Evidencing and Spatially Prioritising Weather and Climate Change Risks in Greater Manchester

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1. Executive Summary

Extreme weather and climate change risks pose an increasing threat to quality of life and economic competitiveness in cities across the world. Greater Manchester (GM) is no different. The core aim of this project is to better understand risks to the Greater Manchester Strategy (GMS), and its goal of promoting sustainable economic growth, from direct weather and climate change impacts. The UK Climate Change Risk Assessment (Defra 2012) highlights the most significant climate change risks facing the UK over the coming century. This project aims to consider these risks at a more local scale.

This report evidences, and where possible spatially prioritises, weather and climate change risks to the GMS. The project findings have the potential to strengthen GM's adaptation response to the changing climate. The project was guided by four milestones. This report designed to meet milestones 1 and 4.

- Identify and report on weather and climate change impacts in GM and use this data to assess associated risks to the delivery of the GMS.
- Identify and engage with GM organisations and structures with a key role in responding to the risks to the GMS.
- Communicate the findings of the research to appropriate GM Commissions, the Local Enterprise Partnership and the Shadow Local Nature Partnership.
- Produce a final report on the project and submit to Defra.

This report designed to meet milestones 1 and 4. A meeting held on the 20th February, which was attended by 21 relevant individuals (see Appendix 1 for a list of attendees) from across GM and Northwest England, supported the achievement of milestones 2 and 3. Ongoing engagement and communication on issues linked to the project, and adaptation more broadly, is being progressed via involvement of the project team in relevant meetings.

This executive summary outlines the key findings of the project. Several broad themes are addressed:

- Assessing weather and climate change risk in Greater Manchester
- Weather and climate hazards in Greater Manchester
- The variable pattern of weather and climate change risks across Greater Manchester
- Adapting to climate change in Greater Manchester
- Key conclusions and recommendations

1.1. Assessing weather and climate change risk in Greater Manchester

Research outputs from the science community point towards an increasingly challenging climate future for cities such as GM. An opportunity exists to lessen the intensity of future changes to the climate and associated risks. In order to do so prompt action is necessary, locally and globally, to reduce greenhouse emissions and to devise strategic adaptation responses to prevalent weather and climate change risks. This project focuses on the latter theme; risks and adaptation responses.

The UK Climate Change Risk Assessment (Defra 2012) outlines climate change risks and opportunities to different broad themes, including business and the natural environment. Under the Climate Change Act of 2008, organisations such as nationally significant utilities companies and infrastructure providers are required to publish reports on how they are adapting to climate change. These have often been underpinned by risk assessments, including those published by United Utilities and Electricity North West for example. This report builds on this emerging body of climate change risk assessment work. It follows a widely used risk assessment approach based around assessing the likelihood and consequence of risks. The approach set out in this report is replicable, and could be used to further assess weather and climate change risk in GM.

The goal of this report is to support the GMS through enhancing understanding of risks to its delivery from weather and climate change impacts, and in doing so to build capacity to respond to climate change in GM. The project was commissioned by the Greater Manchester Combined Authority on behalf of the Greater Manchester Local Enterprise Partnership (LEP). The University of Manchester (UoM) were appointed to undertake a spatial analysis of the relationship between GMS-relevant strategic locations and infrastructures and weather and climate change hazards, and to use this to assess and report on the risk of related impacts. The project has been undertaken within the context of the National Adaptation Programme, with funding provided by Defra.

1.2. Weather and climate hazards in Greater Manchester

Flooding stand out as one of the key weather and climate threats to the conurbation, not just in the future but also in the present day. Indeed, evidence from the EcoCities project suggests that flooding has been the most prominent hazard facing GM over recent decades, and that surface water flooding is superseding fluvial flooding (from main rivers) as the most common type of event (Carter and Lawson 2011). Although fluvial flooding is relatively uncommon in GM, given the location of key assets and infrastructures within Flood Zones and the high consequences of related impacts should they occur, the associated risks remain high. In addition to the damage flooding causes to buildings and infrastructure, flooding also brings knock-on secondary impacts which must be recognised. One example is the effect of flood damage to people’s homes, and the subsequent psychological stress that this can cause flood victims. Understanding the scope of potential flooding impacts, and recognising particular risks of relevance to GM, can support the development of a more comprehensive range of adaptation responses.

In addition to flooding, this assessment also considers risks associated with heat waves, drawing on mapping of GM's urban heat island as a basis for determining which locations are more likely to experience high temperatures under heat wave conditions. Although heat waves are extremely rare in GM in the present day, climate change projections indicate that they will become more common in the future. This increases the risk of negative impacts linked to high temperatures, such as negative health effects and reductions in the productivity of employees. The spatial pattern of GM's urban heat island demonstrates that certain areas, generally those where development density is at its highest, are more likely to suffer from negative impacts as a result. There is also an equality dimension to heat stress. For example, looking at GM's housing development types, there is greater potential exposure to heat stress in more deprived areas. In effect, groups that are vulnerable to heat stress, due to factors including poverty and poor health, show the highest potential exposure to this climate change impact. Spatial data is available on the vulnerability of people in GM to extreme weather and climate change hazards (Kazmierczak and Cavan 2011), which can support the development of adaptation responses targeted to the areas of greatest need.

This report does not cover the full scope of weather and climate change hazards with the potential to impact on GM. The focus on themes linked to the GMS, and weather and climate hazards that can be assessed spatially, has identified a particular set of prominent locally relevant weather and climate change risks. However, these hazards also include cold weather events and high winds, which have generated significant impacts in GM in the past. Although these are not considered, they will continue to affect the conurbation over the coming years. Further, the impending implications for GM of climate change in other parts of the world have not been addressed, yet must be acknowledged. A recent report from the UK's Government Office for Science looked at the international implications of climate change, noting that;

- …the consequences for the UK of climate change occurring in other parts of the world could be as important as climate change directly affecting these shores. (The Government Office for Science 2011: 7)

Several impacts that are relevant to GM were identified. These include the potential for increased incidence of infectious diseases, disruption to resources and infrastructure relied upon by individuals and businesses (e.g. energy supplies, food production, communications networks), and changes in the balance of risks faced by the finance sector and businesses. GM is the region's economic powerhouse, and is connected to global networks of goods, services and people. It relies on the effective functioning of these networks to sustain its economy and society. The risks posed by extreme weather and climate change to the sectors and processes that connect the conurbation globally are highly significant and deserve further research and policy attention to increase GM's resilience to these threats.

1.3. The variable pattern of weather and climate change risks across Greater Manchester

This assessment demonstrates that the likelihood of weather and climate change hazards affecting different themes linked to the GMS varies considerably across GM. Given that risk depends on likelihood and consequence, this has a significant bearing on the distribution of weather and climate risks across the conurbation. This is clear looking at the regional centre and town centres, where each location shows a high likelihood of at least one hazard occurring. However, these hazards differ according to which area is considered. For example, the likelihood of fluvial and surface water flooding is high in Rochdale and Wigan, yet the likelihood of heat stress in these town centres appear to be relatively low. Similarly, although Altrincham is not within Flood Zones 2 or 3 (and hence the likelihood of fluvial flooding is very low), it is within the GM's urban heat island. As a result, Altrincham town centre is potentially highly exposed to heat stress under heat wave conditions (in comparison to locations such as Rochdale and Wigan town centres), particularly under climate change conditions where the frequency and intensity of heat wave events are projected to increase. Valuable conclusions can be made on the basis of the spatially informed assessment of the likelihood of weather and climate change hazards. Indeed, it is important to remember that the risk associated with a given extreme weather or climate change impact will always be higher where the likelihood of the hazard causing the impact is higher.

In addition to the spatial variability of weather and climate change risks across GM, this assessment also emphasises that these risks affect a broad range of themes and sectors. Six themes linked to the GMS were included in the risk assessment; housing, regional centres and town centres, employment locations, transport infrastructure, science and innovation assets and energy and water infrastructure. There are examples of areas and assets related to each theme where the risk of weather and climate impacts, both in the present day and under climate change, is high. This highlights that extreme weather and climate change has the potential to disrupt a wide range of issues linked to the GMS. Integrated adaptation responses spanning sectors and spatial scales are therefore required. To achieve this, GM will need to develop a collaborative adaptation approach, which will require good communication, sharing of information and the development of joint actions.

1.4. Adapting to climate change in Greater Manchester

A key contribution of this report is to demonstrate the value of a spatial approach to weather and climate change risk assessment through displaying the diversity of these risks across GM. This has important implications for the development of adaptation responses, emphasising that their focus will differ according to the location being considered. In addition, this report lays the foundations for more detailed investigations of weather and climate change risk at a local scale. Indeed, where resources are available to reduce weather and climate change risks to core GMS priorities, this study can contribute by helping to targeting these at locations and risk where there is an identified need for a response.

The report also includes the findings of an assessment that looks at the impact of land cover change on local climate in different areas across GM (including Bramhall North, Harpurhey, Rochdale town centre, Oldham town centre and Airport City). This highlights that changing the land cover characteristics of an area, by altering the amount of green cover versus buildings and other impervious surfaces, has real implications for local climate. This is due to the influence that land cover has on processes including rainwater runoff and surface temperature regulation. Green infrastructure (street trees, parks, gardens etc) acts to moderate temperatures and reduce surface water runoff after heavy rainfall events. Hence, reducing its extent increases the likelihood of impacts linked to heat waves and floods. Conversely, this effect can be lessened through incorporating measures such as green roofs and sustainable urban drainage into developments where green infrastructure resources are being lost. The spatial planning system has a strong role to play in facilitating related adaptation actions.

Green infrastructure is just one of a wide range of possible adaptation responses. Others include, for example, the development of emergency response plans for weather and climate extremes. This suggests the benefits of integrating adaptation planning with the civil contingencies and resilience agendas. These sectors can benefit from the core messages contained within this report regarding the spatial diversity of weather and climate change risk across GM. Indeed, a better understanding of where risks are most prevalent can support the development of more spatially focused emergency response plans.

It is important to stress that that the weather and climate change risks outlined within this report are not necessarily barriers to achieving the core priorities of the GMS. Extreme weather and climate change does present clear risks to sustainable economic growth in GM, through its potential impacts on critical infrastructure networks and sites of wealth creation for example. However, carefully targeted adaptation strategies and interventions can help to reduce related risks, lessening the threat that extreme weather and climate change pose to GM's future growth and development. There are opportunities to be gained, in addition to risks avoided, from developing strategic and spatially targeted adaptation response, which can offer benefits beyond reducing weather and climate risk. Taking green infrastructure as an example, these include providing recreation space, protecting and enhancing biodiversity, generating employment opportunities and reducing energy bills linked to cooling buildings. The multiple benefits that certain adaptation responses can encourage should be promoted as part of GM's response to the changing climate.

1.5. Conclusions and recommendations

A summary of the headline conclusions emerging from this project are outlined below.

- Extreme weather and climate change is a threat to quality of life and economic competitiveness in cities. GM can react proactively in response to the challenges and potential opportunities linked to extreme weather events and changing climate patterns. This report helps to develop a better understanding of weather and climate risks locally, and supports the task of prioritising related actions and strategies to reduce these risks in GM.

- Climate change risk assessments have become more common in recent years, with the UK Climate Change Risk Assessment published in 2012 standing out as the most prominent of these to date in this country. This report builds on this emerging body of risk assessment work. It is guided by a widely used and replicable risk assessment approach.

- The goal of this project has been to identify where the risk of weather and climate change impacts to selected GMS themes is greatest. This project has drawn on available spatial data on weather and climate hazards, and the potential receptors of those hazards, to better understand weather and climate risk in GM. The risk assessment outcomes are based on the chance of hazard events occurring, the level of potential exposure of particular sites and infrastructures to these events should they happen, and the magnitude of the consequences of related impacts. This process has revealed the spatial diversity of certain weather and climate change risks across GM. Several headline outcomes have emerged from this risk assessment:

    - ***Housing development areas:*** Impacts linked to flooding, particularly fluvial flooding, pose a greater risk to housing development areas in GM than other hazards. However, with climate change and the increased likelihood of heat waves, there is the potential for negative impacts such as heat stress to vulnerable groups in areas where exposure to the urban heat island is highest.
    - ***GM's regional centre and eight town centres:*** GM's regional centre and eight town centres each show a high level of risk to one or more weather and climate impact. Risks differ according to which area is considered, with each location having its own risk profile.
    - ***Strategic employment locations:*** The broad picture is one of relatively low weather and climate risk to strategic employment locations. However, risk associated with extreme events (to this and the other themes considered) cannot be fully discounted due to variability in the climate system. Yet, there are high risks to certain sites, including those linked to fluvial flooding in Carrington and Port Salford and heat stress (particularly under climate change) in Hollingwood, Trafford Core and Wharfside.
    - ***Transport infrastructure:*** Although there are clear risks to possible future transport investment sites from extreme weather and climate change, on balance these appear to be less widespread and of a lower magnitude than risks to existing transport infrastructure. These risks connect to the high likelihood of hazards, including flooding

and heat stress, to certain stretches of the conurbation's transport network and related infrastructure assets such as stations.

  - ***Science and innovation assets:*** The likelihood of fluvial flooding affecting the science and innovation assets assessed by this study is high. The risk of related impacts is therefore also generally high, particularly those with high consequences such as damage to buildings. Heat stress brings potential risks. Of particular concern are negative impacts on worker productivity, although based on current understanding it is under future climate change projections for the 2050s that this issue comes to the forefront.
  - ***Critical infrastructure:*** The key hazard facing waste water treatment works and electricity sub-stations appears to be fluvial flooding. This especially concerns Flood Zone 2, which encompasses areas covered by a lower frequency higher volume flooding event. Related risks to water and electricity services and supplies have the potential to affect a wide range of sectors and groups of people, and therefore deserve further analysis.

- Supportive adaptation policies, and resulting targeted strategies and actions addressing prominent local risks, can help to equip GM for extreme weather and changing climate patterns that look set to influence its future growth and competitiveness.

Building on these conclusions, a series of recommendations are proposed which target the GMS themes around which the risk assessment is based.

- A spatially informed approach to identifying and responding to flood risk to GM's housing is needed, encompassing the existing housing stock and prospective future development sites. This report supports existing and ongoing studies into flood risk in GM, and builds the case for strengthening the position of flood risk management within housing development plans, policies and guidance documents.

- Strategies designed to strengthen and redevelop GM's regional centre and town centres could usefully recognise the varying patterns of weather and climate change risks that they face. Locally appropriate measures to adapt these areas for the changing climate are needed. Focusing on risks that this study suggests are most significant would provide a good starting point.

- The risk of weather and climate impacts to the strategic employment locations covered by this study appear to generally be quite low. However, there are notable risks to certain sites and further investigation of these areas is warranted. Following on from this project, additional studies can now focus on particular sites and specific risks in more detail to better understand the full extent of risks from weather and climate impacts.

- The focus of the GMS is on future transport investment priorities, some of which this assessment has shown are at risk from weather and climate impacts. However, risks to the existing transport network appear to be more prevalent, and corresponding strategies to better understand these risks and build resilience to weather and climate extremes would be valuable.

- The risk of fluvial flooding impacts to the science and innovation sites covered by this study is high. More detailed investigations are needed to establish the extent to which specific sites are actually exposed to this form of flooding, taking into account factors including local topography and land cover. Long term strategies to reduce the threat of heat stress in the Oxford Road Corridor also advisable given the significance of this area for GM's future growth prospects and its potential exposure to heat stress.

- The key hazard facing the waste water treatment works and electricity sub-stations included in this study appears to be fluvial flooding. An important next step is to assess the levels of flood protection provided to these critical infrastructure instillations to determine the residual risk under an extreme fluvial flooding event.

Looking beyond these thematic issues, several cross-cutting recommendations are proposed which would strengthen GM's response to the changing climate.

- Where it is practical and appropriate, promote a spatial approach to understanding and responding to weather and climate risk. Given the spatial nature of many weather and climate change hazards, if data and resources are available, there is real value in assessing related risks spatially. Particular sectors that can benefits from the outcomes of such assessments include emergency planning and spatial planning, both of which are central to climate change adaptation in GM.

- Encourage the development of cross-sector collaborative responses to weather and climate risks. The breadth of sectors and themes at risk from weather and climate change impacts, and the scope of the connections between them, indicates that an integrated cross-sector adaptation strategy for GM is needed in response. This should be collaborative in nature, requiring good communication, sharing of information and the development of joint actions.

- Explore the connections between adaptation to climate change and broader themes linked to making cities resilient. A report from the United Nations Office for Disaster Risk Reduction (UNISDR) recognises that within cities and urban areas, disaster risk reduction, adapting to climate change and promoting sustainable development are inseparable (UNISDR 2012). It would be useful for GM to explore this agenda, and how it can position itself as a resilient city.

2. Project overview

This report presents the outputs of a project established to evidence and where possible spatially prioritise weather and climate change risks to the GMS. The project was commissioned by the Greater Manchester Combined Authority (GMCA) on behalf of the Greater Manchester Local Enterprise Partnership (LEP). The University of Manchester (UoM) were appointed to undertake a spatial analysis of the relationship between GMS-relevant strategic locations and infrastructures and weather and climate change hazards, and to use this to assess and report on the risk of related impacts. The project has been undertaken within the context of the National Adaptation Programme, with funding provided by the Department for Environment, Food and Rural Affairs (Defra).

The goal of this project is to support the GMS through enhancing understanding of risks to its delivery from extreme weather and climate change impacts. The project outputs, presented within this report, offer data and insights with the potential to inform the prioritisation of related actions and strategies to reduce these risks in GM. To achieve this broad objective, the project was guided by four milestones.

1. Identify and report on weather and climate change impacts in GM and use this data to assess associated risks to the delivery of the GMS (led by UoM with support from the Association of Greater Manchester Authorities (AGMA)).
2. Identify and engage with GM organisations and structures with a key role in responding to the risks to the GMS (led by AGMA with UoM support).
3. Communicate the findings of the research to appropriate GM Commissions, the LEP and the Shadow Local Nature Partnership (led by AGMA with UoM support).
4. Produce a final report on the project and submit to Defra (led by UoM with AGMA support).

This report is designed to achieve milestones 1 and 4. A meeting held on the 20th February, which was attended by 21 relevant individuals (see Appendix 1 for a list of attendees) from across GM and Northwest England, supported the achievement of milestones 2 and 3. Ongoing engagement and communication on issues linked to the project, and adaptation more broadly, is being progressed via involvement of the project team in relevant meetings.

3. The climate change adaptation imperative

A significant shift in climate is projected for the twenty-first century. The level of future climate change will depend on factors including the direction of greenhouse gas emissions and the sensitivity of the biosphere to these emissions. The Intergovernmental Panel on Climate Change (IPCC) low emissions scenario puts a best estimate of temperature increases by the end of this century at 1.8°C above the 1980–1999 baseline level, whilst a scenario dominated by fossil fuel-based energy results in a best estimate of a 4°C increase above this baseline (IPCC 2007). Research suggests that policy makers have few options available, short of instigating rapid and sustained emissions cuts, to achieve the goal adopted by world leaders at the UN Copenhagen Climate Change Conference (2009) of keeping global surface temperatures to no more than 2°C above pre-industrial levels (Huntingford et al 2012, New et al 2009).

The Stern Review provided a high level global assessment of the potential implications of climate change for economic growth, citing significant reductions in gross domestic product (GDP) depending on the extent of future climate change and the nature of the policy response (Stern 2007). However, this is not purely a future-oriented issue. Extreme weather and climate change is already producing major impacts. Over the last thirty years the majority of Europe's catastrophic events have been weather related, bringing huge economic and social costs (EEA 2010). In the UK, insured losses associated with weather and climate extremes average around £1.5 billion annually (ASC 2010), although this figure can fluctuate greatly from year to year.

The headline conclusion of the Stern Review is scalable. GDP in cities is also threatened by the changing climate. The impacts of climate change pose a real risk to economic growth prospects in GM. Manchester's Mini-Stern (Deloitte 2008) highlighted that responding to climate change legislation, policy and regulations could provide a significant financial opportunity to the conurbation. This report on weather and climate change risks to the GMS emphasises that there are similar opportunities to be gained, in addition to risks avoided, from developing a planned, strategic and spatially targeted adaptation response in GM. The Adaptation Sub-Committee (ASC) provides advice and information to the UK government on adaptation issues, and underscore the immediacy of adaptation noting that, 'Adaptation involves taking definite actions today to reduce possible damages and capture future benefits' (ASC 2010: 25). Supportive adaptation policies, and resulting targeted strategies and actions, can help to equip cities such as GM for the changing climate patterns that look set to influence their future growth and competitiveness.

4. Greater Manchester's changing weather and climate

4.1. Greater Manchester's climate: recent trends and future projections

There is real value in developing a better understanding of the incidence and consequence of recent trends and present day extremes in weather and climate. With climate change already having observable impacts adaptation is, in part, related to responding to current extremes. GM has seen changes to its climate over recent decades. Warming throughout the year, particularly during the winter months, can be observed and is coupled with an emerging seasonal pattern of drier summers and wetter winters (Cavan 2010). Details of the incidence of different extreme weather and climate events affecting the conurbation have also been gathered (Carter and Lawson 2011). For the period 1945-2008 the key findings were;

- Floods are the most prevalent type of event across the conurbation.
- Surface water flooding is increasing, where as river flooding events are declining.
- Floods appear to occur most frequently in the summer months, but can be common in autumn and winter. Few floods have occurred during the spring.
- Storms (including high winds) and cold events occur regularly, but less often than floods.
- To date, other types of events, including heat waves, droughts and fog have been relatively infrequent over GM.

Our understanding of future climate change projections for GM has also expanded. Table 1 details projected changes in climate variables (temperature and precipitation) across three distinct zones of GM (shown in Figure 1). Probabilistic projections, such as those presented in Table 1, provide details of the relative likelihood that a particular outcome will be realised (e.g. a 3°C temperature rise by 2050 under a high emissions scenario). The different probability levels included in Table 1 can be interpreted as:

- 10th - unlikely to be less than.
- 50th - as likely as not.
- 90th - unlikely to be greater than.

Broadly, projections for GM point towards warmer drier summers and warmer wetter winters with an increased risk of extreme events such as high temperatures and intense rainfall. Recent cold winters and wet summers in the UK highlight that weather extremes more generally are becoming increasingly prominent. This also points towards the sensitivity of the climate system to forcing by greenhouse gases, which is increasingly recognised by climate scientists. This can be difficult to reflect in climate models.

Figure 1: Three climate zones across GM (Cavan 2011).

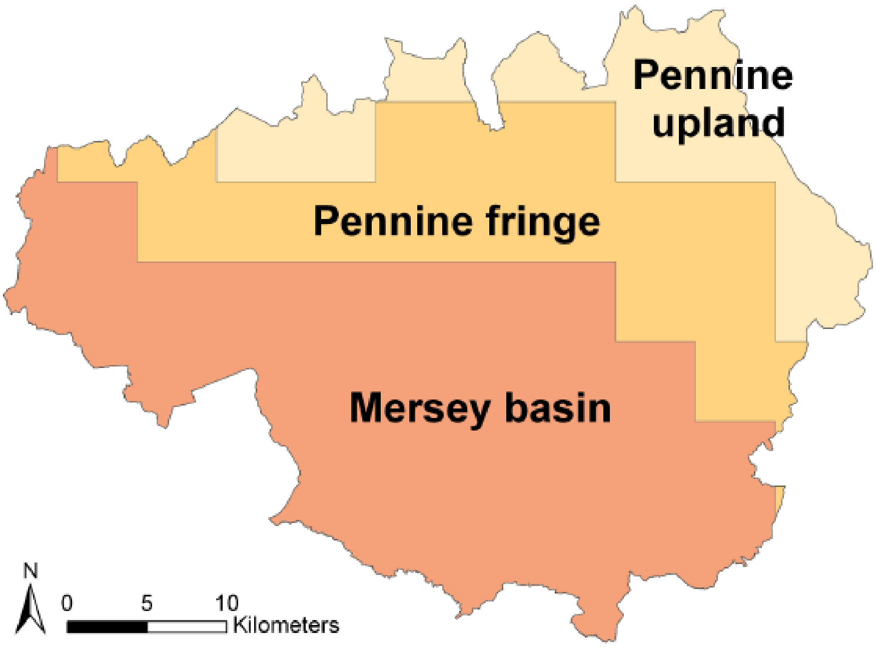


Table 1. Summary of changes from the baseline for key climate variables under the high and low emissions scenarios for the 2050s (Cavan 2011).

Climate variable (changes from the baseline)	Zone*	Low emissions scenario			High emissions scenario		
		Probability level			Probability level		
		10th	50th	90th	10th	50th	90th
Annual mean temperature (°C)	MB	1.4	1.9	2.9	1.8	2.4	3.6
	PF	1.4	1.9	2.9	1.8	2.5	3.6
	PU	1.4	1.9	2.9	1.8	2.4	3.6
Summer mean daily maximum temperature (°C)	MB	1.1	2.5	4.3	1.4	2.9	5.6
	PF	0.9	2.4	4.1	1.4	3.0	5.5
	PU	1.1	2.5	4.2	1.5	3.0	5.7
Warmest day in summer (°C)	MB	1.3	2.6	4.6	1.5	3.1	6.0
	PF	1.1	2.6	4.3	1.6	3.4	6.0
	PU	1.2	3.0	4.7	1.6	3.4	5.9
Summer mean daily minimum temperature (°C)	MB	0.9	1.7	2.9	1.3	2.1	4.0
	PF	1.0	1.8	3.0	1.2	2.3	4.0
	PU	1.1	1.8	3.0	1.2	2.3	4.0
Warmest night in summer (°C)	MB	0.9	1.8	3.6	1.3	2.6	4.4
	PF	1.1	2.0	3.4	1.3	2.6	4.6
	PU	1.0	2.0	3.5	1.4	2.6	4.4
Winter mean daily minimum temperature (°C)	MB	0.9	1.9	3.3	1.7	2.4	3.9
	PF	1.0	1.9	3.2	1.8	2.5	3.9
	PU	0.9	1.9	3.4	1.7	2.4	3.9
Coldest night in winter (°C)	MB	0.6	1.9	3.3	1.3	2.4	3.5
	PF	1.2	2.0	3.3	1.7	2.4	3.8
	PU	0.8	2.0	3.7	1.4	2.6	3.7
Annual mean precipitation (%)	MB	-6	0	9	-5	2	9
	PF	-5	3	12	-4	5	13
	PU	-4	3	13	-3	4	12
Summer mean precipitation (%)	MB	5	-15	-29	-5	-20	-36
	PF	15	-12	-26	0	-20	-36
	PU	13	-13	-27	-2	-21	-36
Wettest day in summer (%)	MB	-13	1	18	-15	0	19
	PF	-12	7	31	-17	2	25
	PU	-14	5	27	-20	-3	20
Winter mean precipitation (%)	MB	-3	9	23	0	14	28
	PF	-2	10	23	1	16	36
	PU	-4	9	22	3	16	33
Wettest day in winter (%)	MB	-6	7	18	1	11	31
	PF	-1	11	22	2	15	38
	PU	-1	10	25	2	14	31

*MB=Mersey basin; PF=Pennine Fringe; PU=Pennine Upland

4.2. Understanding the consequences of Greater Manchester's changing climate

Details of changes to weather and climate variables, both recent observations and future projections, raise awareness of how the climate is changing and may evolve in the future. However, these insights are of more use when they can be related to the consequences of these changes locally. Looking at the implications of extreme weather events impacting on GM over recent decades (1945-2008), the following trends were observed (Carter and Lawson 2011);

- More than two-thirds of the consequences of weather and climate events resulted from floods and storms.
- Critical infrastructure and health and wellbeing appear to be particularly susceptible to impacts from weather and climate events.
- Floods are the key cause of impacts on critical infrastructure, health and wellbeing and social and emergency infrastructure.
- Storms emerge as the most damaging type of event for the natural and built environment.

These observations are based on reports of extreme weather events contained within GM's news media, supplemented by records from groups including local authorities and emergency services.

The EcoCities project offered a broad overview of the scope of climate change impacts that could affect GM, positively and negatively, to 2050 (Carter and Lawson 2011). Five 'receptors' were considered: critical infrastructure, health and wellbeing, natural environment, built environment and social and emergency infrastructure. The key findings of this assessment were:

- River flooding remains a risk, particularly concerning the projections for increased winter rainfall and increased frequency of heavy downpours. These changes in the climate also threaten to raise surface water flood risk with impacts across sectors.
- Current projections indicate that some impacts, for example those linked to cold weather and poor air quality, are set to reduce over the coming decades with benefits for human health and reduced costs to authorities and the economy.
- GM has little experience of impacts linked to heat stress and drought, yet current projections highlight that these will become more common. Impacts on human health, emergency services and infrastructure are likely.
- There is some uncertainty over future storm frequency and intensity, although more winter gales are possible with implications for the built environment in particular.
- Climate change will also bring secondary impacts, for example the psychological stress following flooding of residential properties and the economic impacts of disruption to infrastructure.
- Looking beyond these impacts on the conurbation, it is important to recognise that GM will be impacted by climate change impacts occurring in other parts of the world.

Gaining a sense of the nature and extent of current and potential future weather and climate hazards can support the development of locally relevant and in some cases spatially targeted adaptation responses. Drawing on this assessment, two headline issues concerning the projected changes to GM's weather and climate can be identified. These are:

- The increasing risk of surface water flooding
- The emerging risk of heat stress

These issues (in addition to fluvial flooding) provide the basis for the assessment of risks that weather and climate change impacts pose to the GMS outlined in this report. They are discussed in more detail below.

4.3. The increasing risk of surface water flooding

An increase in heavy rainfall events is projected across the conurbation (Cavan 2011), raising the prospect of increased flooding. Nationally, the UK Climate Change Risk Assessment highlights that the threat of flooding will increase as the climate changes (Defra 2011). Fluvial flooding, from main rivers, is a risk in GM. Nearly 7% of GM is located in Flood Zone 2 (medium probability of flooding), and 4.75% is in Flood Zone 3 (high probability of flooding)[1] (Kazmierczak and Cavan 2011). However, given the success of historic and ongoing investments in flood defences, it is surface water flooding that is emerging as the more significant problem. Despite this, the risk of river flooding should certainly not be discounted. Surface water flooding, which is often caused by short duration intense rainfall events occurring locally, is difficult to forecast, warn against and prepare for (Falconer et al 2009, Golding 2009). Surface water flood risk is prevalent across the conurbation. Of GM's 1646 lower super output areas, 78% include areas that are highly susceptible to surface water flooding (Kazmierczak and Cavan 2011). With surface water flooding events increasing in frequency in GM, and climate change projections threatening a rise in intense downpours, attention needs to be paid to protecting people, buildings and infrastructure from the associated consequences.

4.4. The emerging risk of heat stress

High temperatures have deadly consequence. Nearly 95% of deaths resulting from natural hazards in post-industrial societies can be attributed to extreme temperatures. Experience from the United States and Australia emphasises that heat waves kill more people than hurricanes, tornadoes, lightning and floods combined (Poumadere et al., 2005). In England, during the hottest period of August 2003 (which coincided with a European heat wave) there were 17% (2,091) more deaths than the average for this month, with a 42% increase in deaths observed in London (Johnson et al 2005).

[1] This assessment is based on Environment Agency data. These flood zone maps have since been updated, and the new maps are used within this assessment of risks to the GMS.

Currently, temperatures in GM rarely breach the threshold for a heat wave. This is established by the Heat wave Plan for England (NHS, 2009) as two days above 30°C and 15°C or above in the intervening night. GM's warmest day is between 25-27°C; and the warmest night varies between 15-18°C (Cavan, 2010). However, temperatures are projected to rise with climate change. Under the high emissions scenario for the 2050s, the central estimate of increase in the warmest summer day is 3.1-3.4°C above the 1961–1990 baseline level. It is often the extremes events that cause the greatest damage (IPCC 2012), and with GM's warmest day potentially as much as 6°C above the baseline by the 2050s (see Figure 2), risks linked to heat stress look set to intensify. Under these conditions, disruption to infrastructure and harm to human health caused by heat stress would become more prominent. The EPSRC-funded Sustainable Cities: Options for Responding to Climate Change Impacts and Outcomes (Scorchio) project mapped GM's urban heat island (Figure 3), enabling locations at higher risk of heat stress to be identified. As climate change is set to intensify the heat island effect, these areas also appear to be at greatest risk in the future. The UK's Climate Change Risk Assessment indicates that there is a high degree of confidence that risks linked to rising temperatures will increase over the coming decades (Defra 2012), and this also appears to be the case for GM.

Figure 2: Temperature of the warmest day of summer across GM for the baseline and 2050s high emissions scenario

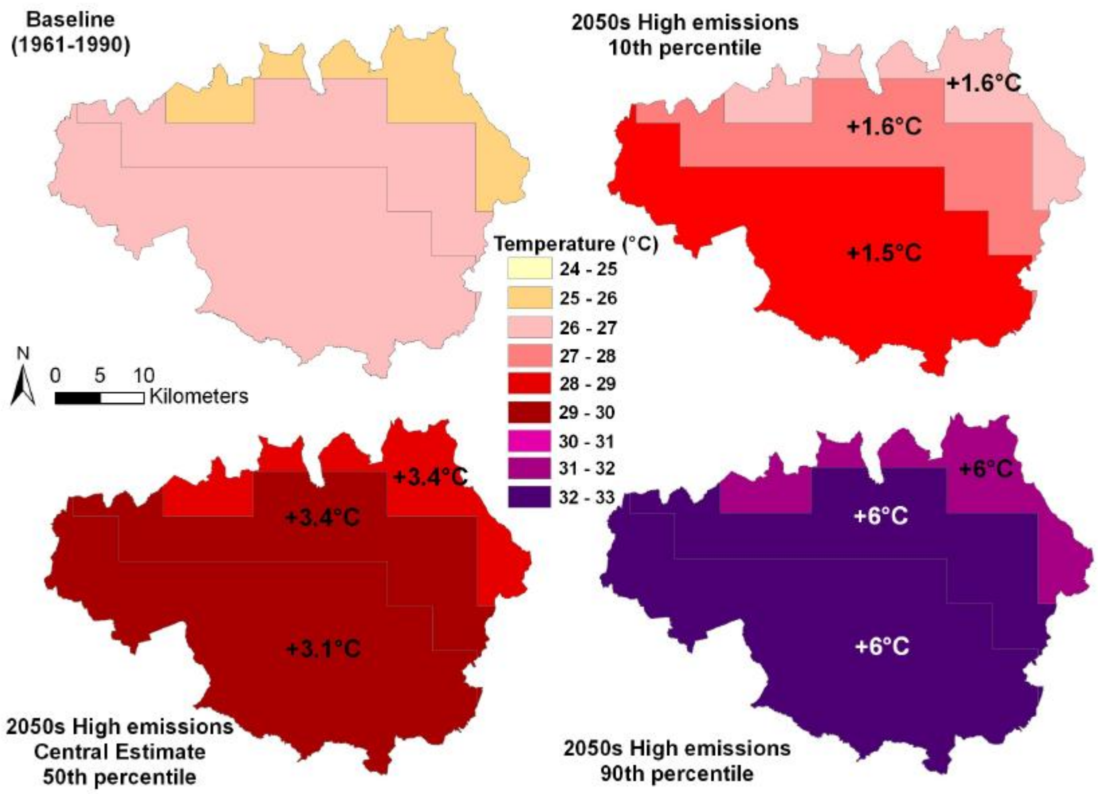
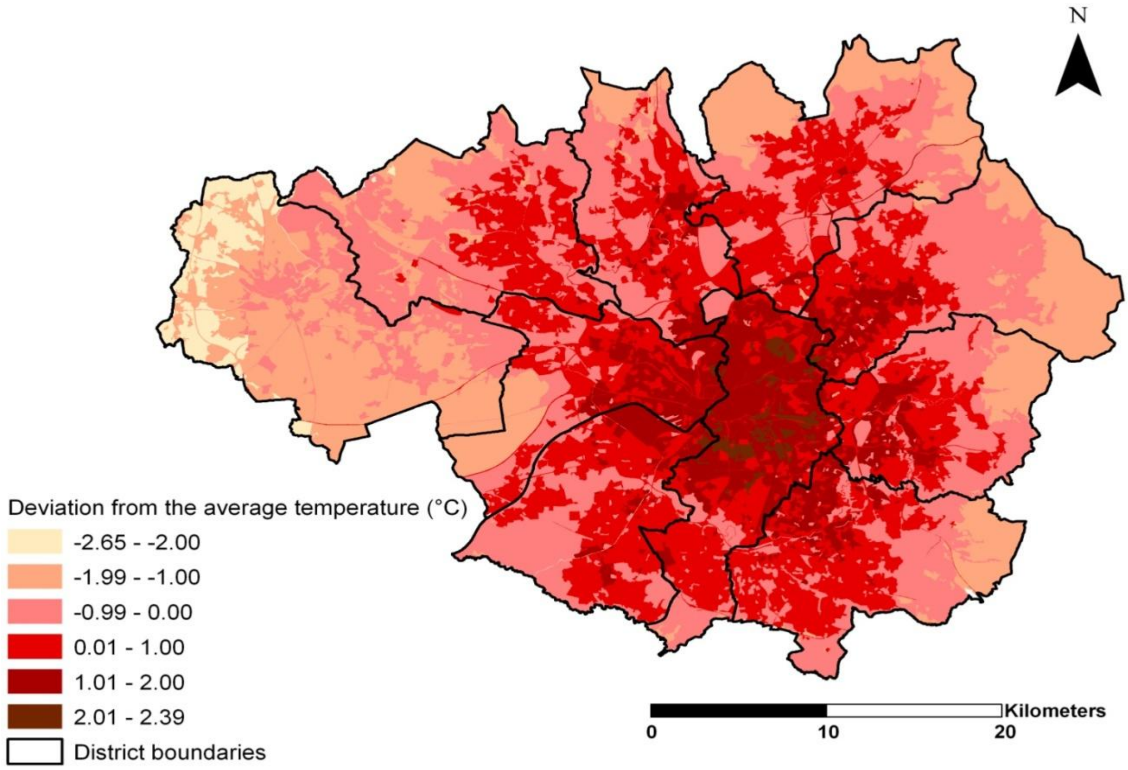


Figure 3: Extent and intensity of the Urban Heat Island in GM (Smith et al 2011)



5. The risk assessment process

The UK Climate Change Risk Assessment (Defra 2012) highlights the most significant climate change risks facing the UK over the coming century. This project aims to consider these risks at a more local scale, focusing on GM and the GMS. Risk can be gauged by applying the following widely recognised formula, which is also proposed by the IPCC for assessing climate change risks (IPCC 2007):

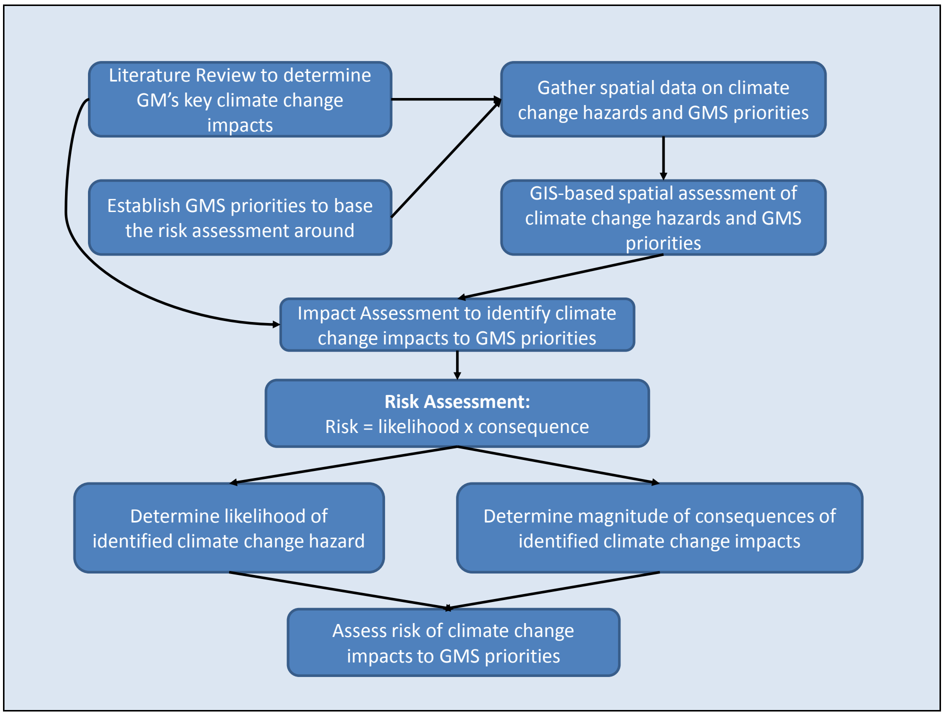
Risk = Probability x Consequence

Within this project, *probability* concerns the likelihood of a hazard occurring (for example a flood or heat wave), and *consequence* relates to the potential magnitude of impacts arising from the hazard on themes linked to the GMS. This approach is reflected in the following risk assessment formula:

Risk = likelihood of a hazard occurring X consequence of impacts arising from the hazard

Figure 4 outlines the methodology followed during the project.

Figure 4: Project methodology.



Many weather and climate change impacts are highly place specific. Indeed, flooding from rivers only has the potential to affect certain areas of GM. Similarly, certain locations are particularly threatened by heat stress due to factors including their topography and land cover. As a result it is important, where data is available, to assess weather and climate change risks spatially. Within this project, spatial data was gathered on extreme weather and climate change hazards (focusing on flooding and heat stress) and six themes central to the GMS's objectives (including transport infrastructure and town centres). Geographic Information Systems (GIS) techniques were applied to analyse the potential exposure of the different themes to the weather and climate change hazards.

5.1. GMS themes forming the basis of the risk assessment

To assess risks to the GMS from weather and climate change impacts, it was necessary to establish which dimensions of the strategy to use as the basis for the assessment. There were several relevant considerations, which acted as selection criteria to identify relevant themes.

- ***Climate change connection:*** Not all aspects of the GMS have a direct link to climate change. For example, issues linked to enhancing skills and improving children's early years experiences do not have an immediate connection (although there are of course links). However, other aspects such as infrastructure and the built environment are more likely to be affected by weather and climate. Hence it was appropriate for the risk assessment to focus on issues such as these.
- ***Spatial dimension:*** The project concentrates on weather and climate change hazards that can be mapped spatially, such as flood risk zones. To assess weather and climate change impacts and risks spatially, it was therefore also necessary to focus on GMS themes that can be viewed in this way, such as town centres and transport infrastructure for example.
- ***GMS priorities:*** The GMS highlights issues that the GMCA, AGMA and the GM LEP will focus on to 2020. These are focused on boosting economic growth and public service reform. When selecting GMS themes to focus the risk assessment around, it was necessary to take this broad underlying goal into account.
- ***Identified impact on economic performance:*** The Manchester Independent Economic Review (MIER) exerted a strong influence on the GMS (2009), which has extended into the 2012-13 refresh process. The MIER identified issues that impact strongly on GM's current and potential future productivity and economic performance. Given the fundamental objective of the GMS to boost economic growth, it is appropriate to focus on themes identified as connecting to this agenda. These were identified by MIER as including housing and infrastructure (especially transport infrastructure).

Taking these issues into account, six themes emerge that meet these criteria; that is they have a direct climate change connection, they can be considered spatially, they link to priorities within the GMS and they will have a bearing on GM's productivity and economic performance. These themes were selected in collaboration with AGMA colleagues.

- ***Housing development areas*** (using an AGMA generated typology of six categories of housing market wards based on levels of deprivation and market strength).
- ***Regional centre and town centres*** (the regional centre boundary covers Manchester city centre and surrounding areas, and there are eight other principal town centres in GM).
- ***Employment locations*** (using a list of ten strategic employment sites from across GM)
- ***Transport infrastructure*** (using data on railways, motorways, metrolink and future transport expansion plans).
- ***Science and innovation assets*** (using postcode data for 42 key assets, with a particular focus on the Oxford Road Corridor which houses 13 of these)
- ***Energy and water infrastructure*** (using data for waste water treatment works, power stations and electricity sub-stations)

5.2. Weather and climate change hazards considered

This assessment is based around three hazard types; river flooding, surface water flooding and heat stress. Local spatial data is available for these hazards. There are other hazards that are relevant to GM such as cold events, high winds and drought. However, these are not included in this assessment. This is principally due to a lack of available relevant spatial data. The following data on flooding and heat stress was used to undertake the spatial analysis for this project:

- ***River flooding:*** Two Flood Zone maps were provided under licence by the Environment Agency. These were:
    - Flood Zone 3 is the Agency's best estimate of the areas of land with a 100 to 1 (or greater) chance of flooding each year from rivers, or with a 200 to 1 chance (or greater) of flooding each year from the sea.
    - Flood Zone 2 is the Agency's best estimate of the areas of land between Zone 3 and the extent of the flood from rivers or the sea with a 1000 to 1 chance of flooding in any year. It includes those areas defined in flood zone 3.
- ***Surface water flooding:*** JBA Consulting produced surface water flood mapping as part of the GM Surface Water Management Plan (2012). Two surface water flood layers developed by JBA Consulting were provided and used as the basis of this assessment. They relate to a rainfall event with a 1 in 200 year return period with resulting surface water flooding to a depth of 300mm, one for the current situation and one with climate change. The climate change layer includes a 20% increase in the rainfall volume. This can be taken as an extreme surface water flooding event.
- ***Heat stress:*** The Scorchio project produced mapping of the extent and intensity of the urban heat island in GM. This showed the deviation of surface temperatures from the average surface temperature in GM, and was used at the basis for the assessment of heat stress. Those areas that are situated where the urban heat island is most intense are taken to be areas where the threat of heat stress is greatest.

5.3. Assessing the likelihood of hazards

Assessing the likelihood of hazard events occurring in GM is a key stage in the risk assessment process. Within this assessment, likelihood is determined based on two factors. The first is the chance of a hazard event occurring. This can be determined for the present day, and where data is available under climate change, using recorded data and modelling on the return period of these events. Within this project, the focus is on extreme hazard events, which cause the most severe impacts to people and infrastructure.

Secondly, likelihood depends on whether and to what extent a 'receptor' (e.g. an infrastructure asset or area such as a town centre) is exposed to a hazard should one occur. This is assessed through the analysis of spatial data using GIS. It is important to note that this project does not consider whether or not features are in place to reduce exposure to hazards. As a result, we use the term 'potential exposure.' This emphasises that without more detailed on-site investigations, considering features including local topography, the existence of adaptation measures (e.g. flood defences) and land cover (e.g. green spaces in the area), it is not possible to determine whether potential exposure in fact equates to actual exposure. To use an example, is a train station located in a flood zone actually threatened by inundation in the event of a flood, or is it raised above the level that would be affected by flood waters? This issue was brought to light by a 2012 court case relating to flooding around the Manchester Ship Canal[2]. Developers owning around 100 hectares of land in this area, which was deemed by the Environment Agency to be within Flood Zone 3 (with a high probability of flooding), won the case at the High Court to have the classification of this area as Flood Zone 3 amended based on the Agency's interpretation of sluices as formal flood defences. The Environment Agency has since applied to the Court of Appeal over this judgement. This case demonstrates that detailed site level studies are needed when determining whether an area appearing to be exposed to flooding will actually be exposed in a flooding event.

This principle also applies when considering exposure to future weather and climate change hazards; surface water flooding and heat waves are considered from a future perspective within this report. Indeed, it is not possible to determine whether, over the coming decades, land use change and the implementation of adaptation responses will act to reduce or enhance exposure to hazards. For example, a town centre may be located in a part of GM that is potentially exposed to high temperatures in the future. Yet, by the 2050's, potential exposure to heat stress may decline (or increase) as a result of land cover change and modifications to the built environment.

The analysis of potential exposure outlined within this report, both to current and future weather and climate hazards, provides an indication of areas, assets and infrastructures that may be exposed to these hazards if hazard events do occur. Determining actual exposure requires additional site-level assessment (for example via flood risk assessment), which are beyond the scope of this project.

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[2] http://www.planningresource.co.uk/news/1137349

A simple formula can be used to represent the approach taken to assessing likelihood:

Likelihood = chance of a hazard event occurring x level of potential exposure to the hazard

The chance of and potential exposure to hazard events are assessed on a three point scale. Following this approach, the assessment of likelihood can be interpreted in matrix format (Figure 5) where;

- Low likelihood = 1,2
- Medium likelihood = 3,4
- High likelihood = 6,9

Figure 5: Assessing the likelihood of hazard events.

Potential exposure to the hazard	High (3)	3	6	9
	Medium (2)	2	4	6
	Low (1)	1	2	3
		Low (1)	Medium (2)	High (3)
		Chance of a hazard event occurring		

5.3.1. Determining the chance of a hazard event occurring

The assessment of the chance of hazard events occurring utilised available data on the return periods of these events in GM.

Fluvial flooding: The Department for Communities and Local Government (DCLG) provide guidance on the interpretation of fluvial flood risk maps, and associated zones, produced by the Environment Agency (DGLG 2012). Within this project we have focused on flood zones 3 and 2. Following DCLG's advice, the chance of flooding of this extent occurring is taken as;

- ***Flood Zone 3:*** In the context of river flooding, Flood Zone 3 is the Environment Agency's best estimate of the areas of land with a 100 to 1 (or greater) chance of flooding each year (i.e. greater than 1% chance annually). DCLG note that this can be regarded as land where there is a 'high probability' of flooding, which we adopt for this assessment.
- ***Flood Zone 2:*** In the context of river flooding, Flood Zone 2 is the Environment Agency's best estimate of the areas of land with a chance of flooding each year of between 1 in 100 and 1 in 1000 (i.e. between 1% and 0.1% chance annually). DCLG note that this can be regarded as land where there is a 'medium probability' of flooding, which we adopt for this assessment.

Where an area or asset lies completely outside Flood Zone 2 or 3, for the purpose of this assessment we assume that there is no chance of a fluvial flood occurring.

The DCLG guidance (DCLG 2012) also refers to accounting for climate change within assessments of flood risk. This states that an asset or area currently located in a zone where there is a lower probability of flooding may, as a result of reduced return periods for flood events under climate change linked to increasing rainfall intensity and peak river flow (of 25% beyond 2025), be re-classified as lying within a higher probability zone (i.e. the potential for FZ3 to extend to FZ2). This will depend on factors including the characteristics of the flood plain, an assessment of which was outside the scope of this project. Hence the focus here is on the present day chance of fluvial flooding events.

Surface water flooding: This project is focusing on the risks to the GMS of extreme weather and climate change events. These are events that occur less frequently, but if they do happen have the potential to generate significant disruption. In the case of surface water flooding, spatial data was used on the extent of surface water flooding event to a depth of 300mm with a 1 in 200 year return period. With a 0.5% annual probability, following the approach taken to fluvial flood risk within DCLG's technical guidance (DGLG 2012), this was classed as a medium chance event. Data was available for present day conditions and with climate change. For the latter, an additional 20% volume of rainwater was added to the flood model.

Heat wave: The Heatwave Plan for England places threshold temperatures for heat waves at two days above 30°C with the intervening night above 15°C (NHS 2009). The EcoCities project analysed the extent to which this threshold is broken in Manchester city centre in the present day and under different climate change scenarios (Cavan 2011). Further analysis could potentially reveal that the incidence of heat waves would vary for different areas of GM. This was not possible in this project given that the requirement was to base the assessment on available information. Hence, the data for Manchester city centre is taken as a proxy for the chance of heat wave events occurring across GM. As heat waves generally affect large areas, this was thought to be a reasonable indicative approach for assessing the incidence of these events across the conurbation.

- Present day: The mean number of heat wave events per year in central Manchester is 0.004 (1961-1990 baseline). For this assessment, this is deemed a low chance event.
- 2050s: The mean number of heat wave events per year in central Manchester under the 2050s high emissions climate change scenario is 0.78. For this assessment, this is deemed a medium chance event.

5.3.2. Determining levels of potential exposure

The level of potential exposure of the six GMS themes to weather and climate change hazards has been determined through the use of GIS to overlay associated spatial data sets. The results of this analysis (which are presented in Appendix 2) were used to establish which of three broad potential exposure classes (high, medium, low) each different receptor fell into (e.g. a particular employment site to flood zone 2). These classes for areas (e.g. town centres, employment sites) and lines (e.g. motorways, train lines) are defined according to the average potential exposure of GM to the different hazards (Table 2) where;

- Low potential exposure = 50% or more below the GM average
- Medium potential exposure = between 50% below and 50% above the GM average
- High potential exposure = more than 50% above the GM average

This approach, developed to assess the level of potential exposure to hazards, was a necessary element of this risk assessment. Based on the simple thresholds outlined above (and in Table 2), this replicable approach could be used in the future to assess the level of potential exposure of other GM receptors to weather and climate hazards.

Table 2: Potential exposure classes for different weather and climate hazards.

	% of GM area potentially exposed (the GM average)	**Low potential exposure (% of area)**	**Medium potential exposure (% of area)**	**High potential exposure (% of area)**
Flood Zone 2	6.84	<3.43	3.43-10.28	>10.28
Flood Zone 3	4.61	<2.31	2.31-6.92	>6.92
Surface water flooding (current)	2.83	<1.42	1.42-4.25	>4.25
Surface water flooding (with climate change)	3.77	<1.89	1.89-5.66	>5.66
Greater that 1^{o}C above the GM mean	11.97	<5.99	5.99-17.96	>17.96

Points (e.g. train stations, waste water treatment plants) were assessed according to whether they are located in an area potentially exposed to a hazard event.

5.4. The Surface Temperature And Runoff (STAR) tools

Green infrastructure (including parks, street trees, gardens etc) has an important role to play, amongst other responses, in adapting cities to climate change. Green infrastructure can moderate surface and air temperatures via shading, evaporative cooling and through encouraging cool air flow into urban centres. Green infrastructure can also slow the pace and reduce the volume of water runoff during heavy rainfall events, via interception and infiltration. This can lessen the risk of fluvial and surface water flooding. The Surface Temperature And Runoff (STAR) tools for assessing the potential of green infrastructure in adapting urban areas to climate change were developed by the Mersey Forest and the University of Manchester as part of the EU Interreg GRaBS project.

The STAR tools can be used at a neighbourhood scale (in the North West of England and beyond) to provide an indicative test of the impact of different land cover scenarios, and in particular the proportion of green space versus built and impervious surfaces, on maximum surface temperatures during extremely hot summer days and runoff for an extreme rainfall event (the type of rainstorm that could be expected once during the winter months), under different temperature and precipitation scenarios. The tools were applied within this project to look at the implications of possible future land cover change on local climate in different areas of GM. This gives an indication of how adaptation responses, particularly those linked to green infrastructure, can reduce risks linked to high temperatures and flooding. Further information on the STAR tools is available on the following website - http://82.69.33.138/grabs/.

6. The likelihood of hazards affecting GMS themes: assessment results

Following the approach outlined above, the likelihood of weather and climate hazards affecting each of the six GMS themes is now discussed. The detailed findings of the assessment of likelihood are presented in Appendix 2.

6.1. Housing development areas

The findings of the assessment of the likelihood of hazard events affecting the six different types of housing development areas (at the ward level)[3] are summarised in Table 3.

Table 3: Likelihood of weather and climate hazards affecting different types of housing development areas.

	Housing development area types					
	Type 1: not deprived/strong market	**Type 2:** not deprived/weaker market	**Type 3:** mixed deprivation/strong market	**Type 4:** mixed deprivation/weak market	**Type 5:** deprived/strong market	**Type 6:** deprived/weak market
FZ3	High	High	High	High	High	High
FZ2	Medium	Medium	High	Medium	Medium	Medium
SWF	Medium	Medium	Medium	Medium	Medium	Medium
SWF+cc	Medium	Medium	Medium	Medium	Medium	Medium
Heat now	Low	Low	Medium	Low	Medium	Medium
Heat+cc	Medium	Low	High	Medium	High	High
KEY[4]	High likelihood		Medium Likelihood		Low Likelihood	
	FZ2 and 3 – Flood Zones 2 and 3 **SWF** – Surface Water Flooding **Heat now** – heat wave under current conditions			**SWF+cc** – Surface Water Flooding under climate change **Heat+cc** – heat wave under climate change		

Flood Zones 2 and 3

Housing development area type 3 (mixed deprivation / strong market) has high potential exposure to Flood Zone 2. The potential exposure of the other five types is around the GM average. Figure 6 maps Flood Zone 2 across the six different housing types, displaying areas threatened by this form of flooding. A report by AGMA's Planning and Housing Team to the GMCA indicates that housing development is most likely to take place in areas where the market remains relatively robust[5]. This analysis suggests that new developments taking place in housing development area type 3 should be supported by flood risk assessments, and where necessary ensure that appropriate steps are taken to reduce flood risk. It may also be necessary to direct development towards locations with lower

[3] Type 1 - not deprived/strong market, Type 2 - not deprived/weaker market, Type 3 – mixed deprivation/strong market, Type 4 – mixed deprivation/weak market, Type 5 - deprived/strong market, Type 6 - deprived/weak market

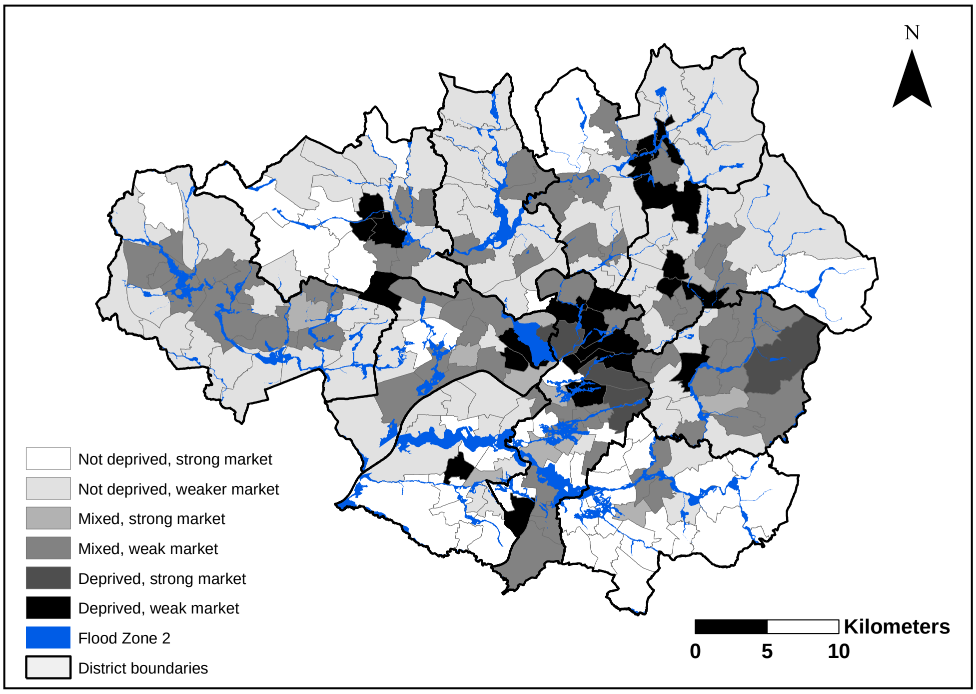
[4] This key also applies to tables 4-7.

[5] http://www.agma.gov.uk/cms_media/files/10_delivering_housing_growth_in_gm.pdf

potential exposure to flooding. This will ultimately be necessary for all housing developments in Flood Zones.

As was the case for Flood Zone 2, housing development area type 3 stands out as having high potential exposure to Flood Zone 3, with the other five types closer to the average for GM. However, flooding within Flood Zone 3 is defined by DCLG as a high chance event, which increases its likelihood. This analysis emphasises that flood risk assessments should accompany plans for new housing developments, particularly within housing development area type 3 (and also types 1 and 5 which are assessed as having a stronger market and hence are more likely to attract new development).

Figure 6: Relationship between Flood Zone 2 and six housing development area types across GM.



Surface water flooding

The six housing development area types show similar potential exposure to surface water flooding (both current and accounting for climate change), which is at a level close to the average for GM. This reflects the dispersed nature of surface water flooding across the conurbation, with many different areas potentially affected. According to this analysis, the likelihood of the surface water flooding event considered (an event with a 1 in 200 year return period producing 300mm of flooding) is rated as medium across all six housing development area types. It is important to emphasise that the six housing development areas are broad categories each containing numerous housing wards, some of which may have a high or low likelihood of surface water flooding if considered individually.

Heat wave

This analysis demonstrates that the degree of potential exposure to heat stress in GM's housing development area types links to deprivation. Types 5 and 6, where levels of deprivation are highest, are exposed to potential heat stress much above the GM average. That is, more of their area is contained within GM's urban heat island, and under heat wave conditions these areas are more likely to be affected by higher temperatures. This is also the case for type 3, where levels of deprivation are mixed. Conversely, where deprivation is lowest (types 1 and 2) potential exposure to heat stress is much lower. This indicates that regeneration efforts targeted at reducing deprivation through modifying urban landscapes could usefully include measures to reduce the threat of heat stress to people and communities. These could include expanding green infrastructure (such as street trees and green roofs) or providing anti-overheating measures for individual buildings (such as shading and natural ventilation).

Housing development area types where the market remains relatively robust and where new housing development is therefore most likely to be focused - 1, 3 and 5 – show different likelihoods of heat stress. Whereas type 1 is potentially exposed to high temperatures at a level below the GM average, types 3 and 5 are threatened to a greater extent. If new housing development does take place in wards falling within types 3 and 5, it would be valuable to accompany this with measures to reduce the threat of heat stress (such as those noted above) where this is feasible.

The impact of land cover change on local climate in GM housing wards

Using the STAR tools, the impact of land use change on surface temperature and rainwater runoff was assessed for two wards. These were Bramhall North (type 1; located in the Stockport suburbs) and Harpurhey (type 6; located in inner city Manchester). These two wards were selected by AGMA colleagues to represent contrasting areas of GM in terms of land cover and socio-economic factors. Using data obtained during the University of Manchester's ASCCUE project (Gill 2006), three land cover scenarios for the two wards were developed based on the land cover characteristics of low, medium and high density residential areas across GM.

Land cover in Bramhall North is most similar to the characteristics of a low density residential area. Under the central projection for the 2050s high emissions scenario, keeping land cover in its current form, maximum surface temperatures reach 21.7^{o}C and rainwater runoff levels during an extreme rainfall event stand at 78.3%. If, in the future, Bramhall North develops along the lines of a typical medium density residential area in GM (which would involve increased building cover, more roads, increase in impervious surfaces, reduction in green cover), this will have implications for local climatic conditions. The STAR tools project that under these changed land use conditions, maximum surface temperatures increase to 25.9^{o}C, and rainwater runoff levels during an extreme rainfall event rise to 84.1% of the total volume of water falling under these conditions. This analysis demonstrates that land cover change can exert a significant influence over environmental processes such as rainwater runoff and temperature regulation, which can in turn affect local climate.

The STAR tools run for Harpurhey produced similar headline conclusions to the Bramhall North analysis, that residential development density has a noticeable influence on local climate. Although Harpurhey is starting from a position of higher building density and lower green cover than Bramhall North, the same broad principles apply. Increasing density further raises maximum surface temperatures and runoff rates whilst reducing density (and increasing green cover) has the opposite effect. With climate change projections for GM highlighting the potential for more heat waves and intense rainfall events, building commensurate adaptation responses into residential areas appears to be necessary.

6.2. Regional centre and town centres

The findings of the assessment of the likelihood of hazard events affecting GM's regional centre and town centres are summarised in Table 4.

Table 4: Likelihood of weather and climate hazards affecting GM's regional centre and different town centres.

	Regional centre and town centres								
	Regional Centre	Altrincham	Ashton	Bolton	Bury	Oldham	Rochdale	Stockport	Wigan
FZ3	High likelihood	Low Likelihood – no potential exposure	Medium Likelihood	Medium Likelihood	Medium Likelihood	Low Likelihood – no potential exposure	High likelihood	High likelihood	High likelihood
FZ2	High likelihood	Low Likelihood – no potential exposure	Medium Likelihood	Medium Likelihood	Medium Likelihood	Low Likelihood – no potential exposure	High likelihood	High likelihood	High likelihood
SWF	Medium Likelihood	Medium Likelihood	Medium Likelihood	High likelihood	Medium Likelihood	Medium Likelihood	High likelihood	Medium Likelihood	High likelihood
SWF+cc	Medium Likelihood	Medium Likelihood	Medium Likelihood	High likelihood	Medium Likelihood	Medium Likelihood	High likelihood	Medium Likelihood	High likelihood
Heat now	Medium Likelihood	Medium Likelihood	Medium Likelihood	Low Likelihood	Medium Likelihood	Medium Likelihood	Low Likelihood	Medium Likelihood	Low Likelihood
Heat+cc	High likelihood	High likelihood	High likelihood	Low Likelihood	High likelihood	High likelihood	Low Likelihood	High likelihood	Low Likelihood
KEY	High likelihood	Medium Likelihood	Low Likelihood	Low Likelihood – no potential exposure					

Flood Zones 2 and 3

The regional centre, Stockport, Rochdale and Wigan show high potential exposure to Flood Zone 2 (in comparison to the GM average). No areas of Altrincham and Oldham town centres are situated within this Flood Zone.

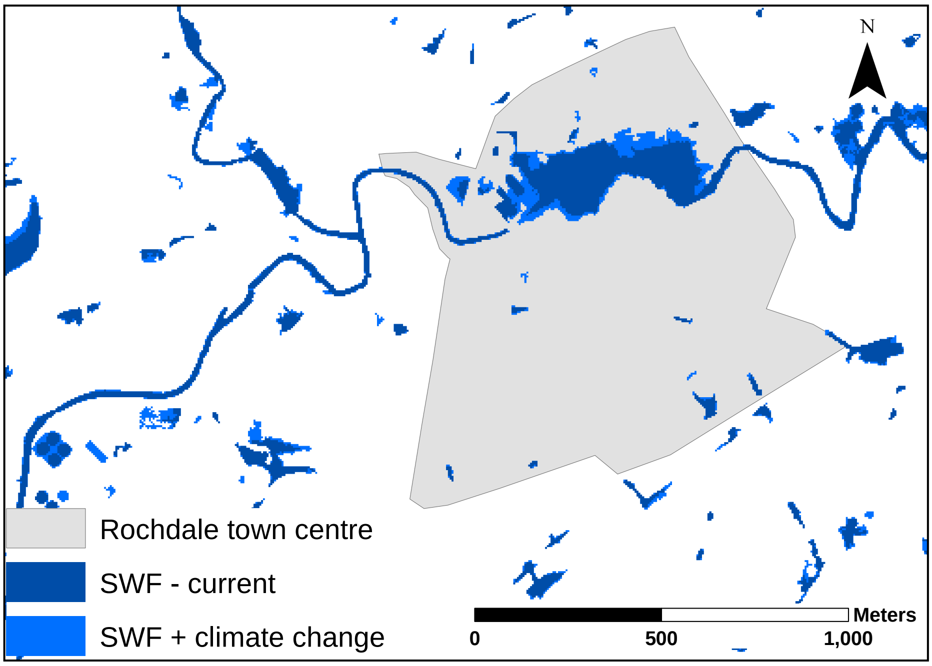
The same spatial pattern of potential exposure across GM's regional and town centres is seen for Flood Zone 3 (as for Flood Zone 2). However, the likelihood of flooding in Flood Zone 3 is higher as the chance of floods occurring in these locations is greater than in Flood Zone 2.

The findings of the analysis on the likelihood of flooding (from Flood Zone 2 and 3) in GM's regional centre and town centres emphasises the value of including spatial data on potential exposure to weather and climate hazards as part of the assessment of likelihood. Likelihood differs significantly as a result, something that basing the assessment purely on the chance of the hazard event occurring would not reveal. This spatial approach supports the development of more targeted responses to assessing, and then if necessary reducing, the threat of weather and climate change hazards.

Surface water flooding

Three of GM's town centres, Bolton, Rochdale and Wigan, have high potential exposure to surface water flooding in comparison to the average for the conurbation. This increases the likelihood of this form of flooding in these locations. This is the case under current conditions and with climate change factored into the flooding model. Figure 7 maps the extent of surface water flooding in Rochdale town centre. Given that town centres are an important element of GM's growth and employment prospects, actions to reduce their exposure to surface water flooding would be beneficial. It is also important, when progressing new development or redevelopment, to ensure where possible that this does not increase the threat of surface water flooding through the loss of pervious surfaces. Given the pervasive nature of surface water flooding across GM's regional and town centres, this would be a valuable strategy more generally.

Figure 7: Potential exposure of Rochdale town centre to current and future (with climate change) surface water flooding.



Heat wave

Spatial patterns of potential exposure to the urban heat island (and hence heat stress under heat wave conditions) vary markedly between GM's regional centre and town centres. Aside from Bolton, Rochdale and Wigan, where potential exposure is low, the other town centres and the regional centre display high levels of potential exposure to heat stress. With the increased chance of heat wave events linked to the changing climate, the likelihood of heat wave events in the regional centre and several town centres is set to increase.

The level of potential exposure in the regional centre is high; over 14km² is situated in areas where temperatures are 1°C or more above the GM average. The corresponding figure for Oldham is 0.79 km². Figure 8 maps the potential exposure of Oldham town centre to the urban heat island. This demonstrates that it is the regional centre where long term measures to adapt to heat stress would be particularly valuable, although other town centres where likelihood of heat stress is high should not be excluded from such actions.

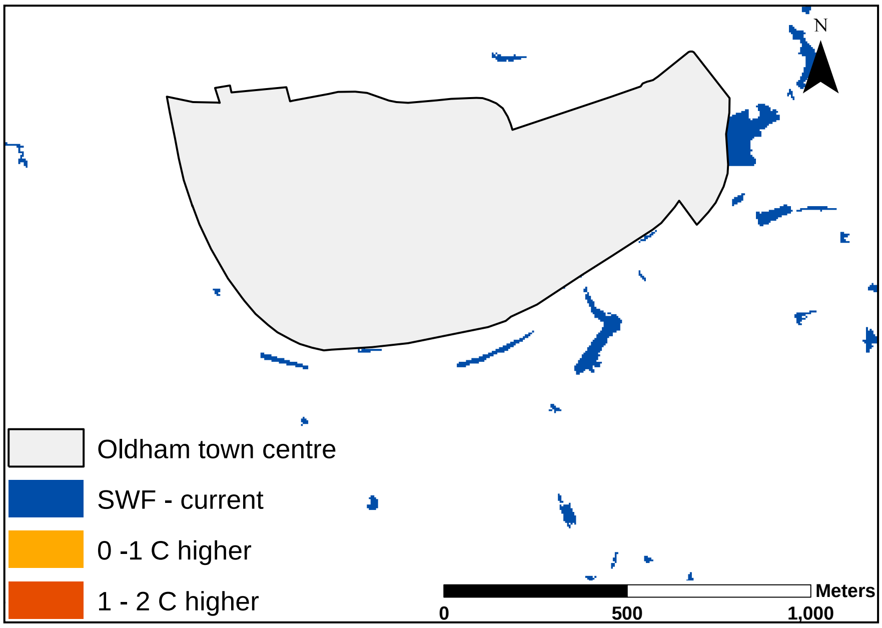
The impact of land cover change on local climate in GM's town centres

Using the STAR tools, we looked at three different green cover scenarios for Rochdale and Oldham town centres. These were chosen to look at the implications of land cover change in town centres where the likelihood of surface water flooding (Rochdale) and heat stress under climate change (Oldham) is high. The baseline scenario assumed that land cover remained the same, one scenario added 10% green cover, and the third scenario reduced green cover by 10%.

For Rochdale, the modelling suggested that under the central projection for the 2050s high emissions scenario, if current land cover remains unchanged this leads to 84.8% runoff under an extreme rainfall event. Looked at another way, only 15.2% of rain falling during such an event is intercepted and absorbed into the landscape. Under the same scenario, if green cover is increased by 10% from current levels runoff falls to 77.8%, whereas if green cover falls by 10% runoff increases to 88.1%. The clear message is that increasing green cover is an effective means of reducing surface water runoff, and hence surface water flood risk, in Rochdale town centre. Measures to promote this approach, via planning and development control, can therefore be recommended.

For Oldham, the implications of the three green cover scenarios on surface temperatures were considered given the high potential exposure of the area to heat stress. GM's urban heat island (see Figure 3) is influenced by factors including topography, the mass of buildings, land cover (broadly the proportion of vegetated surfaces and impervious built surfaces) and levels of heat emissions from human activity (Smith et al 2011). In Oldham, local characteristics related to these factors combine to create temperatures 1-2°C above the GM average. According to the STAR tools, if land cover in the town centre remains unchanged, under the central projection for the 2050s high emissions scenario, maximum surface temperatures reach 34.8°C. Under the same scenario, if green cover is increased by 10% from current levels maximum surface temperatures falls to 31.1^{o}C, whereas a reduction in green cover by 10% sees this figure rising to 39.5^{o}C. This analysis demonstrates that green infrastructure has a valuable role to play moderating high temperatures in town centres in a future where climate change becomes more severe. Adaptation responses based around protecting and enhancing green infrastructure can therefore be recommended.

Figure 8: Potential exposure of Oldham town centre to heat stress.



6.3. Employment sites

The findings of the assessment of the likelihood of hazard events affecting strategic employment sites across GM are summarised in Table 5.

Table 5: Likelihood of weather and climate hazards affecting key strategic employment sites across GM.

	Manchester Airport	Airport City	Airport Strategic Site	Carrington	Cutacre	Hollinwood	Kingsway	Port Salford	Trafford Core	Wharfside
FZ3										
FZ2										
SWF										
SWF+cc										
Heat now										
Heat+cc										
KEY	High likelihood		Medium Likelihood			Low Likelihood		Low Likelihood - no potential exposure		

Flood Zones 2 and 3

Analysing patterns of potential exposure to fluvial flooding, both Flood Zones 2 and 3, demonstrates that the majority of strategic employment sites (8 out of the 10 included in this assessment) are not located in these areas, and hence the likelihood of this form of flooding in these locations low due to lack of exposure.

However, Port Salford shows high potential exposure to Flood Zones 2 and 3, particularly to Flood Zone 3, making the likelihood of fluvial flooding in this location high. This is also the case for Carrington, especially concerning Flood Zone 2. Figure 9 overlays Flood Zone 2 onto the boundaries of these two strategic employment sites. It is important to note that the classification of the area around the Manchester Ship Canal as Flood Zone 3, which includes Port Salford, is currently being contested at the Court of Appeal (as noted in Section 5.3). However, the Flood Zone maps provided by the Environment Agency, and used as the basis of this assessment, were the most up to date at the time of undertaking this assessment.

Surface water flooding

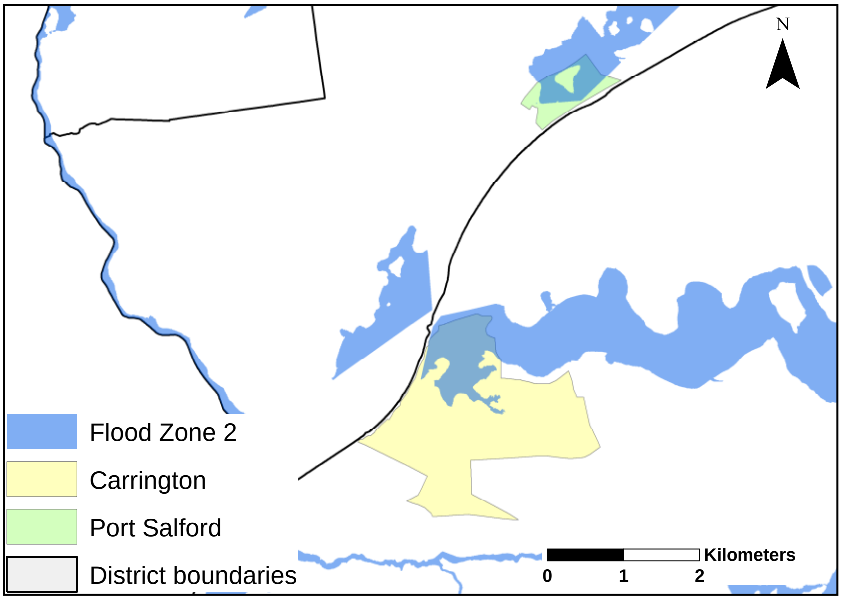
The majority of the strategic employment sites covered by this assessment are potentially exposed to surface water flooding (both in the present day and accounting for climate change) to a level just below the average for GM. The exception is Kingsway, although the level of potential exposure here is within 50% of the GM average.

Overall, the current and future (accounting for climate change) likelihood of surface water flooding in strategic employment sites is generally medium and in two cases is low. There are no sites where, according to this analysis, the likelihood of this type of flooding is high. As with other hazards, it is important to emphasise that it is not possible to rule out unpredictable extreme events occurring in any location.

Heat wave

Potential exposure to the urban heat island varies considerably across the 10 strategic employment locations analysed. The majority show low potential exposure; that is they are not located in areas where temperatures are 1^{o}C or above the GM average. Three sites – Hollinwood, Wharfside and Trafford Core – are situated where according to this analysis potential exposure to heat stress is high. The likelihood of heat stress under climate change consequently rated as high in these particular employment sites. Figure 10 visualises Wharfside and Trafford Core in this respect. Actions to reduce the extent of impacts linked to high temperatures, through modifications to buildings and the spaces around them, could be usefully considered, particularly where new development or redevelopment takes place in these sites.

Figure 9: Potential exposure of Carrington and Port Salford to Flood Zone 2.



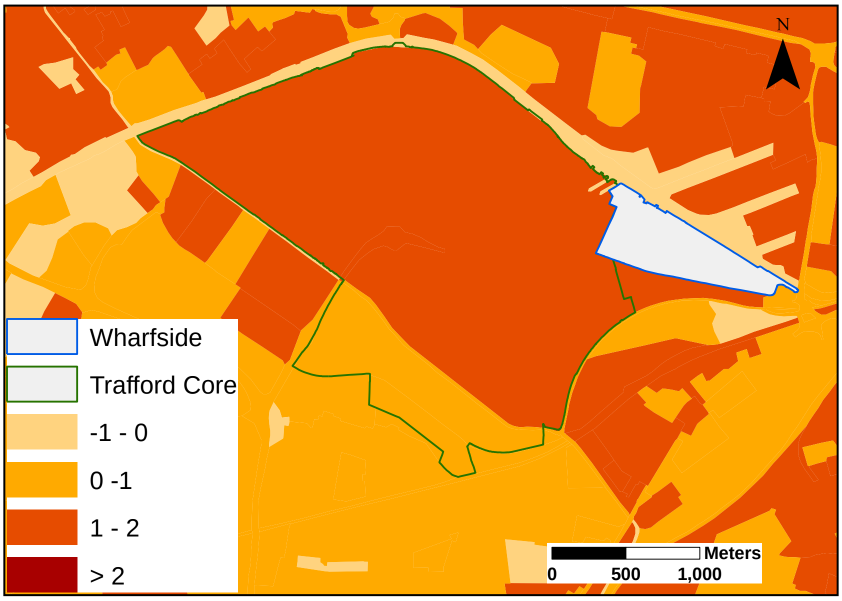
The implications of land cover change for local climate in employment sites: a focus on Airport City

Airport City aims to bring several million square feet of new business space to a site just to the north of Manchester Airport. Plans for Airport City have been approved by Manchester City Council, and work is expected to commence in 2013 and is projected to take 10-15 years. The STAR tools were applied to look at the implications of this development on local climate.

Currently, the site predominantly consists of green space and impervious surfaces (particularly car parking). There are few buildings in the site boundary. The master plan for the site[6] demonstrates that significant new building will take place, which will predominantly provide offices and manufacturing space. According to the STAR tool, under current conditions (which is based on observations for a 1961-1990 baseline), maximum surface temperatures reach 22.3°C, with runoff levels at 80.9% for an extreme rainfall event. Using data on the average land cover characteristics for office spaces in GM as a proxy (drawing on the outcomes of the ASCCUE project), if Airport City was to develop along these broad lines, impacts on the environmental processes influencing local climate can be expected. Under the 2050's high emissions scenario, maximum surface temperatures increase to 26.9°C, with runoff levels reaching 84.5% for an extreme rainfall event. These findings have implications for the design of the site, which could usefully consider responses to reduce and adapt to local climate change risks.

[6] http://www.airportcity.co.uk/master-plan/airport-city-north/

Figure 10: Potential exposure of the Wharfside and Trafford Core strategic employment sites to heat stress.



6.4. Transport infrastructure

The findings of the assessment of the likelihood of hazard events affecting elements of GM's transport infrastructure (both existing and planned) are summarised in Tables 6 and 7. Table 6 includes four metrolink lines. These are:

- 1n2 - Bury to Altrincham
- 2cc - Piccadilly to Eccles
- 3a - new routes: Mediacity in 2010, Chorlton in 2011, Oldham and to Rochdale Railway Station and Droylsden in 2013
- 3b – Piccadilly to the Airport

Table 6: Likelihood of weather and climate hazards affecting existing elements of GM's transport infrastructure.

	Railway lines	Motorway network	Metrolink line 1n2	Metrolink line 2cc	Metrolink line 3a	Metrolink line 3b
FZ3						
FZ2						
SWF						
SWF+cc						
Heat now						
Heat+cc						
KEY	High likelihood	Medium Likelihood	Low Likelihood	Low Likelihood – no potential exposure		

Table7: Likelihood of weather and climate hazards affecting planned expansions to GM's transport infrastructure.

	Cross city metrolink	Leigh busway	Ashton northern bypass region	Longendale region	Semmms region	Wigan IRR region
FZ3	High likelihood	High likelihood	Low Likelihood – no potential exposure	Medium Likelihood	Medium Likelihood	High likelihood
FZ2	Medium Likelihood	Medium Likelihood	Low Likelihood – no potential exposure	Low Likelihood	Low Likelihood	Medium Likelihood
SWF	Medium Likelihood	Medium Likelihood	Medium Likelihood	Medium Likelihood	Medium Likelihood	High likelihood
SWF+cc	Medium Likelihood	Medium Likelihood	Medium Likelihood	Medium Likelihood	Medium Likelihood	High likelihood
Heat now	Medium Likelihood	Medium Likelihood	Medium Likelihood	Low Likelihood	Low Likelihood	Low Likelihood
Heat+cc	High likelihood	High likelihood	High likelihood	Low Likelihood	Low Likelihood	Low Likelihood
KEY	High likelihood	Medium Likelihood	Low Likelihood	Low Likelihood – no potential exposure		

Flood Zones 2 and 3

A small number of current railway stations are potentially exposed to fluvial flooding; only 1 out of GM's 88 stations is within flood zone 3. However, 3 stations that form part of the proposed expansion package (25% of the total) are situated within Flood Zone 2.

Almost 10% of GM's motorway junctions are sited within Flood Zone 2. In terms of the motorway network itself, over 7% (which equates to more than 12km of road) lies within Flood Zone 2. Again, it is important to emphasise that these findings relate to potential and not actual exposure. Further assessment of local conditions is needed to establish actual exposure of GM's motorways (and other GMS-relevant areas and assets) to hazards such as fluvial floods.

Looking at the Metrolink network, potential exposure to Flood Zone 3 is relatively low, aside from line 3a. This is not the case for Flood Zone 2 where potential exposure increases markedly, particularly for line 3a. Lines 1n2 and 2cc show a large jump in potential exposure between Flood Zone 3 and 2, from zero to 9% in the case of line 2cc.

Potential exposure to fluvial floods in areas where transport expansion is proposed or planned varies. It is the Wigan Inner Relief Road area that appears most likely to experience fluvial flooding.

Surface water flooding

One in eight of GM's railway stations are located in areas potentially exposed to surface water flooding. This is the case for one in ten motorway junctions. With heightened surface water flooding under climate change these figures increase, but only slightly. Some railway stations and motorway junctions are likely to be elevated and as a result will not be actually exposed to flooding even though they sit within a flood zone. 'Ground-truthing' at the site level is needed to establish this.

Future transport plans to build new interchanges and park and ride facilities are not sited in areas potentially exposed to surface water flooding, although this is the case for 25% of railway stations in the proposed expansion package.

GM's railway network shows high potential exposure to the surface water flooding event considered during this assessment. Currently over 11% of the network is potentially exposed, with this figure rising to over 15% (or close to 60km of track) where climate change is factored in. The likelihood of surface water flooding to parts of the railway network, both now and in the future, is rated as high by this assessment; although the chance of the event is medium, levels of exposure are high. Additional studies could usefully highlight areas of the network where features including local topography reduce actual exposure to surface water flooding.

All metrolink lines (particularly 2cc and 3a) exhibit high potential exposure to surface water flooding (current and future). Figures 11 and 12 show the fragments of lines where this is the case, both in the present day and in the future under climate change. Comparing these figures, it is clear that a greater amount of the line running through to the south east through Chorlton and Didsbury is potentially exposed under climate change. The likelihood of surface water flooding on the metrolink network, both now and in the future, is rated as high by this assessment.

The conurbations motorway network also has high potential exposure to surface water flooding, both now and in the future, although not to the same extent as the railway and metrolink lines. Nevertheless, under climate change, almost 10km of motorway is potentially exposed to the surface water flooding event assessed (a 1 in 200 event producing 300mm of flooding). The likelihood of surface water flooding on the motorway network, both now and in the future, is rated as high by this assessment.

Areas proposed for possible future transport expansion schemes are potentially exposed to surface water flooding (current and future) at a level around the average for GM. The exception is the Wigan Inner Relief Road where levels are high, with the likelihood of this form of flooding appearing to be high if the scheme was to proceed.

This analysis demonstrates that despite the high likelihood of fluvial flooding in some areas, based on levels of potential exposure, surface water flooding is a bigger threat to GM's transport network. This is understandable given the diffuse nature of surface water flooding and the wide spread of the transport network across the conurbation.

Figure 11: Potential exposure of Metrolink lines to current surface water flooding.

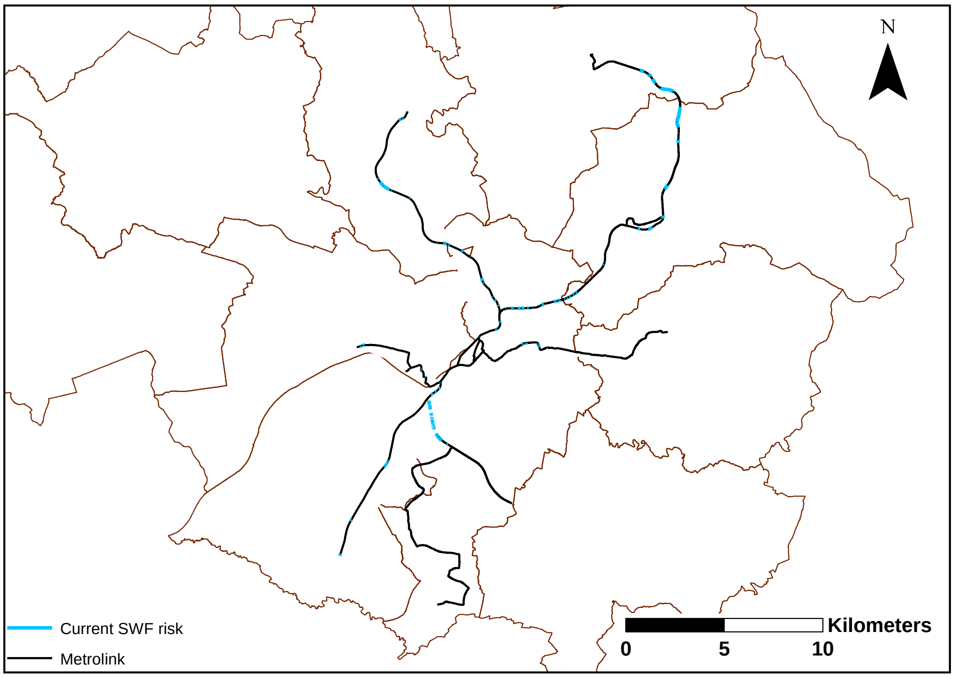
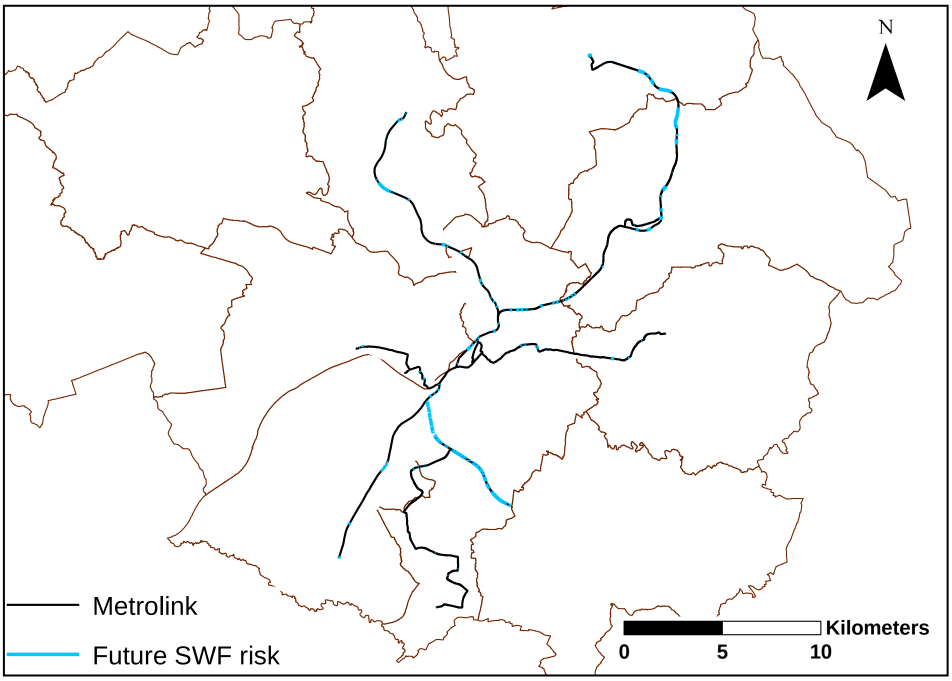


Figure 12: Potential exposure of Metrolink lines to future surface water flooding.



Heat wave

Close to 1 in 5 of GM's existing railway stations are located in areas potentially exposed to heat stress under heat wave conditions. This rises to one in three stations included in the future rail station expansion package. The railway and motorway network is exposed to potential heat stress at a level around the average for GM.

The metrolink network shows high potential exposure to heat stress, due in part to the location of the lines which generally connect and run through urbanised areas. Under projected conditions in the 2050s, where the occurrence of heat waves increases and are consequently rated as a medium chance event, the likelihood of heat stress to the metrolink network is high. In the present day likelihood is assessed as medium because despite high levels of potential exposure, the chance of heat wave events is low.

The future plans for the cross city metrolink and Leigh bus way go through areas that are potentially highly exposed to heat stress. Under future conditions where the chance of heat waves increases, the likelihood of heat stress is high in these locations.

6.5. Science and innovation assets

This analysis focused on postcodes containing 42 of GM's key science and innovation assets. Particular attention was paid to the Oxford Road Corridor (the Corridor), which houses 13 of these assets. The Corridor was analysed separately from the remaining group of 29 assets.

Flood Zones 2 and 3

Of group of 29 science and innovation assets situated outside the Corridor, 7 are in postcodes part of which are potentially exposed to Flood Zone 3. Looking at Flood Zone 2, this figure increases to 10 assets. On the basis of this analysis, the Corridor shows high potential exposure to fluvial flooding, both Flood Zones 2 and 3, to levels much higher than the GM average.

The likelihood of fluvial flooding to science and innovation assets is assessed as high for those sites included in this analysis, both the group of 29 sites and the Corridor. Further analysis of the individual sites is needed in order to determine issues including local topography, which sites are protected by flood defences, and where modification of the river channel may have reduced flood risk to the surrounding area. Where actual exposure to fluvial flooding is enhanced by factors including the built environment or lack of flood defence work, adaptation action should be considered.

Surface water flooding

Of the group of 29 science and innovation assets, 18 (62% of the total) are located in postcodes part of which are potentially exposed to surface water flooding (current). With climate change added to the flood model, this figure increases slightly to 19 (66%). Just over 2% of the Oxford Road Corridor area is potentially exposed to surface water flooding (current and accounting for climate change), which places it at a level close to the GM average. The likelihood of surface water flooding on the Corridor is assessed as medium.

Overall, although there are clear risks to science and innovation assets from surface water flooding, both now and in the future with the influence of climate change, levels of potential exposure are around the GM average. Hence, the likelihood of surface water flooding to all the assets is assessed as medium. However, as previously noted, the risk of extreme events cannot be discounted. This is particularly the case for surface water flooding, the location and intensity of which can be difficult to predict.

Heat wave

The science and innovation assets appear, as a result of their location, to show high potential exposure to heat stress. Over 50% of the area covered by the postcodes containing group of 29 key assets has temperatures 1^{o}C or above the GM average. In the case of the Corridor, this rises to nearly 90% of the area. With the increased frequency of heat waves projected for the future in GM, the likelihood of these events impacting on science and innovation assets is high. Research within the EcoCities project demonstrated that increasing green cover on the Oxford Road Corridor is an effective way of reducing surface temperatures (Cavan and Kazmierczak 2011).

6.6. Critical infrastructure

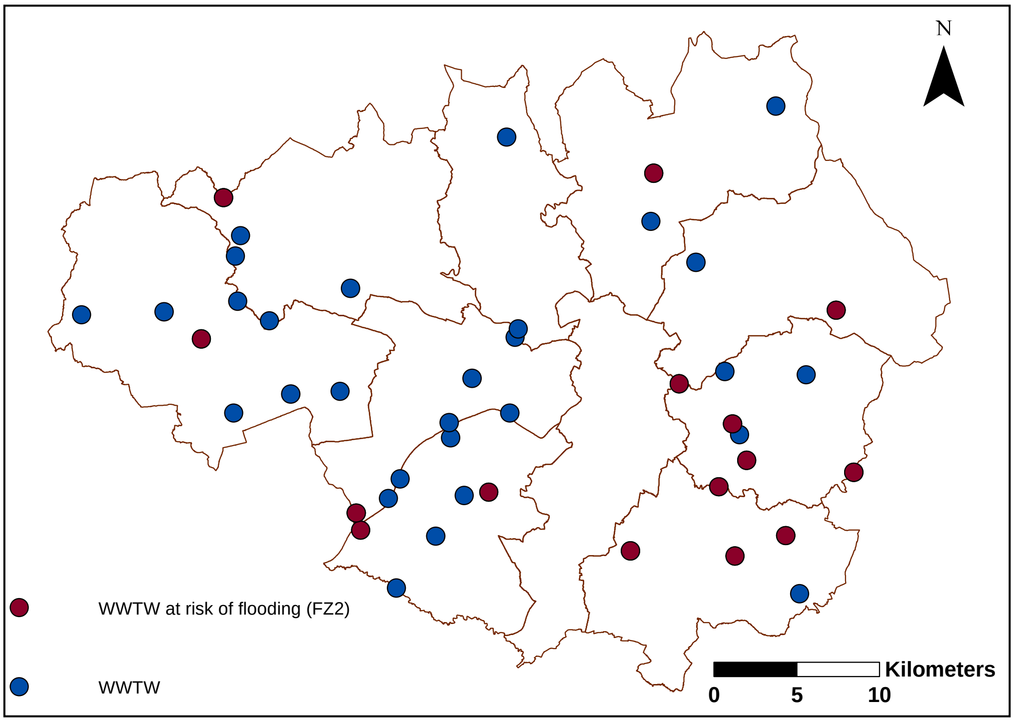
The findings of the assessment of the likelihood of hazard events affecting elements of GM's critical infrastructure (focusing on waste water treatments works (WWTW), and electricity sub-stations) are discussed below.

Flood Zones 2 and 3

No electricity sub-stations are included in Flood Zone 3 (the areas at highest risk of fluvial flooding). However, looking at Flood Zone 2, which encompasses areas covered by a lower frequency higher volume flooding event, 5 of 12 of GM's electricity sub-stations are potentially exposed. This analysis has not looked at the levels of flood protection provided to these sites, but it does suggest that electricity sub-stations that are not adequately protected are at threat under an extreme fluvial flooding event.

25% of GM's WWTW are situated within Flood Zone 3, with this figure rising to 34% when Flood Zone 2 is considered. Figure 13 plots the location of WWTW, highlighting those situated in Flood Zone 2. This analysis emphasises the potential for negative consequences linked to fluvial flooding where these assets are not projected.

Figure 13: Waste water treatment works (WWTW) potentially exposed to Flood Zone 2.



Surface water flooding

On the basis of this assessment, electricity sub-stations do not appear to be potentially exposed to surface water flooding. However, four WWTW (just under 10% of the total for GM) are located where there is potential for exposure to this form of flooding. This figure stays the same when climate change is factored into the surface water flooding model.

7. Weather and climate change impacts

A wide range of weather and climate impacts have the potential to affect GM. It is necessary to identify weather and climate impacts in order to assess the risk posed by these to the GMS themes. A review of relevant reports and literature, focusing where possible on those relating to North West England, identified some of the most prominent impacts. The review considered impacts stemming from the direct effect of hazards, concentrating on flooding and high temperatures. For example, looking at heat wave conditions in employment sites, impacts including negative effects on worker productivity were identified. The impacts reflect tangible and intangible losses, for example damage to buildings and psychological harm to victims of flooding.

Following this approach, a list of extreme weather and climate change impacts on the six GMS themes was developed. This is presented in Appendix 3. This list is not exhaustive, yet tries to capture key impacts of particular relevance to the GMS themes considered within this risk assessment. They are grouped into 4 categories; impacts on the built environment themes from flooding and heat, on critical infrastructure and on transport infrastructure. These are listed below, and cover some of the key impacts, linked to flooding (combining fluvial and surface water flooding) and heat waves, with the potential to affect GM. Each impact is given an abbreviation, and is numbered impact (I) 1 to 13.

Flooding impacts on built environment: residential housing, regional and town centres, employment growth sites and science and innovation assets

I1. Flood damage to buildings (residential, retail and commercial, public).

I2. Increased pressure on the emergency services during flood events.

I3. Negative health and wellbeing effects arising from flood events.

I4. Higher insurance premiums in areas prone to flooding.

Heat impacts on built environment: residential housing, regional and town centres, employment growth sites and science and innovation assets

I5. Reduction in worker productivity during heat waves.

I6. Health problems during heat wave events.

I7. Increased energy use during heat waves.

Flooding and heat impacts on critical infrastructure

I8. Disruption and loss of services from flooding of waste water treatment works, sewage pumping stations and sludge treatment facilities.

I9. Disruption to and loss of services from the effect of weather and climate hazards on electricity sub-stations and transmission equipment.

Flooding and heat impacts on transport infrastructure

I10. Reduction in transport network capacity (motorway, rail, metrolink) due speed restrictions, temporary loss of services and repair work caused by weather and climate hazards (flooding, buckling of rail lines etc).

I11. Knock-on congestion to other routes and forms of transport where transport disruption arises from weather and climate hazards.

I12. Heat stress affecting rail and metrolink passengers.

I13. Safety issues and some accidents (linked to aquaplaning, excessive spray) due to flooding on motorway network.

8. Assessing the consequences of weather and climate impacts

Assessing the magnitude of consequences of impacts is a key stage in the risk assessment process. As part of this project we involved relevant individuals from AGMA and other organisations from the region (listed in Appendix 1) within a workshop exercise to explore options and challenges linked this task. This confirmed that assessing the magnitude of consequence of impacts is a subjective process dependant on a wide range of factors including their scale, their frequency and duration and the degree to which measures are in place to moderate their effect. The workshop clarified that for this project, it is most appropriate to apply a simple approach to assessing the consequence of weather and climate change impacts.

A range of approaches have been applied by different organisations to assess the consequences of weather and climate impacts. Examples include:

- The ***United Utilities Climate Change Risk Assessment*** (United Utilities Water PLC 2011) involved workshops which engaged relevant experts from within the company to assess the consequence of climate change impacts for their business. This involved judging which of four degrees of consequence (severe, high, medium, low) a particular climate change impact was thought to fall into. Each of these different consequences was given a description. For example, a high consequence impact was described as: “High impact to corporate objectives. High level of stakeholder concern with a potential impact to shareholder value.”
- Within the ***Electricity Northwest Climate Change Risk Assessment*** (ENW 2011), the relative impact (or consequence) of climate change risks on the functions, mission, aims and objectives of the business was assessed qualitatively by an internal team on a five point scale; extreme, significant, moderate, minor, limited. These were given descriptions. For example, a risk of moderate impact was described as: “Large town or conurbation off supply for up to a week OR significant increase in cost of network strengthening.”
- The assessment of consequences within the ***UK’s Climate Change Risk Assessment*** (Defra 2012) was based around three magnitude classes, low, medium and high. Positive and negative consequences were included. Consequences were assessed for three time periods (2020’s, 2050’s, 2080s), and a level of confidence was ascribed to each assessment (high, medium, low). The assessment of the magnitude of consequences was principally informed by expert judgement.

It is clear from these examples that there is no definitive approach for assessing the consequences of impacts, although they tend to be qualitative in nature and informed by expert judgement. Quantitative approaches to assessing consequences are applied in some cases, for example within the field of disaster risk reduction. Here, estimates are made of numbers of injuries and deaths, properties destroyed, and financial costs associated with disasters (earthquakes, floods etc). These estimates are developed based on historical experiences of disasters coupled with the extrapolation of relevant trends such as demographic and land use change.

The approach to assessing the consequence of weather and climate impacts followed within this project is based on assessing the degree to which impacts could affect the achievement of the core priorities of the GMS. There are four of these (AGMA 2013):

1. Creating the conditions for growth.
2. Supporting GM's businesses.
3. Worklessness and skills.
4. Encouraging self-reliance and reducing demand for public services.

Based on these four priorities, and the supporting text within the consultation draft of the refreshed GMS, 7 related cross cutting issues were identified. These are representative of key issues with the potential to affect the achievement of the priorities of the GMS.

1. Quality and functioning of critical infrastructure.
2. Financial costs to public bodies, businesses and residents.
3. Health and wellbeing of citizens.
4. Employment prospects and job creation.
5. Business continuity.
6. Public service delivery.
7. GM's reputation as a city to live, work and invest in.

For each of the 13 weather and climate impacts (identified in Section 7), an assessment was made of whether it would have a direct affect on each of the 7 cross cutting issues outlined above. It is important to emphasise that in making this assessment, the focus was on the impacts of extreme weather and climate events. The outcomes of this assessment, undertaken by the UoM team, are provided in Table 8. This gives a broad sense of the magnitude of the consequences of the different impacts being assessed. Magnitude is deemed to be higher where the impact affects a wider range of the GMS cross cutting issues. Via this approach, each impact was placed into one of three consequence classes; low magnitude (consequence score of 1-2), medium magnitude (consequence score of 3-5) and high magnitude (consequence score of 6-7).

There are weaknesses with this approach, although these are issues that affect the assessment of the consequences of weather and climate impacts more generally. For example, consequences depend on the nature of the impact being assessed (including its scale and frequency) and the degree of preparedness for, and adaptation, to such impacts. Precise details of these issues are generally not easily available. However, the intention of this project is to highlight prominent risks to the GMS from weather and climate impacts. An assessment of the consequences of different impacts is needed to achieve this goal. In the following section we bring together the preceding assessments of likelihood and consequence to look at the risk of weather and climate impacts to the GMS themes included in this project.

Table 8: Assessment of the consequence of weather and climate change impacts on the GMS.

	Impact number												
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13
Quality and functioning of critical infrastructure								X	X	X	X		X
Financial costs to public bodies, firms and residents	X	X		X	X	X	X	X	X	X	X		
Health and wellbeing of citizens	X	X	X			X		X	X			X	X
Employment prospects and job creation	X			X						X	X		
Business continuity	X			X	X			X	X	X	X		
Public service delivery	X	X			X	X		X	X	X	X		
GM's reputation as a city to live, work and invest in	X		X	X				X	X	X	X		
Consequence score	**6**	**3**	**2**	**4**	**3**	**3**	**1**	**6**	**6**	**6**	**6**	**1**	**2**

9. Greater Manchester weather and climate change risk assessment

The risk assessment approach applied within this project is based on the following simple formula:

Risk = likelihood of a hazard occurring X consequence of impacts arising from the hazard

The outcomes of the assessment of the likelihood of hazard events and the consequences of impacts arising from these hazards are applied to assess the risk of weather and climate impacts to different GMS themes. The risk assessment output is based around the following matrix (Figure 14).

Figure 14: Risk assessment matrix.

Likelihood of occurrence of hazard	High (3)			
	Medium (2)			
	Low (1)			
		Low (1)	Medium (2)	High (3)
		Magnitude of consequence of impact for GMS		

Figure 14 places risks within three zones; red, orange and green. Depending on where specific risks are placed, different responses to managing and reducing risks will be appropriate.

- **Red Zone – High Risk:** Implement processes to 'ground-truth' the spatial assessment of weather and climate change risks, establishing where factors including local topography, land use and previous adaptation measures may reduce the level of actual risk. Promote active management to reduce residual risks (those that remain following the ground truthing exercise) through emergency planning and physical interventions to adapt buildings, infrastructure and urban landscapes to weather and climate hazards. Develop and implement long term adaptation strategies and practical responses to lessen risks projected to increase under climate change.
- **Orange Zone – Medium Risk:** Develop contingency plans to ensure that an appropriate emergency planning response is in place in the event of an extreme hazard event occurring. Frequently review risks, monitoring underlying conditions and issues influencing the likelihood of a hazard event occurring. Plan adaptation strategies and response, focusing particularly on those that would bring multiple benefits additional to managing weather and climate risks.
- **Green Zone – Low Risk:** Review risks periodically and establish processes to monitor underlying conditions and issues.

There follows a discussion of the risks from weather and climate impacts to the six GMS themes included in this process. Key thematic findings of the risk assessment can be summarised as:

- ***Housing development areas:*** Impacts linked to flooding, particularly fluvial flooding, pose a greater risk to housing development areas in GM than other hazards. However, with climate change and the increased likelihood of heat waves, there is the potential for negative impacts such as heat stress to vulnerable groups in areas where exposure to the urban heat island is highest.

- ***GM's regional centre and eight town centres:*** GM's regional centre and eight town centres each show a high level of risk to one or more weather and climate impact. Risks differ according to which area is considered, with each location having its own risk profile.

- ***Strategic employment locations:*** The broad picture is one of relatively low weather and climate risk to strategic employment locations. However, risk associated with extreme events (to this and the other themes considered) cannot be fully discounted due to variability in the climate system. Yet, there are high risks to certain sites, including those linked to fluvial flooding in Carrington and Port Salford and heat stress (particularly under climate change) in Hollingwood, Trafford Core and Wharfside.

- ***Transport infrastructure:*** Although there are clear risks to possible future transport investment sites from extreme weather and climate change, on balance these appear to be less widespread and of a lower magnitude than risks to existing transport infrastructure. These risks connect to the high likelihood of hazards, including flooding and heat stress, to certain stretches of the conurbation's transport network and related infrastructure assets such as stations.

- ***Science and innovation assets:*** The likelihood of fluvial flooding affecting the science and innovation assets assessed by this study is high. The risk of related impacts is therefore also generally high, particularly those with high consequences such as damage to buildings. Heat stress brings potential risks. Of particular concern are negative impacts on worker productivity, although based on current understanding it is under future climate change projections for the 2050s that this issue comes to the forefront.

- ***Critical infrastructure:*** The key hazard facing waste water treatment works and electricity sub-stations appears to be fluvial flooding. This especially concerns Flood Zone 2, which encompasses areas covered by a lower frequency higher volume flooding event. Related risks to water and electricity services and supplies have the potential to affect a wide range of sectors and groups of people, and therefore deserve further analysis.

9.1. Housing development areas

The GMS promotes a market facing strategy for future housing development, with growth appearing to be most likely in areas where the housing market has remained relatively robust. This risk assessment (visualised in Table 9) indicates that impacts linked to flooding, particularly fluvial flooding, pose a greater risk to housing development areas in GM than other weather and climate hazards. This is especially the case in locations potentially exposed to Flood Zone 3, where the chance of flooding is greater. Housing development area type 3 (mixed deprivation/strong market) stands out as being most highly exposed to potential fluvial flooding, especially to Flood Zone 2. This increases the risk of flooding impacts in these areas, for example those concerning flood damage to buildings and resulting higher insurance premiums.

According to this analysis, the magnitude of the consequences of impacts linked to high temperatures in housing developments is generally lower than for flooding impacts. Similarly, the likelihood of heat wave events is lower than flood events, particularly in the present day. Hence, the risk of impacts stemming from high temperatures appears lower relative to flooding impacts. However, as climate change will bring an increased likelihood of heat waves, housing development area types 3, 5 and 6, where potential exposure to the urban heat island is high in comparison to other areas of GM, the risk of negative health impacts to vulnerable groups appears to be high.

Table 9: Risk of weather and climate change impacts to housing development area types.

		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
I1	FZ2+3	High	High	High	High	High	High
	SWF	High	High	High	High	High	High
I2	FZ2	Medium	Medium	High	Medium	Medium	Medium
	FZ3	High	High	High	High	High	High
	SWF	Medium	Medium	Medium	Medium	Medium	Medium
I3	FZ2	Low	Low	Medium	Low	Low	Low
	FZ3	Medium	Medium	Medium	Medium	Medium	Medium
	SWF	Low	Low	Low	Low	Low	Low
I4	FZ2	Medium	Medium	High	Medium	Medium	Medium
	FZ3	High	High	High	High	High	High
	SWF	Medium	Medium	Medium	Medium	Medium	Medium
I6	HW	Low	Low	Medium	Low	Medium	Medium
	HW+cc	Medium	Low	High	Medium	High	High
I7	HW	Low	Low	Low	Low	Low	Low
	HW+cc	Low	Low	Medium	Low	Medium	Medium

KEY

I1 – Flood damage to buildings (residential, retail and commercial, public)
I2 – Increased pressure on emergency services during flood events
I3 - Negative health and wellbeing effects arising from flood events
I4 – Higher insurance premiums in areas prone to flooding
I6 – Health problems during heat wave events
I7 - Increased energy use during heat wave events

FZ2+3: Flood Zones 2 and 3
SWF: Surface Water Flooding
HW: Heat Wave
HW+cc: Heat Wave with Climate Change

High risk | **Medium risk** | **Low risk**

9.2. Regional centre and town centres

The GMS highlights that town centres are crucial to GM's communities, yet points out that they are suffering from fundamental challenges including competition from out-of-town shopping centres and shifts to online shopping. The regional centre is crucial not just for GM, but more broadly for North West England and a whole, and faces similar challenges linked to changing market conditions. One of the key priorities of the GMS is to; "Create a blueprint for our town centres, applying creative approaches to the redevelopment of the offer."

A recent report from the Planning and Housing Commission on the outcomes of the GM Town Centres Project emphasises that GM's eight principal town centres face a diverse set of challenges and opportunities, and that strategic interventions to strengthen them will differ from place to place. Table 10 suggests that the risk of impacts linked to extreme weather and climate change should be added to the list of challenges facing these locations. Table 10 also clarifies that these risks differ according to which area is considered, with the regional centre and eight town centres each having its own risk profile. For example, due to their location, risks linked to fluvial flooding in Altrincham and Oldham are very small. Similarly, risks connected to high temperatures and heat waves in Bolton, Rochdale and Wigan appear to be lower than for other town centres in GM.

Table 10: Risk of weather and climate change impacts to GM's regional centre and town centres.

		Regional Centre	Altrincham	Ashton	Bolton	Bury	Oldham	Rochdale	Stockport	Wigan
I1	FZ2+3	High risk	Low risk - no potential exposure	High risk	High risk	High risk	Low risk - no potential exposure	High risk	High risk	High risk
	SWF	High risk	High risk	High risk	High risk	High risk	High risk	High risk	High risk	High risk
I2	FZ2+3	High risk	Low risk - no potential exposure	Medium risk	Medium risk	Medium risk	Low risk - no potential exposure	High risk	High risk	High risk
	SWF	Medium risk	Medium risk	Medium risk	High risk	Medium risk	Medium risk	High risk	Medium risk	High risk
I4	FZ2+3	High risk	Low risk - no potential exposure	Medium risk	Medium risk	Medium risk	Low risk - no potential exposure	High risk	High risk	High risk
	SWF	Medium risk	Medium risk	Medium risk	High risk	Medium risk	Medium risk	High risk	Medium risk	High risk
I5	HW	Medium risk	Medium risk	Medium risk	Low risk	Medium risk	Medium risk	Low risk	Medium risk	Low risk
	HW+cc	High risk	High risk	High risk	Low risk	High risk	High risk	Low risk	High risk	Low risk
I6	HW	Medium risk	Medium risk	Medium risk	Low risk	Medium risk	Medium risk	Low risk	Medium risk	Low risk
	HW+cc	High risk	High risk	High risk	Low risk	High risk	High risk	Low risk	High risk	Low risk
I7	HW	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
	HW+cc	Medium risk	Medium risk	Medium risk	Low risk	Medium risk	Medium risk	Low risk	Medium risk	Low risk

KEY

I1 – Flood damage to buildings (residential, retail and commercial, public)
I2 – Increased pressure on emergency services during flood events
I4 – Higher insurance premiums in areas prone to flooding
I5 – Reduction in worker productivity during heat waves
I6 – Health problems during heat wave events
I7 - Increased energy use during heat wave events

FZ2+3: Flood Zones 2 and 3
SWF: Surface Water Flooding
HW: Heat Wave
HW+cc: Heat Wave with Climate Change

High risk | **Medium risk** | **Low risk** | **Low risk - no potential exposure**

9.3. Strategic employment sites

The ten strategic employment sites assessed are locations where current activity and/or future growth plans are significant for employment and wealth creation in GM. Hence, these locations are likely to exert a large influence on the achievement of the GMS goal to encourage sustainable economic growth. Risks to these sites from weather and climate impacts are outlined in Table 11.

The broad picture is one of relatively low risk to these locations, although risk associated with unexpected extreme weather and climate events cannot be fully discounted. It is positive that seven of the ten sites are not situated in Flood Zones 2 or 3, and hence the risk of related flooding impacts is low. The potential exposure of the ten sites to surface water flooding is at a level around the average for GM. However, surface water flooding is an unpredictable and spatially diffuse hazard, with potential exposure wide spread across GM. Six sites show limited potential exposure to the urban heat island, which lessens considerably the risk of impacts linked to heat waves.

Nevertheless, significant weather and climate change risks do remain to certain strategic employment sites. The risk of impacts linked to fluvial flooding in Carrington and Port Salford, particularly damage to buildings, stands out as a prominent concern. Three of the sites (Hollingwood, Trafford Core and Wharfside) show above average potential exposure to GM's urban heat island, raising the risk of impacts linked to heat stress such as reduced worker productivity.

Table 11: Risk of weather and climate change impacts to strategic employment sites in GM.

		Manchester Airport	Airport City	Airport Strategic Site	Carrington	Cutacre	Hollinwood	Kingsway	Port Salford	Trafford Core	Wharfside
I1	**FZ2+3**	FZ2: Medium; FZ3: High	No exposure	No exposure	High	No exposure	No exposure	No exposure	High	No exposure	No exposure
	SWF	High	High	High	High	High	High	High	High	Medium	Medium
I2	**FZ2+3**	FZ2: Low; FZ3: Medium	No exposure	No exposure	High	No exposure	No exposure	No exposure	High	No exposure	No exposure
	SWF	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low
I4	**FZ2+3**	FZ2: Low; FZ3: Medium	No exposure	No exposure	High	No exposure	No exposure	No exposure	High	No exposure	No exposure
	SWF	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low
I5	**HW**	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	Medium	Low	No exposure	Medium	Medium
	HW+cc	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	High	Low	No exposure	High	High
I6	**HW**	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	Medium	Low	No exposure	Medium	Medium
	HW+cc	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	High	Low	No exposure	High	High
I7	**HW**	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	Low	Low	No exposure	Low	Low
	HW+cc	Dark shading	Dark shading	Dark shading	Dark shading	Dark shading	Medium	Low	No exposure	Medium	Medium

KEY

I1 – Flood damage to buildings (residential, retail and commercial, public)
I2 – Increased pressure on emergency services during flood events
I4 – Higher insurance premiums in areas prone to flooding
I5 – Reduction in worker productivity during heat waves
I6 – Health problems during heat wave events
I7 - Increased energy use during heat wave events

FZ2+3: Flood Zones 2 and 3
SWF: Surface Water Flooding
HW: Heat Wave
HW+cc: Heat Wave with Climate Change

High risk | **Medium risk** | **Low risk** | **Low risk - no potential exposure**

9.4. Transport infrastructure

An efficient and effective transport infrastructure network is crucial to GM's competitiveness and future growth prospects. This is recognised by the GMS, and its priorities include improving GM's transport connectivity to strengthen labour market prospects, in addition to planning for and investing in critical infrastructure (including transport infrastructure) needed to support growth. The GMS notes that infrastructure investment will take place in a coordinated and place-based manner. Planned investments are highlighted in the GMS, including a package of programmes linked to the £1.5 billion Greater Manchester Transport Fund. These include metrolink extensions, new busways and new road schemes.

An assessment of the likelihood of weather and climate hazards affecting a range of these transport infrastructure proposals is summarised in Section 6.4. This highlights the high likelihood of fluvial flooding (from Flood Zone 3) to schemes including the Leigh busway and the Wigan IRR region, and of heat waves under climate change to schemes including the cross city metrolink extension. Planned railway stations are also threatened by flooding. The high likelihood of these hazards brings clear risks to possible future transport investments and the services that they provide, including loss of capacity and knock-on congestion to other forms of transport. Although these require further investigation and possible adaptation action in certain areas where the risk of impacts is highest, on balance risk appear to be less widespread and of a lower magnitude than risks to existing transport infrastructure.

Risks to GM's existing transport infrastructure networks and assets from weather and climate impacts connect to the high likelihood of hazards, including flooding and heat stress, to certain parts of the conurbation's transport system. Surface water flooding is a threat to the network lines included in this analysis (railways, motorways and four metrolink lines), with levels of potential exposure well above the GM average in each case. In the event of a severe surface water flooding incident, the risk of impacts to the transport system and the services it provides is high. These include safety risks on flooded motorways, in addition to a reduction and in some cases loss of certain services which would have implications across a range of sectors. The likelihood of fluvial flooding (from Flood Zone 3), and hence also the risk of high consequence associated impacts, is high to the railway and motorway network, but less so to metrolink lines. However, metrolink lines, which generally connect and run through urbanised areas of GM, are more likely to experience high temperatures under heat wave conditions. This is particularly the case when climate change is factored in over the coming decades, which may lead to impacts including buckling of lines and heat stress to passengers.

9.5. Science and innovation assets

A stated priority of the GMS is to leverage GM's science and technology assets to support ambitions for the conurbation to compete globally in emerging sectors. The GMS notes that science and technology, and research and development are at the heart of GM's plans for growth. This study looked at the likelihood of flooding and heat wave events affecting a series of key science and innovation assets from across GM. Given the significance of these assets, the occurrence of weather and climate change impacts including damage to buildings from flooding and the negative effects of heat stress on the productivity of staff, are of real concern.

Data was provided by AGMA on the post codes housing key science and innovation assets. There were 42 assets in total, of which 13 are situated in the Oxford Road Corridor (the Corridor). This emphasises the strategic importance of the Corridor in this respect, which was considered separately within this study. Looking at the 29 sites outside the Corridor as a group, risks linked to surface water flooding are prevalent given the high consequence of related impacts. The likelihood of fluvial flooding to the group of 29 science and innovation assets is assessed as high. The risk of impacts linked to this form of flooding, particularly those with high consequences such as damage to buildings, is therefore high. Over 50% of the area covered by the postcodes containing the 29 sites have temperatures 1^{o}C or above the GM average, placing these areas at higher risk of impacts linked to heat stress should a heat wave event occur. Of particular concern are negative impacts on worker productivity, although based on current understanding, it is under future climate change projections for the 2050s that this issue comes to the forefront.

The Corridor represents a strategically important site in Manchester, and is a key element of the growth aspirations of the city. It is referred to as the 'backbone of the city's knowledge economy' with over 40% of activity falling within this field, which is close to double the national average. Around 55000 people work in the corridor (18% of the city's total), and it is hoped that this figure could rise to 77000 by 2020. Currently the Corridor contributes £2.8 billion (22.5% of the city's Gross Value Added – GVA), with the aim of raising this figure to £4.7 billion by 2020[7].

According to this risk assessment process, there is a high risk of flood damage to buildings (from fluvial and surface water flooding) in the Corridor. Other risks linked to flooding, including pressure on emergency services and raised insurance premiums, are higher for fluvial flooding (as the Corridor has high potential exposure to Flood Zones 2 and 3) than for surface water flooding (where levels of potential exposure are around the GM average). Heat stress is a potential threat to the Corridor. Nearly 90% of the area is potentially exposed to temperatures 1^{o}C or above the GM average, increasing the likelihood of high temperatures during heat wave events in this location, particularly under climate change. This raises the level of risk associated with heat wave impacts, including reduction in worker productivity and health problems.

[7] The figures in this summary are taken from the Corridor Partnership's Strategic Vision to 2020.

9.6. Critical infrastructure

The GMS emphasises the importance of ensuring that energy and water infrastructure (amongst other forms including digital and transport infrastructure) is in place to support growth. The provision of infrastructure is central to the market-facing strategy for growth and investment outlined within the GMS. Consequently, one of the core priorities outlined within the GMS is to plan for and deliver the necessary investment in critical infrastructure to support growth.

Risks to transport infrastructure were discussed above. Within this project, weather and climate change risks to waste water treatment works (WWTW) and electricity sub-stations were also assessed. Section 8 points to the high magnitude of consequences of weather and climate impacts to these forms of infrastructure. Disruption and/or loss of water supply and wastewater treatment services, and those linked to electricity sub-stations, has the potential to negatively affect a wide range of sectors and groups of people. The key hazard facing WWTWs and electricity sub-stations appears to be fluvial flooding, especially concerning Flood Zone 2 which encompasses areas covered by a lower frequency higher volume flooding event. Although no electricity sub-stations are within Flood Zone 3, almost half of GM's sub-stations are located in Flood Zone 2. One quarter of GM's WWTWs are situated within Flood Zone 3, with this figure rising slightly when Flood Zone 2 is considered. It is clear that given the high magnitude of related consequences, risks linked to fluvial flooding threaten GM's economic competitiveness. A process of ground-truthing the actual level of risk to these critical infrastructure assets is needed.

10. Conclusions and recommendations

10.1. Conclusions

- Climate change risk assessments have become more common in recent years. The UK Climate Change Risk Assessment published in 2012 standing out as the most prominent of these to date in this country. This report builds on this emerging body of risk assessment work. It is guided by a widely used risk assessment approach, which is based around assessing the likelihood and consequence of risks. Many organisations from the public and private sectors assess risk in this way. The approach set out in this report is replicable, and could be used to assess additional weather and climate change risks to GM in the future.

- Extreme weather and climate change is a threat to quality of life and economic competitiveness in cities. The focus of this report is on risks to the GMS, and its goal of promoting sustainable economic growth, from weather and climate change impacts. Given the spatial focus of this project, particular attention is paid to GMS themes that can be mapped such as town centres and transport infrastructure. GM can react proactively in response to the real challenges and potential opportunities posed by weather and climate risks. This report has enhanced understanding of these risks locally, and supports the task of prioritising related actions and strategies to reduce these risks in GM.

- Key weather and climate change hazards facing GM include flooding and heat stress. Flooding is a threat both now and in the future, with surface water flooding (as opposed to fluvial flooding from main rivers) currently standing out as the most frequent form of flooding occurring in GM. With climate change projections pointing towards an increase in extreme rainfall events, without an effective adaptation response, floods risks becoming a greater problem for GM over the coming decades. Heat stress is not common in GM at present, but is projected to become more significant in the future under climate change. In addition to these hazards, it is also important for GM to acknowledge the potential implications of climate change globally for residents and businesses locally. These international implications are not considered as part of this project, but deserve further attention as part of additional studies on weather and climate change risk in GM.

- The EcoCities project identified that more than two-thirds of the impacts of weather and climate events in GM, recorded within sources including the print media and emergency services logs, resulted from floods and storms. These sources also suggest that, in GM, critical infrastructure and health and wellbeing are particularly susceptible to weather and climate events. As the climate changes, raising the frequency and intensity of some hazards and introducing new threats, the nature of these impacts will alter. Monitoring is necessary to identify shifts in weather and climate impacts in GM, which will strengthen capacity to respond accordingly.

- A key theme of this report, and the project that underpinned it, is the spatial approach taken to assessing risk. This has strongly influenced the conclusions that have been reached, and has built understanding of assessing and interpreting the spatial nature of weather and climate change risks at the conurbation scale. Many weather and climate hazards are highly place specific. This is clear in terms of flooding from rivers for example, which only has the potential to affect certain areas of GM. It is also apparent that particular parts of the conurbation are threatened by heat stress and surface water flooding to a greater or lesser extent. This is due to factors including local topography, building density and land cover. As a consequence, the likelihood of weather and climate hazards impacting on, say, a series of strategic employment sites, differs significantly depending on their location.

- This project has drawn together spatial data on weather and climate hazards, and potential receptors of those hazards that can be viewed spatially, to better understand related risk to themes linked to the GMS. This has revealed the spatial diversity of certain weather and climate change risks across GM, highlighting the value of taking a spatial approach to assessing them. To use an example, the likelihood of fluvial flooding (from Flood Zones 2 and 3) in GM's eight principal town centres differs significantly. This is because potential exposure to this form of flooding is greater in some town centres (e.g. Rochdale, Stockport and Wigan) than others (e.g. Altrincham and Oldham). Where the consequence of impacts linked to fluvial flooding is high, such as damage to buildings, the corresponding level of risk from this impact will be higher in town centres such as Rochdale, but lower in Oldham. Insights such as this can support additional spatially targeted policy, action and research into weather and climate risks in GM.

- The goal of this project has been to identify where the risk of weather and climate change impacts to selected GMS themes is greatest. This assessment is based on the chance of the event occurring, the level of potential exposure of particular areas and assets to these events should they happen, and the magnitude of the consequences of related impacts. Several headline outcomes have emerged from this process:

    - ***Housing development areas:*** Impacts linked to flooding, particularly fluvial flooding, pose a greater risk to housing development areas in GM than other hazards. However, with climate change and the increased likelihood of heat waves, there is the potential for negative impacts such as heat stress to vulnerable groups in areas where exposure to the urban heat island is highest.

    - ***GM's regional centre and eight town centres:*** GM's regional centre and eight town centres each show a high level of risk to one or more weather and climate impact. Risks differ according to which area is considered, with each location having its own risk profile.

    - ***Strategic employment locations:*** The broad picture is one of relatively low weather and climate risk to strategic employment locations. However, risk associated with extreme events (to this and the other themes considered) cannot be fully discounted due to variability in the climate system. Yet, there are high risks to certain sites, including those linked to fluvial flooding in Carrington and Port Salford and heat stress (particularly under climate change) in Hollingwood, Trafford Core and Wharfside.

- ***Transport infrastructure:*** Although there are clear risks to possible future transport investment sites from extreme weather and climate change, on balance these appear to be less widespread and of a lower magnitude than risks to existing transport infrastructure. These risks connect to the high likelihood of hazards, including flooding and heat stress, to certain stretches of the conurbation's transport network and related infrastructure assets such as stations.

- ***Science and innovation assets:*** The likelihood of fluvial flooding affecting the science and innovation assets assessed by this study is high. The risk of related impacts is therefore also generally high, particularly those with high consequences such as damage to buildings. Heat stress brings potential risks. Of particular concern are negative impacts on worker productivity, although based on current understanding it is under future climate change projections for the 2050s that this issue comes to the forefront.

- ***Critical infrastructure:*** The key hazard facing waste water treatment works and electricity sub-stations appears to be fluvial flooding. This especially concerns Flood Zone 2, which encompasses areas covered by a lower frequency higher volume flooding event. Related risks to water and electricity services and supplies have the potential to affect a wide range of sectors and groups of people, and therefore deserve further analysis.

- Supportive adaptation policies, and resulting targeted strategies and actions, can help to equip GM for the changing climate patterns that look set to influence its future growth and competitiveness. There are opportunities to be gained, in addition to risks avoided, from developing a planned, strategic and spatially targeted adaptation response for the conurbation. These include stimulating local employment linked to implementing adaptation responses and capturing the multiple environmental, economic and social benefits that some adaptation measures (for example green infrastructure) can generate.

10.2. Recommendations

10.2.1. Thematic recommendations

There follows a series of recommendations that focus on the six GMS themes forming the basis of this risk assessment:

- The provision of safe and secure housing is key to GM's future growth and prosperity. The risk of flooding to housing developments and their residents is therefore of real concern. A spatially informed approach to identifying and responding to flood risk is needed, encompassing the existing housing stock and prospective future development sites. This report provides some insights into how this can be done, and suggests housing development area types where risks are most prevalent. This report supports existing and ongoing studies into flood risk in GM, and builds the case for putting flood risk management at the heart of housing development plans, policies and guidance alongside other core agendas. Developing approaches within the spatial planning system to reduce weather and climate risks to the current and future housing stock can bolster GM's ambitions for future growth and development under a changing climate.

- Strategies designed to strengthen and redevelop GM's regional centre and eight principle town centres could usefully recognise the varying patterns of weather and climate change risks that they face. Locally appropriate measures to adapt these areas for the changing climate are needed. Focusing on risks that this study suggests are most significant would provide a good starting point. Given the potential impacts of extreme weather and climate change on people and properties in these areas, coupled with their importance for future growth prospects, indicates that a planned, collaborative and strategic adaptation response is necessary at this scale.

- Further investigation of the strategic employment sites that this report highlights as showing high risk of weather and climate change impacts is warranted. Following on from this project, additional studies can now focus on particular sites and specific risks in more detail. Given the strategic importance of the sites included in this analysis, incorporating measures such as sustainable urban drainage and enhancing green cover in new developments and re-developments would be valuable where this is practical.

- The focus of the GMS is on future transport investment priorities, some of which this assessment has shown are at risk from weather and climate impacts. These risks should be investigated in more detail, and action taken to reduce them where further studies show this is appropriate. However, given that risks to the existing transport network appear to be more prevalent, strategies to build resilience to weather and climate extremes are also needed here. There are real risks to this sector, including disruption to services, damage to infrastructure and knock-on effects such as congestion to parts of the transport network, which have the potential to negatively affect GM and its residents.

- The risk of fluvial flooding impacts to the science and innovation sites covered by this study is high. More detailed investigations are needed to establish the extent to which specific sites within the post codes assessed are actually exposed to this form of flooding. Their strategic importance to GM's growth strategy suggests that this would be a useful exercise following on from this project. Although the sites studied are exposed to surface water flooding at a level close to the GM average, it would be valuable to look at this hazard in more detail on a site-by-site basis given the damage that can be cause by this unpredictable form of flooding. Further, long term strategies to reduce the threat of heat stress in the Corridor also advisable given its strategic significance and its high potential exposure to heat stress. Taking opportunities to implement adaptation responses in, on and around buildings and infrastructure in key science and innovation sites would support the process of equipping them for a changing climate.

- The key hazard facing the WWTWs and electricity sub-stations included in this study appears to be fluvial flooding. An important next step is to assess the levels of flood protection provided to these critical infrastructure instillations to determine the residual risk under an extreme fluvial flooding event. There is a range of additional infrastructure assets and networks, from digital infrastructure to telecoms, at risk from weather and climate change hazards. A comprehensive study of risks to a wider range of critical infrastructure would be valuable.

10.2.2. Cross-cutting recommendations

In addition to the thematic recommendations outlined above, this project has generated a series of cross-cutting recommendations relating to understanding and responding to weather and climate risk in GM. These can be summarised as:

- Where it is practical and appropriate, promote a spatial approach to understanding and responding to weather and climate risk.
- Encourage the development of cross-sector collaborative responses to weather and climate risks.
- Explore the connections between adaptation to climate change in GM and broader themes linked to making cities more resilient.

A spatial approach to understanding and responding to weather and climate risk

Given the spatial nature of many weather and climate change hazards, if data and resources are available, there is real value in assessing related risks spatially. There are important caveats that come with this approach. These include that it is not possible to be clear where unpredictable extreme events may occur; the chance of an extreme surface water flooding event happening in any part of the conurbation cannot be completely discounted. Further, not all weather and climate change hazards can be readily mapped. This is difficult in the case of storms and high winds for example. Despite these issues, the spatially focused assessment provided by this project offers valuable local insights on significant weather and climate risk, and can help to more effectively target resources available to address these risks in GM.

Crucially, this project lays the foundations for more detailed investigations of high priority weather and climate change risk at a local scale. It was not intended that this study consider whether features are in place to reduce exposure to a particular hazard in a defined location, such as surface water flooding to a strategic employment site. More detailed on-site investigations, considering features including local topography, the existence of adaptation measures (e.g. flood defences) and land cover (e.g. green spaces in the area), are needed to determine whether potential exposure to a hazard in fact equates to actual exposure that could generate negative impacts and risks.

Particular sectors that can benefits from this approach include emergency planning and spatial planning, both of which are central to climate change adaptation in GM. Emergency planning has a role to play in preparing for and responding to the impacts of extreme weather events should they occur. An improved understanding of where weather and climate change risks are most prevalent can support the development of more spatially focused emergency response plans. Spatial planning is central to the development of long term proactive adaptation responses, potentially reducing the need for an emergency response. In particular, this report highlights the influence of land cover on the environmental processes that affect local climate. The STAR tools case studies outlined in Section 6 demonstrate that increasing urban density raises maximum surface temperatures and runoff rates whilst reducing density (and increasing green cover) has the opposite effect. The spatial planning system stands out as a key mechanism to modify the development and use of land to reduce weather and climate risk. Local Plans and planning responses to proposals for new development can apply learning on weather and climate change risk locally to underpin a more robust evidence base to support policies and decisions.

Cross-sector collaborative adaptation responses

Six themes linked to the GMS were included in this risk assessment; housing, regional centres and town centres, employment locations, transport infrastructure, science and innovation assets and energy and water infrastructure. This report identifies examples of areas and assets from each theme where the risk of weather and climate impacts is high, both in the present day and under climate change. Although it is not been explored within this project, there are strong connections linking the different themes. For example, the impacts of weather and climate extremes on the transport system will reach across communities, business and public services that rely on its efficient operation. This introduces the issue of cascading impacts, where an extreme event can affect a particular area or asset with knock-on implications for other interdependent sectors. The breadth of themes at risk from weather and climate change impacts, and the scope of the connections between them, indicates that an integrated cross-sector adaptation strategy is needed in response. This should be collaborative in nature, requiring good communication, sharing of information and the development of joint actions.

Adaptation and resilience in Greater Manchester

Hazards linked to extreme weather and climate change have the potential to affect the health and wellbeing of GM's residents and the competitiveness of its economy. The United Nations Office for Disaster Risk Reduction (UNISDR) recognises that cities are threatened by the changing climate, and has launched a global campaign focused on 'Making Cities Resilient.' This broadens the scope of climate change adaptation. The UNISDR defines resilience as:

> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."[8]

[8] http://www.unisdr.org/we/inform/terminology

A recent report from the UNISDR establishes that within cities and urban areas, disaster risk reduction, adapting to climate change and promoting sustainable development are inseparable, and that a ‘resilient city’ is one that addresses these themes in an interconnected manner (UNISDR 2012). Seen in this way, adaptation strategies and actions can be positioned as playing a central role in building capacity to support the effective functioning of GM over the coming decades. Climate change adaptation has, to date, been unable to find a position alongside headline agendas that exert a strong influence over city planning and policy making, such as economic growth and social welfare. This report highlights that weather and climate extremes in fact pose significant risks to these headline agendas in GM. In order to bring adaptation closer to the mainstream, developing a broader understanding of how it links to making cities resilient would be a valuable step forward.

11. Acknowledgements

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Appendix 1: List of attendees to the 20th February 2013 project workshop

Name	Organisation
Roger Milburn	GM LEP
Richard Sharland	Manchester City Council
Michael Hemmingway	Salford City Council
David Hodcroft	GM Planning and Housing Team
Anne Morgan	GM Planning and Housing Team
Jill Holden	GM Planning and Housing Team (Flood Risk)
Lex Massey	GM Environment Team
Becca Heron	GM Integrated Support Team (GMS)
Anna McDonald-Hughes	GM Integrated Support Team (Low Carbon/Environment)
Susan Ford	GM Integrated Support Team (LEP)
Brian Morrow	United Utilities
Caroline Duckworth	Climate Ready
Bob Bailey	Quantum
Jeremy Carter	University of Manchester
Dan Griffiths	Climate Ready
Ian Povey	Electricity North West
Kathy Oldham	GM Civil Contingencies and Resilience Unit
Susan Ford	GM New Economy
Alison Gillespie	GM New Economy
Simon Warburton	Transport for Greater Manchester

Appendix 2: Detailed results on assessment of likelihood of hazards

This appendix presents the detailed results of the assessment of likelihood of hazard events to the six GMS themes forming the basis of this project. In each case, data on the potential exposure of areas, assets and infrastructures to different weather and climate change hazards is presented. Based in the average potential exposure across GM to the different hazards, an assessment is made of the level of potential exposure (as described in Section 5.3.2). Potential exposure is rated on a scale of 1-3 where, 1=low (L), 2=medium (M), 3=high (H). The chance of the hazard event is rated using the same scale. The chance and potential exposure scores are multiplied together to provide an assessment of likelihood, the results of which can be interpreted using the following matrix where;

- Low likelihood (L) = 1,2
- Medium likelihood (M) = 3,4
- High likelihood (H) = 6,9

Potential exposure to the hazard				
	High (3)	M-3	H-6	H-9
	Medium (2)	L-2	M-4	H-6
	Low (1)	L-1	L-2	M-3
		Low (1)	Medium (2)	High (3)
		Chance of a hazard event occurring		

Housing wards type

Surface water flooding (current)

Housing wards type	Potential exposure (m^2)	Potential exposure (km^2)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
1	8626055	8.63	2.76	M-2	M-2	M-4
2	15514475	15.51	2.91	M-2	M-2	M-4
3	925458	0.93	2.50	M-2	M-2	M-4
4	8215559	8.22	2.95	M-2	M-2	M-4
5	854350	0.85	2.33	M-2	M-2	M-4
6	1982504	1.98	2.57	M-2	M-2	M-4

Surface water flooding (with climate change)

Housing wards type	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
1	11348471	11.35	3.63	M-2	M-2	M-4
2	20562703	20.56	3.86	M-2	M-2	M-4
3	1329687	1.33	3.59	M-2	M-2	M-4
4	11027549	11.03	3.95	M-2	M-2	M-4
5	1110007	1.11	3.03	M-2	M-2	M-4
6	2685566	2.69	3.48	M-2	M-2	M-4

Flood Zone 2

Housing wards type	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
1	23443407	23.44	7.51	M-2	M-2	M-4
2	31224344	31.22	5.85	M-2	M-2	M-4
3	4279727	4.28	11.56	H-3	M-2	H-6
4	203017667	20.30	7.27	M-2	M-2	M-4
5	2787979	2.79	7.61	M-2	M-2	M-4
6	5244791	5.24	6.79	M-2	M-2	M-4

Flood Zone 3

Housing wards type	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
1	16814563	16.81	5.38	M-2	H-3	H-6
2	20086987	20.09	3.77	M-2	H-3	H-6
3	3303095	3.30	8.92	H-3	H-3	H-9
4	12581114	12.58	4.50	M-2	H-3	H-6
5	2440449	2.44	6.65	M-2	H-3	H-6
6	3613529	3.61	4.69	M-2	H-3	H-6

Heat wave

Housing wards type	Area potentially exposed to > 1°C above GM mean (m²)	Area potentially exposed to > 1°C above GM mean (km²)	% of area potentially exposed to > 1°C above GM mean	Potential exposure level	Chance of event - current	Likelihood – current	Chance of event - future	Likelihood - future
1	23369829	23.37	7.48	M-2	L-1	L-2	M-2	M-4
2	30295857	30.30	5.68	L-1	L-1	L-1	M-2	L-2
3	36924248	15.59	42.09	H-3	L-1	M-3	M-2	H-6
4	15588743	36.92	13.21	M-2	L-1	L-2	M-2	M-4
5	15721124	15.72	42.90	H-3	L-1	M-3	M-2	H-6
6	30804126	30.80	39.88	H-3	L-1	M-3	M-2	H-6

Regional centre and town centres

Surface water flooding (current)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Regional Centre	390444	0.39	2.30	M-2	M-2	M-4
Altrincham	5433	0.01	1.75	M-2	M-2	M-4
Bolton	82112	0.08	6.41	H-3	M-2	H-6
Oldham	21204	0.02	2.62	M-2	M-2	M-4
Stockport	5387	0.01	2.51	M-2	M-2	M-4
Ashton	28255	0.03	3.11	M-2	M-2	M-4
Bury	55093	0.06	4.11	M-2	M-2	M-4
Rochdale	77308	0.08	8.18	H-3	M-2	H-6
Wigan	65499	0.07	4.64	H-3	M-2	H-6

Surface water flooding (with climate change)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Regional Centre	579306	0.58	3.41	M-2	M-2	M-4
Altrincham	8180	0.01	2.63	M-2	M-2	M-4
Bolton	116097	0.12	9.07	H-3	M-2	H-6
Oldham	25582	0.03	3.17	M-2	M-2	M-4
Stockport	5829	0.01	2.72	M-2	M-2	M-4
Ashton	35407	0.04	3.89	M-2	M-2	M-4
Bury	75269	0.08	5.61	M-2	M-2	M-4
Rochdale	105912	0.11	11.21	H-3	M-2	H-6
Wigan	90225	0.09	4.64	M-3	M-2	H-6

Flood Zone 2

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Regional Centre	2278683	2.28	13.4	H-3	M-2	H-6
Altrincham	0	0	0	L-0	M-2	L-0
Bolton	85474	0.09	6.67	M-2	M-2	M-4
Oldham	0	0	0	L-0	M-2	L-0
Stockport	23938	0.02	11.17	H-3	M-2	H-6
Ashton	73500	0.07	8.08	M-2	M-2	M-4
Bury	63192	0.06	4.71	M-2	M-2	M-4
Rochdale	120515	0.12	12.76	H-3	M-2	H-6
Wigan	369012	0.37	26.12	H-3	M-2	H-6

Flood Zone 3

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Regional Centre	1482202	1.48	8.74	H-3	H-3	H-9
Altrincham	0	0	0	L-0	H-3	L-0
Bolton	19607	0.02	1.53	L-1	H-3	M-3
Oldham	0	0	0	L-0	H-3	L-0
Stockport	12015	0.01	5.61	M-2	H-3	H-6
Ashton	3888	0.004	0.43	L-1	H-3	M-3
Bury	14181	0.01	1.06	L-1	H-3	M-3
Rochdale	95717	0.10	10.13	H-3	H-3	H-9
Wigan	169416	0.17	11.99	H-3	H-3	H-9

Heat wave

	Area potentially exposed to > 1°C above GM mean (km²)	Area potentially exposed to > 1°C above GM mean (km²)	% of area potentially exposed to > 1°C above GM mean	Potential exposure level	Chance of event - current	Likelihood - current	Chance of event - future	Likelihood - future
Regional Centre	1405840	14.06	82.85	H-3	L-1	M-3	M-2	H-6
Altrincham	271700	0.27	87.40	H-3	L-1	M-3	M-2	H-6
Bolton	0	0	0.00	L-1	L-1	L-1	M-2	L-2
Oldham	793940	0.79	98.28	H-3	L-1	M-3	M-2	H-6
Stockport	115488	0.12	53.89	H-3	L-1	M-3	M-2	H-6
Ashton	688594	0.69	75.70	H-3	L-1	M-3	M-2	H-6
Bury	931037	0.93	69.37	H-3	L-1	M-3	M-2	H-6
Rochdale	0	0	0.00	L-1	L-1	L-1	M-2	L-2
Wigan	0	0	0.00	L-1	L-1	L-1	M-2	L-2

Employment sites

Surface water flooding (current)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Cutacre	27913	0.03	2.07	M-2	M-2	M-4
Hollinwood	16938	0.02	2.51	M-2	M-2	M-4
Kingsway	71023	0.07	4.10	M-2	M-2	M-4
Wharfside	700	0.0007	0.17	L-1	M-2	L-2
Trafford Core	55539	0.06	1.06	L-1	M-2	L-2
Port Salford	11638	0.01	2.17	M-2	M-2	M-4
Airport Strategic Site	87706	0.09	1.93	M-2	M-2	M-4
Airport City	5972	0.01	1.71	M-2	M-2	M-4
Manchester Airport	109881	0.11	1.68	M-2	M-2	M-4
Carrington	85099	0.09	2.12	M-2	M-2	M-4

Surface water flooding (with climate change)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Cutacre	35484	0.04	2.63	M-2	M-2	M-4
Hollinwood	19052	0.02	2.83	M-2	M-2	M-4
Kingsway	94940	0.09	5.48	M-2	M-2	M-4
Wharfside	1375	0.001	0.34	L-1	M-2	L-2
Trafford Core	91273	0.09	1.74	L-1	M-2	L-2
Port Salford	19749	0.02	3.69	M-2	M-2	M-4
Airport Strategic Site	126278	0.13	2.78	M-2	M-2	M-4
Airport City	7122	0.007	2.04	M-2	M-2	M-4
Manchester Airport	157470	0.16	2.41	M-2	M-2	M-4
Carrington	160071	0.16	4.00	M-2	M-2	M-4

Flood Zone 2

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Cutacre	0	0	0	L-0	M-2	L-0
Hollinwood	0	0	0	L-0	M-2	L-0
Kingsway	0	0	0	L-0	M-2	L-0
Wharfside	0	0	0	L-0	M-2	L-0
Trafford Core	0	0	0	L-0	M-2	L-0
Port Salford	182495	0.18	34.06	H-3	M-2	H-6
Airport Strategic Site	0	0	0	L-0	M-2	L-0
Airport City	0	0	0	L-0	M-2	L-0
Manchester Airport	12824	0.01	0.20	L-1	M-2	L-2
Carrington	742503	0.74	18.53	H-3	M-2	H-6

Flood Zone 3

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Cutacre	0	0	0	L-0	H-3	L-0
Hollinwood	0	0	0	L-0	H-3	L-0
Kingsway	0	0	0	L-0	H-3	L-0
Wharfside	0	0	0	L-0	H-3	L-0
Trafford Core	0	0	0	L-0	H-3	L-0
Port Salford	182495	0.18	34.06	H-3	H-3	H-9
Airport Strategic Site	0	0	0	L-0	H-3	L-0
Airport City	0	0	0	L-0	H-3	L-0
Manchester Airport	10198	0.01	0.20	L-1	H-3	M-3
Carrington	157417	0.16	3.93	M-2	H-3	H-6

Heat wave

	Area potentially exposed to > 1°C above GM mean (m²)	Area potentially exposed to > 1°C above GM mean (km²)	% of area potentially exposed to > 1°C above GM mean	Potential exposure level	Chance of event – current	Likelihood - current	Chance of event - future	Likelihood - future
Cutacre	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2
Hollinwood	424128	0.42	62.96	H-3	L-1	M-3	M-2	H-6
Kingsway	0.00	0.00	0.03	L-1	L-1	L-1	M-2	L-2
Wharfside	405262	0.41	98.80	H-3	L-1	M-3	M-2	H-6
Trafford Core	4487545	4.49	85.69	H-3	L-1	M-3	M-2	H-6
Port Salford	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2
Airport Strategic Site	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2
Airport City	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2
Manchester Airport	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2
Carrington	0.00	0.00	0.00	L-1	L-1	L-1	M-2	L-2

Transport infrastructure

Surface water flooding (current)

Points	Total number	Number potentially exposed (current)	% of total number potentially exposed (current)	Number potentially exposed (future)	% of total number potentially exposed (future)
Railway stations	88	11	12.5	14	15.91
Motorway junctions	52	5	9.6	6	11.54
Interchanges (future)	2	0	0	0	0
Park and ride (future)	14	0	0	0	0
Rail station package (future)	12	3	25	3	25

Lines	Length potentially exposed (km)	% of total length potentially exposed	Potential exposure level	Chance of event	Likelihood
Railway	43.45	11.48	H-3	M-2	H-6
Motorway	7.35	4.55	H-3	M-2	H-6
Metrolink 1n2	2.38	6.45	H-3	M-2	H-6
Metrolink 2cc	0.36	19.16	H-3	M-2	H-6
Metrolink 3a	6.22	19.41	H-3	M-2	H-6
Metrolink 3b	3.01	11.11	H-3	M-2	H-6
Cross city metrolink (future)	0.86	2.78	M-2	M-2	M-4
Leigh busway (future)	0.76	3.10	M-2	M-2	M-4

Potential future transport expansion areas	Potential exposure (m^2)	Potential exposure (km^2)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Ashton northern bypass region	73886		2.46	M-2	M-2	M-4
Longendale region	183551		1.65	M-2	M-2	M-4
Semmms region	310255		1.88	M-2	M-2	M-4
Wigan IRR region	113058		5.76	H-3	M-2	H-6

Surface water flooding (climate change)

Lines	Length potentially exposed (km)	% of total length potentially exposed	Potential exposure level	Chance of event	Likelihood
Railway	59.35	15.68	H-3	M-2	H-6
Motorway	9.79	6.06	H-3	M-2	H-6
Metrolink 1n2	3.05	8.27	H-3	M-2	H-6
Metrolink 2cc	0.42	23.38	H-3	M-2	H-6
Metrolink 3a	7.73	24.13	H-3	M-2	H-6
Metrolink 3b	4.02	14.83	H-3	M-2	H-6
Cross city metrolink (future)	1.04	3.37	M-2	M-2	M-4
Leigh busway (future)	0.92	3.75	M-2	M-2	M-4

Potential future transport expansion areas	Potential exposure (m^2)	Potential exposure (km^2)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Ashton northern bypass region	90946	0.09	3.02	M-2	M-2	M-4
Longendale region	234730	0.23	2.10	M-2	M-2	M-4
Semmms region	453982	0.45	2.75	M-2	M-2	M-4
Wigan IRR region	148369	0.15	7.56	H-3	M-2	H-6

Flood Zone 2

Points	Total number	Number potentially exposed	% of total number potentially exposed
Railway stations	88	2	2.27
Motorway junctions	52	5	9.62
Interchanges (future)	2	0	0
Park and ride (future)	14	0	0
Rail station package (future)	12	3	25

Lines	Length potentially exposed (km)	% of total length potentially exposed	Potential exposure level	Chance of event	Likelihood
Railway	30.65	8.10	M-2	M-2	M-4
Motorway	12.32	7.63	M-2	M-2	M-4
Metrolink 1n2	3.61	9.79	M-2	M-2	M-4
Metrolink 2cc	0.16	9.09	M-2	M-2	M-4
Metrolink 3a	3.63	11.33	H-3	M-2	H-6
Metrolink 3b	0	0	L-0	M-2	L-0
Cross city metrolink (future)	1.62	5.27	M-2	M-2	M-4
Leigh busway (future)	1.19	4.89	M-2	M-2	M-4

Potential future transport expansion areas	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Ashton northern bypass region	0	0	0	L-0	M-2	L-0
Longendale region	231736	0.23	2.08	L-0	M-2	L-0
Semmms region	99648	0.10	0.6	L-0	M-2	L-0
Wigan IRR region	121518	0.12	6.19	M-2	M-2	M-4

Flood Zone 3

Points	Total number	Number potentially exposed	% of total number potentially exposed
Railway stations	88	1	1.14
Motorway junctions	52	2	3.85
Interchanges (future)	2	0	0
Park and ride (future)	14	0	0
Rail station package (future)	12	1	8.33

Lines	Length potentially exposed (km)	% of total length potentially exposed	Potential exposure level	Chance of event	Likelihood
Railway	15.42	4.08	M-2	H-3	H-6
Motorway	8.36	5.18	M-2	H-3	H-6
Metrolink 1n2	0.51	1.38	L-1	H-3	M-3
Metrolink 2cc	0	0	L-0	H-3	L-0
Metrolink 3a	0.77	2.41	M-2	H-3	H-6
Metrolink 3b	0	0	L-0	H-3	L-0
Cross city metrolink (future)	0.92	2.98	M-2	H-3	H-6
Leigh busway (future)	0.96	3.92	M-2	H-3	H-6

Potential future transport expansion areas	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Ashton northern bypass region	0	0	0	L-0	H-3	L-0
Longendale region	199685	0.2	1.79	L-1	H-3	M-3
Semmms region	76352	0.08	0.46	L-1	H-3	M-3
Wigan IRR region	76218	0.08	3.88	M-2	H-3	H-6

Heat wave

Points	Total number	Number potentially exposed	% of total number potentially exposed
Railway stations	88	16	18.18
Motorway junctions	52	7	13.64
Interchanges (future)	2	1	50
Park and ride (future)	14	1	7.14
Rail station package (future)	12	4	33

Lines	Length potentially exposed (km)	% of total length potentially exposed	Potential exposure level	Chance of event - current	Likelihood - current	Chance of event	Likelihood - future
Railway	47.53	12.56	M-2	L-1	L-2	M-2	M-4
Motorway	25.72	15.93	M-2	L-1	L-2	M-2	M-4
Metrolink 1n2	20.38	55.23	H-3	L-1	M-3	M-2	H-6
Metrolink 2cc	1.36	75.13	H-3	L-1	M-3	M-2	H-6
Metrolink 3a	10.35	32.31	H-3	L-1	M-3	M-2	H-6
Metrolink 3b	7.55	27.83	H-3	L-1	M-3	M-2	H-6
Cross city metrolink (future)	16.27	52.90	H-3	L-1	M-3	M-2	H-6
Leigh busway (future)	9.41	38.55	H-3	L-1	M-3	M-2	H-6

Potential future transport expansion areas	Potential exposure (m²)	Potential exposure (km²)	% of total area exposed	Potential exposure level	Chance of event – current	Likelihood – current	Chance of event - future	Likelihood - future
Ashton northern bypass region	1399509	1.40	46.51	H-3	L-1	M-3	M-2	H-6
Longendale region	0	0	0	L-0	L-1	L-0	M-2	L-0
Semmms region	0	0	0	L-0	L-1	L-0	M-2	L-0
Wigan IRR region	0	0	0	L-0	L-1	L-0	M-2	L-0

Science and innovation assets

Surface water flooding (current)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
Science and innovation assets (postcodes)	21761	0.02	1.73	M-2	M-2	M-4
The Corridor	54299	0.05	2.32	M-2	M-2	M-4

Surface water flooding (climate change)

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
29 science and innovation assets (postcodes)	33048	0.03	2.63	M-2	M-2	M-4
The Corridor	73374	0.07	2.32	M-2	M-2	M-4

Flood Zone 2

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
29 science and innovation assets (postcodes)	160070	0.16	12.72	H-3	M-2	H-6
The Corridor	732759	0.73	31.26	H-3	M-2	H-6

Flood Zone 3

	Potential exposure (m²)	Potential exposure (km²)	% of area potentially exposed	Potential exposure level	Chance of event	Likelihood
29 science and innovation assets (postcodes)	94240	0.09	7.49	H-3	H-3	H-9
The Corridor	550560	0.55	23.49	H-3	H-3	H-9

Heat wave

	Potential exposure (m²)	Potential exposure (km²)	% of total area potentially exposed	Potential exposure level	Chance of event – current	Likelihood - current	Chance of event - future	Likelihood - future
29 science and innovation assets (postcodes)	683845	0.68	54.33	H-3	L-1	M-3	M-2	H-6
The Corridor	2085397	2.09	88.97	H-3	L-1	M-3	M-2	H-6

Critical infrastructure

Surface water flooding (current)

	Total number	Number potentially exposed	% of total number potentially exposed
Waste water treatment plants	44	4	9.09
Power station	1	0	0
Electricity sub-stations	12	0	0

Surface water flooding (climate change)

	Total number	Number potentially exposed	% of total number potentially exposed
Waste water treatment plants	44	4	9.09
Power station	1	0	0
Electricity sub-stations	12	0	0

Flood Zone 2

	Total number	Number potentially exposed	% of total number potentially exposed
Waste water treatment plants	44	15	34.09
Power station	1	0	0
Electricity sub-stations	12	5	41.67

Flood Zone 3

	Total number	Number potentially exposed	% of total number potentially exposed
Waste water treatment plants	44	11	25
Power station	1	0	0
Electricity sub-stations	12	0	0

Appendix 3: Key weather and climate change impacts on the six GMS themes

	Flooding from rivers and streams	Surface water flooding	Heat wave events
		TRANSPORT INFRASTRUCTURE	
Railways	- Flooding of track and lineside equipment - Flooding of railway stations - Scouring of and flood damage to bridges - Speed restrictions and cancellation of services - Reduction in capacity due to repair and adaptation work - Knock-on congestion to other routes and forms of transport	- Flooding of track and lineside equipment - Flooding of railway stations - Speed restrictions and cancellation of services - Reduction in capacity due to repair and adaptation work - Knock-on congestion to other rail routes and forms of transport	- Buckling of rail lines due to heat stress - Speed restrictions and cancellation of services - Reduction in capacity due to repair and adaptation work - Health impacts of heat stress on passengers
Metrolink	- Flooding of track and lineside equipment - Flooding of stations - Cancelation of services - Reduction in capacity due to repair and adaptation work - Knock-on congestion to other rail routes and forms of transport	- Flooding of track and lineside equipment - Flooding of stations - Cancelation of services - Reduction in capacity due to repair and adaptation work - Knock-on congestion to other rail routes and forms of transport	- Buckling of rail lines due to heat stress - Health impacts of heat stress on passengers - Reduction in capacity due to repair and adaptation work
Motorways	- Flooding of road surface - Scouring of and flood damage to bridges - Congestion on other parts of the road network - Disruption to road users (closing of junctions, speed restrictions, road works) - Reduction in capacity due to repair and adaptation work - Safety issues (aquaplaning, excessive spray)	- Flooding of road surface - Congestion on other parts of the road network - Disruption to road users (closing of junctions, speed restrictions, road works) - Reduction in capacity due to repair and adaptation work - Safety issues (aquaplaning, excessive spray)	- Deterioration of road surface, with road works reducing capacity. - Increased need for maintenance work
		HOUSING SITES	
Residential housing	- Flood damage to residential properties - Flooding of supporting infrastructure - Higher insurance premiums in flood zones - Psychological impacts and loss of quality of life	- Flood damage to residential properties - Flooding of supporting infrastructure - Higher insurance premiums in flood zones - Psychological impacts and loss of quality of life	- Heat stress and associated negative health on residents - Increased pressure on health services - Increased energy costs linked to cooling
		REGIONAL AND TOWN CENTRES	
Regional centre	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Reduction in worker productivity due to heat stress - Heat stress and negative health on citizens - Increased pressure on health services - Increased energy costs linked to cooling - Tourism opportunities in a warming climate - Health problems linked to higher summer ozone pollution

Town centres	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Reduction in worker productivity due to heat stress - Heat stress and associated negative health on citizens (particularly vulnerable groups) - Increased energy costs linked to cooling
EMPLOYMENT GROWTH SITES			
Employment sites	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Reduction in worker productivity due to heat stress - Heat stress and associated negative health on citizens - Increased pressure on health services - Increased energy costs linked to cooling
CRITICAL INFRASTRUCTURE			
Waste water treatment plants	- Flooding of WWTWs, sewage pumping stations and sludge treatment facilities with associated service failure. - Loss of power to water supply and WWT assets with associated service failure.	- Flooding of WWTWs, sewage pumping stations and sludge treatment facilities with associated service failure. - Loss of power to water supply and WWT assets with associated service failure.	- Foul odours from WWTWs
Power station	- Not exposed in GM hence impacts not considered	- Not exposed in GM hence impacts not considered	- Not exposed in GM hence impacts not considered
Electricity sub-stations	- Flooding of sub-stations - Loss of power to residents, services and businesses - Reduction in electricity supply capacity and loss of service in some areas.	- Flooding of sub-stations - Loss of power to residents, services and businesses - Reduction in electricity supply capacity and loss of service in some areas.	- Increased demand for energy for mechanical cooling leading to overloading of transformers - Higher temperatures reduce the efficiency of energy transmission - Reduction in electricity supply capacity and loss of service in some areas.
SCIENCE AND INNOVATION ASSETS			
Science and innovation assets	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Flood damage to retail and commercial buildings - Flooding of supporting infrastructure - Negative economic impact - Higher insurance premiums in flood zones	- Heat stress and associated negative health on citizens - Reduction in worker productivity due to heat stress - Increased pressure on health services - Increased energy costs linked to cooling