Looking back and projecting forwards: Greater Manchester’s weather and climate.

Jeremy Carter and Nigel Lawson
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EcoCities is a joint initiative between the School of Environment and Development at the University of Manchester and commercial property company Bruntwood. The project looks at the impacts of climate change and at how we can adapt our cities and urban areas to the challenges and potential opportunities that a changing climate presents.

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Summary

Significant shifts in climate variables are projected for the twenty-first century. Coupled with the observed impacts of extreme weather and climate events, adaptation to climate change becomes an ever-more pressing policy issue. This EcoCities paper concerns the type of weather and climate data used by decision makers when developing adaptation responses. Future projections dominate the debate even though predicting the future is uncertain. Should policy-making be based upon what we already know about the climate and its impacts? Can records of incidence and impacts of recent weather and climate events help us to make adaptation decisions? Or, is it now time to look past this historic information and continue to place greater weight on the climate change projections that are now available for the coming decades? Using Greater Manchester as a case study, this report considers both types of data at a number of interrelated scales. Drawing on the Greater Manchester (GM) LCLIP report (Carter and Lawson 2009) as well as future projections (Cavan 2011), it suggests that both issues need to be considered when considering how best to adapt.
1 Introduction and context

Current climate change scenarios for the UK do not show significant changes in climate variables (e.g. temperatures, precipitation levels) until the 2050s. However, rapid non-linear change with positive feedback loops could potentially force substantial changes in the shorter term (Lenton et al 2008). This, and the often long timescales needed to enhance the resilience of societies, economies and ecosystems, requires adaptation action to be progressed in the short term. Adaptation can be regarded as an important way of moderating the severity of climate change impacts by reducing levels of vulnerability and exposure to climate hazards. Other policy goals – such as greenhouse gas emission reduction or biodiversity conservation – can also benefit from adaptation actions. The sooner that societies begin this process, the more effective and beneficial adaptation strategies will be. We now have a strong ‘adaptation imperative’ to contend with.

When forming adaptation responses, the analysis of recent weather and climate events can inform the consideration of short-term risks. Ideally, this should be balanced with an assessment of the implications of long-term projections for changes in the climate. Furthermore, understanding the incidences and consequences of recent events provides a useful input to developing adaptation responses to future changes in weather and climate due to the existence of a ‘climate signal’ in recent climate trends and events. Useful as this is, a number of issues will not appear in the historical record for a city such as Manchester. These include events not yet prevalent in our temperate climate such as heat stress and droughts. Moreover, climate change impacts in other parts of the world have implications for Greater Manchester as do secondary climate change impacts, such as increasing insurance premiums following flooding. Attention must be directed towards changing patterns of risk across different sectors and spatial scales associated with future climate change projections.

This paper begins by providing an overview of current understanding on observed changes in weather and climate from several spatial perspectives. Following this is an analysis of the impacts of recent trends in weather and climate events (such as floods and storms) in Greater Manchester dating back to 1945. Details of recorded consequences of these events on different receptors, including critical infrastructure and the natural environment, are outlined. Having discussed these trends in the occurrence of weather and climate events in Greater Manchester and
patterns relating to their consequences, the paper then turns to the future. Current projections for changes in climate variables are outlined, again beginning at the global scale before moving down to describe the key features of Greater Manchester’s climate horizon. A broad assessment of the potential impacts of the changing climate on key receptor groups in Greater Manchester completes the presentation of data and insights into the conurbations past and potential future climate. This provides the basis for a concluding discussion concerning the extent to which recent trends in weather and climate events should inform the way that we adapt to future climate change.
2 Recent trends in weather and climate: from the global scale to Greater Manchester

Information is available on recent changes in weather and climate at different spatial scales. At the global scale the Intergovernmental Panel on Climate Change (IPCC) notes that:

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC 2007: 30).

Table 1 highlights significant recent trends in weather and climate phenomenon from a global perspective, provides an assessment of the likelihood of human influence on the trend, and considers whether trends observed during the late twentieth century are likely to continue over the course of the twenty-first.

The following statistical definitions connect to the terms included within table 1:

- Virtually certain: greater than 99% probability of occurrence.
- Very likely: greater than 90% probability of occurrence.
- Likely: greater than 66% probability of occurrence.
- More likely than not: greater than 50% probability of occurrence.

In many cases, it is likely or very likely that trends relating to the weather and climate phenomenon described in table 1 occurred in the late twentieth century. Humans have, more likely than not, contributed to the generation of these trends. There is a significant chance that these trends will continue. The phenomena described within table 1 can be interpreted as early warning signals of human-induced climate change.
Table 1. Observed weather and climate phenomenon at a global scale (adapted from IPCC 2007)

<table>
<thead>
<tr>
<th>Phenomenon and observed direction of trend</th>
<th>Likelihood that the trend occurred in the late 20th century (typically post 1960)</th>
<th>Likelihood of human contribution to observed trend</th>
<th>Likelihood of continuation of trends based on IPCC projects for 21st century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fewer cold days and nights</td>
<td>Very likely</td>
<td>Likely</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>More frequent hot days and nights</td>
<td>Very likely</td>
<td>Likely (nights)</td>
<td>Virtually certain</td>
</tr>
<tr>
<td>Increased frequency of warm spells/ heat waves</td>
<td>Likely</td>
<td>More likely than not</td>
<td>Very likely</td>
</tr>
<tr>
<td>Increased frequency of heavy rainfall events</td>
<td>Likely</td>
<td>More likely than not</td>
<td>Very likely</td>
</tr>
<tr>
<td>Increase in area affected by droughts</td>
<td>Likely in many regions since 1970s</td>
<td>More likely than not</td>
<td>Likely</td>
</tr>
<tr>
<td>Increased tropical cyclone activity</td>
<td>Likely in many regions since 1970s</td>
<td>More likely than not</td>
<td>Likely</td>
</tr>
<tr>
<td>Increased incidence of extreme high sea levels</td>
<td>Likely</td>
<td>More likely than not</td>
<td>Likely</td>
</tr>
</tbody>
</table>
Recent research from one of the leading climate change research institutes, NASA’s Goddard Institute for Space Studies (Hansen et al 2010), confirms IPCC findings by noting that the global surface temperature has risen by an average of 0.17°C per decade over the last 4 decades. They add that global surface temperatures in the past decade are 0.8°C higher than at the start of the twentieth century with two thirds of this warming having occurred since 1975. 2010 was identified as the warmest year on record.

Increasing temperatures above the global average are typical of the higher northern latitudes (IPCC 2007). The Central England Temperature monthly series, the longest running temperature record with data from 1659 onwards, shows a rise of about 1°C since the 1970s (Jenkins et al 2008). Rainfall patterns over England and Wales appear to be showing increased seasonal variation with less rain in summer and more in winter.

Information is also available on changes in some regional climates. Between 1961 and 2006, mean annual temperatures in the north west of England have increased by 1.4°C (Jenkins et al 2008). The general warming trend over the same period is mirrored across the seasons; with the temperature rise in the winter particularly marked. Changing precipitation patterns are also evident. These confirm the seasonal distinction with summer rainfall decreasing by 13% and winter rainfall rising by 43%. Table 2 provides further details of changes in key climate variables for the north west of England.

Table 2. Changes in key climate variables in Northwest England (1961-2006) (adapted from Jenkins et al 2008)

<table>
<thead>
<tr>
<th></th>
<th>Spring (M,A,M)</th>
<th>Summer (J,J,A)</th>
<th>Autumn (S,O,N)</th>
<th>Winter (D,J,F)</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Temperature (ºC)</td>
<td>1.44</td>
<td>1.45</td>
<td>1.07</td>
<td>1.81</td>
<td>1.40</td>
</tr>
<tr>
<td>Daily max temperature (ºC)</td>
<td>1.67</td>
<td>1.63</td>
<td>1.13</td>
<td>1.93</td>
<td>1.55</td>
</tr>
<tr>
<td>Daily min temperature (ºC)</td>
<td>1.25</td>
<td>1.31</td>
<td>1.03</td>
<td>1.70</td>
<td>1.29</td>
</tr>
<tr>
<td>Days of air frost</td>
<td>-5.9</td>
<td>-0.1</td>
<td>-3.2</td>
<td>-13.1</td>
<td>-24.4</td>
</tr>
<tr>
<td>Total precipitation (% change)</td>
<td>6.3</td>
<td>-13.2</td>
<td>5.6</td>
<td>43.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Days of rain &gt; 1mm</td>
<td>0.4</td>
<td>-1.1</td>
<td>2.9</td>
<td>6.8</td>
<td>7.5</td>
</tr>
</tbody>
</table>
Investigations of recent trends in weather and climate variables have been downscaled to Greater Manchester as part of the EcoCities project (Cavan 2011). Table 3 summarises the findings. Looking at two overlapping time periods (1961 – 1990 and 1971 – 2000), analogous to the UK Climate Projections report (Jenkins et al 2008), we see small but significant changes to climate variables. General warming across all seasons, particularly during the winter months, is matched by an emerging seasonal pattern of drier summers and wetter winters. These patterns confirm the direction of change identified by Jenkins et al (2008) for the north west of England.

### Table 3. Recent trends in Greater Manchester’s climate (adapted from Cavan 2011).

<table>
<thead>
<tr>
<th>Variable / time period</th>
<th>1961-1990</th>
<th>1971-2000</th>
<th>Absolute change between the 2 time periods</th>
<th>% change between the 2 time periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mean temp</td>
<td>8.94°C</td>
<td>9.21°C</td>
<td>+0.28°C</td>
<td>3%</td>
</tr>
<tr>
<td>Summer daytime temp</td>
<td>18.58°C</td>
<td>18.90°C</td>
<td>+0.32°C</td>
<td>1.7%</td>
</tr>
<tr>
<td>Summer night-time temp</td>
<td>10.82°C</td>
<td>11.03°C</td>
<td>+0.21°C</td>
<td>1.9%</td>
</tr>
<tr>
<td>Winter daytime temp</td>
<td>7.10°C</td>
<td>7.49°C</td>
<td>+0.39°C</td>
<td>5.5%</td>
</tr>
<tr>
<td>Winter night-time temp</td>
<td>1.04°C</td>
<td>1.42°C</td>
<td>+0.38°C</td>
<td>37%</td>
</tr>
<tr>
<td>Annual precipitation</td>
<td>1072 mm</td>
<td>1068 mm</td>
<td>- 4 mm</td>
<td>-0.4%</td>
</tr>
<tr>
<td>Summer precipitation</td>
<td>257 mm</td>
<td>243 mm</td>
<td>- 14 mm</td>
<td>-5.5%</td>
</tr>
<tr>
<td>Winter precipitation</td>
<td>276 mm</td>
<td>291 mm</td>
<td>+ 15 mm</td>
<td>5.3%</td>
</tr>
</tbody>
</table>

The evidence clearly shows climate change across a range of variables and spatial scales. Although the global climate is always changing, the key driving force behind recent changes is the release of greenhouse gas emissions due to human activity (IPCC 2007, Zhang et al 2007). Recent research has gone further and has attributed recent extreme weather events such as the European heat wave of 2003 and the UK floods of
2007 to human-induced forcing of the climate system (e.g. Pall et al 2011).

Having identified recent changes in climate from the global to Greater Manchester scale, the discussion now turns to the impacts of these changing patterns.
3 Exploring the impacts of changing weather and climate in Greater Manchester

Recent studies that detail the impacts of observed changes to the climate have addressed this issue at the global level (Blunden et al 2011), the European level (EEA 2008) and for individual countries (e.g. Jenkins et al 2008; Karl et al 2009). Their insights offer several routes into understanding the impacts of observed climate change. Trends in different bio-physical variables can be used as indicators of a changing climate including the cryosphere (glaciers and ice caps), hydrology (e.g. precipitation, river discharge, lake levels, soil moisture) and the status of biodiversity and ecosystems. They also address the implications of recent climate trends on different economic sectors, for example agriculture, tourism and utilities, and impacts on human health. Collectively, they confirm that recent trends in weather and climate have discernable consequences across a range of issues and spatial scales.

The EcoCities project included an investigation of the occurrence of extreme weather and climate events across Greater Manchester (Lawson and Carter 2009). We identified events with impacts on human health and well-being and that caused damage to urban infrastructure or severely disrupted services. This followed a method established by the UK Climate Impacts Programme known as a ‘Local Climate Impacts Profile’, or an ‘LCLIP’ (UKCIP 2008). In compiling the LCLIP for Greater Manchester, five key sources of data were utilised:

1. The Environment Agency for England and Wales.
2. Literature review, including strategic flood risk assessments.
3. Consultation with local academics, a local amateur weather forecaster, the insurance industry, the Greater Manchester Fire and Rescue Service, the Manchester City Council Civil Contingencies office, the Health Protection Agency, NHS Northwest and the Northwest Public Health Observatory.
4. Data supplied by local authorities in Greater Manchester who were asked to collate data from their civil contingencies, education, highways, social services, drainage, media and archive departments.
5. The local media.

In addition, and importantly, key events were further identified by reference to extreme weather events recorded at Ringway. The Ringway Manchester International Airport weather station, transferred in 2009 to
the nearby Woodford Airport, offers the only long, uninterrupted record of observed meteorological data in Greater Manchester. Weather parameters that might cause impacts were established in consultation with the Meteorological Office’s Regional Advisor for the north west of England (Alan Goodman 2009).

Days when precipitation exceeded 25mm/day, wind exceeded 60 knots, day time heat exceeded 30ºC and where night time temperatures were below -12ºC were the parameters. Since local authorities and emergency service providers do not record weather systematically, media outlets (principally local newspapers) are a key source of data on the occurrence and consequences of the impacts of past weather events. The parameters were cross-referenced with reports in the media to assess the extent to which the weather on a particular day had impacted on human health and well-being, disrupted services and affected infrastructure. This is the only accessible method to identify all severe and moderately severe weather events prior to the digitisation of the local media in 1999. The caveat is that the local media is entirely subjective, the consistency of reporting influenced by the existence (or lack of) other newsworthy events and levels of interest in the weather at the time.

Nevertheless, we compiled a large sample of recorded events to undertake an analysis, identifying 377 events back to 1945. These covered eight different themes: floods, storms (including high winds), cold, fog, heat, smog, drought and air quality. Table 4 records the incidence of these events over several different times periods.

Table 4. Recorded incidence of extreme weather and climate events across Greater Manchester under different time slices.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood</td>
<td>18</td>
<td>44</td>
<td>44</td>
<td>52</td>
<td>158</td>
</tr>
<tr>
<td>Storm</td>
<td>12</td>
<td>25</td>
<td>26</td>
<td>22</td>
<td>85</td>
</tr>
<tr>
<td>Cold</td>
<td>7</td>
<td>20</td>
<td>25</td>
<td>11</td>
<td>63</td>
</tr>
<tr>
<td>Heat</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>Fog</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Smog</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Drought</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Air Quality</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>
By cross-referencing this information with the recent weather and climate data for Greater Manchester in table 3, keeping to the same time-periods, it is possible to identify whether there are any links between the incidence of these events and observed changes in weather and climate variables. Table 5 records the analysis of weather and climate events over these two time periods.

**Table 5. Changes in the incidence of extreme weather events across Greater Manchester between two time periods (1961 – 1990 and 1971 – 2000).**

<table>
<thead>
<tr>
<th>Weather and climate events</th>
<th>Recorded events: 1961-1990</th>
<th>Recorded events: 1971-2000</th>
<th>Absolute change between the 2 time periods</th>
<th>% change between the 2 periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Average per year</td>
<td>Total</td>
<td>Average per year</td>
</tr>
<tr>
<td>Flood</td>
<td>44</td>
<td>1.47</td>
<td>44</td>
<td>1.47</td>
</tr>
<tr>
<td>Storm</td>
<td>25</td>
<td>0.83</td>
<td>26</td>
<td>0.87</td>
</tr>
<tr>
<td>Cold</td>
<td>20</td>
<td>0.67</td>
<td>25</td>
<td>0.83</td>
</tr>
<tr>
<td>Heat</td>
<td>4</td>
<td>0.13</td>
<td>8</td>
<td>0.27</td>
</tr>
<tr>
<td>Fog</td>
<td>8</td>
<td>0.27</td>
<td>13</td>
<td>0.43</td>
</tr>
<tr>
<td>Smog</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>Drought</td>
<td>2</td>
<td>0.07</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>Air Quality</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 5 demonstrates that, according to the data gathered by the LCLIP study, each event appears to be occurring more regularly over time except for floods. Although the number of events is, in some cases, small, this analysis suggests that newsworthy weather and climate events are becoming more common in Greater Manchester (as the majority of data came from the local media, it is important to qualify this statement in this way). The rising number of reported heat events tallies with the recorded temperature increases. Interestingly, the higher number of cold weather events seems to run counter to the recorded warming trend, although Hansen et al (2010) note that the likelihood of cold winters will decrease as global warming increases. However, climate change projections for the north west of England do indicate that extreme weather events are likely
to become more frequent (Murphy et al 2009) over time. Also, a rise in recorded cold weather events could be reflective of a decline in the capacity of individuals and organisations to cope with extreme cold events when they do occur.

The analysis of 2001–2008 data cannot be included in a time series comparison with data gathered for the previous periods. There are significantly more events recorded but this is coloured by the fact that the Manchester Evening News, a key source of data, officially launched its online edition in 2001 (with an online archive going back to 1999). Therefore, the 2001–2008 data was considered separately. This analysis revealed that across the conurbation, the prevalent events remain floods and storms for this period.

### 3.1 Detailed analysis of recorded flood and storm events

Flooding appears to be the most frequent event occurring in Greater Manchester and was considered in greater depth to develop a richer picture. Firstly, this determined, where possible, whether these were fluvial (floods from rivers, streams or brooks) or pluvial (surface water floods resulting from the overland flow of water) flood events. Table 6 shows the results and highlights a clear trend toward the greater incidence of pluvial over fluvial flood events across the conurbation. Whereas 55.6% of floods were fluvial between 1945 and 1960, this figure fell to 34% between 2001 and 2008. Correspondingly, 16.7% of flood events were pluvial between 1945 and 1960, with this figure rising to 53.6% for the period 2001–2008.¹ Several factors may explain the marked shift in flood type highlighted in table 6. Firstly, flood risk management strategies designed to manage fluvial floods may be proving successful. Secondly, development activity leading to more hard surfaces at the expense of green cover makes pluvial flooding more likely. Finally, pluvial floods are often associated with short, intense rainfall events; it could be that their increasing frequency across Greater Manchester is a symptom of changing climate patterns.

The occurrence of flood events from a seasonal perspective was also assessed. Table 6 includes these results. According to the LCLIP, summer is the season when most floods occur in Greater Manchester. A significant

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¹ This analysis included the 2001–2008 series because this assessment is not mapping linear trends over the full time period of the LCLIP assessment; it is considering a breakdown of the characteristics of floods in different time slices.
number of flood events happen in autumn and winter, although between 1945 and 2008 the total number of flood events recorded over these two seasons (82) is roughly the same as the total for just the summer months (77). Few flood events occur in spring. Table 6 also provides an insight into the occurrence of fluvial and pluvial flood events across the seasons. This highlights that in the most recent time-period (2001–2008), summer flood events were predominantly pluvial. The prevalence of recorded pluvial flood events in the summer months across Greater Manchester may reflect an emerging seasonal trend in respect of extreme precipitation events.
Table 6. Analysis of number of flood events in Greater Manchester by type and season of occurrence.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F (%)</td>
<td>P (%)</td>
<td>Un (%)</td>
<td>F (%)</td>
</tr>
<tr>
<td>Spring (M,A,M)</td>
<td>0 (50)</td>
<td>0 (50)</td>
<td>1 (50)</td>
<td>0 (75)</td>
</tr>
<tr>
<td>Summer (J,J,A)</td>
<td>5 (50)</td>
<td>3 (30)</td>
<td>2 (20)</td>
<td>6 (36.8)</td>
</tr>
<tr>
<td>Autumn (S,O,N)</td>
<td>2 (40)</td>
<td>0 (60)</td>
<td>3 (45.5)</td>
<td>5 (45.5)</td>
</tr>
<tr>
<td>Winter (D,J,F)</td>
<td>2 (100)</td>
<td>0 (60)</td>
<td>0 (60)</td>
<td>4 (26.7)</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1 (100)</td>
<td>0 (100)</td>
<td>0 (100)</td>
<td>0 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>10 (55.6)</td>
<td>3 (16.7)</td>
<td>5 (27.8)</td>
<td>22 (45.8)</td>
</tr>
</tbody>
</table>

F = fluvial, P = pluvial, Un = unspecified i.e. data available was not sufficient to support an assessment of flood type.
Behind floods, storms are the most commonly recorded event that impacted on Greater Manchester. Together, they account for almost two-thirds of all recorded weather and climate events. Table 7 shows that the most damaging storms occur in winter (inclusive of events relating to high winds). This valuable information is potentially useful for emergency planners to develop strategies and allocate resources that respond to the immediate aftermath of extreme weather events.

**Table 7. Seasonal analysis of Greater Manchester storm events.**

<table>
<thead>
<tr>
<th>Season/time period</th>
<th>1945–1960 % of storm events</th>
<th>1961–1990 % of storm events</th>
<th>1971–2000 % of storm events</th>
<th>2001–2008 % of storm events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>16.67 (N=2)</td>
<td>8.00 (N=2)</td>
<td>7.69 (N=2)</td>
<td>18.18 (N=4)</td>
</tr>
<tr>
<td>Summer</td>
<td>66.67 (N=8)</td>
<td>28.00 (N=7)</td>
<td>19.23 (N=5)</td>
<td>18.18 (N=4)</td>
</tr>
<tr>
<td>Autumn</td>
<td>0 (N=0)</td>
<td>8.00 (N=2)</td>
<td>15.38 (N=4)</td>
<td>13.64 (N=4)</td>
</tr>
<tr>
<td>Winter</td>
<td>16.67 (N=2)</td>
<td>56.00 (N=14)</td>
<td>57.69 (N=15)</td>
<td>50.00 (N=11)</td>
</tr>
</tbody>
</table>
4 Consequences of recent trends in Greater Manchester’s weather and climate

The LCLIP study of recent weather and climate events across Greater Manchester also looked at their consequences. The analysis determined that all of the events could be categorised into five broad 'receptor types'. These are critical infrastructure, health and wellbeing, natural environment, built environment and social and emergency infrastructure. More details of these consequences are included in table 8. The impacts on critical infrastructure and health and wellbeing constitute the largest proportion, over two-thirds, of recorded consequences.

Table 8. Analysis of the consequences of weather and climate events on different receptors in Greater Manchester.

<table>
<thead>
<tr>
<th>Receptor type</th>
<th>Examples of consequences of weather/climate events on each receptor</th>
<th>Total number of recorded consequences (1945-2008)</th>
<th>% of total recorded consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical infrastructure</td>
<td>Impact on transport (e.g. flooding of roads, tree falls, rail and flight disruption), water supply/wastewater treatment, power cuts, telephone services.</td>
<td>155</td>
<td>37.5%</td>
</tr>
<tr>
<td>Health and wellbeing</td>
<td>Deaths, injuries and illness, disruption to people’s lives (e.g. flooding of properties, flooding of parks and recreation spaces, sporting events cancelled).</td>
<td>128</td>
<td>31%</td>
</tr>
<tr>
<td>Natural environment</td>
<td>Damage to trees, water pollution due to heat or contaminated storm runoff, fish kills, moorland fires, insect infestations.</td>
<td>56</td>
<td>13.6%</td>
</tr>
<tr>
<td>Built environment</td>
<td>Properties damaged by tree falls and high winds, damage to properties from flooding, lightening strikes and subsidence.</td>
<td>54</td>
<td>13.1%</td>
</tr>
<tr>
<td>Social and emergency infrastructure</td>
<td>Impacts on schools (e.g. flooding and cold weather), disruption to ambulance services, doctors’ surgeries closed.</td>
<td>20</td>
<td>4.8%</td>
</tr>
</tbody>
</table>
Table 9 provides a richer picture of the varying consequences associated with the weather and climate events for each receptor type. Between 1945 and 2008, 68% of the total number of recorded consequences of weather and climate events resulted from floods and storms, inflicting widespread consequences across each receptor type. For critical infrastructure, health and wellbeing and social and emergency infrastructure, floods are responsible for a greater number of impacts than any other weather and climate event. Since floods are the most prevalent type of event (see table 4), they accordingly cause the largest number of recorded consequences.

Storms, the second most common event (see table 4), emerge as the most damaging event for the natural and built environment; as measured by the number of recorded consequences. Extreme cold events also have prominent impacts on critical, social and emergency infrastructure. The recorded consequences of other weather and climate events feature much less, commensurate with their less frequent occurrence. However, the data indicates that when they do occur, droughts have a disproportionally higher number of consequences than other events suggesting that they can equally have severe impacts. It is also important to highlight that the number of consequences is greater than the number of events since one event may have numerous consequences. For example, during severe flooding from the River Irwell in 1954, four landslides blocked railways and thousands of homes in Salford were flooded; two effects from the same event. (*Manchester Evening News* 1954: 1)

We recognise that the consequences of the climate and weather events identified by the LCLIP differ in their severity. This relates to issues including the scale of events (e.g. number of properties flooded, number of people injured in a storm) and the degree of harm and damage caused by events to different receptors (e.g. the extent of damage to buildings or the severity of injury to people). In an associated EcoCities report (*Lawson and Carter 2009*) we classify events according to their severity. The classification is entirely subjective; relying on the authors’ interpretation of the media reports and somewhat dependent on occasional inconsistency in news reporting. For the purpose of this paper all events of differing levels of severity are included.
### Table 9. Consequences of weather and climate events (1945-2008) across Greater Manchester.

<table>
<thead>
<tr>
<th>CLIMATE/WEATHER EVENTS</th>
<th>Critical infrastructure</th>
<th>Health and Wellbeing</th>
<th>Natural Environment</th>
<th>Built Environment</th>
<th>Social and Emergency Infrastructure</th>
<th>Total consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>% of total</td>
<td>Number</td>
<td>% of total</td>
<td>Number</td>
<td>% of total</td>
</tr>
<tr>
<td>Floods (N=132)</td>
<td>61</td>
<td>39.5</td>
<td>70</td>
<td>54.7</td>
<td>20</td>
<td>35.7</td>
</tr>
<tr>
<td>Storms (N=67)</td>
<td>25</td>
<td>16.1</td>
<td>18</td>
<td>14.1</td>
<td>24</td>
<td>42.9</td>
</tr>
<tr>
<td>Cold (N=52)</td>
<td>39</td>
<td>25.2</td>
<td>15</td>
<td>11.7</td>
<td>3</td>
<td>5.4</td>
</tr>
<tr>
<td>Fog (N=22)</td>
<td>16</td>
<td>10.3</td>
<td>6</td>
<td>4.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Heat (N=19)</td>
<td>8</td>
<td>5.2</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>12.5</td>
</tr>
<tr>
<td>Air Quality (N=7)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Smog (N=6)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>3.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Drought (N=6)</td>
<td>6</td>
<td>3.9</td>
<td>5</td>
<td>3.9</td>
<td>2</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Table 10 records changes in the instances of consequences when comparing the two time series (1961–1990 and 1971–2000). Aside from the built environment, consequences for each of the other receptor groups increase over time.

**Table 10. Changes incidence of consequences of weather and climate events in Greater Manchester over time.**

<table>
<thead>
<tr>
<th>Consequences of weather and climate events</th>
<th>Recorded consequences (1961-1990)</th>
<th>Recorded consequences (1971-2000)</th>
<th>Absolute change between the 2 time periods</th>
<th>% change between the 2 periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Average per year</td>
<td>Total</td>
<td>Average per year</td>
</tr>
<tr>
<td>Critical Infrastructure</td>
<td>64</td>
<td>2.13</td>
<td>71</td>
<td>2.37</td>
</tr>
<tr>
<td>Health and Wellbeing</td>
<td>42</td>
<td>1.4</td>
<td>51</td>
<td>1.7</td>
</tr>
<tr>
<td>Natural Environment</td>
<td>17</td>
<td>0.57</td>
<td>24</td>
<td>0.8</td>
</tr>
<tr>
<td>Built Environment</td>
<td>31</td>
<td>1.03</td>
<td>27</td>
<td>0.9</td>
</tr>
<tr>
<td>Social and Emergency Infrastructure</td>
<td>5</td>
<td>0.17</td>
<td>9</td>
<td>0.3</td>
</tr>
</tbody>
</table>
5 Addressing the challenges of recent trends in Greater Manchester’s weather and climate

Several broad conclusions can be drawn from the LCLIP analysis. The events can be summarised as:

• Floods are the most prevalent type of event across the conurbation.
• Whereas fluvial floods accounted for the majority of events from 1945–1960, the 2001–2008 data indicates that pluvial floods are now dominant.
• Floods occur more regularly in the summer months are but can be common in autumn and winter. Very few flood events appear to happen during the spring.
• Storms (including high winds) and cold events occur regularly, but less often than floods.
• Damaging storms appear to occur in winter.
• Other types of events, including heat waves, droughts and fog have been relatively infrequent over recent decades in Greater Manchester.

Focusing on the effects of these events across Greater Manchester, several significant issues emerge. These are:

• Over the period 1945–2008, more than two-thirds of the recorded consequences of weather and climate events resulted from floods and storms.
• Impacts of weather and climate events are felt most acutely on critical infrastructure and health and wellbeing.
• Floods are the key cause of impacts on critical infrastructure and health and wellbeing, in addition to social and emergency infrastructure.
• In the case of the natural and built environment, storms emerge as the most damaging type of event.

These key conclusions present individuals and organisations tasked with responding to extremes of weather and climate with a clearer picture of specific impacts of most relevance to Greater Manchester. According to the findings of this study, there are several prominent challenges.
Firstly, the prevalence of flooding and its evident impacts on critical infrastructure should focus resources here. Climate change impacts on critical infrastructure are receiving greater attention nationally (HM Government 2011, URS Corporation Ltd 2010) given the potential economic and societal implications that damage to critical infrastructure networks will have. EcoCities researchers have assessed the current risk of fluvial and pluvial flooding to different types of infrastructure in Greater Manchester to help planners and decision makers respond to the risk (Kazmierczak and Kenny 2011). This study maps critical infrastructure and flood risk, identifying those services, such as the supply of electricity and water, which are at most risk in Greater Manchester. Certain motorways and A-roads are also at risk from pluvial flooding.

Equally, health and wellbeing are significantly at risk from flooding, and should be addressed in adaptation strategies. Research undertaken into the impacts of climate change on vulnerable sections of society within the EcoCities project (Kazmierczak and Cavan 2011) and in other studies (e.g. Lindley et al 2011) established that the groups of people that are particularly vulnerable to flooding and excess heat include the elderly and people experiencing poverty and poor health. Certain locations in Manchester contain large concentrations of these groups. Identifying these spatial patterns supports activities that can reduce the impacts of flooding on peoples’ health and wellbeing.

As well as setting thematic priorities concerning the allocation of available resources towards response, the LCLIP study reveals the seasonal dimension to weather events. While emergency services should be in a position to react to any event at any time of the year, the study suggests that an emergency response plan should be prepared in advance to deal with the likelihood of summer flooding.

When assessing the relationship between recent trends in weather and climate and recorded incidences of associated events, it is necessary to consider the receptor of these events, for example people or infrastructure. For the media to deem an event worthy of recording, it needs to have an impact on or a consequence for a receptor. More incidences of recorded events may not solely be linked to changes in weather and climate. The vulnerability of receptors to weather and climate events, that is their susceptibility to harm, is also relevant. The higher frequency of recorded events may reflect changes in the level of vulnerability of receptors. For example, if the elderly are especially vulnerable to flood events then an ageing population may feel a greater impact from floods. Equally, events can become more common if
vulnerable receptors become more exposed to these events. Exposure is heightened when receptors are located in areas where events, such as floods or heat waves, are more prevalent.

Using flooding as an example, exposure can increase as a result of numerous factors. For example, people may prefer to live close to water. Alternatively, there may be issues due to the strength (or weakness) of spatial planning frameworks and a corresponding tendency for historically dense urban conurbations, such as Greater Manchester, to develop flood prone areas and sparse, undeveloped green spaces. Infill in the urban environment, when coupled with climate change, is increasingly linked to the growth in pluvial flood events in parts of Greater Manchester (Douglas et al 2010). The present Coalition Government propose the removal of the presumption in favour of development on brownfields contained in Planning Policy Statement (PPS) 3. This comes on top of the removal of PPS 25, which ensures that flood risk is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding. This is likely to exacerbate the situation. This analysis demonstrates that it is also necessary to consider how levels of vulnerability and exposure of receptors of these events might change over the course of the coming decades. An associated EcoCities report addresses this issue (Carter and Ravetz 2011).

Looking beyond the multiple potential factors underlying the greater frequency of extreme weather events, the increase strengthens calls for the development of appropriate adaptation responses. While the impacts of recent weather and climate variability provide a powerful catalyst for adaptation action, planners and decision makers should not use this solely as a platform to move rapidly towards considering future climate change projections. Indeed, the UK Government’s Adaptation Sub-Committee (ASC 2010, ASC 2011) recommends that this should act as a precursor to a more formal assessment of future climate change impacts. It is to this issue that this report now turns.
6 Projecting forwards: understanding the impact of Greater Manchester’s future weather and climate

6.1 Climate change projections

IPCC projections suggest that the global average surface temperature will increase by around 0.2°C within the next two decades. Further warming is anticipated beyond that point, the level of which will depend on future greenhouse gas emissions (IPCC 2007). The IPCC’s lowest emissions scenario puts a best estimate of temperature increases by the end of this century at 1.8°C above the 1980–1999 baseline level. The emissions scenario centred on fossil fuel-based energy results in a best estimate of a 4°C increase above this baseline. Projected changes in temperature and precipitation are not evenly distributed across the globe and are thought to be greatest over high northern latitudes. The IPCC’s 5th Assessment Report is due in 2013, and will update the knowledge and awareness of the physical science basis surrounding climate change.

With increasing regularity, research findings show that the magnitude and pace of climate change impacts may be more severe than expected just a few years ago. James Hansen, a prominent NASA scientist, notes that if the stability of the Greenland and Antarctic ice sheets breaks down (which is likely if global average surface temperature rises more than 2 degrees), then the sea-level may rise higher than the IPCC's estimates of 18–59cm by the end of the century (Hansen 2007). Climate change scientists and researchers are increasingly speculating that, for scientific and geopolitical reasons, we should be seriously considering the prospect of climate change being towards the high end of scale of IPCC’s scenarios; where catastrophic risks become more rapid (Betts et al 2011, Hamilton 2010). The implications are that global average surface temperature rises of around 4°C during are possible during the twenty-first century.

Although climate change is a global phenomenon, scientific advances have made it possible to present local perspectives. The UK Climate Impacts Programme (UKCIP) has produced climate change scenarios for the north west of England that originate from models developed by the Met Office Hadley Centre and the Tyndall Centre for Climate Change (Murphy et al 2009). These are 'scenarios' because they are based on different future amounts of greenhouse gas emissions, which reflect different possible global socio-economic pathways. Murphy et al (2009) look at climate
change projections for the English regions. They highlight a warming trend for the north west, accompanied by the seasonal rainfall patterns that are already recorded (Jenkins et al 2008). They also indicate that the region is likely to experience an increasing frequency and intensity of some climate events, such as heatwaves, and, importantly, winter storms (Murphy et al 2009). Additional detail on regional climate change projections are given in an earlier EcoCities report (Cavan et al 2010).

EcoCities researchers have refined the climate change projections data further, down to the level of the Greater Manchester conurbation. Tables 11 and 12 summarise the projected changes in climate variables (temperature and precipitation) across three defined zones of Greater Manchester. Broadly the projections suggest that we can expect warmer temperatures, wetter winters and drier summers, in addition to increased potential for extreme weather events such as intense rainfall events, heat waves and droughts. The different percentile projections included in tables 11 and 12 indicate the relative likelihood, taking into account current understanding of climate science, that the stated projection will be at or less that the level highlighted (Murphy et al 2009). An accessible route into understanding the implications of the different percentile projections is provided by Cavan (2011):

- **10th percentile projection**: change in the climate variable unlikely to be less than the projection.
- **50th percentile projection**: change in the climate variable as likely to be at the projected level as not.
- **90th percentile projection**: change in the climate variable unlikely to be greater than the projection.

Cavan (2011) provides a more detailed overview of the projections summarised in tables 11 and 12. It can be difficult to appreciate the scale of the projected change to the climate highlighted in tables 11 and 12. Climate analogues provide a more tangible way of grasping the extent to which Greater Manchester’s climate could change in the future. This approach identifies locations that currently experience a similar climate (in terms of temperature and rainfall) to that which is projected for the future in another location taking into account the impacts of climate change. Work undertaken by the Forestry Commission (West and Morison 2009) draws the analogy that under climate change, towards the end of this century the south of England will become more like the south of France. Although this does not relate directly to Greater Manchester, the Forestry Commission study does indicate the extent of projected climatic shifts.
Table 11. Projected change to temperature variables for Greater Manchester under the 2050’s high emissions scenario for three probability levels (MB-Mersey Basin, PF-Pennine Fringe, PU-Pennine Uplands) (adapted from Cavan 2011).

<table>
<thead>
<tr>
<th>Variable</th>
<th>10th percentile projection</th>
<th>50th percentile projection</th>
<th>90th percentile projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean annual temperature (°C change from 1961-1990 baseline)</td>
<td>1.8 MB 1.8 PF 1.8 PU 2.4 MB 2.5 PF 2.4 PU 3.6 MB 3.6 PF 3.7 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum summer temperature (°C change from 1961-1990 baseline)</td>
<td>1.4 MB 1.5 PF 1.5 PU 2.9 MB 3.0 PF 3.0 PU 5.6 MB 5.6 PF 5.7 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warmest day in summer (°C change from 1961-1990 baseline)</td>
<td>1.5 MB 1.6 PF 1.6 PU 3.1 MB 3.4 PF 3.4 PU 6.0 MB 6.0 PF 6.0 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warmest night in summer (°C change from 1961-1990 baseline)</td>
<td>1.3 MB 1.3 PF 1.4 PU 2.6 MB 2.6 PF 2.6 PU 4.4 MB 4.6 PF 4.4 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum winter temperature (°C change from 1961-1990 baseline)</td>
<td>1.7 MB 1.8 PF 1.7 PU 2.4 MB 2.5 PF 2.4 PU 3.9 MB 3.9 PF 3.9 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coldest night in winter (°C change from 1961-1990 baseline)</td>
<td>1.4 MB 1.7 PF 1.4 PU 2.4 MB 2.4 PF 2.6 PU 3.5 MB 3.8 PF 3.7 PU</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12. Projected change to precipitation variables for Greater Manchester under the 2050’s high emissions scenario for three probability levels (MB-Mersey Basin, PF-Pennine Fringe, PU-Pennine Uplands) (adapted from Cavan 2011).

<table>
<thead>
<tr>
<th>Variable</th>
<th>10th percentile projection</th>
<th>50th percentile projection</th>
<th>90th percentile projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average summer precipitation (% change from 1961-1990 baseline)</td>
<td>-5.4 MB -0.5 PF -2.4 PU -20 MB -20 PF -21 PU -36 MB -36 PF -36 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wettest day in summer (% change from 1961-1990 baseline)</td>
<td>-15 MB -17 PF -20 PU 0 MB 2 PF -3 PU 19 MB 25 PF 20 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average winter precipitation (% change from 1961-1990 baseline)</td>
<td>0.3 MB 1.2 PF 3.3 PU 14 MB 16 PF 16 PU 28 MB 36 PF 33 PU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wettest day in winter (% change from 1961-1990 baseline)</td>
<td>1.4 MB 2.4 PF 1.7 PU 10.7 MB 14.6 PF 14.1 PU 31 MB 38 PF 31 PU</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The possibility of developing quantifiable climate risk indices for the case study area of Greater Manchester has been explored by Smith and Lawson (2011). For extremes that are the function of a single meteorological variable (e.g. heat waves, pluvial flooding and heavy snowfall) the thresholds proved to be reliable when matched against archival evidence. The following thresholds are found to be indicative of weather-related impacts which have, in the past, affected human health and well-being, have caused damage to the urban infrastructure or have severely disrupted services in Greater Manchester:

- Days where the maximum daily temperature is greater than or equal to 29.2°C.
- Days where precipitation exceeds 38mm.
- Days where snowfall amounts to greater than or equal to 6 cm.
- Maximum wind gusts greater than or equal to 60 knots.

These thresholds are, of course, only indicative of potential impacts by weather related events. For example, many flood events happened when the daily precipitation at Ringway was in the region of 25–30mm and even lower (Lawson and Carter, 2009). Nevertheless, the thresholds study can support efforts to understand how changes in Greater Manchester’s climate might impact on different receptors across the city. Furthermore, there is a significant NE-SW precipitation gradient across Greater Manchester with a 14 mm difference in the defining threshold for extreme precipitation (figure 1). This precipitation gradient explains why the north east of Greater Manchester is more vulnerable to flood events and the south west (see Lawson and Carter 2009 for further details). The spatial nature of intense precipitation episodes means that there will be significant variances in potential impacts across Greater Manchester over the coming decades, with the Pennine fringe and Pennine uplands projected to receive the most precipitation (table 12).
Figure 1. (Top map) Met Office precipitation stations situated in Greater Manchester shown as graduated symbols indicative of the 99th percentile daily precipitation amount in millimetres. (Bottom map) Contour map showing the precipitation gradient across Greater Manchester based on the 99th percentile daily precipitation amount in millimetres (Source: Smith and Lawson 2011).
6.2 Assessing climate change impacts

Assessing climate change impacts involves an analysis of the potential implications of changing weather and climate patterns on different receptors. At the supranational scale, the IPCC provides a forum for assessing and reporting on climate change impacts and risks from a global perspective. An early report (Carter et al 1994) sets out a general framework for assessing climate change impacts, which is identified as an important stage in the process of developing adaptation responses. This report makes specific reference to the assessment of the biophysical and socio-economic impacts of climate change, and defines these impacts as:

...the differences over the study period between the environmental and socio-economic conditions projected to exist without climate change and those that are projected with climate change. (Carter et al 1994: ix)

Following this definition, an assessment has been undertaken that offers a broad overview of the scope of climate change impacts that could affect Greater Manchester, positively and negatively, to 2050. This compliments the study of past records of weather and climate, and the consequences of these events on different receptors across the conurbation.

Table 13 records the findings of the assessment, drawing on the outputs of relevant studies of climate change impacts undertaken for the north west of England. There are a number of studies that have looked at this issue at the regional scale and many of their key conclusions are directly transferable to the Greater Manchester context (Centre for Urban and Regional Ecology and Tyndall Centre North 2003; Glynn 2005; Holman et al 2002; Natural England 2010; Ove ARUP and Partners Ltd 2009; Sustainability Northwest 1998; URS Corporation Ltd 2009).

The list of receptors used for the assessment of potential future climate change impacts follows those identified through the LCLIP analysis of the consequences of weather and climate events (see table 8). The weather and climate event summaries within table 13 are based on projections for Greater Manchester developed within the EcoCities project (Cavan 2011). These projections relate to the 50th percentile projection for the 2050s high emissions scenario. Given the threat of rapid climate change introduced in section 1, and the current lack of action on emissions reduction (Anderson and Bows 2011), the high emissions scenario was

<table>
<thead>
<tr>
<th>CLIMATE/WEATHER EVENTS</th>
<th>PROJECTIONS FOR GREATER MANCHESTER</th>
<th>IMPACTS OF CLIMATE/WEATHER EVENTS ON RECEPTORS</th>
<th>Critical infrastructure</th>
<th>Health and Wellbeing</th>
<th>Natural Environment</th>
<th>Built Environment</th>
<th>Social and Emergency Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluvial floods (including increased winter rainfall)</td>
<td><strong>Increasing:</strong> Increase in winter rainfall. Higher risk, across the year, of extreme rainfall events.</td>
<td>Flooding of infrastructures and disruption of services. Damage to bridges. Bank erosion. Risk of silting and overtopping of reservoirs. Landslips around roads and rail lines.</td>
<td>Risk of injury, illness and potential associated fatalities. Psychological impacts. Higher insurance premiums in flood prone areas. Road safety issues.</td>
<td>Contamination of water courses from agricultural pollutant and urban runoff. Soil erosion. Flood damage to riparian zones and sensitive habitats.</td>
<td>Internal and external building damage. Risk of slope instability linked to heavy rainfall.</td>
<td>Higher demand for emergency services and care providers. Risk to service provision e.g. social care, ambulances. Flooding of facilities.</td>
<td></td>
</tr>
<tr>
<td>CLIMATE/WEATHER EVENTS</td>
<td>PROJECTIONS FOR GREATER MANCHESTER</td>
<td>IMPACTS OF CLIMATE/WEATHER EVENTS ON RECEPTEORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------</td>
<td>-------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Storms** (including high winds) | **Variable:** Possible fall in summer storms (Murphy et al 2009). Possible rise in winter gales. More wind storms (Jenkins et al 2008). | Critical infrastructure: Risk of storms to overhead electricity cables. Risk of high wind to transport infrastructure and services. Disruption to wind energy generation. Lightening damage.  
Health and Wellbeing: Loss of electricity to homes and businesses. Health risks e.g. associated with flying debris and falling trees, including potential fatalities.  
Natural Environment: Increased risk of tree falls in high wind conditions.  
Built Environment: Greater risk of structural damage to buildings (e.g. tree falls, damage to roofs). Risk of rain penetration in exposed upland areas. Lightening damage.  
Social and Emergency Infrastructure: Higher demand for emergency services. Risk to service provision e.g. social care ambulances. Damage to facilities (e.g. schools, surgeries). |
| **Cold events** | **Decreasing:** Winter temps increasing. Winter night time minimum temps decreasing. | Critical infrastructure: Lower risk of transport trouble from snow/ice, yet lack of preparedness may increase this risk. Reduction in potholes on roads. Icing risk to overhead cables where temp moves closer to freezing.  
Health and Wellbeing: Reduction in some cold related injury, illness and death. Some viruses may increase if the cold does not kill them off. Lower fuel poverty.  
Natural Environment: Lower risk of frost damage to some species. Impact on phenology of flora and fauna. Longer growing season could increase soil stability.  
Built Environment: Reduction in cold related stresses on buildings (e.g. freezing pipes, frost heave on stonework). Less energy used for space heating.  
| **Heat waves** (including temp increase) | **Increasing:** Increasing summer temps. Higher summer night time and warmest summer day temps. | Critical infrastructure: Higher energy demand (and costs) for cooling, potentially exceeding supply. Water supply constrained. Risk of rails buckling and roads deteriorating.  
Health and Wellbeing: Illness and deaths - food poisoning, heat stress, drowning whilst avoiding, heat induced fire etc. More chance for outdoor recreation and linked health and wellbeing benefits.  
Natural Environment: Impacts on species health, distribution and phenology. More pressure from expansion of arable farming linked to longer growing season. Visitor pressure on natural areas.  
Built Environment: Risks linked to soil shrinkage and subsidence, particularly in clay soil areas. Higher rates of deterioration of concrete. Internal overheating of some buildings.  
Social and Emergency Infrastructure: Higher demand for emergency services and care providers. Rising demand for outdoor leisure facilities. Overheating of some buildings e.g. care homes. |
<table>
<thead>
<tr>
<th>CLIMATE/WEATHER EVENTS</th>
<th>PROJECTIONS FOR GREATER MANCHESTER</th>
<th>IMPACTS OF CLIMATE/WEATHER EVENTS ON RECEPTORS</th>
</tr>
</thead>
</table>
Health and Wellbeing: Reduction in air pollutants including particles, nitrogen dioxide and sulphur dioxide. Risk of low level ozone increasing with linked respiratory problems.  
Natural Environment: Some trees e.g. willow, oak, emit volatile organic compounds which support ozone production, lowering air quality. Linked risks are highest where temps are high e.g. in urban centres.  
Built Environment: Reduction in airborne pollutants could slow the deterioration of building materials where this is caused by pollution.  
Social and Emergency Infrastructure: Fewer hospital emissions linked to air pollution incidents taking pressure off the hospitals and GP surgeries. |
| Drought (including reduced summer rainfall) | Increasing: Reduction in summer rainfall. Increase in summer temp. | Critical infrastructure: Less water for cooling power stations. Impact on water utility planning and processes. Risks linked to soil shrinkage and subsidence, yet risks are low in Greater Manchester where clays are generally boulder clays.  
Health and Wellbeing: Health effects linked to higher levels of dust particles in the air where there is less rainfall to suppress this.  
Natural Environment: Stress on water bodies via lower water volume and quality levels. Risk to protected species and ecosystems. Rise in moorland and forest fires. Water stress on urban green infrastructure.  
Built Environment: Risks linked to soil shrinkage and subsidence, yet risks are low in Greater Manchester where clays are generally boulder clays. Less water for building maintenance.  
Social and Emergency Infrastructure: Pressure on fire service from increased moorland and forest fires. Water stress on outdoor leisure facilities e.g. public parks and gardens. |
selected as the most appropriate basis for this impact assessment. The climate event summaries are supported by additional climate change projections for the north west of England and the UK (Cavan et al 2010, Murphy et al 2009). The summaries draw on this available data to judge the extent to which the occurrence of different weather and climate events affecting Greater Manchester may change by the 2050s. Smog is incorporated with air quality, and fog is omitted since the available data does not support an assessment of how this particular event could evolve in the future.

Table 13 identifies some of the most significant impacts of climate change with the potential to affect Greater Manchester over the coming decades. Following the IPCC’s definition of climate change impacts, the assessment focuses purely on possible challenges and opportunities and does not take into account the moderating effect that potential adaptation responses may have. No assessment is made of the level of risk associated with potential climate change impacts. This can be gauged in a broad sense through applying the following widely recognised formula.

\[
\text{Risk} = \text{Probability} \times \text{Consequence}
\]

This is the approach proposed by the IPCC (IPCC 2007a) for assessing climate change risks. Probability concerns the likelihood of occurrence of an impact (for example the flooding of transport infrastructure), and consequence relates to the potential effect of that impact on the economy, environment and society. Accordingly, in the Greater Manchester context, the risk to residential properties of a major pluvial flood event likely to be greater than the risk of isolated examples of drought induced soil shrinkage and subsidence to these properties. However, the IPCC (2007a: 140) note that risk assessment should ideally be a collaborative process involving communication and collaboration with stakeholders, in addition being oriented towards decision making (rather than research). In the Greater Manchester context, it would therefore be valuable to undertake a risk assessment with appropriate decision-makers to establish relative levels of risk associated with climate change impacts.

Just as the degree of future climate change will be influenced by decisions relating to the emission of greenhouse gases, the development (or lack of) strategies and actions to adapt to changes in climate variables will determine the frequency and severity of climate change impacts in a city-region such as Greater Manchester. Indeed, if adaptation strategies and actions are developed strengthening the potential role of spatial planning as an important element of
adaptation responses (Blanco and Alberti 2009, Davoudi et al 2010). Appropriate spatial planning responses to lessen the severity of any impacts include enhancing green cover in urban areas to provide benefits including cooling air temperatures and reducing rainwater runoff (Gill et al 2007); or implementing responses to make better use of grey water for irrigation of urban green space.

Table 13 highlights the scope of potential climate change impacts facing Greater Manchester, which cross sectors and spatial scales. The receptors on which the impact assessment is based on recorded impacts (as identified in the LCLIP described in section 3). Principally, this covers the direct impacts of extreme weather and climate events, such as damage and harm to properties, infrastructure and human health. Some receptor categories are unrecorded in such sources including secondary effects and the implications of climate change in other countries that may, nevertheless, be significant. For example, the conurbation will also be exposed to the implications of climate change in other parts of the world. A recent report from The Government Office for Science (2011) highlights the international dimensions of climate change for the UK and states that:

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

That report identified several key threats and challenges that are relevant to Greater Manchester. These include the potential for increased incidence of infectious diseases, disruption to resources and infrastructure relied upon by individuals and businesses (e.g. energy supplies, food production, communications networks), and changes in the balance of risks faced by the finance sector and businesses. The regional economic powerhouse is Manchester, a city connected to global networks of goods, services and people. It relies on the effective functioning of these networks to sustain its economy and society. The risks posed by climate change to the sectors and processes that connect the city globally are highly significant and deserve further research and policy attention.

This assessment of future climate change in Greater Manchester has been designed to complement the study of the consequence of recent weather and climate events impacting on the conurbation. The principal focus of table 13 is therefore on direct climate change impacts. There are also secondary climate change impacts that will manifest themselves, some of which are highlighted within table 13. One example is the effect of flood damage to people’s homes, and the subsequent psychological stress that this can cause flood victims. Another is the possibility of rising insurance premiums in areas prone to floods, and even the removal of insurance in some extreme cases in the future.
Understanding these secondary impacts, and recognising particular challenges and opportunities relevant to Greater Manchester, will support the development of a comprehensive range of adaptation responses.

EcoCities has undertaken two detailed Greater Manchester focused ‘risk-response’ case studies that support this broad assessment of future climate change impacts (Kazmierczak 2011; Kazmierczak and Connelly 2011). They concern the flooding of buildings and the impact of heat stress on human health. The in-depth analyses of two of the key weather and climate risks facing Greater Manchester in the present day (flooding of buildings) and over the coming decades (heat stress and human health), help to identify appropriate policy responses to adapt to these risks.
Climate change adaptation: looking back and projecting forwards

The significant shifts in climate variables projected for the twenty-first century, coupled with the observed impacts of ongoing extreme weather and climate events, makes adaptation to climate change a pressing policy issue. To respond to this agenda, there is real value in developing a better understanding of the incidence and consequences of past events. This was recognised by the UK government through the inclusion of the LCLIP process within National Indicator 188 (NI188). Until the change in government in 2010, NI188 was part of the local government performance assessment framework, and aimed to strengthen the integration of adaptation within local authority planning and decision making (LRAP 2008). NI188 recognised that climate change adaptation does not purely concern developing responses to projected future climate change, emphasising that it is also important to raise awareness of, and develop responses to, present day events and extremes particularly where these are projected to intensify in the future.

Established as part of the 2008 Climate Change Act, the Adaptation Sub-Committee (ASC), working under the Committee on Climate Change, provides advice and information to the UK government on adaptation issues. The ASC (2010: 2) identifies two key priorities for adaptation action. The first is to assess those ‘...assets and institutions that are sensitive to current climate risks.’ They go on to underscore the immediacy of adaptation for: ‘Adaptation involves taking definite actions today to reduce possible damages and capture future benefits’ (ASC 2010: 25). The ASC points to several benefits of taking action to better understand and then reduce current climate risks. These are:

- Building the case for prompt action to reduce current risk.
- Protecting against current damage and harm from weather and climate events.
- Increasing resilience to future climate change hazards.
- Establishing a baseline against which changes in risk and vulnerability can be tracked over time. (ASC 2010: 29 and ASC 2011: 11)

Despite the loss of NI188, responding to current weather and climate impacts remains a concern for influential organisations such as the ASC. Climate change adaptation does not relate exclusively to action that will be taken in future decades at a point where climate change impacts are projected to be more severe. The climate is changing right now and its impacts are an issue for today. Adaptation must deal with current challenges to reduce exposure and
vulnerability to climate hazards in the future. Identifying patterns within recent weather and climate events is an important part of incremental adaptation responses to long term climatic change. For example, surface water flooding is increasingly prevalent across parts of Greater Manchester, a risk that climate change will heighten as extreme downpours increase. Appropriate adaptation responses, such as permeable paving and increasing green cover, will help to address current vulnerabilities and reduce future risks linked to pluvial flooding. Planners and decision makers should also be aware that exposure and vulnerability to extreme weather and climate events will evolve over time, with implications for the severity of climate risks experienced in the future (see Carter and Ravetz 2011).

One counterargument to consider is whether studying and responding to recent weather and climate extremes during an era of rapid climate change diverts scarce time and resources. As our climate envelope is projected to shift radically, it is possible that learning from historic records on extreme events is at odds with the magnitude of future projections (Engle 2011). As noted by Karl et al (2009: 49) in reference to water resource planning in the United States: ‘the past century is no longer a reasonable guide to the future for water management.’ Adger et al (2011: 764) agree noting that: ‘[adaptation] responses based on past experience can lock systems into pathways that reduce future options.’ The threat of rapid climate change appears increasingly real, and should certainly force serious contemplation of what this means for ecosystems, economies and societies.

Equally, there is a danger that focusing exclusively on future projections will not offer the current generation enough incentive to commit time and resources to adaptation planning. For adaptation strategies to gain traction with policy makers and the public, they must deliver benefits now. Lessening the risks linked to extreme weather events is one way to achieve this.

Adaptation strategies that protect and enhance green infrastructure offer a range of multifunctional benefits beyond reducing climate risks, in terms of improving human health, protecting biodiversity and proving opportunities for recreation. It can also be argued that failure to develop responses to reduce the frequency and severity of current events will lead to an eroding of capacity to meet future challenges linked to the changing climate, where dealing with the impacts of events such as floods steadily saps resources and diverts effort from developing long-term adaptation strategies. In addition, if it is accepted that the impacts of climate change are already experienced, responding to current extreme events can legitimately be seen as an integral element of the climate change adaptation response.
For these reasons, adaptation strategies should be developed that address current weather and climate risks, targeting those that are most prevalent in a particular location. It is possible, in the case of Greater Manchester, that current impacts are reflective of some of those projected for the future, albeit at higher frequency and intensity. Current impacts can therefore be seen as a ‘climate signal’ to help guide adaptation response decisions. It is, of course, also necessary to appreciate that new climate impacts will be faced which have not been often experienced in the past. For example, disruption to infrastructure and harm to human health caused by heat stress has not been prominent in Greater Manchester. Yet climate projections indicate that with the warmest day in summer potentially as much as 6°C above the 1961–1990 baseline by the 2050s, risks linked to heat stress are set to intensify. The impending implications for Greater Manchester of climate change in other parts of the world should also be acknowledged.

Researchers at the University of Oxford have, for the first time, documented a direct link between climate change and observed extreme weather events. By studying the UK floods of 2000 (an event that resulted in £3.5 billion in insurance claims), computer modelling demonstrated that it was two to three times more likely to have occurred due to climate change (Pall et al 2011). A key factor is that a warming atmosphere holds more water and, therefore, raises the risk of heavy rainfall events of extreme downpours. Min et al (2011) have established that greenhouse gas emissions (and the atmospheric warming that they generate) have contributed to the intensification of extreme rainfall events observed over land in the northern hemisphere. Increasing urbanisation has led to greater surface sealing, which raises the speed and volume of rainwater runoff and consequently the risk of flooding (Gill et al 2007). The imprint of human induced climate change can be recognised in events happening right now.

The implication of the research by Pall et al (2011) moves the adaptation debate squarely into the present day. It is important for stakeholders in Greater Manchester to acknowledge that extreme weather and climate events (such as the pluvial floods that are affecting the conurbation) are, in part, linked to the changing climate. Therefore, they are likely to increase in their frequency and magnitude over the coming decades. Heywood is an area of Greater Manchester which was urbanised during the industrial revolution. It did not experience flooding until severe pluvial flooding occurred in 2004, and again in the summer of 2006. Some 90 dwellings, many of them over one hundred years old, were filled with sewage-infested water up to 90cm in height (Douglas et al 2010).
Implementing adaptation responses to damaging events such as these must be seen as an integral part of planning for urban growth and development over the coming decades. Unlike the mitigation agenda, which is ultimately focused on reducing emissions to the global atmosphere, the locus of control and benefits associated with climate change adaptation resides firmly in Greater Manchester. Progressing adaptation in the short-term can enhance quality of life in the conurbation by reducing risks. Only then can the potential opportunities linked to current and potential futures climates be grasped.
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