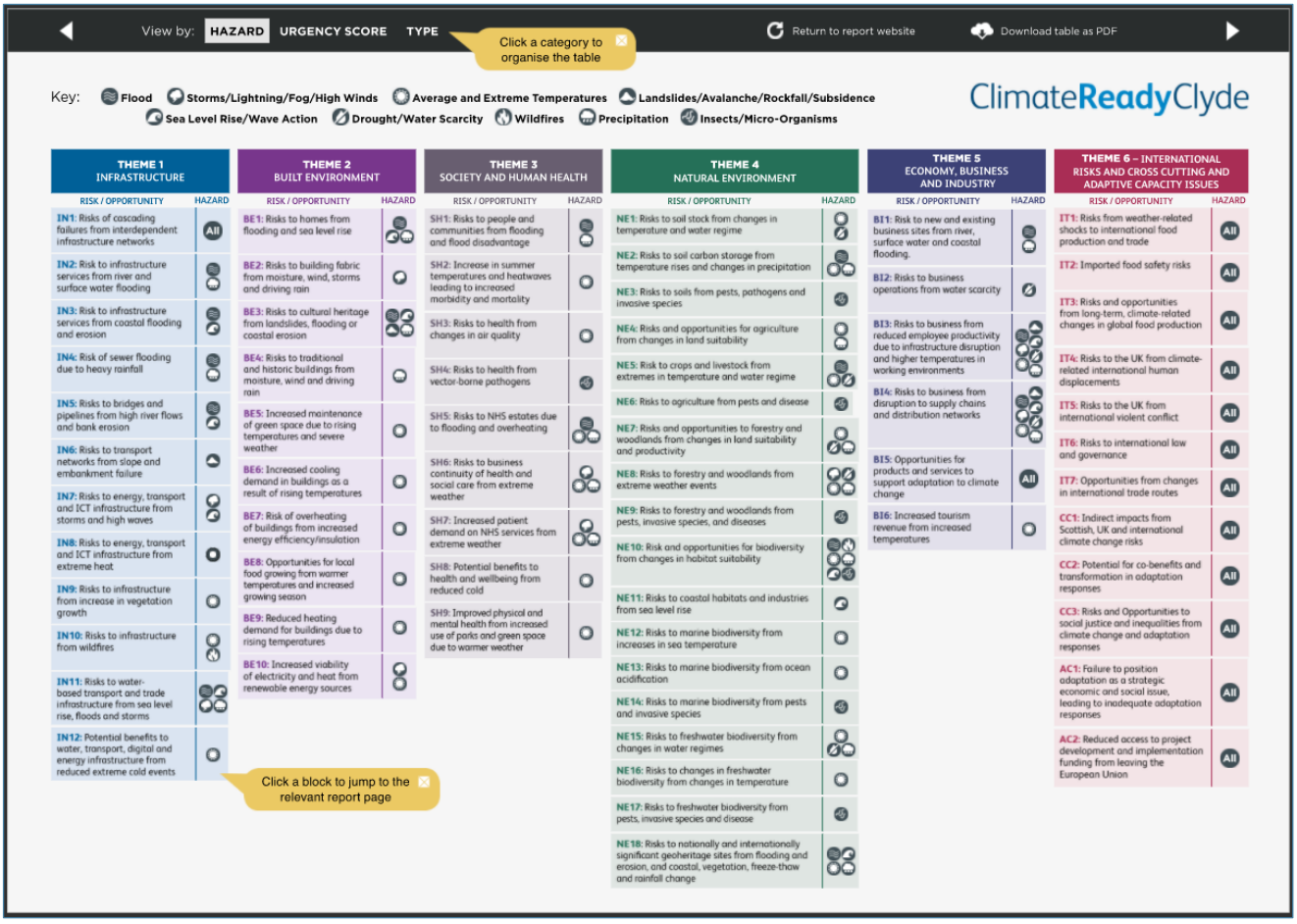
A possible methodology for conducting a climate risk assessment is detailed by C40 in their 2018 document *Climate Change Risk Assessment Guidance*. The UK Climate Change Committee have also provided advice for undertaking a climate change risk assessment, including the identification of principles and key steps (2020). Other generic methodologies also exist. In addition, methodologies have been established by other cities/ city-regions.

Any bespoke climate risk assessment for Manchester will forever be a work in progress. As with all risk assessments, it requires iterative development and periodic review, not least as our knowledge regarding Manchester's vulnerabilities to climate change evolves, and as collaboration with city-wide partners intensifies. In particular:

- Data and information is incomplete requiring ***regular and continual updating as new information comes to light***. Climate risk is dynamic, altering with time, and requiring updating and monitoring as climate projections evolve.
- Effort is required to isolate the implications of climate change for Manchester, particularly in evaluating the vulnerabilities and capacity to respond of ***particular communities, businesses, organisations and infrastructures throughout the city***. An authoritative assessment should, therefore, be co-developed with city partners and stakeholders. This will have the added benefit of enhancing collaboration and mutual learning as we collectively attempt to make the city more resilient to climate change.
- This and any further work to assess risk and vulnerability should take care to ***identify where information is incomplete or contested and where further work is necessary*** – both now and in the future. This will ensure our assessment of climate risks and vulnerabilities is as comprehensive as possible.[iv]
- The risk assessment should take account of ***issues arising across local authority boundaries and beyond***. It will, therefore, benefit from liaison with colleagues across the other nine Greater Manchester local authorities, with the Greater Manchester Combined Authority (GMCA) and beyond into other regional jurisdictions.
- On a related note, given the data requirements of the task, the complexity of risk assessing at a city scale, and the fact that risk and risk management is fundamentally a phenomenon that rarely adheres to administrative boundaries, it is possible that the ***most appropriate spatial scale for data collection and analysis will be at the regional scale (Greater Manchester)***.

It is likely that such a risk assessment will become an important element of the city's obligations to report progress in climate change policy. It may also become an important factor in investment decision-making. In any case, it is something that other cities have already undertaken, or are very likely to undertake in the next few years.

For instance, Climate Ready Clyde has developed a comprehensive climate risk, vulnerability and opportunity assessment for the city-region (see below for a summary). The main impacts have been comprehensively assessed, evaluated and ranked. The assessment was developed over an extended period of time, included a region-wide call for evidence, stakeholder workshops and a wider consultation.



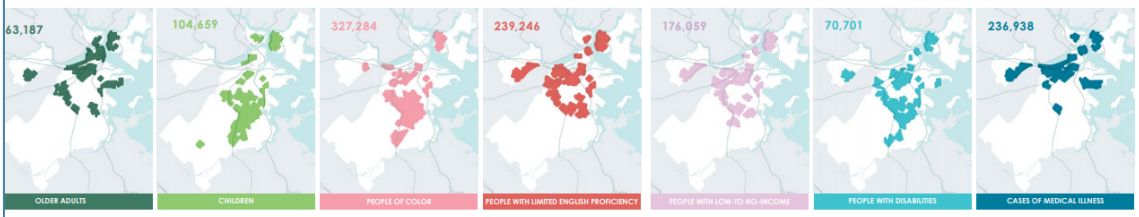
Overview of the outputs of Climate Ready Clyde's climate risk assessment

Climate Ready Boston, Massachusetts has also recently published a climate vulnerability assessment. The assessment evaluates three climate hazards and their plausible changes over time due to climate change: Chronic extreme heat; frequent stormwater flooding; acute and chronic coastal and riverine flooding. This included an exposure and **consequence** analysis for focus areas to provide deeper insight into specific vulnerable areas within Boston communities. Importantly, this work demonstrates the role that spatial analysis can play in understanding climate risk (see below).

SOCIAL VULNERABILITY

CONCENTRATIONS OF SOCIALLY VULNERABLE POPULATIONS[45]

Social vulnerability is defined as the disproportionate susceptibility of some social groups to the impacts of hazards, including death, injury, loss, or disruption of livelihood.



Numbers show a representation of citywide populations or cases.

KEY VULNERABILITIES BY POPULATION GROUP

OLDER ADULTS

Older adults (those over age 65) have physical vulnerabilities in a climate event; they suffer from higher rates of medical illness than the rest of the population and can have some functional limitations in an evacuation scenario, as well as when preparing for and recovering from a disaster. Furthermore, older adults are physically more vulnerable to the impacts of extreme heat. Beyond the physical risk, older adults are more likely to be socially isolated. Without an appropriate support network, an initially small risk could be exacerbated if an older adult is not able to get help.

CHILDREN

Families with children require additional resources in a climate event. When school is cancelled, parents need alternative childcare options, which can mean missing work. Children are especially vulnerable to extreme heat and stress following a natural disaster.

PEOPLE OF COLOR

People of color make up a majority (53 percent) of Boston's population. People of color are more likely to fall into multiple vulnerable groups as well. People of color statistically have lower levels of income and higher levels of poverty than the population at large. People of color, many of whom also have limited English proficiency, may not have ready access in their primary language to information about the dangers of extreme heat or about cooling center resources. This risk to extreme heat can be compounded by the fact that people of color often live in more densely populated urban areas that are at higher risk for heat exposure due to the urban heat island effect.

PEOPLE WITH LIMITED ENGLISH PROFICIENCY

Without adequate English skills, residents can miss crucial information on how to prepare for hazards. Cultural practices for information sharing, for example, may focus on word-of-mouth communication. In a flood event, residents can also face challenges communicating with emergency response personnel. If residents are more socially isolated, they may be less likely to hear about upcoming events. Finally, immigrants, especially ones who are undocumented, may be reluctant to use government services out of fear of deportation or general distrust of the government or emergency personnel.

PEOPLE WITH LOW-TO NO-INCOME

A lack of financial resources impacts a household's ability to prepare for a disaster event and to support friends and neighborhoods. For example, residents without televisions, computers, or data-driven mobile phones may face challenges getting news about hazards or recovery resources. Renters may have trouble finding and paying deposits for replacement housing if their residence is impacted by flooding. Homeowners may be less able to afford insurance that will cover flood damage. Having low or no income can create difficulty evacuating in a disaster event because of a higher reliance on public transportation. If unable to evacuate, residents may be more at risk without supplies to stay in their homes for an extended period of time. Low- and no-income residents can also be more vulnerable to hot weather if running air conditioning or fans puts utility costs out of reach.

PEOPLE WITH DISABILITIES

People with disabilities are among the most vulnerable in an emergency; they sustain disproportionate rates of illness, injury, and death in disaster events.[46] People with disabilities can find it difficult to adequately prepare for a disaster event, including moving to a safer place. They are more likely to be left behind or abandoned during evacuations. Rescue and relief resources—like emergency transportation or shelters, for example—may not be universally accessible. Research has revealed a historic pattern of discrimination against people with disabilities in times of resource scarcity, like after a major storm and flood.

[45] Socially vulnerable populations were mapped by number of people per land acre in each census tract in the City of Boston. Census tracts whose concentrations of vulnerable populations in each group fall in the top quartile (25 percent) of census tracts are highlighted in the series of maps.

[46] For example, research indicates the mortality rate among people with disabilities was twice that of the rest of the population during the 2011 Japan earthquake and tsunami.

Screenshot from Climate Ready Boston's Climate Vulnerability Assessment

APPENDIX 2: SOURCES THAT HAVE INFORMED THE FRAMEWORK

Work hs been undertaken not only at the city-region scale, but nationally and internationally to understand climate risk hazards and vulnerability. Some of this work has been reviewed and used to inform this document.

The report attempts to align with assessments at other spatial scales. Of note here is the Combined Authority's *Community Risk Register* (GMCA 2021) and academic research on climate hazards and vulnerability, in particular Ecocities and RESIN.

At a national scale work from the UK Climate Projections (UKCP) 2018 was used to inform the risk assessment. The *National Risk Register 2020* published by central Government's Cabinet Office was used to provide context to weather related hazards and how these will evolve with climate change. Previous versions of this document framed the GM Community Risk Register. The work of the Climate Change Committee and the Adaptation Committee has informed both the hazard assessment and the development of the framework for understanding vulnerability. On-going work to inform the UK's Third Climate Change Risk Assessment and the work of Adaptation Scotland have also been useful.

From an international perspective, work from the Intergovernmental Panel on Climate Change Working Group II, the EU's recently published *Adaptation Strategy*, the UN's *Adaptation Gap Report*, and work from C40 Cities, the Rockefeller 100 Resilient Cities network and the Carbon Disclosure Project (CDP) has further helped to shape the understanding of climate hazard and vulnerability.

To assist with the articulation of the framework, the risk assessment of numerous other cities and regions have been reviewed. Of particular note, here is the work of Climate Ready Boston, Climate Ready Clyde, Thrive Indianapolis, and the London Climate Change Partnership.

In addition, the author has spoken to or interviewed several individuals and representatives of organisations to inform the framework, and to establish a context for further work on adaptation and resilience planning. These include: the Carbon Disclosure Project; Greater Manchester Combined Authority; London Climate Partnership; Manchester City Council; Manchester Arts Sustainability Team; Manchester Climate Change Agency; Manchester Climate Youth Board; Manchester Metropolitan University; and the University of Manchester.

The work has been reviewed and commented on by the recently established Manchester Climate Change Partnership Adaptation and Resilience Advisory Group.

The author extends sincere thanks to all participants and reviewers.

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[i] Manchester City Council has its own population forecasting model (MCCFM). The MCCFM 2020 estimates that the residential population in 2019 was 576,500. The higher figure takes account of local intelligence such as construction, rising numbers of international students and increasing demand for school places.
[ii] Measured at the Woodford weather station: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcqrqyr80
[iii] Further information is also available through Climate Just, an information tool designed to help with the delivery of equitable responses to climate change at the local level. Mapping GM may also be a useful tool for identifying communities potentially more vulnerable to climate change or that might have reduced capacity to respond to climate change.
[iv] A further discussion of the limitations of data coverage is available in RESIN (2016).