The University of Manchester: Extreme weather and climate change impacts, risks and adaptation responses

Jeremy Carter & Angela Connelly
University of Manchester
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1 EXECUTIVE SUMMARY

The University of Manchester is currently the largest university in the UK with more than 35, 000 students and 11, 000 members of staff. The University spreads over an estate comprising of 339 buildings and 711 acres of land across Greater Manchester. The University's estate is crucial to achieving its vision of becoming a world leading centre of further education and learning, and in delivering its social responsibility goals.

Extreme weather and climate change risk is a concern for the University of Manchester as it is for all long term land owners, especially those located in urban areas where weather and climate risk is generally at its highest. The University recognises this risk and commissioned a project to better understand how extreme weather and climate change could impact on their estate. The principal aims of this project were:

- To assess and report on extreme weather and climate change impacts, risks and adaptation responses to the University of Manchester's estate.
- To increase the University of Manchester's capacity to develop policies, decisions and actions targeted at reducing weather and climate risks to their estate.

In meeting these aims, this project has built capacity for developing risk reduction strategies and responses to enhance the resilience of the University's estate to extreme weather and climate change. In particular, the following insights and issues have emerged from the project:

- Flooding is the key risk currently facing the estate, as it is for Greater Manchester more generally. Wetter winters and more extreme downpours across the year are projected for the coming decades, suggesting that flood risk will intensify.
- This project has provided insights into those buildings and locations where risk from flooding is greatest, and therefore where actions to reduce risk and enhance emergency response and contingency plans would be most valuable.
- Given the diverse form and function of buildings across the estate, and the fine grained nature of exposure to hazards such as flooding, buildings close to each other can display quite different risk profiles.
- Due to limitations of available flood maps, stemming from difficulties in predicting the behaviour of flood waters locally, building scale flood risk assessments are needed to confirm the level and nature of risk to individual buildings. This is particularly the case where investments to reduce flood risk are being considered.
- There is currently a low risk of heat stress to the estate, although projections suggest this risk will increase with rising temperatures over the coming decades.
- The benefit of increasing green cover as an adaptation response, particularly for lowering surface temperatures under a warming climate, has been demonstrated.
- The University has gained a number of new buildings over the last decade, with several high profile developments set to complete over the coming years. Despite this growth, the estate is dominated by older buildings that have largely not been developed with climate change in mind. This emphasises the importance of developing strategies to retrofit existing buildings to ensure that they can operate efficiently under a changed climate.

Given the risk to University buildings from weather and climate hazards, and the projections for accelerating climate change over the coming decades, at a minimum the University should review risks periodically and establish processes to monitor underlying conditions and issues that influence risk. Also, it would be useful to develop and maintain a database on University buildings regarding aspects of their form and function that influence climate risk. The database would usefully inform emergency responses in the event of a flood or heat stress event occurring, and would provide a basis for prioritising sites for adaptation responses should opportunities to take action arise.

A more ambitious response would be to develop and implement long term adaptation strategies and practical responses to lessen current risks and those risks projected to increase under climate change. This would be informed by the risk assessment work undertaken within this project, and by ongoing and previous research undertaken at the University of Manchester. Ideally, when considering adaptation responses, the focus would be on actions offering multiple benefits additional to managing weather and climate risks, for example increasing the health and wellbeing of staff and students. Enhancing green spaces is a particularly valuable strategy in this respect.

In addition to the key observations arising from the project outlined above, specific recommendations to progress adaptation of the University estate are as follows:

- Look for opportunities to expand green cover, particularly within the south campus and in areas prone to surface water flooding.
- Where buildings are to be refurbished, take the opportunity to consider adaptation options to build resilience to flooding and heat stress, especially where they are identified as being at risk from these hazards.
- Request that project teams responsible for new builds take weather and climate risk into consideration. Project teams should demonstrate how buildings will be resilient to future risks whilst not exacerbating risk to other buildings on the estate.
- Update emergency and contingency plans to reflect knowledge of weather and climate risks, particularly for buildings shown to be at high risk from flooding.
- Consider applying to European funding sources, such as INTERREG or LIFE+, to access match funding to deliver adaptation activities on the estate.
- Continue to engage with Manchester City Council and AGMA on activities that build the resilience of Greater Manchester to weather and climate risks.
- Support student projects to build knowledge and awareness of weather and climate risks and adaptation responses on the estate.

Hazard events including floods and heatwaves have broader implications with the potential to impact on the University. Related issues include flooding of transport infrastructure and its impact on access to the University by staff and students. Similarly, flooding or storm damage to electricity generation or supply infrastructure would negatively affect the University's operations. The examples emphasise the importance of ensuring that the University sits within a resilient city. There is related activity ongoing within AGMA and Manchester City Council via the development of climate change strategies, and the University should look to encourage and support this work through research and engagement. Given the division of responsibilities for the built environment and infrastructure in cities such as Manchester, co-ordinated city-wide approaches to adaptation should, ultimately, be more successful in the long-term.

2 BACKGROUND AND CONTEXT

The University of Manchester is currently the largest university in the UK with more than 35, 000 students and 11, 000 members of staff. The University spreads over an estate comprising of 339 buildings and 711 acres of land across Greater Manchester.[1]

In 2012, the Estates Masterplan outlined a £1 billion investment in the campus, £700 million of which will be delivered in the period to 2018. Significant public realm works will take place in addition to the creation of new centres of engineering, biomedical sciences & business. More recently, the UK government has announced a £235 million investment in an institute for the study of advanced materials at the University of Manchester, which has been christened as the 'Crick of the North'.[2]

Such new developments will be in line with The University of Manchester's environmental sustainability plan. This includes a targeted 40 per cent reduction in carbon emissions in order to meet an overall vision of: '…transform[ing] The University of Manchester into a low carbon institution, whilst educating our students and delivering leading research, to address the global challenge of sustainability.'[3]

The University of Manchester is not alone in its endeavour: national and global attention is focussed on mitigating the effects of climate change as scientists make it clear that human activity is changing the climate. The frequency and intensity of weather extremes is increasing, and future projections suggest that significant change in temperature and precipitation patterns can be expected over the coming decades. The University of Manchester is thus compelled not only to reduce carbon emissions that are driving the problem, but also to adapt to unavoidable climate change impacts.

Along with its staff and students, the University of Manchester's Estate is central to delivering its vision to create a world leading centre of further education and learning. The Estate, like other physical assets across the city, is at risk from impacts linked to weather extremes and climate change. These range from direct impacts such as the flooding of buildings to the implications of extreme weather on transport networks that provide access to the University for staff and students. Increasing knowledge and raising awareness of these risks can provide a platform to progress strategies and action to reduce the threat of extreme weather.

With these broad issues framing the project, the principal aims were:

- To assess and report on extreme weather and climate change impacts, risks and adaptation responses to the University of Manchester's estate.
- To increase the University of Manchester's capacity to develop policies, decisions and actions targeted at reducing weather and climate risks to their estate.

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[1] University of Manchester Estates. 'The Facts…'. Available at: http://www.estates.manchester.ac.uk/ourestate/

[2] P. Jump. 'Crick of the North confirmed for Manchester', *Times Higher Education*, 3rd December 2014, http://www.timeshighereducation.co.uk/news/crick-of-the-north-confirmed-for-manchester/2017375.article [accessed 8th December 2014].

[3] Environmental Sustainability Policy Statement, 2013, Directorate of Estates, http://www.estates.manchester.ac.uk/media/services/estatesandfacilities/Environmental%20Sustainability%20Policy%20Statement.pdf

In addition to enhancing understanding of prominent extreme weather and climate change risks to the University's estate, further benefits of the project include:

- Building internal capacity to develop targeted climate change adaptation responses to retrofit buildings (and their surrounding landscapes) to reduce risk stemming from extreme weather and climate change.
- Enhancing capacity to promote the inclusion of adaptation and resilience responses within new developments taking place on the University's estate.
- Enhancing University's ability to bid for funding linked to progressing adaptation responses, from INTERREG and Life+ funding sources at the European scale to resources available locally.
- Providing support to meeting Enabling Strategies 2, 7 and 8 of the University of Manchester's Strategic Vision, 2020[4]: 'A World Class Estate', 'Quality Processes' and 'Environmental Sustainability'.
- To act as an exemplar on tackling the implications of a changing climate change to businesses and organisations throughout the Greater Manchester region; thus helping to fulfil Goal 3 ('Social Responsibility') of the strategic vision through addressing a major societal challenge.

This report continues with a discussion of the 'adaptation imperative' facing the University, that is the aspects of the changing climate that emphasise that action needs to be taken to reduce associated risks (section 3). The methodology underpinning the project is then outlined (section 4). An overview is provided of current and projected weather and climate hazards facing the University (section 5). Particular focus is paid to flooding within this report given the prominence of this hazard locally and the availability of spatial data to support an analysis of related risks (section 6). Although there is less publically accessible spatial data on high temperatures, insights are provided into the nature of this risk as with the changing climate heat stress is projected to become more of a concern for Greater Manchester, particularly in the city centre (section 7). A series of case studies is then presented, chosen from those buildings shown by the project analysis to be at risk from weather and climate change impacts. The cases provide insights on relevant weather and climate risks and adaptation responses for the selected buildings (section 8). The report concludes with a discussion of managing weather and climate risk at the University of Manchester (section 9).

[4] The University of Manchester. 2013. Manchester 2020 The Strategic Plan for The University of Manchester. Available at: http://documents.manchester.ac.uk/display.aspx?DocID=11953

3 THE 'ADAPTATION IMPERATIVE'

There is increasing recognition locally, nationally and internationally that action needs to be taken to build resilience to the changing climate. The University of Manchester faces risks connected to present day weather extremes and future changes to the climate. These risks will arise from the direct effects of weather and climate within Manchester, and from climate change occurring in other parts of the world.

Hazardous events such as floods, heatwaves and storms often affect people and assets and can commonly be attributed to extreme (or unusual) weather events rather than changes in the climate. However, with ongoing climate change, weather events such as these may increase in frequency and intensity. Box 1 describes the difference between weather and climate.

BOX 1: Weather and Climate

Climate describes the average weather over a period of time (usually 30 years) which allows us to describe trends. For example, in the UK, spring temperatures are generally warmer now than in the 30-year period 1961 to 1990.

Weather describes what is happening at any point in time, including high temperatures, rain, snow, sleet and high winds.

Source: The Met Office (2014)

Urban areas are faced with a particularly strong adaptation imperative. They concentrate people and assets, increasing the risks associated with extreme weather events if they do occur. The Intergovernmental Panel on Climate Change (IPCC) indicates that there is high agreement amongst the scientific community that urban areas will face increased risks from a number of weather-related events.[5]

Extreme weather events have significant repercussions for businesses. Direct and insured losses from weather-related disasters have increased substantially in Europe in recent decades.[6] As cities are the locus for higher numbers of people and assets, this means that with the climate changing, the *economic* losses from weather- and climate-related disasters may increase in urban areas if adaptation does not occur.[7]

The Stern Report into the economic effects of climate change indicates that planned adaptation will be much more cost-effective than reactive responses in the future.[7] Increasing the understanding and awareness of weather and climate change risks is an important step in building capacity to develop planned adaptation responses, which this project has sought to do for the University of Manchester.

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[5] Intergovernmental Panel on Climate Change. 2014. Climate Change 2014 Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, p. 538. Available at: http://www.ipcc.ch/report/ar5/wg2/

[6] Ibid, p. 680.

[7] N. H. Stern. 2007. The Economics of Climate Change: The Stern Review. Cambridge: Cambridge University Press.

4 METHODOLOGY

4.1 BACKGROUND

This report focuses on extreme weather and climate risks to the University of Manchester estates and its built assets. In consultation with the University of Manchester Estates, four main study areas were identified as particular important to look at in terms of current buildings and future development plans and strategies. These are (see Figures 1 – 4):

- Study Area 1: The South Campus
- Study Area 2: Victoria Park
- Study Area 3: Owens Park
- Study Area 4: Jodrell Bank Estate

Weather and climate data was utilised from previous University of Manchester projects including EcoCities, which looked at weather and climate change hazards impacts and adaptation responses across Greater Manchester. Earlier projects such as Sustainable Cities: Options for Responding to Climate cHange Impacts and Outcomes (SCORCHIO), which developed GIS tools to explore heat and human comfort in urban areas, and the Adaptation Strategies for Climate Change in the Urban Environment (ASCCUE) project, which investigated the adaptation potential of green space, were also utilised.

One of this project's key elements was in developing a set of customised GIS layers of the University estates, building types, and climate related data. This enabled analysis to be undertaken of the location of University buildings in the context of areas at risk from flooding. In this, the team were ably assisted by Karl Hennerman and Graham Bowden.

4.2 ASSESSING CLIMATE RISK

Climate change risk assessments offer an accessible and broadly accepted way of increasing understanding of the implications of climate change, and can inform decisions on how to progress adaptation responses to prominent risks. Climate change risk assessments have become more common over recent years. The UK Climate Change Risk Assessment,[8] the first to be mandated by a national government, outlines climate change risks and opportunities to different themes, including business and the natural environment, from a national perspective. Under the UK Climate Change Act of 2008, organisations such as major utilities and infrastructure providers are required to publish climate change adaptation reports, which have often been underpinned by risk assessments.[9] The Estates project builds on this existing body of work in order to improve understanding of weather and climate change risks to the University's estate.

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[8] UK Government. 2012. UK Climate Change Risk Assessment: Government Report. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69487/pb13698-climate-risk-assessment.pdf

[9] Electricity North West. 2011. Climate Change Adaptation Report. Available at: http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/04distribute-trans/electricity-northwest.pdf and United Utilities Water. 2008. Report on Adaptation under the Climate Change Act 2008.

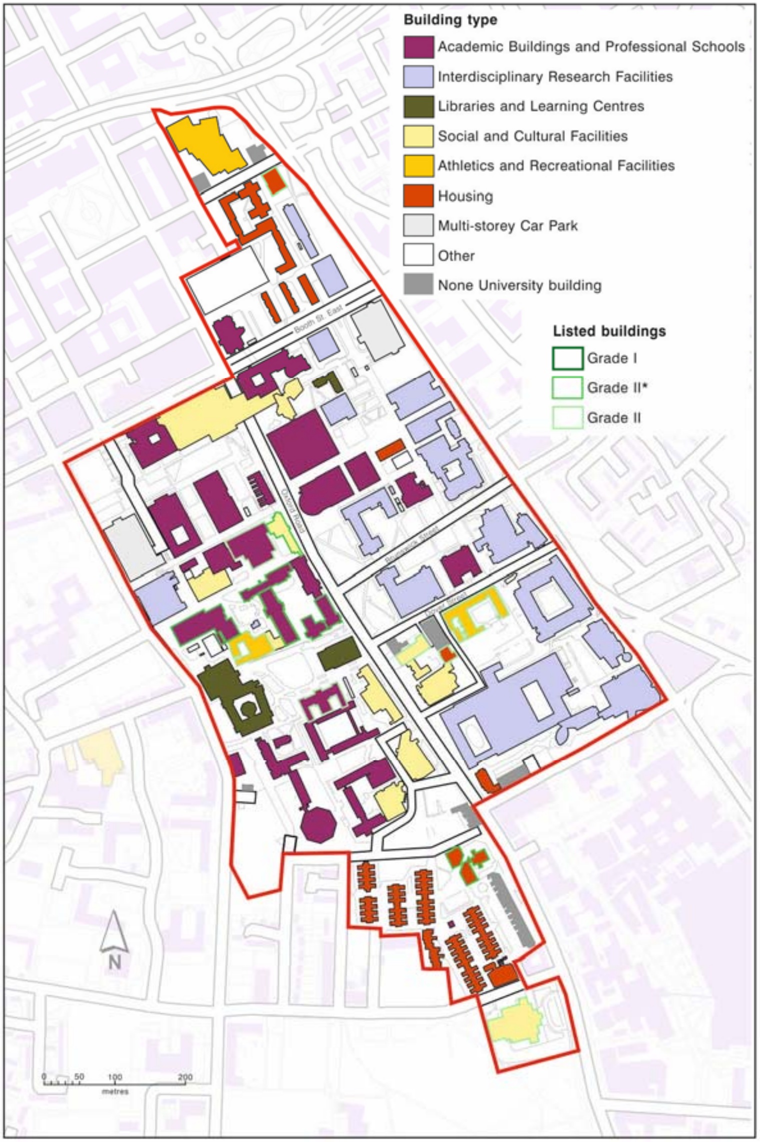

Figure 1: The distribution of building types across Study Area 1. Drawn by Graham Bowden.

Figure 2: The distribution of building types across Study Area 2. Drawn by Graham Bowden.

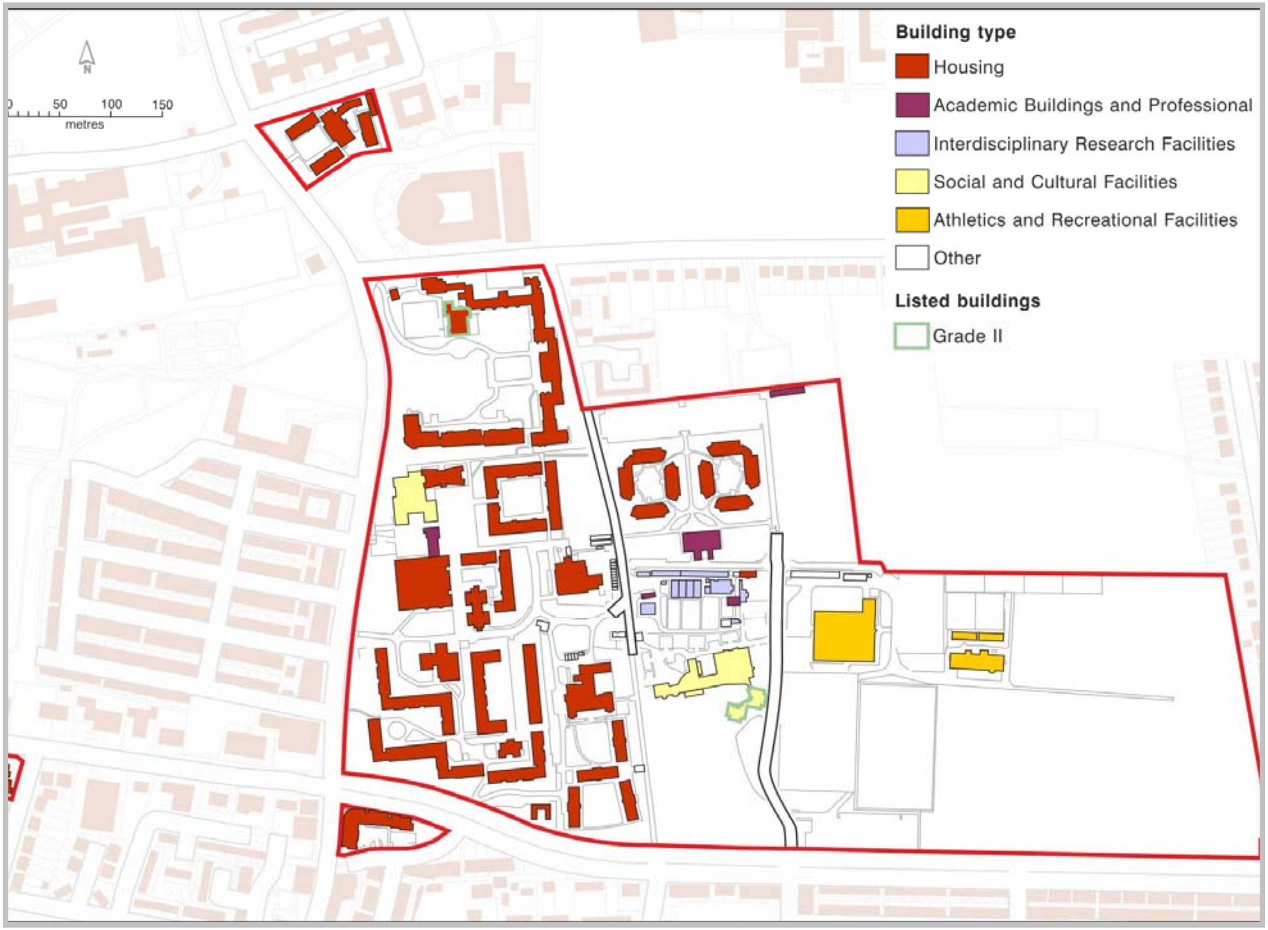

Figure 3: The distribution of building types across Study Area 3. Drawn by Graham Bowden.

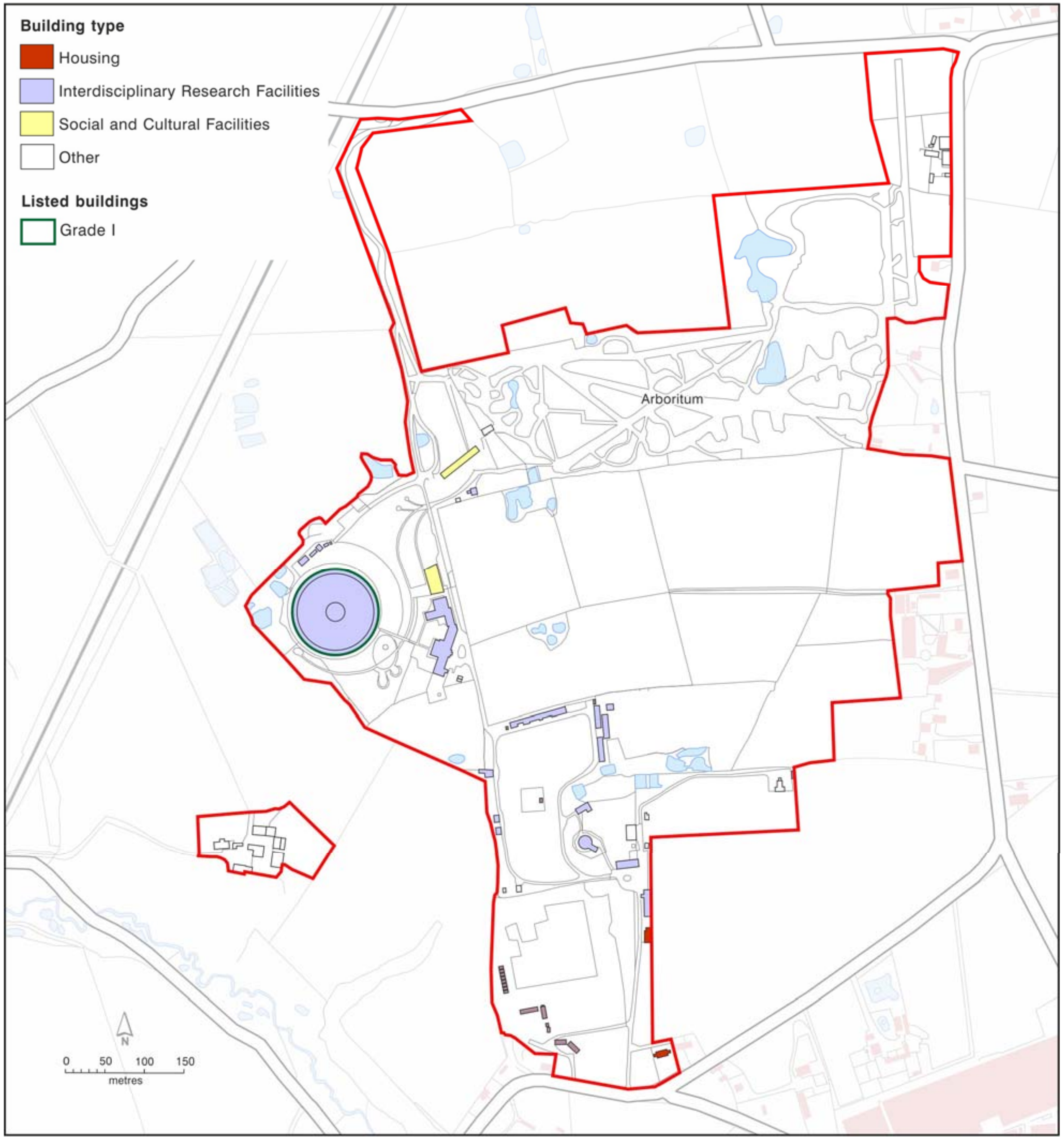

Figure 4: The distribution of building types across Study Area 4.
Drawn by Graham Bowden

The IPCC, the key global organisation working on climate change impact, risk and adaptation, notes that: 'Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur'.[10] This matches the University of Manchester's own method for assessing and scoring risk, which is based on understanding the likelihood and impact (or consequence) of actions and events. Building on these approaches, the following formula informed the risk assessment outlined in this report.

Risk = likelihood of a hazard event occurring x consequence of impacts arising from the hazard event for University buildings.

An assumption was made that certain buildings on the University campus will be at higher risk from extreme weather and climate change than others owing to a number of factors related to their function, location, and form (Section 5.3.1). This means that, from a safety and reputational point of view, threats to certain buildings may pose higher risks than others and warrant a more immediate adaptation response.

To progress the risk assessment on this basis, data was collected on the building, its type, whether it is susceptible to flooding. Further data revealed whether the building had a basement (which may be the first place to flood) and whether the building was listed (which may inhibit adaptation measures). Following this approach, the risk assessment process identified buildings that are at higher risk from extreme weather and climate change impacts. This then supports the process of prioritising and acting on prominent risks and identifying clusters of buildings where 'neighbourhood' scale adaptation approaches may be most useful. The risk assessment findings also inform the recommended adaptation options to prominent risks or categories of risks (Section 9).

4.3 DATA

4.3.1 FLOODING

Data on the present day risk of fluvial and pluvial flooding was obtained from the Environment Agency and is discussed in greater detail when the analysis is presented (Section 6). Flood data on groundwater sources and reservoir failure were not part of this project. Fluvial flooding indicates flooding for rivers and ordinary watercourses. The Environment Agency fluvial maps are updated on a quarterly basis to reflect new information. The Environment Agency divides areas into four Flood Zones and, for this report, Flood Zones 2 and 3a were analysed (Table 1). This is because Flood Zone 1 is considered to be low probability with minimal action needed to address the risk. Flood Zone 3b is functional flood plain and preliminary analysis indicated that no part of the University estates is constructed on a flood plain.

Available at:
http://corporate.unitedutilities.com/documents/UUW_Climate_change_adaptation_report_FINAL.pdf

[10] Intergovernmental Panel on Climate Change. 2014. Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Flood Zone	Definition
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding
Zone 3 High Probability	Land having a 1 in 100 or greater annual probability of river flooding

Table 1: Environment Agency Flood Zone Definitions for Zones 2 and 3. Source: The Environment Agency. 2014. Planning Practice Guidance.

Pluvial flooding occurs when an extremely heavy rainfall event saturates the urban drainage system and excess water cannot be absorbed. It is frequently referred to as 'surface water flooding' (SWF).

The Environment Agency's most recent national SWF map was released in December 2013 and has been compiled with detailed local data where available. When local data has been used, the area is given a suitability indicator of 'town to street'. Where local data is not available, the input data for flood modelling is derived from average national estimates, and this is indicated by the suitability indicator of 'national to county'. This project's Study Areas 1, 2 and 3 are 'town to street' whereas Study Area 4 is 'national to county'. This means that the SWF maps are suitable for identifying areas that would flood and which streets may be at risk of flooding within Study Areas 1, 2 and 3.

It should be noted that both the fluvial and pluvial flood maps are indicative and are not intended to be used to identify a particular building as at risk of flooding. Where a building is a source of concern, then a full flood risk assessment should be undertaken that takes account of topography, hydrology, and building science (amongst other factors).

4.3.2 HEAT

It was not possible to use available heat data as the maps for Greater Manchester developed as part of the EcoCities and SCORCHIO projects are at too coarse a scale to assess the effect of temperature on individual buildings. Therefore, in this report data is provided to give a broad overview of how heat may impact on the University's estate. Neighbourhood and buildings scale heat modelling would need to be undertaken to develop a more detailed perspective of heat risks to the estate.

4.4 THE STAR TOOLS

Green spaces have an important role to play in building resilience to extreme weather and climate change. They have been shown to reduce the rate of surface water run-off as well as providing cooling areas in the event of high temperatures and heatwaves, particularly if there are trees present.[11]

In order to help demonstrate these benefits, the Surface Temperature and Runoff (STAR) tools[12] were developed by the Mersey Forest and the University of Manchester as part of the EU Interreg GRaBS project. One application of the STAR tools is in comparing changes in maximum surface temperature and surface water runoff rates given different land cover scenarios for a particular area.

Scenarios were developed in order to gauge the effect of increasing or decreasing green spaces using the default OS MasterMap data available through the STAR tools (Table 2). Scenario 1 took the current baseline land cover situation, using OS MasterMap data as this contained the necessary variables required to input into the surface water runoff too (whereas the heat stress tool uses Estates data). Working from this baseline situation, Scenario 2 *decreased* green space by 10 per cent (a mix over different surface types) and increased the amount of buildings and other impermeable surfaces by 10 per cent. Scenario 3 *increased* green space by 10 per cent and decreased the amount of buildings and other impermeable surfaces by 10 per cent.

For the surface temperature tool, using data obtained from the University of Manchester's Estates Department, an up-to-date land cover for Study Area 1 was calculated to provide baseline data for the current picture (Table 3). As with the surface water runoff tool, scenarios were developed in which the baseline areas of green space were increased by ten per cent and decreased by ten percent (Scenarios 2 and 3 in Table 3).

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[11] S. E. Gill, J. F. Handley, A. R Ennos, S. Pauleit. 2007. Adapting cities to climate change: the role of the green infrastructure. *Built Environment*, 33 (1), 115 – 133.

[12] The Mersey Forest & The University of Manchester. 2011. STAR tools: surface temperature and runoff tools for assessing the potential of green infrastructure in adapting urban areas to climate change. Part of the EU Interreg IVC GRaBS project. Available at: www.ginw.co.uk/climatechange

	Scenario 1	Scenario 2	Scenario 3
Buildings	35.80%	41.80%	35.80%
Other impervious surfaces	40.80%	44.80%	30.80%
Trees	3.20%	2%	4.20%
Shrubs	0.80%	0.50%	1.30%
Mown grass	2.50%	1%	6.50%
Rough grass	0%	0%	0%
Cultivated surfaces	15.10%	8.10%	19.60%
Water	0%	0%	0%
Bare soil or gravel surfaces	1.80%	1.80%	1.80%

Table 2: Areas of Land Cover in Study Area 1. Source: OS MasterMap via the STAR tools.

	Scenario 1	Scenario 2	Scenario 3
Green space	18 %	8%	28%
Impermeable surface	20%	25%	15%
Buildings	55%	60%	50%
Unclassified (non-university assets such as roads)[1]	7%	7%	7%
Study Area	100%	100%	100%

Table 3: Areas of Land Cover in Study Areas 1. Source: University of Manchester.

[1] Classified as impermeable surface for the STAR tools

5 WEATHER AND CLIMATE HAZARDS AND IMPACTS

5.1 CURRENT EXTREME WEATHER IMPACTS

The most prevalent hazard event reported in Greater Manchester's media between 1945 and 2008 is flooding.[13] There is evidence that the reporting of surface water flooding is increasing whilst, over the same time period, fluvial events are declining. This may be because of better flood defences on the River Irwell, for example. Cold weather events and storms (including high winds) are also reported on a regular basis.

Box 2: Probabilities

Probability is a way of expressing knowledge or belief that an event will occur, and is concept most people are familiar with in everyday life. For further details See the *UK Climate Projections 2009, Index.*

With regard to climate change data (as presented in Table 4), probabilities are expressed as the following:

10th percentile – 'Unlikely to be less than'
50th percentile (central estimate) – 'As likely as not'
90th percentile – 'Unlikely to be greater than'

Information provided by the Professional Services Unit indicated that there are few historic instances of the University of Manchester estates being flooded. Sewer blockages, rather than excessive volumes of water, have caused flooding yet were not considered in this report given the focus on extreme weather and climate change. Heavy rainfall has previously led to pooling of water in some areas of the University's public realm, particularly car parks. Heavy rainfall has caused some issues on Oxford Road and, whilst not affecting the estate directly, this may pose problems for employees trying to gain access to the estate. Indeed, flooding in other parts of Greater Manchester and beyond can have implications for the operation of the University, particularly regarding staff and student access.

[13] Jeremy Carter & Nigel Lawson. 2011. Looking back and projecting forwards reater Manchester's weather and climate, The EcoCities Project. Available at: http://www.adaptingmanchester.co.uk/sites/default/files/EcoCitiesLookingbackprojectingforwards.pdf

5.2 CLIMATE CHANGE PROJECTIONS

Customised climate projections for Greater Manchester created for the EcoCities project indicate a trend towards warmer, drier summers and warmer, wetter winters. Projections also highlight that extreme events, such as heatwaves and intense rainfall, are likely to become more frequent and intense.[14]

That said, weather extremes are becoming more prominent and across the UK and there have been some extremely cold winters and wet summers in recent years. This reflects that as the global climate changes, more variability is introduced which can lead to weather events that stand outside of broader long term climate trends.

Table 4 shows projected changes in several climate variables (temperature and precipitation) for Greater Manchester's Mersey Basin climate zone, which encompasses central Manchester. Probabilistic projections, such as those presented in Table 4, 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) based on current knowledge. Box 2 provides details to help interpret probabilistic projections.

Variable	10^{th} percentile projection	50^{th} percentile projection	90^{th} percentile projection
Annual mean temperature (^{0}C)	1.8	2.4	3.6
Warmest day in summer (^{0}C)	1.5	3.1	6
Summer mean precipitation (%)	-5	-20	-36
Winter mean precipitation (%)	0	14	28

Table 4: Summary of Projected changes to Manchester's climate (2050s high emissions scenario for the Mersey Basin climate zone). Source: Adapted from Cavan 2011.

5.2.1 POTENTIAL IMPACTS OF HIGH TEMPERATURES

Urban locations are often significantly warmer than rural locations because of the 'urban heat island' (UHI) effect. Cities have higher proportions of sealed surfaces, such as roofs and pavements, and the daytime sun warms sealed surfaces more than it does vegetated surfaces. Moreover, air conditioning is often used to cool occupants in urban buildings but the combined waste heat from air conditioning units paradoxically contributes to increasing outside surface temperatures. Buildings also release heat intended for internal space heating. The UHI is more intense in the summer than in the

[14] Gina Cavan. 2011. Climate change projections for Greater Manchester, version 2. The EcoCities Project. Available at: http://www.adaptingmanchester.co.uk/documents/climate-change-projections-greater-manchester-version-2

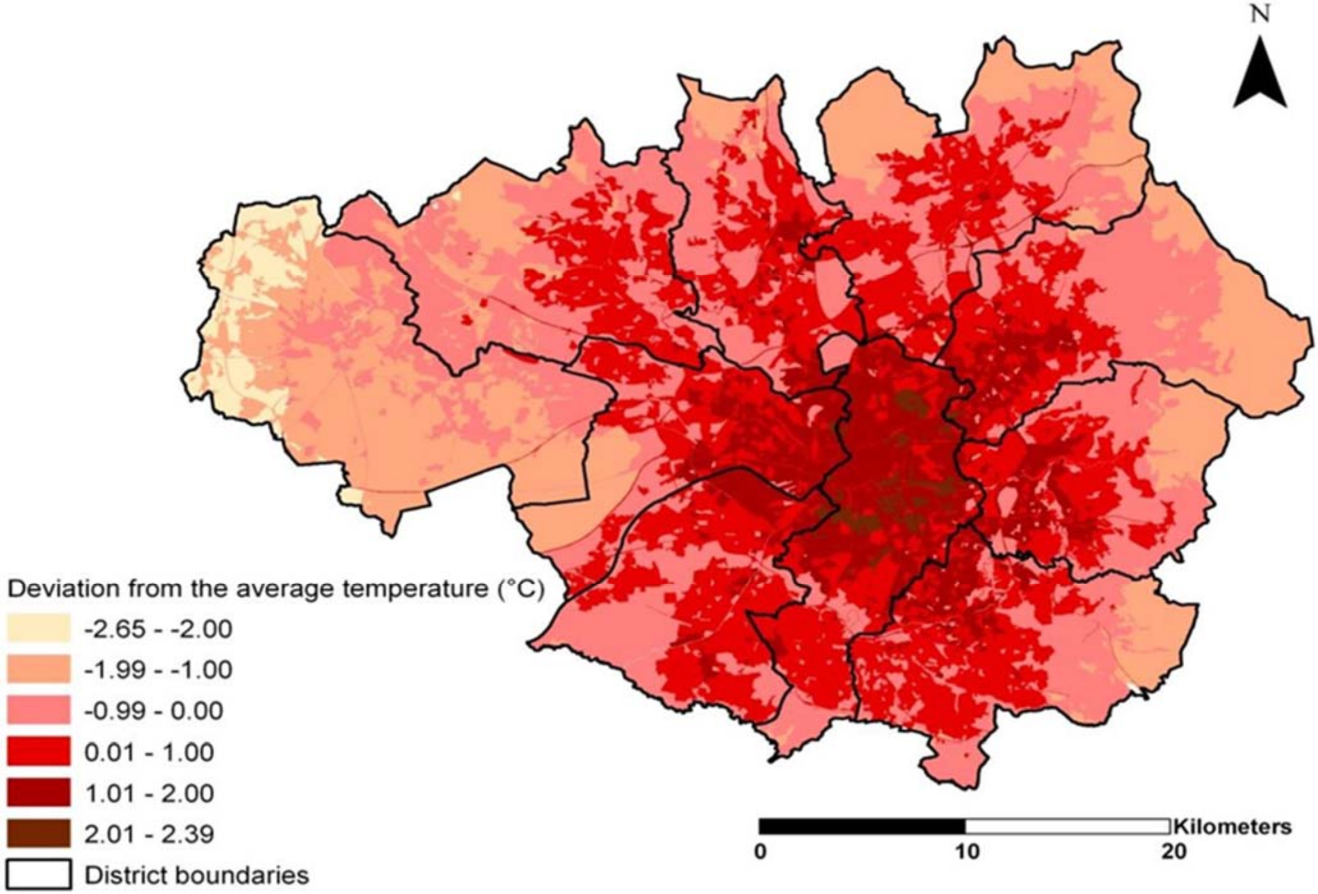

Figure 5: Extent and intensity of the Urban Heat Island in GM. Please see: please see C. Smith et al. 2011. Fine-scale spatial temperature patterns across a UK conurbtion, Climtic Change, 109 (3 -4), pp. 269 - 286.

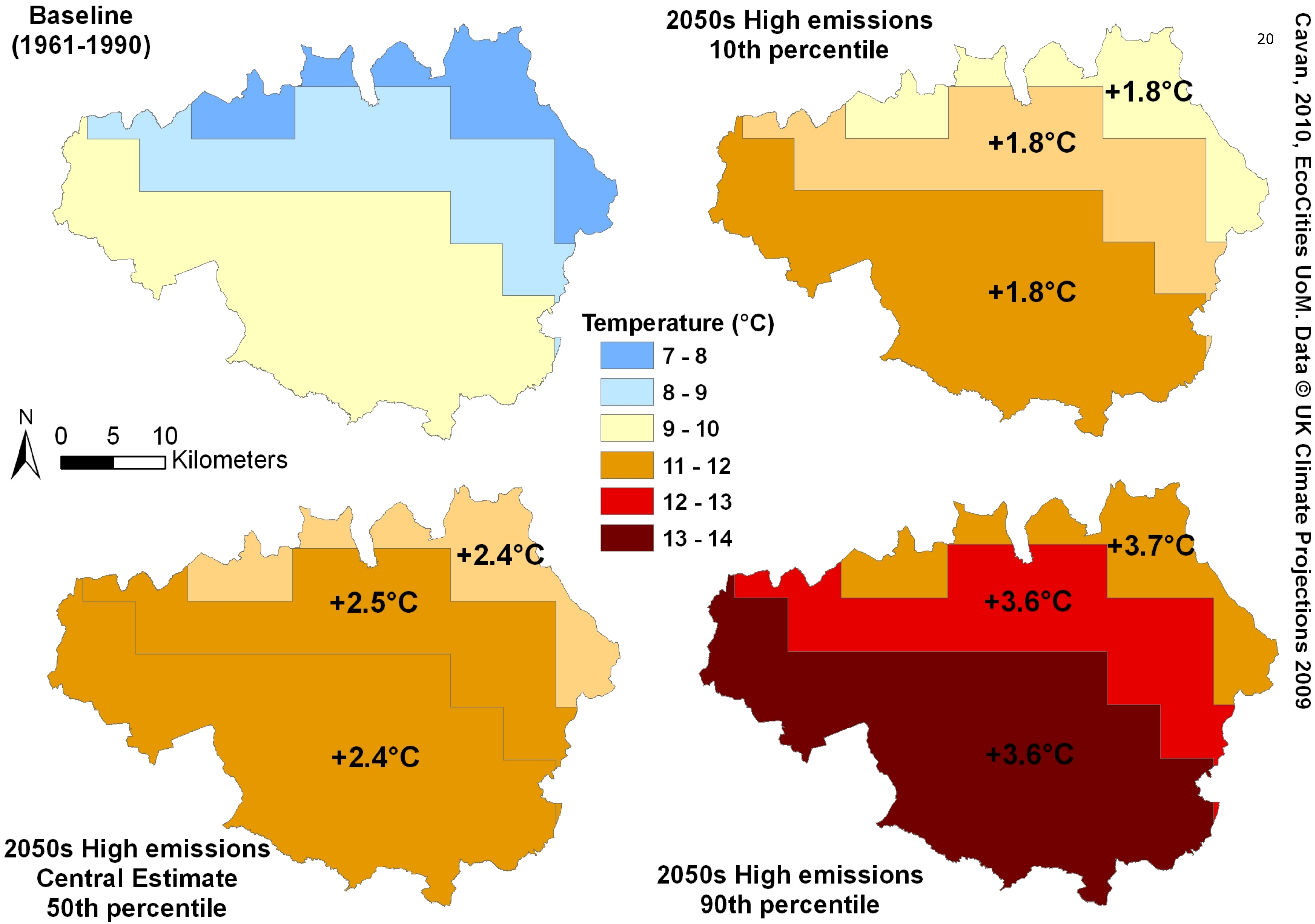

Figure 6: Temperature of the warmest day of summer across GM for the baseline and 2050s high emissions scenario

winter due to the position and intensity of the sun. Figure 5 shows the UHI map for Greater Manchester.

The raised temperatures indicated by climate projections, combined with the projected growth in the number of heatwaves in central Manchester, increase potential risks associated with the UHI (see Figure 6). High temperatures have a number of potential impacts on buildings, particularly to the exterior, the internal environment, and building users.

Heat impacts vary depending on a given building's characteristics including the materials, orientation, and height. Multi-storied office blocks with glass curtain walling, for example, may exacerbate the effects of a heatwave and raise user discomfort, particularly on the upper floors. This effect will be even more pronounced on south-facing façades.

In terms of users, high temperatures may increase instances of ill-health and even mortality. In high-rise buildings, the top floors are often much warmer. If users are in these places for a long duration and/or have reduced mobility or reduced control over the opening of windows, there may be an increased physiological strain placed on them. Risks from high temperatures will be magnified if they have underlying health conditions.

A number of studies demonstrate that productivity decreases when thermal comfort becomes intolerable for some. Factors that influence this include the level of control that people have over varying internal temperatures (for example, ability to change pre-set heating and cooling temperatures), pre-existing health conditions, and dress codes.

5.2.2 POTENTIAL IMPACTS OF FLOODING

Flooding has a number of impacts on the built environment, which depend on factors including a flood's severity, construction characteristics and occupant preparedness. Flood water seeps through porous materials such as bricks, blocks and concrete, particularly where these are poorly maintained. Many key services and equipment are traditionally kept in basements, which being below ground level are often likely to be the first areas of a building to suffer the effects of flooding.

When flood waters reach depths of over 900mm, significant structural damage may occur to a building. Table 5 and Section 6.2.1 discuss flood thresholds in greater detail.

Flood water is often contaminated. This raises the cost of cleaning up and drying a building out. There may be associated costs with the temporary loss of function until a building can be deemed ready to occupy following flood remediation work.

Floods can have significant effects on physical and emotional health of people. Whilst this mainly relates to residential properties, there may be an increase in work stress on the campus through loss of items or displacement from ones normal work space.

Flood Depth (mm)	Threshold
150mm – 300mm	Typically exceeds kerb height (125mm) Likely to exceed the damp-proof course May cause property flooding in certain areas May cause disruption to surrounding areas (pedestrians and emergency services).
300mm – 600mm	Floods reaching depths over 300mm are likely to flood properties. Property level flood resilience measures are effective up depths of 600mm dependent on the floor level.
600mm – 900mm	Property level flood resilience measures are effective up depths of 600mm dependent on the floor level. Such measures may be effective to 900mm although structural damage may begin to occur at depths of over 600mm.
Above 900 mm	Floods above 900mm will cause structural damage and flood resilience measures for individual properties will be ineffective.

Table 5: Flood Depths and Description of Thresholds for Pluvial Flooding.
Source: Environment Agency, 2013. What is the updated Flood Map for Surface Water? p. 25.

5.2.3 OTHER WEATHER AND CLIMATE HAZARDS

High winds often have considerable impact on the integrity of critical infrastructure and buildings. However, downscaled climate projections are highly uncertain with regard to future storm tracks and wind parameters.[15] Modelling of storm tracks, in particular, are not yet considered to be robust enough to enable future projections to be made. Due to uncertainty over whether winds and storms will increase in the future, and the associated lack of future projections on this topic, this issue has not been looked at within this report. In addition, this report has not looked at cold weather extremes given that they are projected to become less common. However, even though the trend is towards a warming world, extremes in cold weather will continue to be felt although less frequently.

5.3 LAND COVER AND CLIMATE CHANGE RISK

Urban areas, and the buildings and infrastructure within them, influence local climate and can intensify, and in some cases moderate, weather and climate change impacts. Table 6 highlights building characteristics that interact with heat and flooding. Equally, the spaces around buildings - streets, car parks, greenspaces – exert an influence over local climate and the nature and intensity of weather and climate change impacts. Key relationships include the effect that hard surfaces have on rainwater runoff. Features including car parks, pavements, and roads have limited infiltration capacity and hence encourage pooling of rainwater and speeding its runoff into drains and watercourses. This in turn increases flood risk. Where the built environment replaces green spaces and vegetation the capacity of the surrounding area to provide natural cooling and shading is

[15] See United Kingdom Climate Projections (UKCP). 2009. Technical Guidance Note: Storm Projections. Available at: http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87875&filetype=pdf

Increased Temperatures	Pluvial and Fluvial Flooding
Building Orientation *- affects how the sun warms a building*	Basements *- basements may often be the first place of water inundation during a flood*
Insulation *- may act as a preventative barrier to solar gain*	Poor Maintenance *- poor building maintenance may lead to openings and cracks where water can seep into*
Building Height *- upper floors of tall buildings may be more susceptible to over heating*	Apertures *- window and door openings are a route of water entry*
Street Canyon Effect *- man-made street canyons retain temperature and contribute to the urban heat island effect.*	Air bricks *- air bricks allow air to circulate through a building but contain small openings that flood waters can seep through*
Sky/daylight view *- may increase solar gain, but is also necessary for occupant well-being*	Service Entry Points *- service entry points can allow water to enter into a building*
Control of Energy Systems *- tenants and occupiers may wish to retain control of energy systems*	Green Infrastructure *- green infrastructure, such as SuDS, can retain water thus keeping it away from a property*
Glazing *- high levels of glazing may increase temperatures*	
Green Infrastructure *- green infrastructure such as trees and grass spaces can moderate high temperatures*	
Thermal Mass *- the thermal mass of a building dictates how well it retains or resists heat gains*	

Table 6: Building factors that interact with increased temperatures and flooding.

reduced. This raises the risk of high temperatures negatively impacting on the built environment and people.

Looking at Study Area 1, the South Campus, over 75% of the total area is covered by buildings and other impervious surfaces (see Scenario 1 in Table 3). This reflects the heavily urbanised nature of this area, and indicates the susceptibility of this part of the University's estate to enhanced weather and climate change impacts. Equally, this suggests that there is capacity to address these impacts via adaptation responses that create more greenspaces (discussed in Sections 6.5 and 7.3) and introduce measures such as sustainable urban drainage systems.

5.3.1 BUILDING TYPOLOGY DESCRIPTION

This project divided the University of Manchester estates into seven broad types of building common to university and college campuses as outlined in architectural guidance.[16] These types are detailed in Table 7, which also indicates how aspects of the buildings may have implications for climate impacts. Some buildings are multi-functional: an academic building may contain a library whereas social and support facilities may contain an element of housing. Where there are multiple functions, the buildings main function was taken account of. Figures 1 - 4 show the location of key building types, and their heritage designation status, for each of the study areas.

It is assumed that particular functions may render a certain building more or less risky when considering climate impacts. Whilst not forming part of the risk assessment, it is important to note that, for example, dedicated research facilities may comprise of high-value assets and may contain hazardous chemicals which could be damaged during a flood. Equally, academic institutes with lecture theatres have large volumes of people entering and exiting throughout the day, and hence may require particular emergency preparedness strategies to take account of this flux. High-rise student residences may pose particular issues during a heatwave, particularly on the upper floors and dependent on factors including how long the inhabitant spends in the room each day and the existence of underlying health conditions.

[16] David Neuman. 2013. Building type basics for college and university facilities, 2nd Edition. Chichester: Wiley.

Type	Complicating Factors
Libraries and Learning Centres	• Concentration of assets and people
Academic Buildings and Professional Schools	• Large auditoriums • Academic and research work space • Concentration of people • IT equipment
Interdisciplinary Research Facilities (inc. hospitals)	• Concentration of specialised equip-ment & materials
Housing	• In 24 hour use • Potentially in use as tourist accommodation.
Athletics and Recreational Facilities	• Hosting of large events
Social and Support Facilities (e.g. Student's Unions)	• Hosting of large events • Concentration of people
Cultural Centres (Dance, Music, Visual Arts)	• Key sites for engaging the public • Hosting of large scale events • Concentration of people

Table 7: Description of Building

6 FLOODING ANALYSIS

6.1 FLUVIAL FLOODING

Of the fours study areas, only Study Area 1 fell within the Environment Agency's Flood Zones 2 and 3 (See Figure 7). Approximately 38.7 per cent of Study Area 1 falls within Flood Zone 2, where there is a medium probability of flooding occurring (according to the Environment Agency), whilst 10.9 per cent falls within Flood Zone 3 where flooding is deemed to have a high probability of occurring. Much of the indicated flooding occurs around Cambridge Street and the site of the current Manchester Business School.

6.1.1 THE RIVER CORNBROOK

The reason that parts of Study Area 1 are identified as being at risk of flooding can be attributed to the River Cornbrook, which is classified as an ordinary watercourse meaning that the Lead Local Flood authority is responsible for its maintenance. The River Cornbrook is now predominantly 'hidden' underground in a culvert as a result of successive urban developments. It flows from Openshaw in east Manchester and discharges into the Manchester Ship Canal, crossing Oxford Road at the University of Manchester (Figure 8).

The culvert was diverted during the University of Manchester's redevelopment in the mid-1960s and runs between the Precinct Centre and the Arthur Lewis Building and Humanities Bridgeford Street. The size of the culvert at this location is approximately 1500mm high x 3600mm wide and it is contained within reinforced concrete. Surface water from surrounding buildings flows into both the culvert and a combined public sewer owned by United Utilities.

Detailed Environment Agency flood risk modelling for the River Cornbrook was undertaken in 2009 (Figure 9; Table 8). This highlights that, though culverted, there is a residual risk of flooding. The Environment Agency model shows that flooding will be to depths of less than 0.5 m and as a result the risk can be considered to be extremely low above ground. However, flood modelling undertaken for the Manchester, Salford & Trafford SFRA found that flooding from the River Cornbrook in this area may reach depths of 1.5 metres in small, localised areas.[17] Further investigation with detailed modelling would be required to investigate how this might impact upon basement level flooding to University buildings.

6.1.2 EXISTING TOPOGRAPHIC SURVEYS

Several publicly available flood risk assessments submitted to the local planning authority in support of new developments on the University of Manchester estate were

[17] JBA Consulting. 2011. Strategic Flood Risk Assessment – Manchester Salford Trafford. Available at: http://www.manchester.gov.uk/downloads/download/3871/strategic_flood_risk_assessment-manchester_salford_trafford

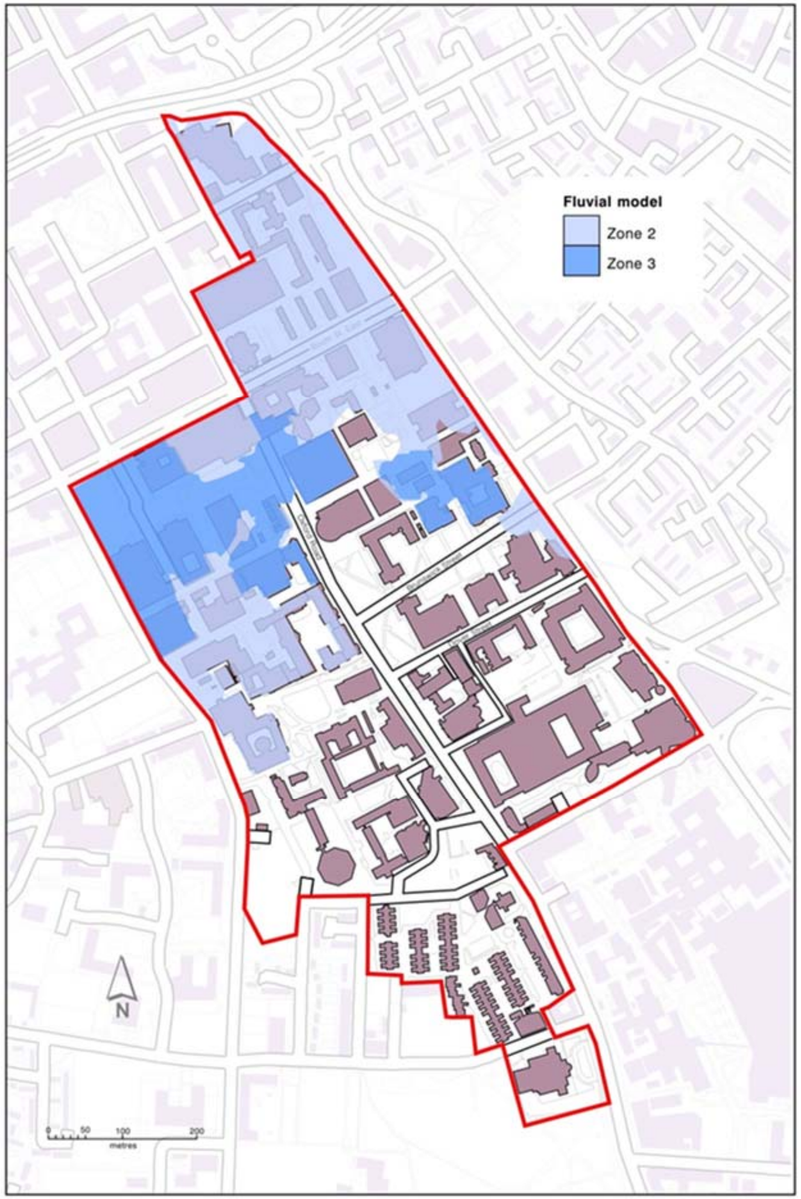

Figure 7: Fluvial Flood Risk for Study Area 1 Source: © Environ-ment Agency copyright and / or database rights 2014. © Crown Copyright and database right. All rights reserved. Drawn by Graham Bowden

Figure 8: Drawing of the River Cornbrook culvert Source: © The University of Manchester Professional Services Unit.

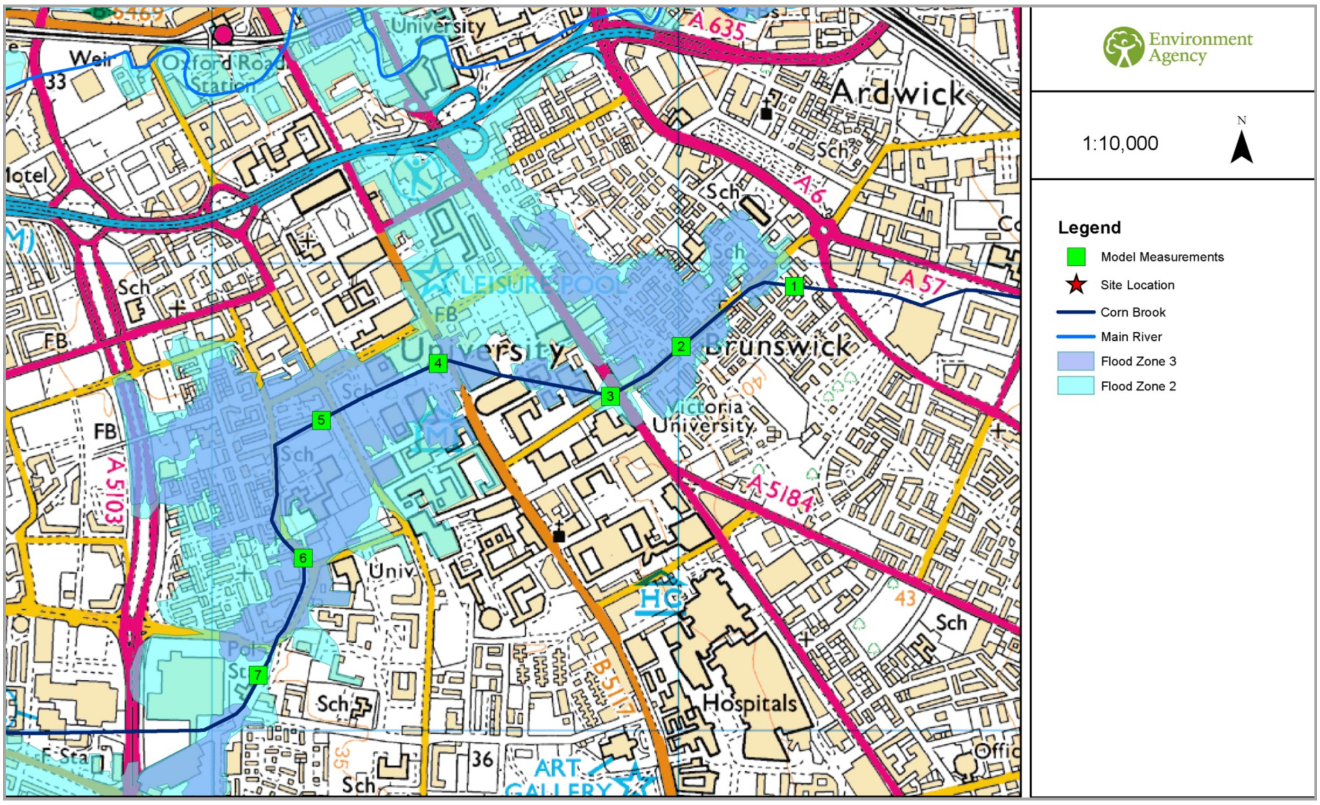

Figure 9: Detailed Flood Map centred on the University of Manchester showing locations of model measurements. Source: © Environment Agency copyright and/or database rights 2014. © Crown Copyright and database right. All rights reserved.

Corn Brook 2009				
Map Reference	Data	1 % AEP	1 % AEP + Climate Change*	0.1 % AEP
2	Modelled Water Level (m aod)	39.46	39.48	39.53
	Modelled Flow (cumecs)	7.91	7.87	7.79
3	Modelled Water Level (m aod)	38.71	38.76	38.94
	Modelled Flow (cumecs)	8.53	8.54	8.43
4	Modelled Water Level (m aod)	36.82	36.85	36.96
	Modelled Flow (cumecs)	8.78	8.82	8.27
5	Modelled Water Level (m aod)	35.78	35.84	35.98
	Modelled Flow (cumecs)	8.35	8.36	8.09

Table 8: Model data taken from the Corn Brook 2009 study.
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Notes: Annual Exceedence Probability (AEP) is the probability or chance of a flood event occurring annually and is typically expressed as a percentage. Larger flood events occur (are exceeded) less often and therefore have a lesser AEP. A 1% Annual Exceedance Probability flood event has a 1% chance of occurring in a year, so once in every 100 years.

Metres above ordnance datum (moad) is the metres above sea level.

reviewed.[18] This helped to understand why there have been permitted developments in a Flood Zone 3 area even though there are strong planning obligations that require justification for developments in flood risk areas such as this. A number of these reports contain detailed topographic surveys. Collectively, they indicate that the ground level of the land is higher than the modelled flood levels with minimal impacts on pedestrians and emergency vehicles therefore anticipated. However, the flood depth is 140mm higher than ground level in a 1 in 1000 extreme event. Whilst damage to buildings typically occurs at depths of over 300 mm, a flood depth of 140 mm may cause disruption for day-to-day working around the University. It is important to emphasise that both flooding and data about flooding are dynamic and thus the risk should be regularly reviewed.

6.2 PLUVIAL FLOODING

6.2.1 THRESHOLDS AND RETURN PERIODS

The SWF data does not look at flood extent, rather the Environment Agency looks at how much the perimeter of the building will get wet. The parameters to define this are discussed with local authorities. In consultation with the Association of Greater Manchester Authorities (AGMA), the mapping for this project has covered two levels of probability – low (1 in 1000 to 1 in 100; that is a 0.1 per cent to 1 per cent chance of occurring annually) and high (1 in 30; 3.3 per cent chance of occurring annually). The SWF layers were extracted for depths up to 300 mm and above 300 mm. These are recognised significant thresholds since 300 mm is the flood depth when damage is likely to occur to buildings (Table 5). The maps and thresholds should indicate an additional threshold of above 600mm as this is typically when building-level flood protection becomes redundant. However, depths over 600 mm are negligible in the University's estate and have therefore been included in the metric 'over 300mm'.

6.2.2 ASSESSMENT RESULTS

For a high probability rainfall event, flood depths of over 300 mm (0.04 per cent of Study Area 1) are indicated to potentially occur around Cecil Street, to the south of Study Area 1 (Figure 10). Potential flooding of less that 300mm depth (0.07 per cent of Study Area 1) is indicated to areas near Prospect House.

For a low probability rainfall event, depths of over 300mm (0.6 per cent of Study Area 1) are potentially indicated to occur around Lloyd Street North, Lime Grove, Brunswick Street, Dover Street, an unnamed street behind the Kilburn building, Crawford House and Burlington Street (Figure 11). Depths of less that 300mm (1.2 per cent of Study Area 1) are potentially indicated to occur around Higher Chatham Street, unnamed streets near Prospect House, and the area adjacent to and behind University Place.

In a high probability rainfall event, the open space of Richmond Park, to the south-east of Study Area 3, is potentially exposed to SWF (Figure 12). However, during a low

[18] Manchester City Council, Planning Public Access System. Available at: http://www.manchester.gov.uk/site/custom_scripts/public_access.php

probability rainfall event, the east of Whitworth Lane may be potentially exposed to SWF to depths of up to 300mm, with a small proportion of the site showing flood depths at above 300mm (Figure 13). The area west of Chancellor's Way also shows susceptibility at depths up to 300mm. The extent and depth of SWF at Richmond Park also shows an increase in a low probability rainfall event when compared to the high probability rainfall event.

Study Areas 2 and 4 show no indications of being potentially exposed to SWF.

6.3 RELATIVE LEVELS OF FLOOD RISK

A key aim of this study was to assess the relative risk to University buildings from flooding. Using Environment Agency flood maps, the likelihood of the University's buildings being exposed to pluvial or fluvial flood events was assessed. This spatial analysis determined whether buildings are exposed to potential fluvial or pluvial flooding. The consequence of flood events, should they occur on the University's estate, was assessed through looking at the type of building, whether it had a basement and whether it was a listed building. This recognises that buildings are not equally susceptible to damage and disruption from flooding, and that negative consequences are likely to be more severe in some buildings due to their form and/or function.

Using this approach, buildings were then assigned a risk category based on the data included in Table 9. Figure 14 provides a visual overview of relative flood risk to University buildings in Study Area 1 where there is potential exposure to flooding. This analysis clarifies that flooding is an issue for the University of Manchester. It demonstrates that risk varies across the University's estate, and increases awareness of buildings and streets where there is a risk from flooding, and strategies and actions to reduce risk, would be valuable. Additional insights and applications resulting from this assessment of relative flood risk to University buildings include:

- There is now a better understanding of those buildings where further investigation, via a targeted flood assessment, would be valuable.
- In the case of risk from SWF, there is now greater clarity of areas of the campus where landscaping work could be usefully considered to increase rainwater infiltration and reduce surface water runoff.
- The assessment provides an indication of areas where modifications to existing buildings, and new developments, could usefully include measures to reduce flood risk.
- There is now a better understanding of where, in the event of extreme rainfall being forecast, flood damage to buildings is most likely.
- This assessment supports the development of contingency plans to ensure that an appropriate emergency planning response is in place in the event of an extreme flood event occurring.

6.4 SURFACE WATER RUNOFF TOOL

Trees, shrubs and green spaces are recognised as having an important role to play in reducing flood risk. Outputs produced by the STAR tools provide an insight into the

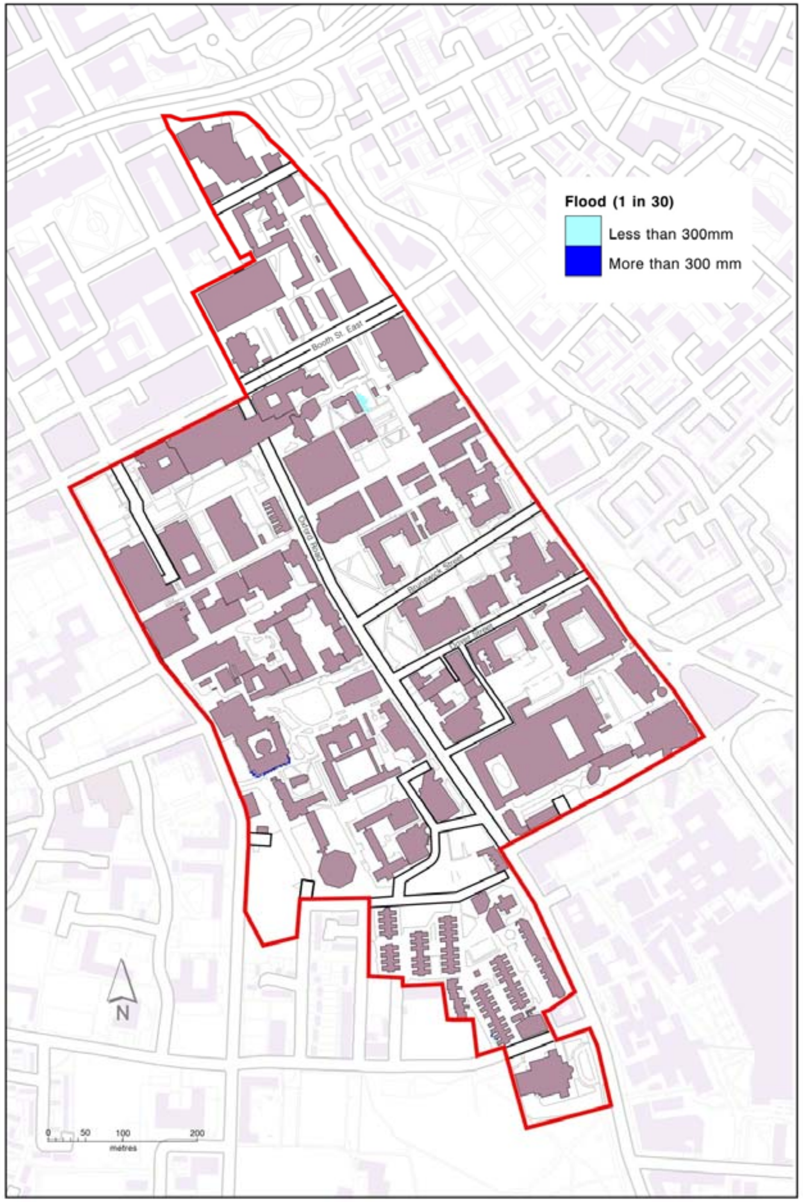

Figure 10: Pluvial Flooding during a 1 in 30 event in Study Area 1 (South Campus) : Source © Environment Agency copyright and/or database rights 2014. © Crown Copyright and database right. All rights reserved. Drawn by Graham Bowden

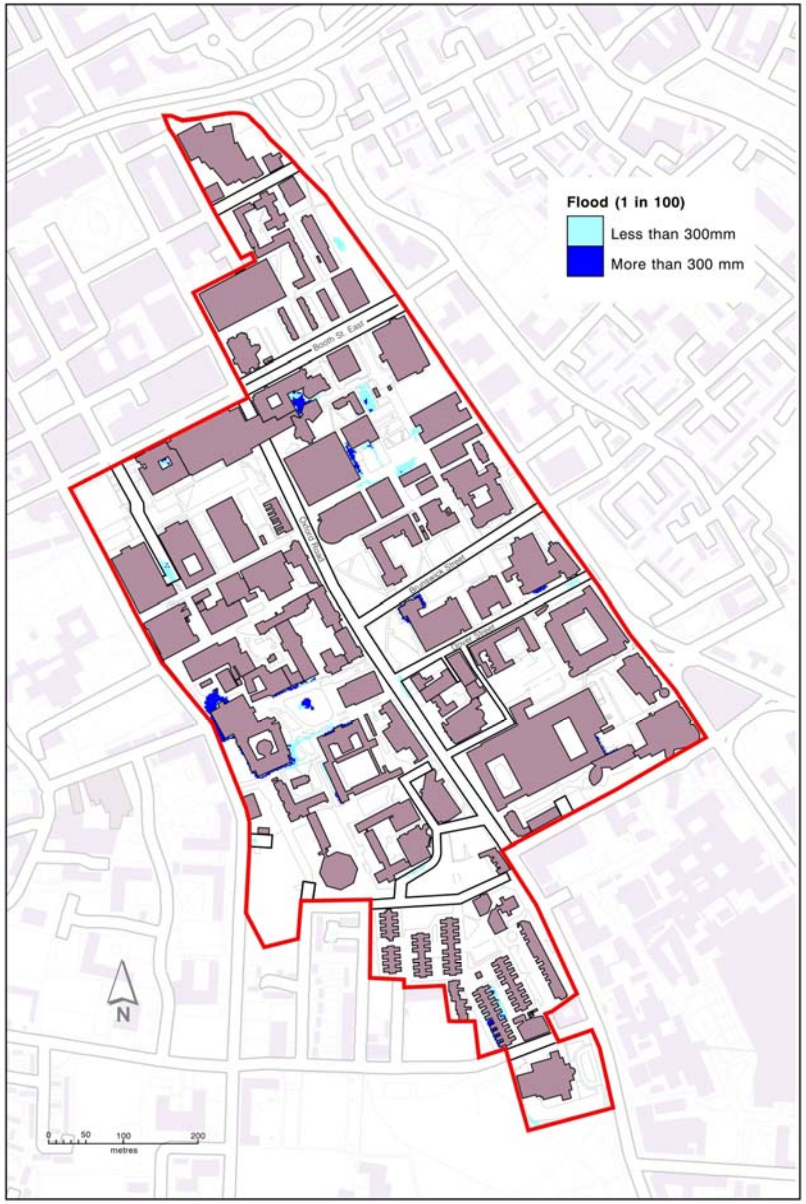

Figure 11: Pluvial Flooding during a 1 in 100 event Study Area 1 (South Campus) . Source: © Environment Agency copyright and/or database rights 2014. © Crown Copyright and database right. All rights reserved. Drawn by Graham Bowden

Figure 12: Pluvial Flooding during a 1 in 30 event in Study Area 3 (Owens Park). Source: © Environment Agency copyright and/or database rights 2014. © Crown Copyright and database right. All rights reserved. Drawn by Graham Bowden

Figure 13: Pluvial Flooding during a 1 in 100 event in Study Area 3 (Owens Park) . Source: © Environment Agency copyright and/or database rights 2014. © Crown Copyright and database right. All rights reserved. Drawn by Graham Bowden

extent to which increasing green space cover can have a moderating effect on surface water runoff.

In the surface water runoff model of the STAR tools, the figures are reported as per cent surface water runoff. That is, the percentage of the total rainfall depth that becomes surface runoff. For example, if there is 10 mm of rain and 50 per cent of it becomes surface runoff, this is equivalent to 5 mm of the rain becoming surface runoff.

The baseline land cover scenario shows 91.7 per cent of surface water runoff on a typical wet winter day. Reducing the amount of green space by 10 per cent increases the amount of surface water runoff to 93.9 per cent. Conversely, increasing the amount of green space reduces the surface water run off on a typical wet winter day to 89.3 per cent.

Under the central estimate for the 2050s high emissions climate change scenario, rainwater runoff levels for the study area are relatively high where land cover remains at baseline levels – at around 92.5 per cent for the wettest day in winter (Figure 15). When the amount of impermeable surfaces and buildings are increased by 10 percent, this raises surface water runoff to 94.5 per cent under the central projection for the 2050s high emissions scenarios. Decreasing the amount of buildings and impermeable surfaces by 10 percent has the opposite effect and reduces surface water runoff to 90.2 per cent.

Although the percentage variation in surface water runoff under the different land cover scenarios is relatively small, the STAR Tools analysis does indicate that increasing green cover has a role to play in reducing surface water flood risk to the University's estate and surrounding buildings.

6.5 REDUCING FLOOD RISK

The STAR Tools show the way in which land cover change has an effect on surface water runoff rates. That said, pluvial flooding is highly localised and contingent on a number of interacting factors which make its mapping very difficult. For example, simple road gradients, kerb positioning, drainage and so on can subtly influence surface water runoff.

The trend towards sustainable drainage systems (SuDS) in new developments, underpinned in planning obligations, is one method of decreasing runoff and is already employed as a strategy in the proposed redevelopment of the Manchester Business School. National Standards on Sustainable Drainage Systems that fulfil Schedule 3 of the Flood Water Management Act are imminent, and these will create a SuDS approval body who will work with the Local Planning Authority to implement the standards. This should ensure that SuDS become even more common place, including on the University campus.

The STAR Tools analysis demonstrates that decreasing the proportion of green space on the University's estate should be discouraged because of its importance in moderating surface water runoff.

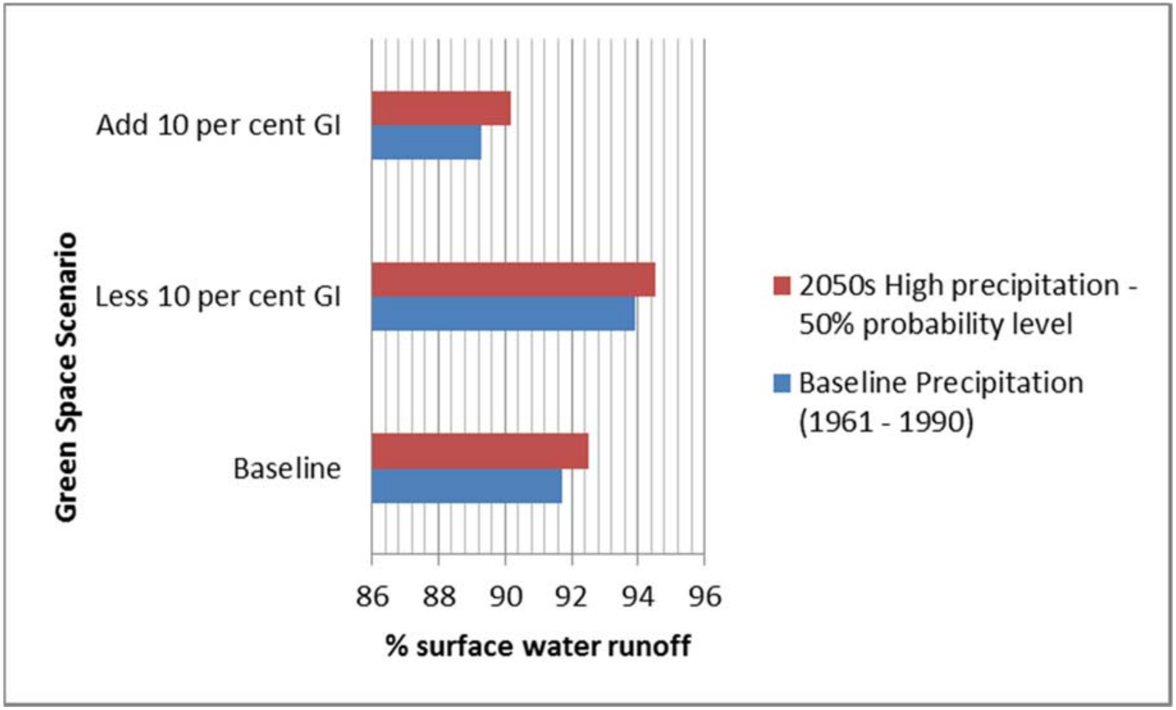

Figure 15: Variations in surface water runoff for Study Areas under different land cover scenarios. Contains Ordnance Survey data © Crown Copyright and database right 2011 Ordnance Survey 100031461 under different land cover scenarios. Soil data © Cranfield University (NSRI) and for the Controller of HMSO 2011; UK Climate Projections data © Crown Copyright 2009. Source: The Mersey Forest & The University of Manchester (2011). STAR tools: surface temperature and runoff tools for assessing the poten al of green infrastructure in adap ng urban areas to climate change. Part of the EU Interreg IVC GRaBS project. www.ginw.co.uk/

For building level flood protection measures, an in-depth flood risk assessment and survey will be required, which should be combined with robust cost benefit analyses.[19] There are two types of solution that can increase the resilience of individual properties to flooding. 'Flood resilient' measures accept that flood waters will enter a property and seek to minimise the damage caused. 'Flood resilient' measures include placing electrical sockets higher up the wall (c. 1.5 metres) and moving valuables to a higher location (i.e. on the first floor of a property or on higher level shelving). Exposed tiles or floorboards are recommended over carpets. It is also possibly to buy water-resistant skirting boards and walls should not use gypsum; instead, horizontal plasterboard or lime-based plaster can be used.

'Flood resistant' solutions aim to keep flood water away from properties. New technologies are emerging that can offer a level of flood protection to buildings. These include demountable flood barriers, automatic air brick covers and automatic door and window barriers. Any decisions on whether such measures are a feasible option need to be underpinned by a detailed flood risk assessment and cost benefit analysis.

[19] Angela Connelly, Stephen Garvin, Nigel Lawson, Paul O'Hare and Iain White. 2013. *Six Steps to Flood Resilience: Guidance for Local Authorities & Professionals*. Available at: www.smartfloodprotection.com

Study Area	Building	River and Sea Flood Zone	Susceptible in High Probabillity Rainfall Event	Susceptible in Low Probabillity Rainfall Event	Construction Date	Listed Status	Type of Building	Basement	Relative Risk
1	Garstang House	No	No	Yes	1977	Not Listed	Housing	No	Low
1	Samuel Alexander Building	No	No	Yes	1919	Grade II	Academic & Professional	Yes	Low
1	Simon Building	No	No	Yes	1953	Not Listed	Academic & Professional	Yes	Low
1	Simon Building	No	No	Yes	1953	Not Listed	Academic & Professional	Yes	Low
1	Arthur Lewis Building	Flood Zone 3	No	No	2008	Not Listed	Academic & Professional	No	Medium
1	Coupland Building 1	Flood Zone 3	No	No	1900	Not Listed	Academic & Professional	Yes	Medium
1	Coupland Building 3	Flood Zone 3	No	No	1874	Grade II	Academic & Professional	Yes	Medium
1	Crawford House	Flood Zone 3	No	Yes	1973	Not Listed	Academic & Professional	Yes	High
1	George Kenyon Building	Flood Zone 3	No	No	2008	Not Listed	Housing	Yes	Medium
1	Humanities Bridgeford Street	Flood Zone 3	No	No	1970	Not Listed	Academic & Professional	Yes	Medium
1	Manchester Business School West	Flood Zone 3	No	Yes	1971	Not Listed	Academic & Professional	Yes	High
1	Manchester Museum	Flood Zone 3	No	No	1911 - 1927	Grade II	Social & Cultural Facility	Yes	Medium
1	Precinct Centre 1	Flood Zone 3	No	No	1970	Not Listed	Academic & Professional	UNKNOWN	Medium

Table 9: List of buildings in Study Areas 1 and 3 assigned with relative risks to flooding

Study Area	Building	River and Sea Flood Zone	Susceptible in High Probabillity Rainfall Event	Susceptible in Low Probabillity Rainfall Event	Construction Date	Listed Status	Type of Building	Basement	Relative Risk
1	Roscoe Building	Flood Zone 3	No	No	1964	Not Listed	Academic & Professional	Yes	Medium
1	Rutherford Building	Flood Zone 3	No	No	1900	Grade II	Academic & Professional	Yes	Medium
1	Schuster Building	Flood Zone 3	No	No	1967	Not Listed	Academic & Professional	Yes	Medium
1	University Dental Hospital	Flood Zone 3	No	No	1938	Not Listed	Interdisciplinary Research Institute	UNKNOWN	Medium
1	Waterloo Place	Flood Zone 3	No	No	1832	Grade II	Academic & Professional	Yes	High
1	Alan Turing Building	Flood Zone 2	No	No	2007	Not Listed	Interdisciplinary Research Institute	No	Low
1	Beyer Building	Flood Zone 2	No	No	1887	Grade II*	Academic & Professional	Yes	Low
1	Bowden Court 2 & 3	Flood Zone 2	No	No	1977	Not Listed	Housing	No	Low
1	Central Plant Building	Flood Zone 2	No	No	1950	Not Listed	Other	Yes	High
1	Chemistry Building	Flood Zone 2	No	Yes	1964	Not Listed	Interdisciplinary Research Institute	Yes	Medium
1	Christie Building	Flood Zone 2	No	No	1898	Grade II*	Academic & Professional	Yes	Low
1	Grosvenor Halls of Residence	Flood Zone 2	No	No	1972	Not Listed	Housing	Yes	Low
1	Grosvenor Street Building	Flood Zone 2	No	No	1994	Not Listed	Housing	No	Low

Table 9 (cont): List of buildings in Study Areas 1 and 3 assigned with relative risks to flooding

Study Area	Building	River and Sea Flood Zone	Susceptible in High Probabillity Rainfall Event	Susceptible in Low Probabillity Rainfall Event	Construction Date	Listed Status	Type of Building	Basement	Relative Risk
1	Information Technology Building	Flood Zone 2	No	Yes	1972	Not Listed	Academic & Professional	No	Low
1	James Chadwick Building	Flood Zone 2	No	No	UNKNOWN	Not Listed	Interdisciplinary Research Institute	UNKNOWN	Low
1	Jean MacFarlane Building	Flood Zone 2	No	No	2008	Not Listed	Academic & Professional	No	Low
1	John Owens Building & Student Services Centre	Flood Zone 2	No	Yes	1870	Not Listed	Social & Cultural Facility	Yes	Medium
1	John Ryland University Library	Flood Zone 2	No	Yes	1936	Not Listed	Library & Learning Centre	Yes	Medium
1	Manchester Acquatics Centre	Flood Zone 2	No	No	1997	Not Listed	Athletics and Recreational Facility	Yes	Low
1	Manchester Business School East	Flood Zone 2	No	No	2000	Not Listed	Academic & Professional	No	Low
1	Martin Harris Centre	Flood Zone 2	No	No	1909	Not Listed	Social & Cultural Venue	Yes	Medium
1	Materials Science Centre	Flood Zone 2	No	No	1976	Not Listed	Interdisciplinary Research Institute	Yes	Medium
1	Oddfellows Hall	Flood Zone 2	No	No	1967	Grade II	Housing	Yes	Low
1	Prospect House	Flood Zone 2	Yes	Yes	1980	Not Listed	Academic & Professional	Unknown	High
1	Ronson Hall	Flood Zone 2	No	No	1989	Not Listed	Housing	No	Low
1	Schuster Building	Flood Zone 2	No	No	1967	Not Listed	Interdisciplinary Research Institute	Yes	Medium

Table 9: List of buildings in Study Areas 1 and 3 assigned with relative risks to flooding

Study Area	Building	River and Sea Flood Zone	Susceptible in High Probabillity Rainfall Event	Susceptible in Low Probabillity Rainfall Event	Construction Date	Listed Status	Type of Building	Basement	Relative Risk
1	Sugden Sports Centre	Flood Zone 2	No	No	1981	Not Listed	Athletics and Recreational Facility	No	Low
1	Whitworth Hall	Flood Zone 2	No	No	1902	Grade II*	Academic & Professional	Yes	Low
1	Kilburn Building	Flood Zone 3	No	Yes	1971	Not Listed	Academic & Professional	No	Medium
3	Ashburne Hall Centre & Reception	No	Yes	Yes	1899	Not Listed	Housing	Yes	Low
3	Beech Court	No	No	Yes	1973	Not Listed	Housing	No	Low
3	Cavendish	No	No	Yes	1959	Not Listed	Housing	No	Low
3	Chancellors Hotel and Conference Centre	No	No	Yes	1851	Grade II	Social & Cultural Venue	Yes	Low
3	Ladybarn House	No	Yes	Yes	Unknown	Unknown	Unknown	UNKNOWN	Low
3	Lindsay	No	No	Yes	1973	Not Listed	Housing	No	Low
3	Morley	No	No	Yes	1973	Not Listed	Housing	No	Low
3	Richmond Park Stores and Maintenance	No	No	Yes	1995	Not Listed	Housing	No	Low
3	Willow Court Flats	No	No	Yes	1995	Not Listed	Housing	No	Low
3	Woolton Hall Main Building & Stores	No	No	Yes	1973	Not Listed	Housing	No	Low

Table 9 (cont): List of buildings in Study Areas 1 and 3 assigned with relative risks to flooding

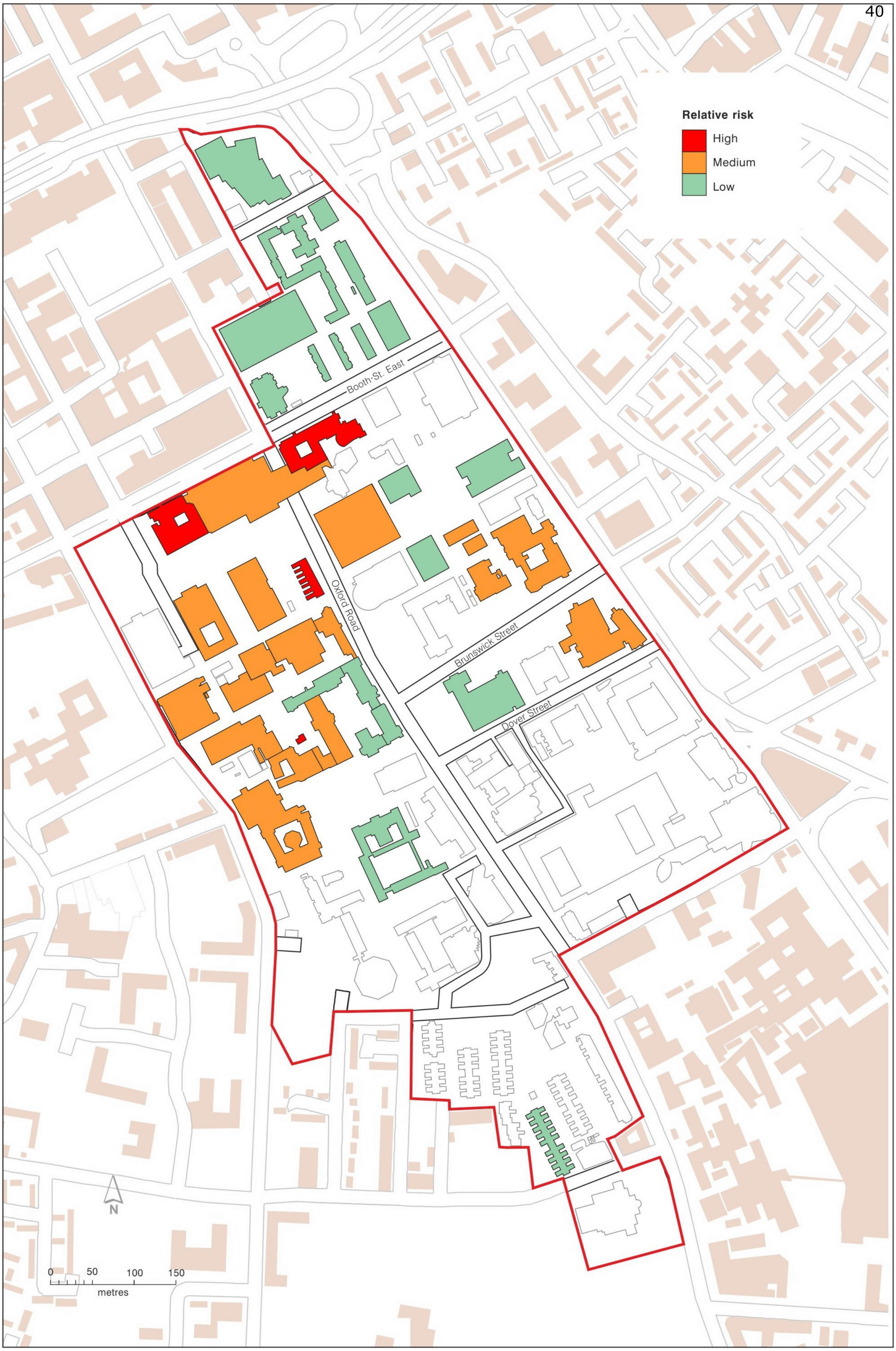

Figure 14: Relative risk of flooding to buildings in Study Area 1. No colour demonstrates that the building is considered not to be at risk of fluvial and pluvial flooding using the best available data.

7 HEAT STRESS ANALYSIS

The SCORCHIO project mapped the extent and intensity of Greater Manchester's UHI. This showed the deviation of surface temperatures from the average surface temperature for the conurbation. At present, Greater Manchester's warmest day sees average temperatures of 26 - 27°C. Where the UHI is most intense (typically in the city core), the temperature increases above this average.

Study Area 4 was not included in the SCORCHIO project's scope and has therefore been discounted for this analysis. Study Areas 1 and 3 (Figures 16 and 18) fall within an area where average temperatures are up to 1.5°C above the GM average. Study Area 2's location (Figure 17) shows that temperatures between 1.5°C and 3°C above the average for Greater Manchester according to the SCORCHIO UHI map.

Much of the University's estate is located where temperatures are relatively high for Greater Manchester, and therefore by extension the north-west region of England. In the event of a heatwave occurring, the University's buildings and their occupants are potentially at risk of heat stress impacts. This risk is set to increase over the coming decades as the climate changes, with the warmest day in summer projected to be around 3°C higher than it is today by the 2050s.[20] This means that by the 2050s, the warmest day in all study areas could exceed 30°C.

7.1 VULNERABILITY OF BUILDINGS AND THEIR OCCUPANTS TO HEAT STRESS

The Met Office has set regional thresholds for the definition of a heatwave. For the north-west of England, this is 30°C during the day with the intervening night above 15°C. The NHS's Heatwave Plan for England indicates that two consecutive days above 30°C with the intervening night above 15°C will have significant implications for people's health.[21]

Until recently, Chartered Institution of Building Services Engineers (CIBSE) guidance indicated that overheating criteria for non-domestic buildings should be defined as not more than 1% of occupied hours should be spent at a temperature above 28°C (defined as 'hot'). Temperatures exceeding 30°C are rarely acceptable for work places in the UK.[22] Optimal work performance tends to occur at temperatures around 21-25◦C although this can be hugely variable depending on an individual worker's characteristics.

There are a number of design guidance documents that indicate physical features that influence the vulnerability of buildings, and their occupants, to high temperatures and how climate change might influence this. These are outlined in Table 10. Multi-storied office buildings constructed during the 1960s and 1970s have been shown to be most

[20] Gina Cavan. 2011. Climate change projections for Greater Manchester, version 2. The EcoCities Project. Available at: http://www.adaptingmanchester.co.uk/documents/climate-change-projections-greater-manchester-version-2

[21] Department of Health. 2014. The National Heatwave Plan for England. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/310598/10087-2902315-TSO-Heatwave_Main_Plan_ACCESSIBLE.pdf

[22] CIBSE (2005) TM36 Climate change and the internal environment. London: Chartered Institution of Building Services Engineers

prone to overheating.[23] There are a number of these types of buildings in the study area, particularly around the Brunswick Street area, such as the Schuster, Roscoe, Simon and Williamson Buildings.

There are physical measures that can be undertaken in buildings to reduce overheating potential and these include fitting external shutters and tinted windows. However, such shading affects visual comfort and so consideration of appropriate daylighting and implications for views should be evaluated before undertaking any strategy.[24] Some of the most (cost)-effective measures take place outside of the building in the provision of trees and green space that provide shading and act to cool the spaces between buildings. In order to quantify the potential of this strategy, the next section presents the results of an analysis of the university estates which demonstrates the effect of varying land cover on surface temperatures.

7.2 SURFACE TEMPERATURE TOOL.

The same land cover scenarios were run as for the assessment of surface water runoff. Figure 19 demonstrates the differing surface temperature values when levels of green space are increased or reduced.[25] Analysis using the STAR tools indicates that the baseline maximum surface temperature is currently 33.2°C. Ten per cent less green space raises the maximum surface temperature to 37.2°C whilst increasing the proportion of green space by ten per cent reduces this to 30.2°C.

7.3 REDUCING HEAT STRESS.

Climate change projections indicate an increasing frequency of heatwave events for central Manchester[26]. It would be prudent for the University to consider how to adapt existing buildings and their surrounding landscapes given how building form and landcover can impact on the thermal comfort of people occupying buildings and the spaces around them. This is particularly significant given the University's role as a teaching and learning institution.

The STAR Tools outputs highlight the significant contribution that land cover can make to surface temperatures around the campus. A cautious approach would seek to increase the levels of green space cover around buildings at higher risk of heat stress. Green roofs, for example, not only insulate and protect existing roofs (thereby lowering temperatures and extending the life of the roof structure), they help to moderate surface water run-off and reduce heating bills in the winter. In addition, raising the albedo rating

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[23] J. N. Hacker, S. E. Belcher, R. K. Connell. 2005. Beating the Heat: keeping UK buildings cool in a warming climate. UKCIP Briefing Report. UKCIP, Oxford. Available at: http://www.ukcip.org.uk/wordpress/wp-content/PDFs/Beating_heat.pdf

[24] K. M. J. Farley and J. A. Veitch. 2001. A room with a view: A review of the effects of windows on work and well-being. National Research Council Canada, IRC-RR-136.

[25] The figures reported here are for the 2050s Central Estimate climate change projection.

[26] Gina Cavan. 2011. Climate change projections for Greater Manchester, version 2. The EcoCities Project. Available at: http://www.adaptingmanchester.co.uk/documents/climate-change-projections-greater-manchester-version-2

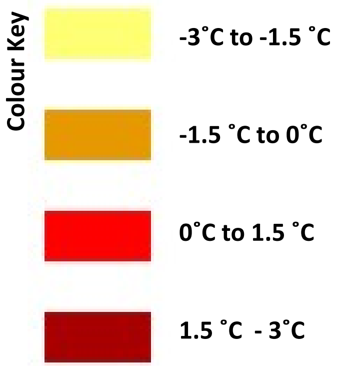

Fig. 16: UHI at Study Area 1 (South Campus)

Fig. 17: UHI at Study Area 2 (Victoria Park)

Fig. 18: UHI at Study Area 3 (Owens Park)

Sources for Figures X—X: EcoCities Spatial Portal. © Crown Copyright & Database Right 2008. All rights reserved. UHI data has been kindly provided by the ESPRC-funded SCORCHIO programme, EP/E017428/1, Newcastle University / University of Manchester. For further information, please see C. Smith et al. 2011. Fine-scale spatial temperature patterns across a UK conurbation, Climatic Change, 109 (3 - 4), pp. 269-286, DOI:[10.1007/s10584-011-0021-0](https://doi.org/10.1007/s10584-011-0021-0). .

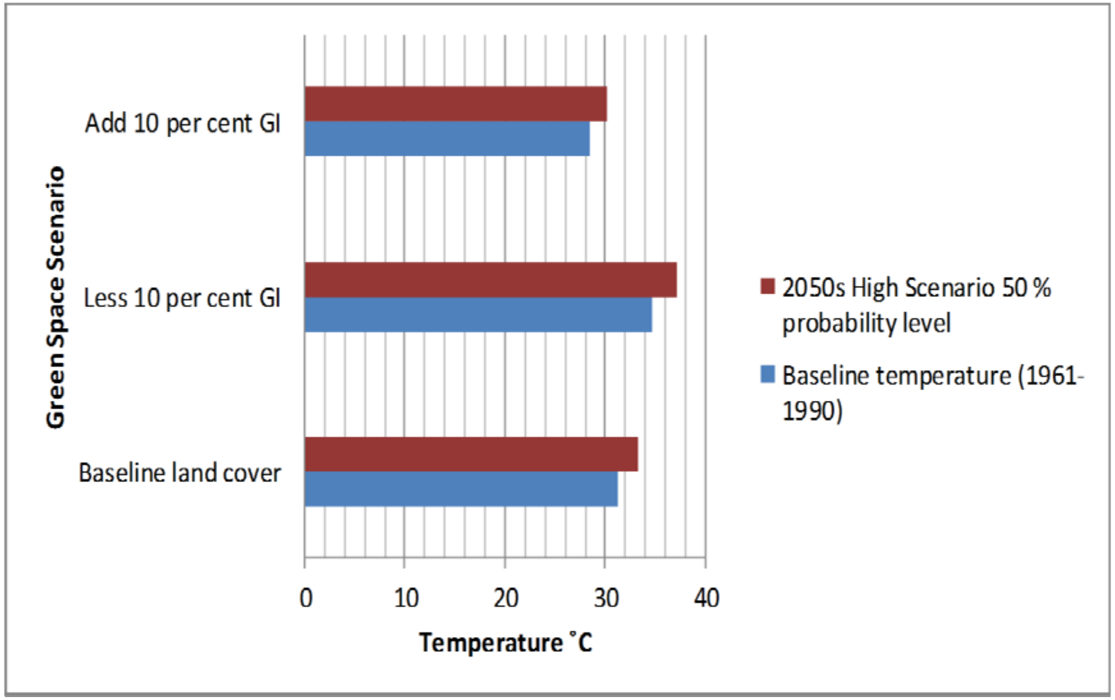

Figure 19: Variations in maximum surface temperature for Study Areas under different land cover scenarios. Contains Ordnance Survey data © Crown Copyright and database right 2011 Ordnance Survey 100031461 under different land cover scenarios. Soil data © Cranfield University (NSRI) and for the Controller of HMSO 2011; UK Climate Projections data © Crown Copyright 2009. Source: The Mersey Forest & The University of Manchester (2011). STAR tools: surface temperature and runoff tools for assessing the potential of green infrastructure in adapting urban areas to climate change. Part of the EU Interreg IVC GRaBS project. www.ginw.co.uk/

of a building (that is, its ability to reflect UV rays) can be done through, for example, using white paint.

There are other building-scale measures available to reduce risks associated with high temperatures. Whilst mechanical cooling can help people cool down in hot weather, such systems tend to be discouraged because of their energy (and carbon dioxide emissions) implications. Passive measures are often recommended, including allowing windows to open so long as the outside temperature remains cooler than the indoor temperature. Other simple passive measures include providing external shutters or solar shading to limit the amount of sunlight entering a building. However, such measures may be restricted in existing urban sites owing to a number of factors such as pollution, noise, and health and safety. For example, many student residences and tall structures have restricted window openings on the upper floors for health and safety reasons. Appropriate passive measures will therefore depend on the building type.

Lower energy mechanical cooling systems are coming to market, such as water-chilled beams, and, during routine upgrades, more invasive measures such as this can be considered. Strategies to modify a building's envelope may include increasing the external insulation to reduce solar heat gain, and increasing air tightness can raise thermal efficiency. In this case, site specific investigations should be conducted in the manner of, for example, a recent study of several buildings on the the University of Salford estates.[27]

[27] Buro Happold. 2013. University of Salford Climate Change Adaptation Study: Final Report. Technology Strategy Board. Available at: http://www.arcc-network.org.uk/wordpress/wp-content/D4FC/D4FC44-Salford-university-full-report.pdf

Impacts on Building Occupants	Design Concerns	Climate Change Implications
Decreased productivity and poor Concentration which may lead to errors.	High levels of glazing can trap heat.	Mechanical ventilation systems with heat recovery may be less beneficial as the heating season shortens
Increased possibility of health issues such as stress & fainting.	**Inadequate ventilation:** combined with high temperatures can compound decreases in worker productivity	Active cooling will be difficult to avoid by the end of the century. However, this may have implications to increased energy use
Exacerbation of pre-existing health conditions such as heart conditions and asthma.	**Thermal Mass:** Building with a low thermal mass may be more susceptible to over-heating.	Lightweight, under-ventilated, over-glazed structures, such as conservatories, will become 'intolerable' even with cooling
Users have shown preferences for natural ventilation.	**Insulation:** Insulation keeps a building warmer in the winter as well as keeping it cool in the summer by acting as a barrier	Window opening to reduce temperatures may become untenable when outside surface temperatures warm.
	Air-tightness: any draughts, small cracks and other points of ingress can allow warm air into the building, disrupting controlled air flows.	
	Conversely, high levels of insulation and air-tightness may intensify future overheating.	

Table 10: Interaction of buldings with increased temperature currently and with climate change projections considered.
Sources: Hacker et al 2005; Seppänen et al 2006; Gething, 2010; Carter et al 2011; Health and Safety Executive 2014.

8 CASE STUDIES

Six case studies were chosen from those buildings that were shown by the assessment conducted within this project to be at risk from weather and climate change impacts (See Table 9, Section 5.2). It should be noted that some buildings deemed to be at 'high risk' are to be replaced under the current Campus Masterplan, including the Manchester Business School and Precinct Centre. Therefore, these were not selected as case studies. There is a spread across different building types in the following case studies. Collectively they give a broad overview of how buildings and their immediate surroundings *may* interact with increased precipitation and temperature and are intended to raise awareness about potential adaptation strategies. They highlight building characteristics that influence exposure and vulnerability to weather and climate change impacts, and adaptation responses that could help to reduce related risk.

Roscoe Building

1964

NOT LISTED

MAIN CAMPUS

ACADEMIC AND PROFESSIONAL SCHOOL

WEATHER AND CLIMATE

The Roscoe Building is at medium risk, being located within Flood Zone 3 and having a basement area.

The building is located in the urban heat island where temperatures are up to 1.5ºC higher than the GM average. The central estimate of climate projections for the 2050s indicates a temperature increase of around 3ºC.

BUILDING CHARACTERISTICS

Opened in 1964, the Roscoe Building is a typical 1960s white concrete building with a glass façade. Of this kind of building on campus, Roscoe is acknowledged to be of particular architectural quality.

The building consists of six floors in addition to a basement. Roscoe mainly houses lecture theatres and classrooms. It is a working place and busy at certain times of the academic year.

The basement houses two lecture theatres in addition to boiler rooms, storage areas and lavatories. Anecdotal evidence indicates that there has been flooding in the past to the basement but the source of that flooding is unconfirmed. Contingency plans may need to be put into operation when considering the potential for flooding.

This type of building has a lower thermal mass and may be prone to overheating. The glass façade, for example, is south facing. Air conditioning has been installed to service Roscoe's lecture theatres. This may mean that future temperature increases may raise summer cooling costs. Overheating to specific rooms should be investigated and contingency plans developed to ensure that the thermal comfort for occupants is retained even during warm periods.

POTENTIAL ADAPTATION OPTIONS

- Increase the scope and variety of green infrastructure around the building and explore the potential for a green roof.
- Move valuable items from basements to upper floors.
- Have contingency and emergency plans that account for all times of day and patterns of use in order to advise on overheating.

John Rylands Library

1935 – 7 (1953-6; 1981)
NOT LISTED
MAIN CAMPUS
LIBRARY AND LEARNING CENTRE

WEATHER AND CLIMATE

The John Rylands University Library is located within Flood Zone 2 and is located in an area which may be susceptible to surface water flooding.

The building is located in the urban heat island where temperatures are on average 0 – 1.5ºC higher than the GM average. The central estimate of climate projections for the 2050s indicates a temperature increase of around 3ºC.

BUILDING CHARACTERISTICS

The John Rylands Library is essentially in three parts. To the east, is a brick and stone construction which was built between 1935 and 1937. This was further extended in 1953 – 6 and was joined by the octagonal Muriel Stott Hall (1978). A further red brick extension, and the current location of the main entrance, opened in 1981.

The library primarily houses the university book collection and archives. In addition it provides ample study areas and IT facilities. At certain times of the year, the building is in 24-hour use. There is a basement in which plant rooms are located along with books and archive stores.

The building is mechanically heated and vented but the plans do not indicate further mechanical cooling. Due to the construction materials, all parts of the building have a fairly high thermal mass.

Given that the building is in a flood risk zone (albeit low risk) and that it is in an area where there is susceptibility to surface water flooding, there may be scope to increase vegetation cover in the surrounding areas, which are predominantly sealed surfaces, in order to moderate surface water runoff. In terms of green roofs, the blue area's roof is largely flat but some of that is reserved for services and there are four roof projections on the east facing side of the building which hinder greening potential. The orange section, with the Muriel Stott centre, has pitched roofs. This reduces possibilities for greening. There is manicured landscaping to the front of the building. Varying the type of land cover in this area by adding, more trees for example, may alter the balance of surface water runoff and provide extra cooling capacity during a heatwave.

POTENTIAL ADAPTATION OPTIONS

- Increase the variety of green infrastructure around the building and explore the potential for a green roof
- Move valuable items from basements to upper floors
- Have contingency and emergency plans that account for all times of day and patterns of use in order to advise on overheating.

George Kenyon Building

2008

NOT LISTED

MAIN CAMPUS

HOUSING ACCOMMODATION

WEATHER AND CLIMATE

The George Kenyon Building is located within Flood Zone 3.

The building is located in the urban heat island where temperatures are up to 1.5ºC higher than the GM average. The central estimate of climate projections for the 2050s indicates a temperature increase of around 3ºC.

BUILDING CHARACTERISTICS

The George Kenyon Building opened in 2008 and was designed by John McAslan & Partners.

The building comprises of 300 student dwellings on the upper floors of the building. Level 1 and a mezzanine area contain an IT cluster and reception areas.

The building is primarily of brick construction which has a zinc cladding. Zinc cladding has become more popular amongst architects in recent years because the relative price of the material mitigates against thefts. In addition, zinc is 100% recyclable and has a long life span. In the George Kenyon building, it acts as a rainscreen that should prolong the life of the building envelope.

As a dwelling place, the building may be in heavy occupancy for certain periods of the year. Overheating criteria for domestic dwellings should therefore be adhered to. For example, residents with pre-existing health conditions may require extra support. Some work could be undertaken to understand thermal comfort in different rooms in order to isolate whether passive and/or behavioural strategies could be used to mitigate over-heating.

Given that the building is in a flood risk zone and is in an area where there is susceptibility to surface water flooding, there may be scope to increase the vegetation in the surrounding areas, which are predominantly sealed surfaces, in order to moderate surface water runoff. There is no basement which reduces flooding concerns and all major building services are located on the roof (which means a green roof is not a possibility).

POTENTIAL ADAPTATION OPTIONS

- Shading windows from direct sunshine, for example by outside shutters.
- If shading is impractical, using thick curtains to reduce heating of the indoor environment.
- Opening windows in the early morning, and shutting them if the outdoor temperature rises above the indoor temperature.

Humanities Bridgeford Street

1970
NOT LISTED
MAIN CAMPUS
ACADEMIC & PROFESSIONAL SCHOOL

WEATHER AND CLIMATE

Humanities Bridgeford Street is in Flood Zone 3, which means that it is at risk of flooding from a 1 in 100 flood from the culverted River Cornbrook.

The building is located in the urban heat island where temperatures are up to 1.5ºC higher than the GM average. The central estimate of climate projections for the 2050s indicates a temperature increase of around 3ºC.

BUILDING CHARACTERISTICS

Humanities Bridgeford Street dates from 1970. The building is of steel frame construction with pre-cast concrete cladding. There have been some structural maintenance issues relating to the cladding. Poor building maintenance can increase potential for water ingress into a building during a flood event.

The building currently hosts lecture rooms and theatres primarily used by the Manchester Architecture Research Centre (MARC), Cathie Marsh Institute for Social Research (CMIST) & Planning and Environmental Management. Support services, including training, media support and the graphics workshop, are located on the top floor, which means that at certain times there is high access from students and staff across the university. This means that should there be a weather-related event, large numbers of people may have to be evacuated from the building.

The basement contains the model-making workshop, the plant room and some study areas. Basements are often the first places that building might flood. It can be prudent to move high value items and services to upper floors.

POTENTIAL ADAPTATION OPTIONS

- The roof could be greened.
- Address structural maintenance issues.
- Move high value items from basement.
- Provide internal/external screens for windows.

THE MANCHESTER MUSEUM

1911 – 1927
Grade II Listed
MAIN CAMPUS
SOCIAL AND CULTURAL FACILITY

WEATHER AND CLIMATE

The Manchester Museum is located within Flood Zone 3 and is located in an area which may be susceptible to surface water flooding.

The building is located in the urban heat island where temperatures are up to 1.5ºC higher than the GM average. The central estimate of climate projections for the 2050s indicates a temperature increase of around 3ºC.

BUILDING CHARACTERISTICS

The Manchester Museum was originally designed by Alfred Waterhouse and conceived of along with the Beyer building and the rest of the Whitworth Hall range. The building was intended to house natural history and geology collections donated to the then Owens College. There was a further extension designed by Waterhouse’s son, Paul and finished by his grandson, Michael which is also Grade II listed. This provided a bridge to link the original building to the new one across Coupland Street. This means that the building is of national importance and that English Heritage must be consulted in order for any adaptation work to take place. This designation does not preclude adaptation – in 2003 the building was remodelled by Ian Simpson architects.

The Museum is in heavy use by members of the public and schools who come to visit the collections. Visitor numbers will be higher at certain times of the year (for example, school holidays) or when there are special exhibitions. The building is used to generate further revenue by letting space for corporate events and weddings.

The building has a basement and given that it is in a flood risk zone, it may be prudent to consider moving valuable items or essential services to upper floors. It is unlikely that the building will overheat although certain rooms could be liable to overheating depending on the glazing and this could be investigated further. It may be that, during a heatwave, the building becomes a source of respite for the users of nearby buildings which are prone to overheating. This may be usefully reflected in room booking times.

POTENTIAL ADAPTATION OPTIONS

- Increase the variety of green infrastructure around the building.
- Move valuable items from basements to upper floors
- Develop contingency plans for Museum closure in the event of a flood.

9 MANAGING WEATHER AND CLIMATE RISK AT THE UNIVERSITY OF MANCHESTER

It is clear that extreme weather and climate change risk is a concern for the University of Manchester, as it is for all long term land owners in urban areas. This study has focused on flooding and high temperatures. There are other relevant weather and climate hazards with the potential to impact on the University's estate, including cold events and storms (including high winds). However, these were not considered within this study due to lack of data, particularly spatial data and associated future climate projections, and because the frequency of cold events is projected to decline as time passes.

Given the risk to University buildings from weather and climate hazards, and the projections for accelerating climate change over the coming decades, at a minimum the University should review risks periodically and establish processes to monitor underlying conditions and issues that influence risk. This would involve keeping up to date with current knowledge related to weather and climate hazards, particularly Environment Agency flood mapping. Also, it would be useful to develop and maintain a database on University buildings regarding aspects of their form and function that influence climate risk. This could build on the approach developed for this project (outlined in Table 9). The database would usefully inform emergency responses in the event of a flood or heat stress event occurring, and would provide a basis for prioritising sites for adaptation responses should opportunities to take action arise.

A more ambitious response would be to begin developing and implementing long term adaptation strategies and practical responses on the University's estate to lessen current risks and those risks projected to increase under climate change. This would be informed by the risk assessment work undertaken within this project, and by ongoing and previous research undertaken at the University of Manchester. Ideally, when considering adaptation responses, the focus would be on those actions offering multiple benefits additional to managing weather and climate risks, for example increasing the health and wellbeing of staff and students. Enhancing greenspaces is a particularly valuable strategy in this respect.

9.1 PROGRESSING ADAPTATION RESPONSES AT THE UNIVERSITY

This project has built capacity for developing strategies and responses to reduce weather and climate risk to the University of Manchester estate. In particular, the following insights and issues have emerged from the project:

- Flooding is the key risk currently facing the estate, as it is for Greater Manchester more generally. Wetter winters and more extreme downpours across the year are projected for the coming decades, suggesting that flood risk will intensify.
- There is now clearer information on those buildings and locations where risk from flooding is greatest and therefore where actions to reduce risk and enhance emergency responses would be most valuable.

- It is important to consider buildings separately when considering weather and climate risk. Given the diverse form and function of buildings across the estate, and the fine grained nature of exposure to hazards such as flooding, buildings close to each other can display quite different risk profiles.
- Due to the limitations of flood maps available from the Environment Agency, which stem from difficulties in predicting the behaviour of flood waters locally, there is a need for building scale flood risk assessments to confirm the level and nature of risk to individual buildings. This is particularly the case where investments to reduce flood risk are being considered.
- There is currently a low risk of heat stress to the estate, although climate change projections suggest that this risk will increase in the future as average temperatures increase. Building scale heat modelling is ultimately needed in order to inform investments to reduce risks associated with high temperatures.
- The benefit of increasing green cover as an adaptation response, particularly for lowering surface temperatures, has been demonstrated by the application of the STAR Tools within this project.
- The University has gained a number of new buildings over the last decade, with several high profile developments set to complete over the coming years. Despite this growth, the estate is dominated by older buildings that will be in service for many years to come. Existing buildings have a long lifespan, and have generally not been developed with climate change in mind. This emphasises the importance of retrofitting existing buildings to ensure that they can operate efficiently under a changed climate.

This report, and the research underpinning it, has focused on the direct impacts of extreme weather and climate change to the University of Manchester's estate. However, hazard events including floods and heatwaves have broader implications with the potential to impact on the University. Related issues include flooding of transport infrastructure and its impact on access to the University by staff and students. Similarly, flooding or storm damage to electricity generation or supply infrastructure would negatively affect the University's operations. Although impacts such as these can be recognised, urban systems are complex and interdependent, which means that there is the potential for cascading effects across sectors and scales. This makes it increasingly difficult to quantify the severity of associated impacts.[28]

Due to the complexity and interconnectedness of weather and climate risks, implementing adaptation responses is best realised through working across sectors and spatial scales. The examples of impacts to transport and electricity infrastructure above emphasise the importance of ensuring that the University sits within a resilient city. There is related activity ongoing within AGMA and Manchester City Council via the development of climate change strategies, and the University should look to encourage and support this work through research and engagement. Given the division of

[28] M. Suter. 2011. Focal Report 7: CIP Resilience and Risk Management in Critical Infrastructure Protection Policy: Exploring the Relationship and Comparing its Use. Risk and Resilience Research Group (3RG), Centre for Security Studies (CSS), ETH Zurich, Zurich, Switzerland. See http://www.css.ethz.ch/publications/pdfs/Focal-Report-7-SKI.pdf2 (accessed 4 November, 2014)

responsibilities for the built environment and infrastructure in cities such as Manchester, co-ordinated city-wide approaches to adaptation should, ultimately, be more successful in the long-term.

In addition to the key observations arising from the project outlines above, further specific recommendations are as follows:

- Look for opportunities to expand green cover, particularly within the south campus and in areas prone to surface water flooding.
- Where buildings are to be refurbished, take the opportunity to consider adaptation options to build resilience to flooding and heat stress, especially where they are identified as being at risk from these hazards.
- Request that developers responsible for new builds take weather and climate risk into consideration. Project teams should demonstrate how buildings will be resilient to future risks whilst not exacerbating risk to other buildings on the estate.
- Update emergency and contingency plans to reflect knowledge of weather and climate risks, particularly for buildings shown to be at high risk from flooding.
- Consider applying to European funding sources, such as INTERREG or LIFE+, to access match funding to deliver adaptation activities on the estate.
- Continue to engage with Manchester City Council and AGMA on projects and activities that build the resilience of Greater Manchester to weather and climate risks.
- Support student projects to build knowledge and awareness of weather and climate risks and adaptation responses on the estate.

Centre for Urban Resilience & Energy (CURE)