'ADAPTATION STRATEGIES FOR CLIMATE CHANGE IN THE URBAN ENVIRONMENT'

Draft final report to the National Steering Group

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Executive summary: A synthesis of key ASCCUE conclusions and recommendations

Drawing on the key ASCCUE research findings, the following executive summary synthesises key conclusions and recommendations that are targeted at assisting urban areas and neighbourhoods within them in the development of planned adaptation responses to climate change. Each of the work package summaries included a series of recommendations aimed at strengthening climate change adaptation efforts within urban environments through changes to policy and practice. These are summarised below and discussed in the context of broader debates including the relationship between adaptation and mitigation, and the influence of socio-economic factors, both of which are set to exert a considerable influence on climate change adaptation efforts in the future. Recommendations for further research into climate change adaptation in urban areas were also proposed within ASCCUE, and are discussed within the individual work package summaries.

A stated objective of the ASCCUE project was to explore policy options for urban planning in response to climate change, with emphasis on changes in urban form and urban management. The following discussion therefore focus particularly on climate change adaptation in urban environments as delivered through spatial planning policy and practice. However, it is important to appreciate that there are a range of other factors that exert an influence on the form and function of the urban environment, such as demographic change (e.g. the shift to an ageing population) and evolving lifestyle choices of urban populations (e.g. the development of a café culture in some city centres). Moreover, the BESEECH socio-economic scenarios indicate that climate change may impact on a society that is considerably different than the one that we live in today. These factors may significantly influence the development of and capacity to implement adaptation measures. Further, it is crucial to acknowledge that the variability of built forms, socio-economic trends and climate change impacts that will characterise different urban areas in the future indicate that climate change adaptation efforts cannot follow a generic template and must instead respond to local circumstances. Nevertheless, spatial planning provides a useful avenue to explore urban climate change adaptation responses and influences much of the following discussion.

The following conclusions and recommendations concerning climate change adaptation strategies for urban environments are organised according to the three exposure units considered within the ASCCUE project; building integrity, urban greenspace and human comfort. Finally, before presenting the conclusions and recommendations, it is important to acknowledge that the multifunctional nature of many of the adaptation strategies discussed below, for example expanding greenspace cover, have the potential to exert benefits beyond lessening the negative impacts of climate change. Indeed, climate change adaptation can help to progress other sustainable development objectives and goals, and can make urban areas more attractive places for people to live, work and visit.

Building integrity: key conclusions

One of the key threats of climate change to building integrity concerns increased coastal, fluvial and pluvial flood risk stimulated by sea level rise, increased storminess and increased winter precipitation. These impacts are exacerbated by creeping urbanisation, which alters natural hydrological regimes through, for example, reducing the infiltration capacity of the ground. Using extreme value joint probability statistics in conjunction with one dimensional hydraulic modelling techniques, WP1 looked beyond traditional approaches to flood risk analysis which consider single flood risk drivers (e.g. rainfall events) to consider the relationship between interacting variables that contribute towards flood risk (e.g. river flows and tidal surges). Flood risk issues in the town of Lewes were considered in this context. Lewes is at threat from coastal and fluvial flooding, and includes significant development on floodplain areas. The research confirmed that the development of an offstream flood water storage area in the floodplain of the river Ouse below Lewes would be enough to mitigate flooding impacts caused by climate change driven sea level rise up to 2080. However, it also established that existing flood defences in the town itself would not be sufficient to provide protection from flood risk in the long term and that solutions to the problem therefore need to be developed.

WP5 also addressed flooding issues. A surface water runoff model was utilised to determine that more highly developed urban areas within Greater Manchester have greater levels of runoff. This research also highlighted that soil type is very important when considering flood risk in urban areas, with greater runoff experienced for clay rather than sandy soils. These are significant finding considering that winter rainfall levels are predicted to increase for the UK, and that more intense rainstorms will be likely throughout the year. It is clear that planning policy preparation and development control decisions concerning the nature and location built forms should increasingly acknowledge these issues.

The challenges posed by climate change in the context of increasing flood risk are common to urban areas across the UK. It is clear that flooding has the potential to damage the built fabric of urban environments. WP2 and WP3 developed tools to help planners and decision makers determine urban areas that are at particular risk of flooding. WP2 developed a GIS-based conurbation scale risk assessment methodology, the application of which during the Greater Manchester case study produced data on the risk of flooding in the city and the vulnerability of the built environment to this impact. WP3 focused on developing and testing a neighbourhood scale risk assessment methodology, which provides mapping and analysis methods to assist in assessing the risk to the built environment, measured in terms of the cost of damage over a set period, from climate change impacts (including flooding and geohazards). This method, which was validated in Lewes, presents the opportunity to assess the costs of climate change to the built fabric of cities were there to be no adaptation strategies put in place.

Although the ASCCUE research focused principally on the impact of flooding on the built environment, other issues were also considered. WP2 produced data on the risk to building integrity from geohazards such as subsidence and land slides. Further, alongside flooding, the risk assessment methodology developed as part of WP3 also included geohazards created by changed soil and geologic conditions that are influenced by moisture content. These issues were considered alongside flooding to establish a single measure of risk to the built fabric of urban areas from climate change impacts. The vulnerability of the built environment to these climate change impacts was represented visually via a GIS overlay process. The conurbation and neighbourhood scale risk assessment methodologies presents planners and decision makers with a resource to help to manage the risk to cities, neighbourhoods, and individual properties from climate change impacts. Moreover, the methodologies can assist in the development of adaptation measures targeted at key climate change impacts and urban locations of particular concern.

Building integrity: key recommendations

Key recommendations arising from the ASCCUE project concerning adapting the built fabric of cities to the challenges of climate change are:

- Emphasise the role of spatial planning, at the regional, local and project scale, in the development and implementation of adaptation measures to impacts such as flooding and geohazards.
- Encourage the use of risk assessment methodologies such as those developed within ASCCUE to encourage a more informed approach to the planning and development of urban areas to adapt to the threats of climate change.
- The challenges associated with climate changes emphasise the importance of recognising the need to look beyond traditional growth-dominated approaches and to encourage a longer term sustainable view of urban development.

The potential insights that risk assessment tools developed within ASCCUE offer to practicing planners present the opportunity to take a more informed approach to flood risk management during the planning and design of development. This will be a particularly important contribution if risks such as flooding and geological disturbance become more common as a result of climate change. Crucially, spatial planning can be seen as both a generator of and provider of solutions to flood risk problems. Consequently, spatial planning can make an important contribution to addressing flood risk issues driven by climate change, a role that is being increasingly recognised by central government and other key stakeholders such as the Environment Agency and the Association of British Insurers. By applying the risk assessment tools developed within WP2 and WP3 to particular boroughs for example, the preparation of Local Development Frameworks (LDFs) could be informed by data concerning areas particularly at risk of flooding from climate change. This could assist the development of LDF policies and/or supplementary planning documents targeted at reducing flood risk in particular locations. At a more strategic level, Regional Spatial Strategy (RSS) policies could also be strengthened by data concerning conurbation scale flood risk issues. Similarly, data generated concerning the risk to conurbations and neighbourhoods of geohazards could usefully inform the development of spatial planning policies at the local and regional level to reduce the vulnerability to and impact of this threat to building integrity. Aside from planners, this data has clear implications for the insurance industry, individual home owners and builders.

The process of determining planning applications for individual developments also has much to benefit from the risk assessment tools developed within ASCCUE. A stronger evidence base on flooding and geohazard issues within particular localities would exist to justify the attachment of planning conditions to planning permission to require, for example, flood resilient building materials or the use of sustainable drainage systems. The risk assessment tools can therefore help to control development in areas at risk of climate change induced threats to building integrity, for example by limiting new development and encouraging a reassessment of permitted development rights. The research findings could also help to strengthen the case to encourage the use of building regulations to aid climate change adaptation measures. Planners and decision makers would also be better informed to exploit opportunities to retrofit existing building stock in certain vulnerable neighbourhoods to minimise the severity and damage of flood risk impacts by, for example, integrating flood resilient flooring or plaster work.

However, there are broader issues at stake concerning adapting the built fabric in vulnerable locations within urban areas to climate change. There is a clear conflict between short term economic benefits associated with new development and consideration of the long term sustainability of the built environment within towns such as Lewes that are at threat from increased flooding in a future driven by climate change. Planners in Lewes are currently faced with exactly this dilemma with an application for 800 residential and industrial properties on a brownfield site in a key flood risk zone. Difficult decisions will need to be taken in Lewes, and in many other planning authorities across the country, concerning the direction of future development when faced by flood risk challenges. Moreover, it is important to acknowledge that engineered solutions cannot be relied upon exclusively for towns such as Lewes which are ultimately poorly situated to meet the challenges of climate change. For example, WP5 indicated that developing green roofs and enhancing greenspace cover can reduce rainwater runoff, although it was established during the Greater Manchester case study that this approach cannot completely counter the predicted increases in rainfall in this location. Therefore, use of storage basins and sustainable drainage systems will be needed. In some cases, particularly in coastal locations, managed retreat may therefore be necessary, although the planning system should nevertheless be encouraged to play a central role in the search for non-structural solutions to the challenges that climate change poses to the built fabric of urban areas.

Urban greenspace: key conclusions

Climate change poses a threat to human comfort in urban areas due to rising temperatures and more intense rainfall events with associated flooding. Further, the urban heat island effect has the potential to compound and accelerate temperature rises in urban centres. WP5 established that urban greenspace can help to moderate the negative impacts of both these climate change impacts through providing shade and evaporative cooling, and by decreasing rainwater runoff through interception, storage and infiltration. These functions of greenspace make it a key adaptation measure in a future for the UK that is predicted to be characterised by warmer summers and wetter winters. Moreover, the use of urban greenspace in this way is particularly significant as the UK has a largely urban population, something which the BESEECH socio-economic scenarios predict is set to continue into the future.

WP2 examined greenspace issues by using aerial photographs to establish the extent of greenspace cover in Greater Manchester. The GIS-based risk assessment methodology that was developed within WP2 culminated in the identification of degrees of risk for different urban morphology types across the conurbation (including those relating to greenspace areas) to different climate change induced hazards including the risk of flooding, geohazards and extreme temperatures. This enabled the vulnerability of the different urban morphology types within the conurbation that are at potential risk to be highlighted. Greenspace was considered specifically during this methodology as one of the key ASCCUE exposure elements. Key greenspace areas within the Greater Manchester conurbation were identified as being particularly at risk of climate change impacts. This information could help local authorities in the planning and design of greenspace adaptation strategies in the city in the future, and in terms of reducing the vulnerability of greenspace areas to climate change impacts.

Complementing and integrating the analyses undertaken within WP2, WP5 assessed the vulnerability of greenspace to climate change impacts at the city and neighbourhood level, and also investigated the potential of greenspace to adapt cities to a changing climate. The impact of climate change on greenspace was explored through determining the soil water deficit and the number of months that grasses would be water stressed in the future. This will have knock-on impacts on human comfort and building integrity. The cooling effect of grass is considerably reduced due to water stress, which could have potential human comfort impacts, and the stability of building foundations could be affected by changes in soil moisture content. Significant increase in water stressed months were predicted from a figure of less than two months at present to over 5 months under the 2080s high scenario, with time taken for full soil water recharge extending from September to November. A surface temperature model was also utilised within WP5 to make predictions for different urban morphology types, climate change scenarios and future time slices. The model predicts that increasing greenspace cover by 10% can potentially eliminate the effects of climate change on increasing surface temperatures. However, reducing greenspace cover by the same percentage could increase surface temperatures by up to 8.2°C under the 2080s high scenario. The role of greenspace as a climate change adaptation strategy is therefore clear.

Urban greenspace: key recommendations

Key recommendations arising from the ASCCUE project concerning enhancing the role of greenspace in adapting cities to the challenges of climate change are:

- Promote the multi-functional benefits of greenspace resources, which extend beyond their role in climate change adaptation.
- Encourage the use of spatial planning, at the strategic, local and neighbourhood level, to design and implement climate change adaptation strategies based around greenspace resources.
- Risk assessment methods, such as the one developed during WP2, should be promoted as a means of encouraging an evidence based approach to developing greenspace climate change adaptation approaches.

The ASCCUE research has established that the creative use of greenspace is a vital climate change adaptation strategy. It is significant that greenspace provides multifunctional benefits, for example by enhancing human health and providing habitats for flora and fauna. Conserving and where possible enhancing greenspace areas must therefore be encouraged. However, it is important that greenspace provision is carefully planned. There is a need for a more strategic approach to be taken to the planning and development of greenspace areas. For example, it is vital that areas such as schools, hospitals, high density residential areas and urban cores are furnished with adequate greenspace cover. It is clear, therefore, that in the same way in which the spatial planning system has a key role to play in addressing flood risk problems, planning can also aid the development of climate change adaptation measures based around greenspace resources. Indeed, spatial planning is increasingly being seen as central to climate change adaptation measures more generally. There is a need for the strategic planning of greenspace via the planning system from national to local level, and at the level of individual developments. At the strategic level, explicit policies concerning the protection and enhancement of greenspace resources are necessary within RSSs and LDFs. As mature trees are particularly important in terms of shade provision and water capture, it is necessary for these modifications to be made to planning strategies in the next round of plan preparation. Consequently, it is vital that Planning Policy Statement 26, which will provide guidance to planners on climate change mitigation and adaptation through the planning system, acknowledges the role of greenspace.

At the neighbourhood scale, spatial planning also has an important part to play in developing climate change adaptation strategies. There are a range of planning mechanisms that can aid in the development of adaptation strategies based around greenspace. For example planners can use development control through the granting of planning permission to require, for example, the inclusion of greenspace areas within new developments. Moreover, section 106 agreements could be targeted at securing green or blue space provision, as could the building regulations system. At a larger scale, government initiatives including Pathfinder regeneration programmes, the Sustainable Communities agenda, and housing market renewal all provide an important avenue to encourage the greater use of greenspace in development projects.

The risk assessment methodology developed within WP2 could play a valuable function in assisting the strategic spatial planning and management of greenspace resource. The method enables the vulnerability of greenspace areas to climate change impacts to be highlighted, and could help to identify areas that may require adaptation measures to reduce the stress on greenspace resources such as the provision of adequate water for irrigation purposes. Maintaining the functionality of greenspace as climate change adaptation measure through adequate watering is crucial. Considering the role of greenspace in moderating temperature rises and reducing flood risk, the vulnerability assessment produced within WP2 concerning locations at threat from these climate change impacts can help planners and decision makers to identify areas where increases in greenspace cover would be most valuable and where measures are necessary to protect greenspace from climate change impacts are most urgently required.

Human comfort: key conclusions

Climate change will affect peoples demand for, use of, and experience of open space. Under the medium-high prediction scenario for Ringway (Manchester Airport) the number of hot days (above 24.3°C) is predicted to increase from 5 days (reference period of 1961-1990) to about 45 days in the 2080s. For the same climate change scenario and time period, the number of warm summer nights may increase from 7 to 44. Significantly, there is the potential for the urban heat island effect to increase temperatures further. It is evident that people living in urban areas will have to adapt to this different climatic regime. This may lead to an increased demand for open spaces in the warmer summer months as changing lifestyles lead to an increased demand for outdoor living.

The comfort of urban populations under such future climate conditions will clearly be affected. This is particularly significant as UK society is predominantly urban and is predicted by the BESEECH socio-economic scenarios to remain so in the future. WP4 aimed to explore this issue further looking at the implications of climate change for the use of urban open spaces and to assess the extent to which open spaces could be utilised as part of climate change adaptation strategies. Studies of thermal comfort in outdoor locations were undertaken in Manchester and Lewes, a novel undertaking considering that human comfort studies have traditionally been undertaken indoors.

The thermal comfort studies undertaken as part of WP4 identified that people feel comfortable across a wide range of outdoor conditions and respond, as expected, to seasons and the weather. Moreover, it was established that people adapt to different climate conditions through, for example, changing their clothing and modifying their activities in particular locations. With the prospect of climate change, however, people will need to be aided in their efforts to adapt to the different climatic conditions that are expected to be experienced within urban areas such as Greater Manchester. This responsibility falls principally on government departments such as Defra, planning authorities at the local and regional level, and the private sector.

WP2, which aimed to identify the range and nature of climate change risks faced by an urban community (encapsulated in the Greater Manchester case study) to assist in the development of adaptation strategies, included a human comfort dimension. WP2 developed a GIS-based model to illustrate conurbation scale heat related risk, identifying different neighbourhoods within Greater Manchester that are of particular concern in this respect according to factors such as the vulnerability of the population to heat stress and urban morphology type. Supplemented with details of BESEECH socio-economic scenarios that can help to incorporate a further dimension into the analysis concerning the vulnerability of particular groups of society in the future, it was possible to produce a visual representation of possible areas of the conurbation (and the populations within them) that are likely to be at particular risk of climate change induced heat stress. It is worrying that climate change may amplify these existing vulnerabilities, as evidenced by the European heat wave of 2003 which hit the elderly most severely. Consideration of equity issues, highlighted clearly by this example, must be an important element of designing climate change adaptation strategies.

Human comfort: key recommendations

Key recommendations arising from the ASCCUE project concerning adapting cities to the challenges of climate change in order to maintain and enhance levels of human comfort are:

- The protection, improvement and expansion of green and blue space areas, which can moderate temperatures and enhance human comfort, must be encouraged.
- Spatial planning, at the regional, local and project scale has a key role to play in the development and provision of adaptation responses targeted at enhancing human comfort. This must be acknowledge and reflected in appropriate planning legislation and guidance
- Collaborations between planners, urban designers and land owners will be necessary to encourage the provision of urban open space resources adapted to climate change impact.

The threats to the comfort of urban populations and visitors from factors including warmer summers and wetter winters pose a real challenge to planners and decision makers in conurbations such as Greater Manchester. The city of Manchester, which has an urban core that has few public spaces with a significant proportion of green and blue space resources, faces particular problems. It is unlikely that the built form of the city centre will change quickly, particularly to the extent that large parks could be created for example. Smaller scale solutions are therefore more advisable, with a concerted effort necessary to adapt existing open spaces to include measures to enhance human comfort. Essentially what is needed is increased provision of shade for the warmer summer months, and more shelters from the wind and rain for the wetter stormier winter months that are predicted to be experienced in cities in the UK such as Manchester. More open spaces for recreation in areas peripheral to the urban core would also be beneficial. Further, it will also be important to consider the multifunctional design and role of open spaces in urban areas, and to acknowledge equity, inclusiveness and accessibility issues.

Spatial planning has a key role to play in designing and implementing measures to enhance human comfort in urban areas to adapt to changed climatic conditions. The maintenance, enhancement and expansion of open spaces (ensuring that there is no net loss of open spaces) and the appropriate use of green and blue space in urban areas must feature strongly in strategic and local planning decisions. This will be particularly important during the development of planning policies within RSSs, LDFs, and supplementary planning guidance documents that are designed to improve or re-structure city centres and inner urban areas, densify suburbs, create urban extensions and develop new settlements. Government policy drivers such as the Sustainable Communities programme and Pathfinder renewal projects must consider human comfort issues. Moreover, the modification of existing planning policy statements (such as PPS 25 which concerns development and flood risk) and development of new planning policy statements (such as PPS 26 on climate change) should also address human comfort issues where appropriate.

The risk assessment tools designed as part of WP2 and WP3 will be able to guide planners in targeting vulnerable areas that could benefit most from the development of adaptation measures to enhance human comfort. Particular adaptation measures to enhance human comfort in the face of climate change impacts include:

- Encourage the expansion of greenspace areas, which WP5 showed can have significant impact on reducing surface temperatures. It will be important to ensure that appropriate species are planted that can thrive under the climatic conditions that are predicted to be experienced by particular localities.

- In urban areas such as Manchester city centre, which has relatively poor greenspace resources at present, the importance of blue space areas such as canals, rivers and water features becomes more important due to the impact that water can have on reducing surrounding air temperatures. Protecting, improving and expanding blue space areas where possible, must therefore be encouraged
- It will be important to ensure that networks of open spaces adapted to climate change predictions are created to enable urban populations to move around cities in relative comfort.
- At the scale of individual developments, urban designers need to consider human comfort adaptation measures such as shading, wind breaks, and green infrastructure. Moreover, it will also be important to consider the full lifetime of developments in this respect.

However, spatial planning faces a particular problem in that the principal influence that the planning system has is over new development, with little control being exerted over existing development. It will therefore be important for local authorities to liaise with private sector interests and land owners to encourage shopping centres, for example, to incorporate adaptation measures. This is particularly significant considering that there is an increasing trend towards the 'privatisation' of open spaces in urban areas due to the increasing involvement of private companies in city centre regeneration programmes. A range of stakeholders must therefore be involved in the development of adaptation measures to enhance human comfort in the face of climate change impacts.

Introduction

Background

This research is about the vulnerability of towns and cities to climate change and the development of adaptation strategies for climate change in the urban environment. It has been carried out within the EPSRC/UKCIP programme on Building Knowledge for a Changing Climate (BKCC) in which research consortia, working with appropriate stakeholders, have undertaken studies of the long term impacts of climate change on the built environment, transport and utilities. Adaptation has been defined as adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts (Burton *et al*, 2001). Adaptation to climate change involves:

- Changes in processes, practices, or structures to moderate damage or realise opportunities;
- Adjustments to reduce the vulnerability of communities, regions or activities.

A general schema for placing adaptation within the climate change agenda is shown in Fig. 1.1.

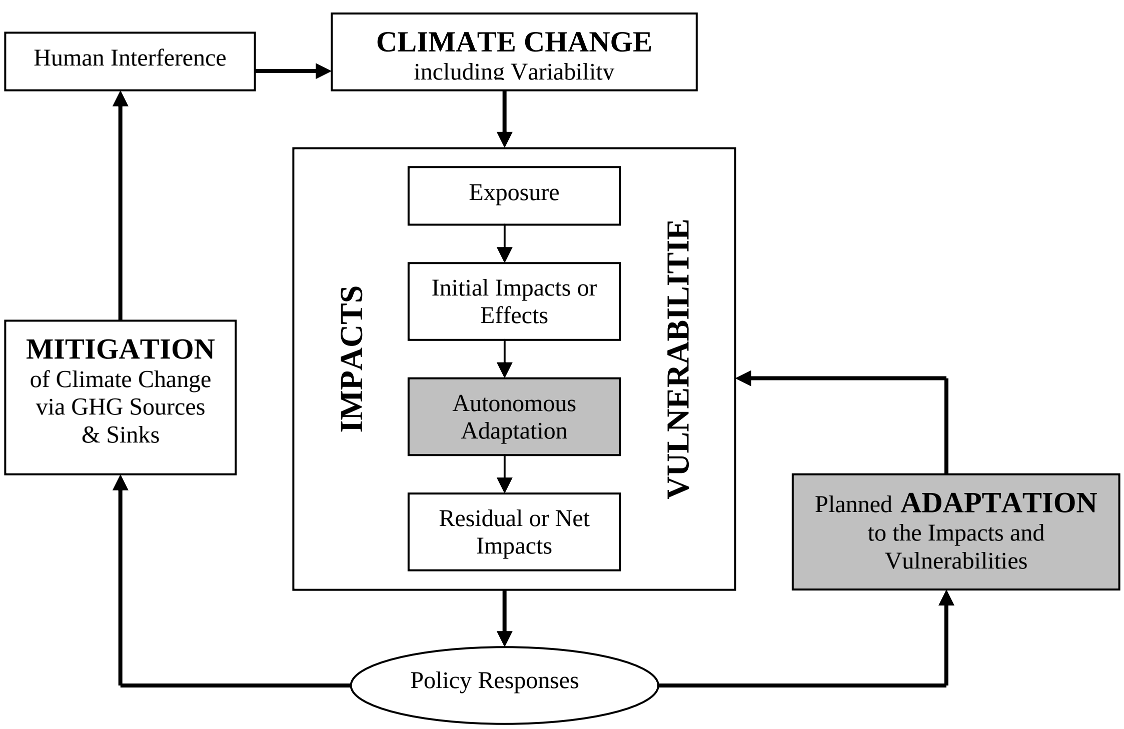


Fig. 1.1 The position of adaptation in the climate change agenda (Smit *et al.*, 1999).

As shown here, adaptation in the first instance is concerned with impacts and vulnerabilities, and the capacity for autonomous adjustment. An authoritative review of the vulnerability of human settlements to climate change (Jauregui *et al*, 2001) assigned low, medium and high impact ratings. For urban settlements in developed (high capacity) economies there is direct or strong research evidence that moderate/high impacts on buildings, infrastructure and populations are associated with flooding/landslides, sea level rise, heat/cold waves, water shortage, hail/windstorm, air pollution and intensification of heat islands. A review for the Construction Research Innovation Strategy Panel (CRISP) for the Climate Change Task Group (WSP Environmental, 2002) emphasised the need to identify the most vulnerable sectors and geographical areas and highlighted three key issues for built environment in the UK:

- Coastal and riverine flooding;
- Subsidence, wind and storm damage;
- Impacts of warmer summers on thermal comfort.

Our own literature review (Gill et al, 2004) confirmed the importance of these issues and utilised a Holling matrix to identify driving, relay and dependent variables. The research addressed these problems by developing and testing tools for impact assessment, followed by adaptation to change through planning and design. The exposure units of particular interest to the consortium are building integrity, human comfort (external) and urban greenspace, especially tree cover. The sensitivity of the building stock and human comfort to climate change is well recognised (Graves & Phillipson, 2000). We include greenspace, not so much for its sensitivity, but for its ability to moderate climate change impacts and its potential as a soft engineering solution within climate change adaptation (Whitford *et al*, 2001, Pauleit & Duhme, 2000). Complementary projects within the EPSRC/UKCIP call addressed the internal environment of buildings, infrastructure (transport and land drainage) and cultural heritage (EPSRC/UKCIP, 2003).

The ability to respond to change depends on adaptation capacity. Smit and Pilifosova (2001) suggest that, whilst scholarship on adaptation capacity is extremely limited in the climate change field, the main features are likely to include economic wealth, technology, information and skills, infrastructure, institutions and equity. The question of adaptive capacity was addressed specifically by the Policy Studies Institute within BESEECH which provides a generic input to BKCC on socio-economic aspects. As a prosperous nation with well developed institutional frameworks, e.g. the town & country planning system, the UK should be well placed to develop and implement adaptive strategies for the urban environment. However, whilst good progress has been made in relation to mitigation, adaptation has received much less attention. ASCCUE has sought to address this deficiency. Our research has confirmed that the problem is complex and multi faceted demanding an integrated, systems-based approach, utilising the full power of GIS to represent the dimensions of impacts and risk at different temporal and spatial scales (Lindley et al, 2006).

Programme and methodology

Aims and Objectives

The principal aims of the proposed research are:

- To develop an improved understanding of the consequences of climate change for urban areas and how these, and the neighbourhoods within them, can be adapted to climate change;
- To explore policy options for urban planning in response to climate change, with emphasis on changes in urban form and urban management;
- To produce a tool-kit for climate-conscious planning and design at various scales from neighbourhood to the whole city level;
- To initiate demonstration projects (to be managed by the stakeholders involved) to make cities and urban neighbourhoods fit for climate change through planning, design and management.

The specific research objectives are:

- To explore the physical template of two contrasting urban areas and to make a city-wide assessment of climate-related risks to and constraints on development;
- To explore the likely consequences of climate change for building integrity, urban greenspace and human comfort at the neighbourhood level in each location;
- Having regard to the potential for autonomous adjustment, to explore the scope for strategic adaptation by planning and design at both scales of inquiry;

- To recognise the potential for interaction (both positive and negative) between adaptation and mitigation and to screen adaptation strategies for this;
- To engage with the stakeholder community (national and local) at all stages in the assessment and with them develop dissemination tools and seek to initiate demonstration projects.

Methodology and Approach: The research framework for ASCCUE is shown in figure 1.2 below.

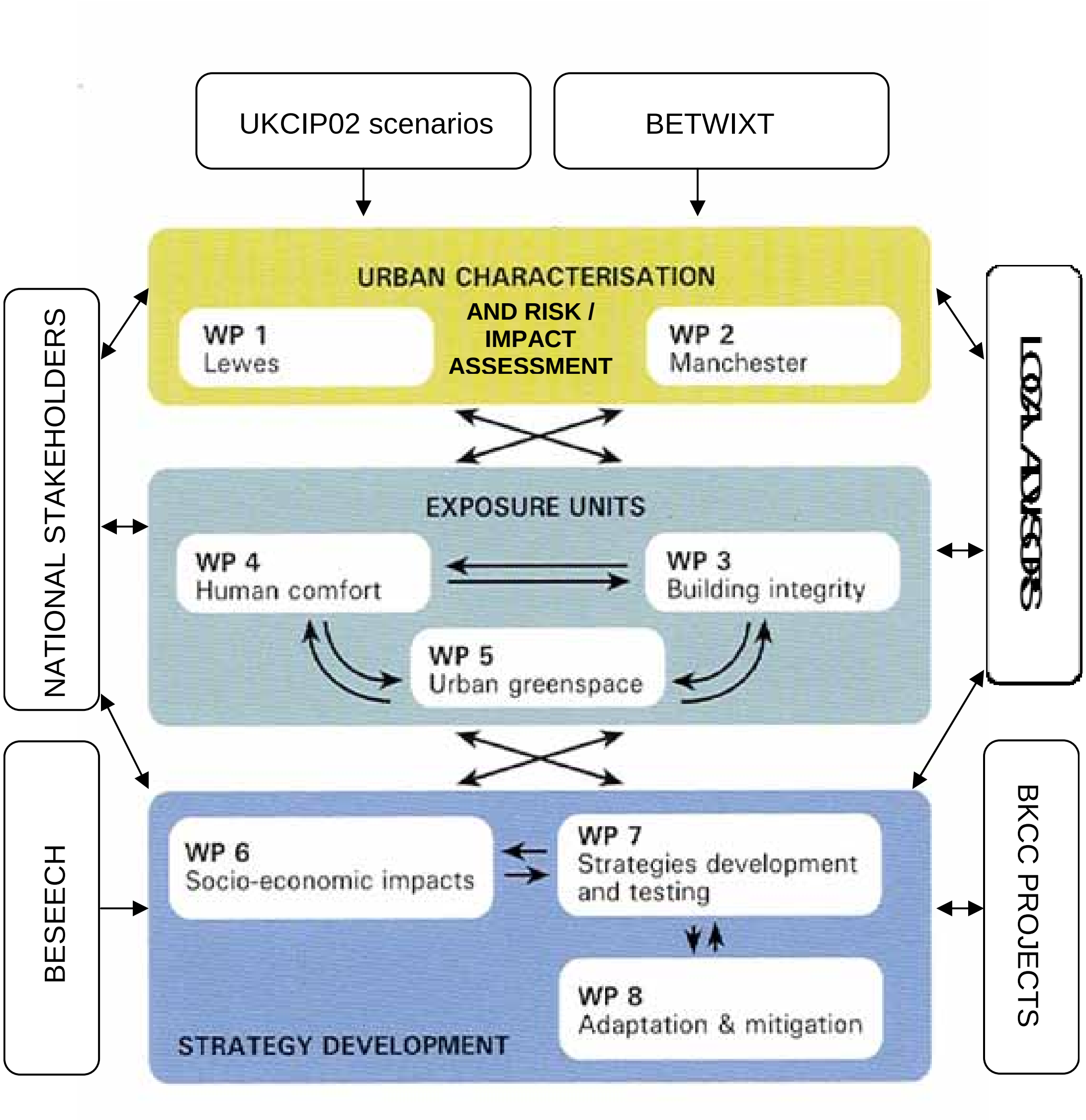


Figure 1.2. ASCCUE research framework.

This research framework is provided by the IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations, refined and updated by Parry & Carter, 1998. They propose a seven step strategy from problem definition to evaluation of adaptation strategies, with four stages of iteration through which an assessment may need to proceed:

Stage 1. feasibility (inventory and vulnerability assessment)
Stage 2. assessment of biophysical impacts;
Stage 3. assessment of socio-economic impacts;
Stage 4. evaluation of adaptation options.

The advantage of using an established research framework is that the research findings can be nested into the IPCC process and international literature. What is novel here is the application of this framework to the urban environment, initially through impact assessment at the whole town or city level (Stage 1) and then the development and testing of methodologies for vulnerability assessment of building integrity, urban greenspace and human comfort, which takes place in Stage 2. In conjunction with the stakeholder community and the BESEECH project we explored socio-economic impacts and their interaction with climate change (see for example Lindley et al 2007) During Stage 4 planning and design workshops were held involving our stakeholder partners to develop and test adaptation options. We were especially interested here in the scope for interaction (both positive and negative) of the three biophysical dimensions: building integrity, urban greenspace and human comfort. Workshops were held, as follows, and in each case reports on minutes are available:

- Workshops on development of risk assessment methodologies, Manchester, July 8th, 2006.
- Workshop on adaptive management and climate conscious deign for urban neighbourhoods, Manchester, January 18th, 2006.
- Joint workshop with DEFRA Cross Regional Project on climate change implications for new development in the growth areas, London, March 20th, 2006.
- Special meeting of ASCCUE National Steering Group in workshop mode to consider research findings of Lewes case study, London, 21st September, 2006.

Outputs from these workshops have also been captured in scientific publications (Gwilliam et al, 2006, Lindley et al 2006 and 2007.

Screening, in Stage 4, examined interactions between adaptation proposals and mitigation (McEvoy et al, 2006). Climate scenarios were provided by UKCIP02 (fine tuned to a 5km resolution in our laboratory) and by the BETWIXT project of the Climatic Research Unit *et al*. The ASCCUE project team also played a wider role in BKCC facilitating communications via the Integrating Framework and leading and managing the BKCC Data Management Group.

Case study selection and local workscope

The research methodology took a case study approach based on and around two conurbations with contrasting size, vulnerability, and climate regime; they are at opposite ends of the SE/NW climate change gradient.

Lewes – a low lying coastal town in South East England: The coastal towns, and particularly those in the east and south, will be the most severely affected by climate change, experiencing increased storminess in conjunction with an estimate sea level rise of between 19 to 86 cm by 2080. As well as the obvious problem of sea defences, the increased winter precipitation will result in significantly greater river flows causing major problems of flooding in towns sited on narrow river mouths, the situation being exaggerated further in the south east due to the increased housing development in the catchments and towns. There is therefore an urgent need to establish both the likely impact in the towns at risk, and to develop acceptable approaches to living with the problem.

Sustainable and affordable technical solutions were not immediately obvious and as anticipated the final solutions may well lie in a creative, integrated, approach to town and country planning in conjunction with soft and hard engineering. These issues were investigated through the use of Lewes, a coastal town in Sussex (population 15,000) as a case study location. This is an extreme case in terms of vulnerability, where sea level rise interacts with enhanced river flows to produce severe and repeated flooding, but is not untypical of many south coast towns. Here, where adaptation is urgently needed but may be difficult to achieve in practice, the research has quantified the scale of the threat, potential solutions and future research priorities.

Greater Manchester – a large and complex conurbation in North West England: To complement the work being carried out on Lewes and to enable the team to draw out generic research findings to help inform wider adaptation strategies for other urban areas in the UK, the second case study area was Greater Manchester. This is a large conurbation (population 2.5m) with substantial scope for adaptation through urban restructuring and renewal. The conurbation offers:

- Sufficient size for full expression of urban environmental character;
- Contrasting soil types (extremes of soil permeability and structure to emphasise climate change interactions);
- Full range of neighbourhood and land use types, including urban restructuring and ‘sustainable’ urban extensions;
- Range of built form (e.g. high/low rise commercial and residential);
- Existing data sets for characterisation and analysis.

The selection of Manchester as the second case study enabled the consortium to make use of an extensive GIS-based database collated in connection with a completed EPSRC project to develop a Regional Interactive Sustainability Atlas (RISA, GR/M59501) (Lindley, 2001). There are further advantages as this will enable the utilisation of an earlier survey and characterisation of non-domestic buildings and a related 3D characterisation of the built environment of Manchester (Brown *et al*, 2000). Preliminary analysis at the city-reion scale paved the way for more detailed studies at the neighbourhood level in the subsequent workscopes.

Report Structure

A commentary on the research findings that discusses the key conclusions and recommendations stemming from the different work packages (included here as an executive summary) has been prepared by Jeremy Carter and John Handley. Darryn McEvoy prepared the discussion concerning the engagement with stakeholders. Reports on the work packages shown in Figure 1.2 follow this commentary form the main body of this report. The authorship of the work package reports is as follows.

- Work package 1: The Lewes case study – Chris White and Trevor Tanton.
- Work package 2: The Greater Manchester case study – Sarah Lindley.
- Work package 3: Integrity of the built environment - Julie Gwilliam and Mike Fedeski.

- Work package 4: External thermal human comfort - Elizabeth Wilson and Fergus Nichol.
- Work package 5: Urban greenspace – Susannah Gill, John Handley and Roland Ennos.
- Work package 6: Socio-economic impacts – Darryn McEvoy.
- Work package 7: Workshop reports are available for this work package.
- Work package 8: Adaptation and mitigation – Darryn McEvoy.

References

Brown, F.E., Rickaby, P.A., Bruhns, H.R. and Steadman, J.P. (2000) Surveys of non-domestic buildings in four English towns, *Environment and Planning B: Planning and Design*, 27, pp 11-24.

Burton, I. *et al* (2001) Adaptation to Climate Change in the Context of Sustainable Development & Equity. In: McCarthy, J.J. *et al* (eds). *Climate Change 2001: Impacts, Adaptation & Vulnerability, Contribution of Working Group II to the 3rd Assessment Report of IPCC*, Cambridge University Press, Cambridge, Chapter 18, pp 877-912.

EPSRC/UKCIP, (2003) Building Knowledge for a Changing Climate Programme, UKCIP, Oxford.

Gill et al (2004) Literature review: Impacts of Climate Change on Urban Environments, CURE, Manchester.

Graves, H.M. & Phillipson, M.C. (2000) *Potential Implications of Climate Change in the Built Environment*, BRE/FBE.

Gwilliam, J Fedeski, M Lindley, S Theuray N and Handley J (2006) Methods for assessing risk from climate hazards in urban areas Municipal Engineer 2006, 159, No. 4, 185-191.

Kane, S., & J.F. Shogren (2002) Linking adaptation and mitigation in climate change policy, *Climate Change* 45: 75-102.

Jauregui, E. *et al* (2001) Human Settlements, Energy & Industry. In: McCarthy, J.J. *et al* (eds). *Climate Change 2001: Impacts, Adaptation & Vulnerability, Contribution of Working Group II to the 3rd Assessment Report of IPCC*, Cambridge University Press, Cambridge, Chapter 7, pp 380-416.

Lindley, S.J. (2001) Virtual tools for complex problems - an overview of the AtlasNW regional interactive sustainability atlas for planning for sustainable development, *Impact Assessment and Project Appraisal,* 19:2, pp 141-151.

Lindley, S. J., Handley, J. F, Theuray, N., Peet, E. and McEvoy (2006) Adaptation Strategies for Climate Change in the Urban Environment - assessing climate change related risk in UK urban areas Journal of Risk Research Vol 9 No 5 pp. 543-568

Lindley, S. J., J. F. Handley, D. McEvoy, E. Peet and N. Theuray (accepted, 2007) Conurbation scale risk assessment and its implications for the development of climate conscious land-use planning in the UK. Journal of Built Environment

McEvoy D., Lindley S. and Handley J. (2006, in press) Adaptation and mitigation in urban areas: synergies and conflicts. Proceedings of the Institution of Civil Engineers, Municipal Engineer, 59, No. 4, 185-191.

Nowak, D.J. and Crane, D.E. (2000) The Urban Forest Effects (UFORE) model: quantifying urban forest structure and functions. In: Hansen, M and Burk, T. (eds). *Integrated Tools for Natural Resources Inventories in the 21st Century,* Boise, ID, August 16-20, 1998. USDA Forest Service, North Central research Station. General Technical Report NC-212, pp 714-720.

Parry, M & T. Carter (1998) *Climate Impact & Adaptation Assessment: A Guide to the IPCC Approach*, Earthscan, London.

Pauleit, S. & F. Duhme (2000) Assessing the environmental performance of land cover types for urban planning, *Landscape & Urban Planning* 52, 1-20.

Smit, B., Burton, I., Klein, .R.J.T. & R. Street (1999): The science of adaptation: a framework for assessment. *Mitigation & Adaptation Strategies for Global Change*, 4, 199-213.

Smithers, J. and Smit, B. (1997) Human adaptation to climatic variability and change, *Global Environmental Change*, 7:2 pp127-146.

Whitford, V., Ennos, A.R. & J.F. Handley, (2001) “City form & natural process” – indicators for the ecological performance of urban areas & their application to Merseyside UK, *Landscape & Urban Planning* 57: 91-103.

Willows, R.I., Reynard, N., Connell, R. and Meadowcroft, I. (2002); *Climate Adaptation: Risk, Uncertainty and Decision-Making*, UKCIP Technical Report - Review Draft, UK Climate Impacts Programme

WPS Environmental (2002) *Draft Report of the CRISP Climate Change Task Group.*

Engaging with stakeholders

Being solutions-oriented, with research findings intended to inform policy and practice, the research team placed a strong emphasis on stakeholder engagement from the outset of the ASCCUE project. Indeed, key national stakeholders [Town and Country Planning Association (TCPA), Royal Town Planning Institute (RTPI), Office of the Deputy Prime Minister (ODPM) and the Environment Agency] were represented at a preliminary workshop in 2002 to help define research objectives and priorities, and subsequently offered written endorsement in support of the proposal before the research process got underway. Continuing collaboration with the stakeholder community has been one of the most critical factors in ensuring quality deliverables from the ASCCUE project.

There were six important strands to the ASCCUE stakeholder engagement process: 1) the involvement of the TCPA as stakeholder champion, 2) a strategic ASCCUE steering group operating at the national level, 3) local advisory groups for each of the two case studies, 4) more informal interactions with local stakeholders as the research developed, 5) the hosting of risk workshops, and 6) the stakeholder forum which acted as a dissemination ‘gateway’ to the outside world as part of the ‘Integrating Framework’ for the wider Building Knowledge for a Changing Climate (BKCC) research programme.

TCPA acted as *Stakeholder Champion* for the project, hosting and facilitating the National Steering Group meetings as well as representing ASCCUE on the BKCC stakeholder forum. Their involvement stemmed from a belief that adaptation was an essential part of any response to climate change, and that spatial planning needs to play a central role. Any response will also need to be informed by the best possible science. In addition to coordinating the stakeholder engagement process at the national level, they were also responsible for developing a coherent communication strategy and ensuring that the key messages arising from the ASCCUE project were disseminated effectively. A core component of the dissemination output is the development of an ‘Adaptation-by-Design’ guide, based on the outcomes of the ASCCUE research. This initiative is currently underway and is due to be published in the first half of 2007.

The *National Steering Group* for ASCCUE met on a six-monthly basis in London and members were selected to represent enablers / policy-makers / users / and other key stakeholders. The group make-up consisted of public, private, and voluntary sectors; with representation from Government departments, quasi-public organisations, regional planning authorities, professional associations, and representatives from the construction, urban design, landscape architecture, and health sectors. The project funders (UKCIP and EPSRC) were also represented at these regular meetings. Contributions from the steering group served several important functions. As a result of their individual knowledge domains and experience, they not only provided authoritative 'guidance' to the solutions-oriented research, but were also able to make valuable contributions to the development of research methodologies within the project. Furthermore, when dealing with specific adaptation issues members of the group were able to use their expert knowledge to highlight other relevant activity and best practice to the research team. This exchange of knowledge was of particular value to the research team. The national steering group was also given the responsibility of contributing to the communications strategy. This was a significant role, ensuring that the implications of the research for policy and practice were made as explicit as possible in the final dissemination of the findings. Over three years of direct involvement, members of the national steering group also used their individual professional networks to raise awareness of ASCCUE research activity.

In addition to the steering group operating at the national level, *Local Advisory Groups* were also set up for the two case studies of Greater Manchester in the North West of England and Lewes in the South East. These two case studies were selected to allow investigation of two contrasting urban areas. The former is a large conurbation chosen as a representative case, enabling the research team to draw out generic findings and inform 'transferable' adaptation strategies, whereas the latter was viewed as a good example of an extreme case in terms of its vulnerability to climate change. In the case of Greater Manchester, a membership of 10-12 stakeholders was considered the optimum size for the advisory group, with stakeholders again representing a spectrum of interests within the urban environment: regional policy-makers, planners, urban designers, members of the insurance industry, local authorities, city managers, emergency planning experts and regulatory authorities. Their collective input, again at six monthly meetings (with additional contributions at other meetings and events), was multi-dimensional – not only did members provide valuable local insights to climate change impacts and adaptation issues, they also commented on the different exposure units under investigation by the research team, contributed their local knowledge at climate risk workshops, assisted with the selection of specific case studies, and used their expert knowledge to assist the development and testing of possible adaptation strategies. Coming from a local perspective, this input acted as a valuable compliment to the contribution from the national stakeholders. For the Lewes case study, which has been subject to severe and repeated flooding, the interaction between the research team and local stakeholders was, out of necessity, much more constrained. Due to important political and economic sensitivities in the case study area (the town was subject to a substantial flooding event as recently as 2002) it proved impossible to hold 'open' group meetings. Instead, the research team had to rely on the expertise of a small number of policy and regulatory stakeholders (representation and input from regional and local authorities, and the Environment Agency).

Engagement with local stakeholders was not limited to the local advisory group meetings. Whenever possible the research team sought to promote more *informal interactions* with other stakeholders. Three examples from the Greater Manchester best illustrate the variety of working relationships that developed during the course of the research. Firstly, the knowledge of local planners from each of the ten metropolitan borough councils was called upon to ensure accuracy when generating urban morphology types for the Greater Manchester conurbation (see WP2 for further detail). Secondly, the research team also performed an ASCCUE 'road-show', visiting the local offices of organisations that were interested in adapting cities to climate change (for example, TEP, the Environment Agency, Association of Greater Manchester Authorities, United Utilities etc.), giving presentations that highlighted the aims and objectives of the ASCCUE project. This process was a useful dissemination vehicle, both informing local stakeholders and eliciting valuable feedback. Thirdly, there was particularly close interaction with the regional planning authority and the Environment Agency, culminating in a 2006 report responding to the Regional Spatial Strategy consultation in the Northwest region. Interactions were not limited to Greater Manchester however, with individual work packages engaging with stakeholders in Lewes according to their research needs.

An important mechanism for facilitating the exchange of knowledge between the research team and the local stakeholder community was the hosting of *risk workshops*. The first of these was held early on in the research programme (July 2004) and was specifically designed to promote active engagement with the local advisory group. The main focus of the half-day event was to obtain feedback on the conurbation scale risk screening methodology which was under development at the time. Not only was there broad support for the ASCCUE methodologies from the participants but they also helped to identify additional expert groups who would be able to make useful contributions to the development of the final toolkit. This was then followed up by a second workshop in January 2006, though in this instance there was a greater emphasis on the development of adaptation options as illustrated by the title of the event: 'adaptive management and climate conscious design of urban neighbourhoods'. The morning session first introduced an overview of research activity before splitting into three breakout groups focusing specifically on each of the three exposure units. In the afternoon, a more cross-cutting and integrated approach was taken with the consideration of impacts and adaptation according to different neighbourhood types (city centre, urban restructuring, and densifying suburb). This semi-structured format provided a useful opportunity for the research team to present work-in-progress from each of the work modules, as well as allowing stakeholders to be an integral part of the research process by commenting on the assessment methodologies under development and contributing to the testing of integrated adaptation options for different neighbourhood types. Representation at this day long workshop was intentionally broader, with the inclusion of experts whose knowledge benefited the research of the different exposure units (see WPs 3-5 for more detail) and a wider representation from the potential 'users' of the ASCCUE findings. A final joint workshop (date) was also held with the DEFRA project on Adaptation in the Growth Areas, to explore some of the findings of ASCCUE in relation to new areas of development such as the Thames Gateway. The workshop included a range of stakeholders from the South East of England.

The final element of the stakeholder engagement process was the dissemination vehicle set up by the BKCC programme, the *stakeholder forum*. This was considered necessary to allow decision-makers the opportunity to become engaged with the overall initiative and more actively involved with individual projects. It also acted as the main dissemination gateway to the outside world. TCPA represented ASCCUE on this panel and although it is acknowledged that the process was a steep learning curve for many, TCPA suggest that those that stayed the course and engaged positively would be better informed as a result.

The importance of the stakeholder engagement activity that developed over the lifetime of the ASCCUE project cannot be overstated. Looking back, it is evident that this form of 'social learning' brought enormous benefits to both sides. Not only did stakeholders contribute their expertise and local knowledge, leading to an enhancement of research activity and findings, but also the two-way exchange between researchers and stakeholders undoubtedly had a positive impact on the potential for more informed decision-making in the future. The social learning process has been promoted by continuous interaction and dialogue between the research and stakeholder communities, a level of trust and openness between different parties, and a collective effort towards developing and testing adaptation options. The build-up of knowledge as a result of this type of collaborative working can only have positive implications for the adaptive capacity of our towns and cities.

Dissemination:

CURE (2004) *ASCCUE: Local Advisory Group workshop report – risk assessment methodologies* CURE, University of Manchester, Manchester.

McEvoy D. and S. Lindley (2006) *Adaptive management and climate conscious design of urban neighbourhoods* CURE, University of Manchester, Manchester.

Work Package 1 Summary: Living With Climate Change In Towns On Tidal Rivers: An Extreme Scenario Case Study At Lewes.

Context

By 2080, an estimated 0.4-0.9m sea level rise and increased storminess resulting from climate change is expected to create major flood defence problems for many coastal and estuarine towns. In addition, increased winter precipitation of an estimated 20% in Southeast England will further aggravate the flooding problem for towns situated next to narrow tidal rivers. The problem is further exasperated due to increased urbanisation of the catchments and towns. There is therefore an urgent need to establish both the likely impact in the towns at risk, and to develop socially and economically acceptable approaches to managing the problem.

Towns lying on tidal rivers can flood as a result of high tide or high fluvial events, but extreme events are most likely to be a result of the interaction between two extreme events. Unfortunately, in many locations urban expansion and changes to the use of historical floodplains have severely restricted the options for flood alleviation. Lewes on the river Ouse in East Sussex is one such town. It lies between two chalk downs astride the tidal reaches if the River Ouse at a location where the width of the flood plain narrows to about 250m. The street level in the lower part of the town is close to normal high water level and without flood defences it would be liable to regular inundation. This area of the town is characterised by many listed buildings and a modern industrial trading park. It is an area already at high risk of flooding from both fluvial and tidal events, a situation that will only get worse with climate change. As such, it was selected as a case study to investigate available engineering approaches to managing the problem and to look at their applicability within a wider social, political and economic context.

The traditional engineering approach to flood risk has been to increase the height of the flood defences. With long-term sea level rise being predicted at a maximum of 4m, this is not a viable long-term option for most locations such as Lewes. Although this study specifically looks in detail at the viability of different approaches to managing flood risk in Lewes up to 2080, it also looks at the long-term issues that we are creating by short-term economic benefits.

Aims and objectives

The aim of the research was to assess the increased risk and extent of flooding within Lewes resulting from climate change and to assess potential solutions for managing the risk.

Specific Objectives:

- To apply extreme joint probability statistics in conjunction with a one-dimensional hydraulic model of the lower Ouse to existing upstream hydrological and sea level gauge data series to predict the present extent of flooding in Lewes and to establish the effectiveness of the approach against historical water level records in Lewes.
- To confirm the significance of the new joint probability approach against the more conventional statistical approach to assessing the probability of flood risk.
- Once tested and verified, to apply this approach to investigate the implications of predicted increases in fluvial discharge and sea level rise resulting from climate change on the flood defence options for Lewes.
- Look at the wider implications on future flood management policy.

Theory and Methodology

Traditional flood risk analyses calculate the probability of a single variable producing extreme water levels, or if more than one variable is included in an analysis to treat them as either whole dependent or independent of each other. Flooding is often related to two or more variables that are only partially independent on each other. In the lower tidal reaches of rivers, where river flows and tides interact, the probability of extreme high water levels is a result of an interaction between fluvial discharge, tide level, tidal surge and wave height. All of these variables are not fully independent of each other, except mean predicted tide level, as they are all partially related to low atmospheric pressure.

To quantify the probability of extreme water levels produced by the combination of more than one variable the relationship between the variables has to be established. This can be calculated by using extreme value joint probability statistics which utilise a dependence measure, allowing a level of dependence to be found between the variables based on the occurrence of extreme values. The theory of the dependence measure is based on two (or more) simultaneously recorded variables of interest (such as river flow and tidal surge), known as observational pairs. If one of the variables exceeds a certain (extreme) threshold, then the dependence measure calculates the percentage risk of the other variable also exceeding an extreme threshold. For example, a dependence value of 0.1 between two variables means there is a 10% chance of the extreme values from both variables occurring at the same time. Extreme event joint probability statistics were used in conjunction with one-dimensional hydraulic modelling techniques to analyse tide, surge, and upstream river flow data to predict the joint frequency of potential flood events in Lewes. The approach to predicting flood frequency was validated using existing historical water level data in Lewes.

To enable the probability of flooding in Lewes to be established from upstream flow gauge data and river mouth sea level data, existing and new survey data was collected to build a hydraulic model of the lower Ouse, the performance of the model was confirmed against gauge data in Lewes and flood records. There are numerous variables which will result in combinations of the extreme events of the variables will result in a given high water level in Lewes. By using the hydraulic model to establish what the combinations are that give different water levels in the town, it is possible to calculate their joint probability of occurrence.

Climate scenarios used to investigate climate change by 2080 were a 20% increase in river flow for an extreme flood event. The recommended design standard for coastal defences on the South Coast of England is 1m to allow for the effects of climate change but the present rate of sea level rise is about 0.18m per hundred years which is due to land levels declining. Since waves do not directly affect Lewes, a sea level rise of 0.5m was taken as a more likely scenario for 2080 although sensitivity analysis up to 1m was included. The model was used to investigate a number of technical solutions for managing the additional risk to flooding posed by sea level rise and the long-term implications for the lower town centre.

Key research findings

The use of extreme joint probability statistics has been shown to be effective in modelling the joint probabilities of wave height, tide and surge to predict the frequency of occurrence of overtopping events of coastal defences. This work shows that the approach is also effective when it is linked to a hydraulic model to predict the frequency of any given event height at any position along a river section. Although the period of reliable tidal records from Lewes is limited, the frequency of the observed more extreme events was in keeping with that predicted by the technique using the longer data sets of upstream flow and sea levels measured at Newhaven. Joint extreme probability analysis of tide, surge and river flow, when used in conjunction with one-dimensional hydraulic modelling techniques, increases the estimated joint probability, and provides a more reliable estimate of flood frequency than more conventional approaches. Even without the effects of climate change, their use increases the predicted frequency of potential flood events.

In many locations around the UK, towns lying on tidal rivers, such as Lewes, are susceptible to a higher risk of flooding due to a combination of a rising sea levels with increased precipitation from climate change. It is anticipated that, as in the case of Lewes, many of these towns can be protected from the additional risk of sea level rise alone by raising the height of the flood defences for several kilometres from the mouth of the river in conjunction with other flood alleviating schemes, such as a flood storage area to take off the peak levels from a flood tide. Hydraulic modelling has shown that an engineered offstream flood water storage area on the floodplain below Lewes would be capable of mitigating flooding in Lewes resulting from any anticipated rise in sea levels up to 2080. The effectiveness of this approach is clearly sensitive to location and availability of land and may be used in collaboration with flow regulation, allowing the offstream storage to accept either tide or fluvial flows as flow conditions change.

Assuming a 20% anticipated rise in precipitation produces a uniform increase in magnitude of fluvial events and is accompanied by a 0.5m rise in sea levels, the joint probability research indicates that the existing flood defence design height in Lewes may need to be increased to provide protection against a 1:200 combined storm event unless other measures to mitigate the problem are implemented. The existing design height of the new defences can handle the climate change in the short-term, but additional work will be needed in the longer-term. Although the amount of gauged river level data in Lewes was limited, the predictions from the statistical and modelling approach were in agreement with the observed data, providing confidence that the approach is sound for predicting more extreme events.

In investigating the implications of a 20% rise in winter precipitation and an increased sea level of 0.5m, due to the weakness of the supporting data, no attempt was made to try to get an understanding of the implications of the possibility of more extreme storms or storm surges changing the frequency distribution of events, but was taken account of in a sensitivity analysis.

Implications for policy and practice

In Lewes, there is a conflict between the clear short-term economic benefits accruing to new developments in the floodplain against the long-term goals of sustainable development. For example, there are planning applications for 800 new residential and industrial properties on a brown field site in one of the most critical parts of the flood risk zone. The project clearly has both financial and economic benefits for the town during the design life of the project, even if the developer were to fund the necessary flood defence works. The site however, will not be able to be defended indefinitely as it lies next to the restricted river channel of the River Ouse. The town therefore faces difficult planning decisions; to plan for the long-term viability and sustainability of the town or favour immediate economic benefit. With increasing pressure on development land this dilemma is becoming very common. To provide planning permission for such a scheme disregards the policy of planning for a sustainable future, whereas refusing planning permission for the development goes against accepted economic good practice. If we are to plan for a sustainable future, then long-term planning goals need to override short-term economic gain. The redevelopment of brown field sites in critical areas should be more actively discouraged in policy as all too often the wishes of the Environment Agency are lost on appeal. Clear legislation needs to be developed at the National and European level to ensure sustainable development of floodplains if future generations are to be able to afford the building and maintenance of flood defences.

Flood defences are built on the basis of cost-benefit analysis which ensures that the limited resources available for flood defence are spent cost effectively. Although this is an economically sound practice, it mitigates away from long-term sustainable design. For example, benefits accruing beyond 20 years have a very low present day value, and hence if we were to include the anticipated incremental rate of climate induced changes on an annual basis in calculating the mean risk it would be very difficult to consider the implications of climate change in many flood defences and establish economic viability. Although the economic approach provides value for money, there is a need to ensure that it is within a wider town planning framework that considers the full implications of climate change.

Where events do not contain fully independent variables, as in the case of Lewes, the use of extreme joint probability statistics to calculate the frequency of a given event increases the estimated frequency of occurrence. Where the dependence is high, it can have a very significant effect on the height of the defences.

Ultimately, towns like Lewes are situated in the wrong place for living with climate change in the long-term. It is clear that we provide an engineered solution for additional flood risk arising from climate change up to 2080, but this cannot be done indefinitely. This issue needs to be addressed in long-term town planning.

Work Package 2 Summary: Greater Manchester Case Study

Context

Much existing research has focussed on understanding potential climate change related impacts and the challenges of mitigation. However, there has been a recent shift towards risk-based approaches and to the identification of processes and mechanisms for adapting to climate change (see for example, Willows & Connell, 2004). This is also the approach which is also being adopted by the Environment Agency, and encouraged within PPG25. As a result, the notion of risk was a central theme for WP2 through its role in providing the overarching methodological framework for the ASCCUE project and the development of more specific methods and tools for assessing the spatial patterns of risk across UK towns and cities.

WP2 used Greater Manchester, as a representative UK conurbation, to develop methodologies to assist the process of identifying areas potentially at risk from climate change impacts associated with ASCCUE's three exposure units: building integrity; human comfort; and urban greenspace. Although most exposure units used the concept of risk, for human comfort the methodology centred on the identification of changes to key receptive environments. A review of the literature and subsequent stakeholder liaison identified an appropriate range of climate change impacts in the urban environment. In particular, stakeholders identified the need to consider human health risks in addition to risks associated with the three exposure unit themes.

The central methodologies were developed with a view to their wider application to other risk themes and to other UK towns and cities. It was considered important that methods used readily available data and transparent techniques which could subsequently be used as the basis for a conurbation scale screening tool to be used by a range of decision-makers. Such a tool could then be extendable by considering the models, methods and results produced by the other ASCCUE work packages, some of which operate at neighbourhood scales whilst others further develop analyses at the conurbation scale.

The key data, methods and models research outputs from the ASCCUE project have been documented through the BKCC Data Management Group with metadatabases available through the SKCC website for research outputs associated with methods/models and through the UK central metadata repository (GIGateway) for data research outputs. WP2 led data management initiatives for the whole BKCC programme.

Aims and objectives

Following the broad aim of WP2 identified in section 1, the objectives and a summary of relevant tasks undertaken and outputs delivered, are provided below.

- Review current knowledge of climate change impacts in the urban environment – this was used to establish the context for the ASCCUE work and to identify an initial set of risk themes in relation to the ASCCUE exposure units
- Review methods and models used to assess climate change impacts in the urban environment - this was helped to identify appropriate methods, frameworks and approaches for assessing risk in the built environment, with particular emphasis on transferable approaches.
- Establish a Local Advisory Group for Greater Manchester and liaise with local stakeholders – the LAG provided an important input to the characterisation of the Greater Manchester case study and to the development of methods and priority risk themes.
- Assess data availability and data management requirements - a data proforma was circulated to the local advisory group to identify relevant data and many local advisors also assisted in gaining access to appropriate data
- Determine appropriate spatial and temporal scales for Greater Manchester case study work and design a GIS template – this was completed through developing the overarching ASCCUE methodology. There were two spatial scales; a conurbation (urban system) scale and a neighbourhood scale based on the spatial framework of an Urban Morphology Typology (UMT) unit representation[1]. A dataset delineating UMT (e.g. residential, commercial, industrial, open space) units for Greater Manchester was created from orhorectified aerial photography to use as the basis of the spatial risk assessment. The temporal framework was taken from UKCIP02 and the BKCC BETWIXT project i.e. climate scenarios based on the 2020s, 2050s and 2080s. Socio-economic scenarios were based on the 2020s and 2050s from the BKCC BESEECH project.

[1] The UMT dataset was produced under WP2 but a more detailed description is provided under the urban greenspace exposure unit summary.

- Develop a city-region and neighbourhood Greater Manchester Inventory – this was completed with particular reference to the identified risk themes,
- Develop conurbation scale assessment methodologies - Datasets from the GM inventory and from BETWIXT and BESEECH were used as the basis for assessing hazard, exposure, vulnerability and risk. For example, vulnerability assessments were made in relation to building density (as an indicator of aggregate damage) and human vulnerability (in relation to heat stress risk). Work was also carried out with stakeholders to establish an appropriate mapping methodology, considering for example, preferred metrics to use for the expression of patterns of vulnerability. TO this end, one of the National Steering Group meetings discussed the relative merits of using indicators associated with mean densities of vulnerable groups within each UMT unit or relative proportions (%) of vulnerable groups in each UMT unit.
- Develop development constraints map through a comparison of vulnerability maps and development plans for Greater Manchester at appropriate scales and for appropriate morphology and exposure units - This part of the analysis was carried out in relation to human health impacts, written up in Lindley et al (accepted).
- Produce maps and analytical work in support of 'toolkit' of adaptation strategies for Greater Manchester – the procedures produced in WP2 are appropriate for the development of a toolkit for Greater Manchester as well as for wider application to UK towns and cities

Theory and Methodology

The ASCCUE overarching methodology is shown in Figure 1. The main focus of WP2 was on components of risk identification and spatial risk assessment. The literature review and stakeholder workshop helped to identify appropriate themes for the analysis (Table 1). The specific methodology for the spatial risk assessment is given in Figure 2 using the example of heat stress (which is explained as a worked example in more detail in Lindley et al 2006). WP2 also involved research which aimed to compile a historic review of climate related events and their consequences within Greater Manchester as a means of verifying the results of the baseline risk assessment. However, it was found that records on such events were not collected in sufficient detail and using a sufficiently standard reporting format to enable their use for verification tasks.

The GIS-based risk screening methodology is shown in Figure 2 is discussed with a case study example in Lindley et al (2006) and Lindley et al (accepted). It is built up from individual layers representing different elements of the risk assessment process including: hazard layers; elements at risk layers; exposure layers, vulnerability layers and a layer representing the urban system itself.

- Hazard layers show the combination of the geographical extent of a particular hazard (e.g. areas susceptible to flooding) and its likelihood (e.g. flood areas associated with a 1/100 years event) and/or severity (e,g, average August maximum temperatures). Hazard layers used quantitative (and ideally probabilistic) data wherever possible, supplemented with qualitative data where necessary. Layers were based on a range of expert data sources such as the Environment Agency and the British Geological Survey. Where precise probabilities were not known a likelihood table has been suggested to be a suitable alternative basis for classifying the likelihood of hazards occurring (New Zealand Climate Change Office (2004).
- Elements at risk layers show the spatial distribution of the entities that may be harmed by a particular set of hazardous events. Here, emphasis was given to human receptors (represented by the population Census); buildings and greenspace parcels (generated from land use data). The latter were drawn from the representation of the urban system.
- The urban system layer was represented by geographical units classified into a set of urban morphology types (UMTs), accounting for the people, infrastructure, and vegetation associated with the urban system of the city. The units were delineated from digital orthorectified aerial photography using land cover interpretation techniques. Most of the work was carried out using photographs surveyed in 1997 but this was supplemented with data from 2001 for areas known to have undergone considerable re-development since the initial survey year. Units were classified based on a pre-defined nomenclature of urban morphology. This was based on a classification scheme, which was originally developed for characterising the urban environment prior to estimating the density of the urban tree population (Land Use Consultants, 1993; Handley et al, 2000). The final scheme consisted of 13 main categories and 29 subcategories, with the classification compatible with the UK National Land Use Database (NLUD, 2005). To authenticate the mapping of the Greater Manchester area, a map of each district of the conurbation was sent for each local authority to verify. The UMT units were further checked against the Derelict, Underused and Neglected (DUN) survey (TEP, 2004), various other data layers (such as the OS

1:50000 colour raster product), with local contextual knowledge used to complete the verification process. This dataset is now being used by Manchester city council for emergency planning purposes in relation to the UK Civil Contingencies Act and has been licensed to a number of other GM authorities (see urban greenspace summary for more information on the UMT unit map and an illustration of the pattern of UMT units in Greater Manchester).

- Vulnerability layers use the spatial framework of the urban system to map the degree of susceptibility of the elements at risk to injury or damage from a particular hazard of interest, in a particular location. A set of vulnerability tables were generated to assess the degree of damage to be expected for different receptor groups if they were to be exposed to a particular hazard. Again this can be rather difficult to quantify – for the ASCCUE project reference was made to a qualitative basis for vulnerability used by the New Zealand Climate Change Office (2004) and Willows & Connell (2004). It is also important to note that there was a vulnerability layer for each hazard of interest, as the level of vulnerability of different parts of the urban system is hazard specific i.e. buildings that are vulnerable to flooding may not be equally vulnerable to other climate-related hazards. Vulnerability layers covered the entire conurbation since vulnerability of elements at risk is independent of actual exposure.
- Exposure layers were used to determine which urban morphology units, and therefore which elements at risk, were actually exposed to a particular hazard of interest. Where available from the hazard layer, the exposure layer was also used to record exposure to different levels of severity of hazard and/or different levels of hazard likelihood.

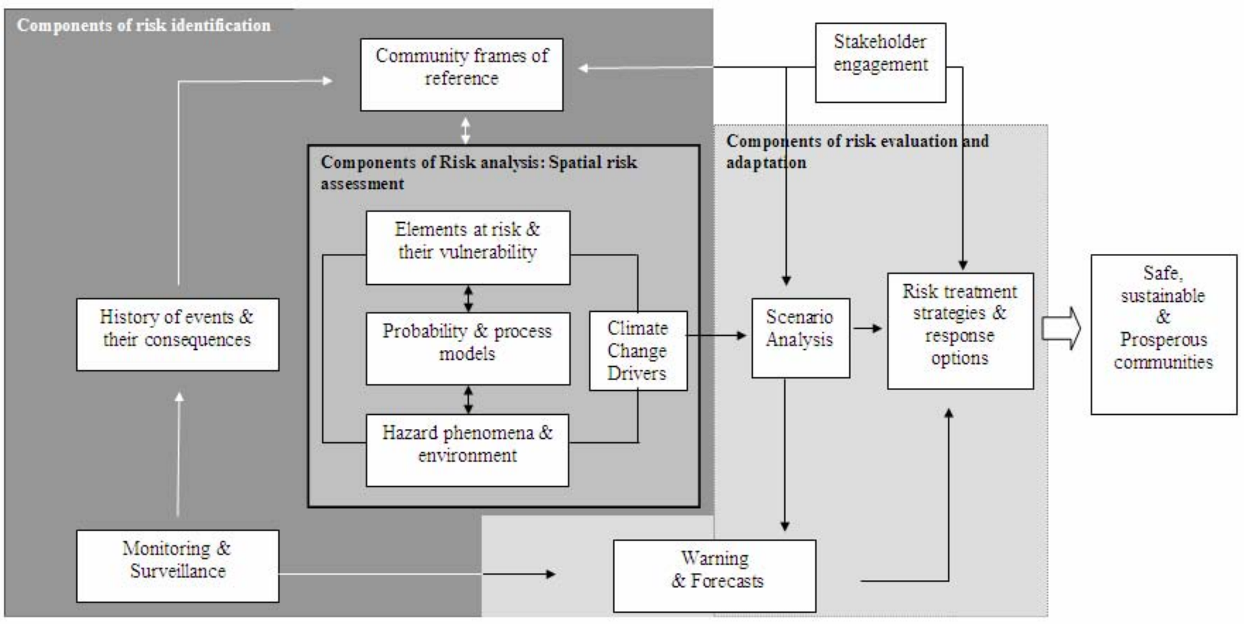


Figure 1: Overarching methodology (after Grainger 2001)

Exposure unit	**Hazard**	**Elements at risk and associated vulnerability**
Built environment	Flooding, geohazards (including running sands, landslides, shrink-swell clays).	Density of the built environment, key infrastructure and services.
Urban greenspace	Drought (available water content), runoff, temperature.	Key greenspace infrastructure such as parks & gardens, density of urban trees.
Human comfort[1]	Temperature (day & night maximums), precipitation.	Receptive environments such as those associated shoppers & commuters.
Human Health[2]	Temperature (day & night maximums).	Population density and characteristics.

Notes:

1. Not specifically expressed as risk themes for this exposure unit group
2. Only considered at the conurbation scale

Table 1: Indicative risk themes included in the ASCCUE project.

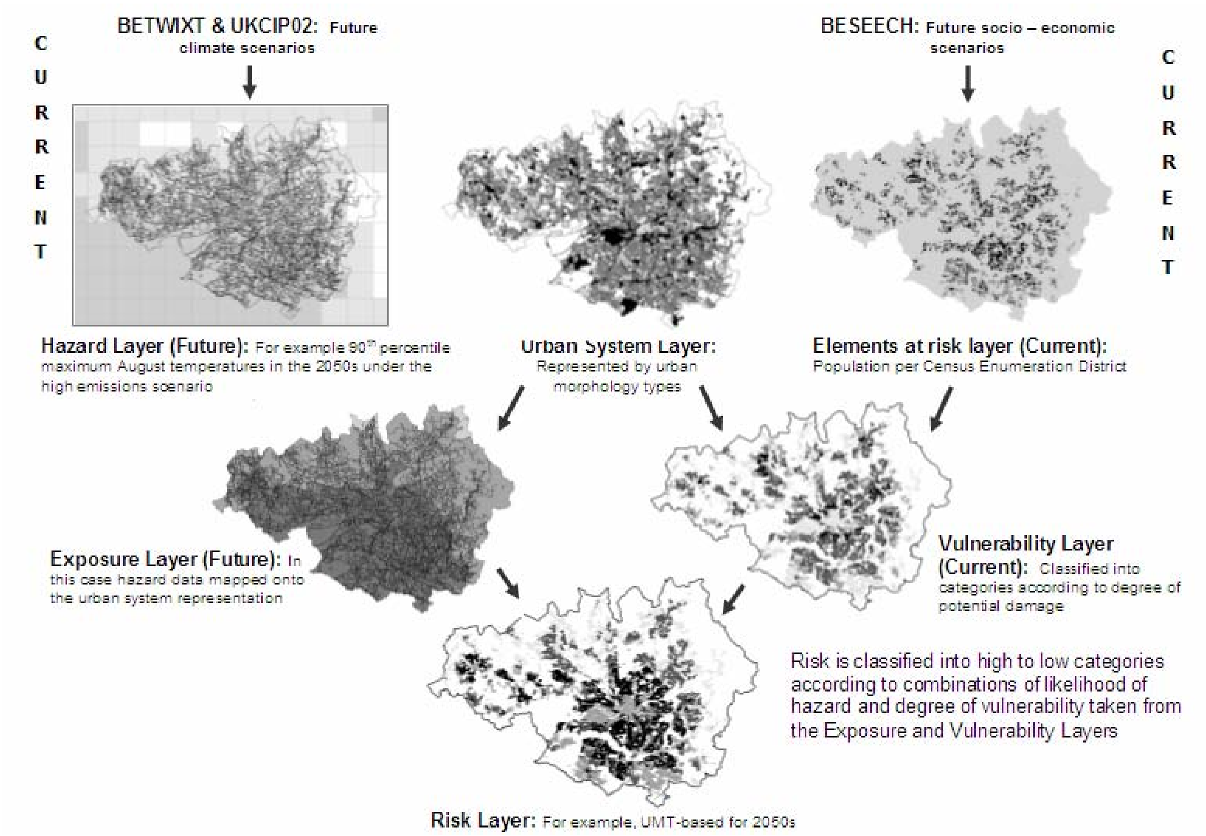


Figure 2: The conurbation scale spatial risk assessment methodology (using the example of heat stress risk).

In general terms, the final risk layer can be considered to identify degree of risk across the conurbation as a function of hazard likelihood and/or severity for exposed UMT units (from the exposure layer) and the estimated degree of vulnerability exhibited by elements at risk within that exposed UMT unit (from the vulnerability layer). A set of risk tables were generated to express these relationships according to different risk categories (such as high, med high, med low and low risk)

The heat stress risk assessment, for example, used data from BETWIXT and BESEECH. BETWIXT (Ringway) and UKCIP02 5km grid data were used as the basis for estimating conurbation scale hazards and resultant patterns of exposure as part of its broader conurbation scale risk assessment methodology. For Greater Manchester as a whole, BETWIXT output was used to calculate the relative proportion of 'hot' days (maximum temperature greater than 30 degrees C) and 'warm nights' (minimum temperature greater than 15 degrees C) under current and projected future scenarios. BETWIXT data were also used to calculate the 90th percentile July and August temperatures for the different UKCIP02 scenarios. Since 90th percentile temperatures were only available for Ringway, the difference between the 90th percentiles and the monthly average maximum temperatures for the UKCIP02 5 x 5 km Ringway grid cell was used as the basis for estimating 90th percentile temperatures in the rest of the conurbation.

The risk assessment methodology analysis also draws on the socio-economic scenarios developed by BESEECH: world markets; global responsibility; national enterprise; and local stewardship. BESEECH data was used as the basis for projections of UMT level data in Greater Manchester to explore trends in vulnerability associated with each of the four scenarios. The specific variables used to represent current and future vulnerability were: number of over 75s; children under 4 and social deprivation indices. Collective vulnerability was also considered. Two scenarios (World Markets and Local Stewardship) have also been used as the basis for developing a set of complementary ‘spatial storylines’. These are designed to explore spatial changes in urban areas, associated with people, buildings other infrastructure etc. that are internally consistent with the qualitative scenarios developed in BESEECH. This was achieved through modification of the current day UMT map.

WP2 was also stronger linked with the other work packages, especially those relating to exposure units. Furthermore, some of the methods were applied to Lewes that had been developed in relation to Greater Manchester (see Gwilliam et al, 2006. WP2 also ran LAG meetings and held a dedicated workshop into the provisional risk assessment methodology. The LAG also supplied many of the initial input layers for the characterisation of the conurbation. The NSG provided comments on the risk assessment work and also helped to determine appropriate metric and mapping categories for representing vulnerable populations in the final risk maps.

Key research outputs

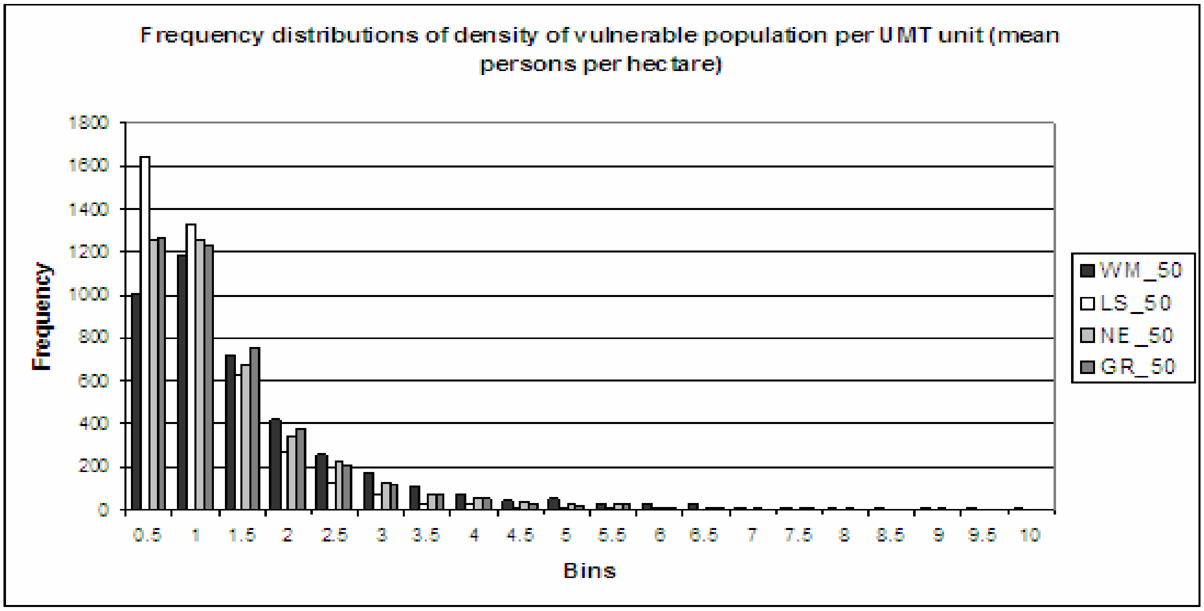
WP2 produced the following research outputs:

- Overarching framework for the ASCCUE project
- A methodology for conurbation scale risk assessment to act as a screening process for policy makers

- A dataset showing patterns of urban land uses in Greater Manchester and their change 1997 to 2004 (nominally 2004).
- Indicative results from the application of the conurbation scale screening risk assessment in relation identified themes from the literature and taking account of stakeholder views (Theuray et al 2005). These were used to generate example outputs which enabled patterns of risk to be assessed for:
- Current day risk of flooding to the built infrastructure;
- Current day risk of various geohazards to the built infrastructure;
- Extreme temperatures in receptive environments for human comfort work taking account of baseline conditions and climate scenarios for the 2020s, 2050s and 2080s; and
- Human health risk from heat related events taking account of baseline conditions and climate scenarios for the 2020s, 2050s and 2080s, together with an assessment of changes to patterns of vulnerability associated with the BESEECH socio-economic storylines and current development plans for Greater Manchester (see Lindley et al accepted). The assessment of changes to human health risks also involved the creation of 'spatial storylines' to identify potential changes to the built fabric of the conurbation in response to different socio-economic scenarios. For example, under World Markets elderly populations are likely to live in similar areas as they do at present whereas under Local Stewardship they are likely to be more concentrated around decentralised local service areas, suggesting that vulnerability might be easier to manage under Local Stewardship. It is also useful to consider the relative densities of vulnerable populations under the various scenarios in the 2050s (Figure 3). Here, it is suggested that the World Markets scenario may be associated with the highest average densities of people vulnerable to heat stress and that vulnerable people may be more widely distributed than under some of the other scenarios. Local stewardship, on the other hand, has a larger proportion of UMT units with low densities of vulnerable populations, which may be due in part to lower aggregate population densities. Analysis and interpretation of these results is ongoing. Other results can be generated from the risk assessment outputs such as estimated changes to the proportions of built compared to natural surface cover under the different socio-economic scenarios. In turn this can help to contextualise findings from the detailed exposure unit work packages, such as urban greenspace.
- Development of a conceptual framework for considering adaptation responses (see Figure 4)

- Development of a conurbation scale adaptation option using housing renewal areas and health risk assessments (a full discussion is given in Lindley et al accepted).

Some of the implications of the findings from the socio-economic work relate to human comfort and human health adaptation strategies, planning responses (see Lindley et al, accepted) and greenspace planning. The conurbation scale work has fed into conurbation and neighbourhood scale analyses of building flood risk in Lewes (Gwilliam et al 2006 – this paper also provides a methodology for the linkage of conurbation scale and neighbourhood scale risk assessment based on flooding).



	WM_2050s	LS_2050s	NE_2050s	GR_2050s
Min	0.00	0.00	0.00	0.00
Max	9.83	9.62	9.95	9.63
Mean	1.38	0.85	1.16	1.10

Figure 3: Estimated density of vulnerable populations in the 2050s under World Markets, Local Stewardship, Global Responsibility and National Enterprise (mean persons per hectare per UMT unit).

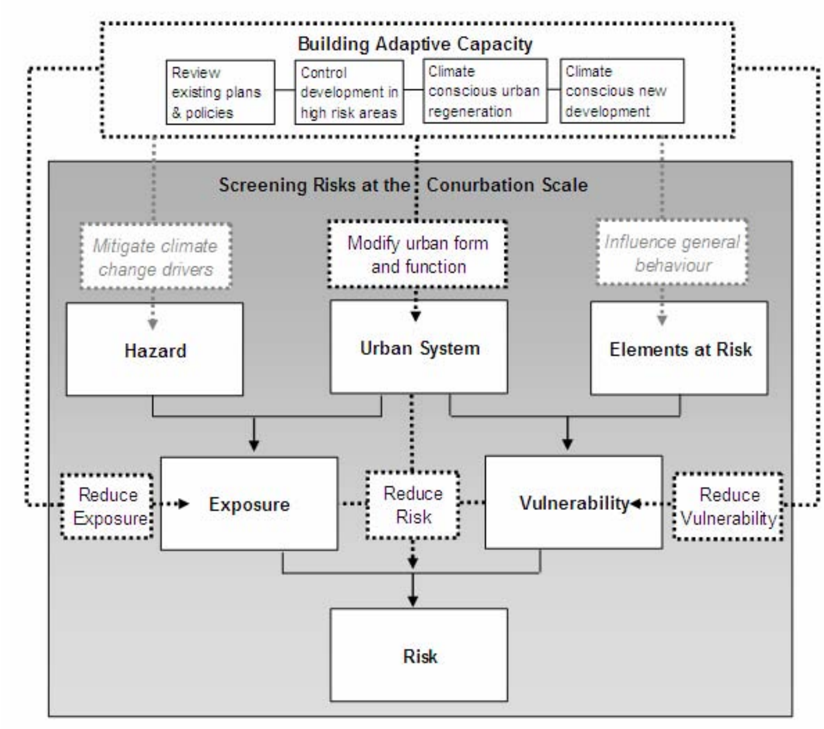


Figure 4 *Relationship of land-use planning mechanisms for building adaptive capacity with components of screening risk assessment methodology (black dashed lines show direct relationships and grey dashed lines show indirect relationships).*

Although WP2 has produced a number of useful research outputs and associated findings. There are also some inevitable limitations from the research undertaken to date. Some of the most important limitations, together with associated recommendations, are given below:

- There has been no means of assessing accuracy of the conurbation risk assessment work. This is largely due to a lack of consistent data on past climate-related hazard events. It is recommended that standardised procedures are developed in order to record climate or potentially climate-related events;
- Not all of the data collated through WP2 were appropriate for analysis at the conurbation scale due to practical or time constraints. Further work could be carried out at the neighbourhood scale to verify initial findings and/or provide neighbourhood scale risk assessments;
- The spatial dimensions of extreme events and socio-economic change difficult to ascertain. Integration of process modelling with conurbation scale risk assessment may help to overcome some of the uncertainties and add further detail to the screening methodologies developed in WP2; and

- The analysis of human health risk from heat related events was not able to take account of changes to the Urban Heat Island. This will be partly addressed through a new EPRSC project due to begin in Feb 2007.

Other recommendations for future research include:

- Further investigation of verification procedures;
- Expansion of the number of risk themes; and
- Development of decision-support tools (either as planning support systems and/or through using a public participatory approach).

Implications for policy and practice

The conurbation scale screening risk assessment methodology is suitable as the basis for a spatial risk assessment screening methodology for UK urban areas. It allows the following tasks to be performed (from Lindley et al 2006):

- Identification of areas of potentially high risk where future development should be avoided without additional investigative work.
- Prioritisation of areas for further investigative study.
- Identification of areas where adaptation strategies may be most urgently required.

Figure 4 identifies the various ways in which risk can be managed through the improvement of adaptive capacity (e.g. by controlling development in high risk areas and making new developments more climate conscious). In turn, these measures allow elements of the risk generation process, such as exposure, vulnerability or the urban system to be modified. Potential adaptation strategies for human health risk are discussed in Lindley et al (accepted), drawing on an assessment of estimated spatial patterns of vulnerability compared with the locations of development areas in Greater Manchester. Findings of WP2 have also fed into adaptation strategies developed in each of the exposure unit work packages.

References

Granger K. (2001) “Geohazards risk to urban communities in Australia”, CCOP technical bulletin Volume 30, *Australian Geological survey organisation*, p 165-174.

Gwilliam, J Fedeski, M Lindley, S Theuray N and Handley J (2006) Methods for assessing risk from climate hazards in urban areas Municipal Engineer 2006, 159, No. 4, 185-191

McEvoy D., Lindley S. and Handley J. (2006) Adaptation and mitigation in urban areas: synergies and conflicts. Proceedings of the Institution of Civil Engineers, Municipal Engineer, 59, No. 4, 185-191.

Lindley, S. J., J. F. Handley, D. McEvoy, E. Peet and N. Theuray (accepted subject to reviewers comments) Conurbation scale risk assessment and its implications for the development of climate conscious land-use planning in the UK. Journal of Built Environment

Lindley, S. J., Handley, J. F, Theuray, N., Peet, E. and McEvoy (2006) Adaptation Strategies for Climate Change in the Urban Environment - assessing climate change related risk in UK urban areas Journal of Risk Research Vol 9 No 5 pp. 543-568

Willows. R.I. and Connell, R.K. (eds.). (2003). *Climate adaptation: Risk, Uncertainty and decision-making*. UKCIP technical report. UKCIP, Oxford.

Work Package 3 Summary: Integrity of the Built Environment

Context

WP3 was interested in the impact of climate change on the integrity of the city's built fabric. Adaptation to such change is partly the responsibility of individual building owners, but there is a need for foresight at a larger scale from local government planners, developers and stakeholders in the insurance industry. WP3 has developed mapping and analysis methods to assist them in assessing the change in risk to the building fabric. These take the form of a general methodological framework, although an instantiation developed in greater detail concerns potential changes in the hydrodynamic regime:

- the direct effects of flooding
- the indirect effects of changes in the hydrodynamic regime on soil and geological conditions.

To keep the research manageable, buildings were selected from the many structures and types of place to be found in a city, and their fabric was studied without regard to their fittings and contents. There were too many unknowns associated with the construction of the transport infrastructure to make it a feasible subject for this research. In order to differentiate between measures to be taken in different parts of a city, planning for adaptation has to take into account the distribution in the built environment of building vulnerability. Literature review emphasised the importance of vulnerability but also revealed its absence from large-scale consideration of building damage.

Climate change will affect coastal and fluvial flood through changes in sea level, storm incidence and rainfall intensity. The frequency of hazardous conditions due to landslides, shrinkable clays, dissolution, and collapsible and compressible deposits are all influenced by moisture content and as a result are likely to be influenced by changes in the hydrological regime described within current climate change scenarios.

Aims and objectives

WP3 aimed to develop a new approach to assessing at a neighbourhood scale the change in risk from natural hazards caused by climate change. To be of most use to adaptation policy, a methodology is needed that can integrate the several hazards influenced by climate change into a single measure of risk. The methodology would accept input about anticipated climate change and its effect on the hazards in question, and would deliver information on risk from which others would make decisions about adaptive measures that should be taken. The research aimed to develop a framework for the methodology such that it could be tested in principle using data relating to flood and geological hazard from Lewes.

The objectives set by WP3, in order of increasing speculation, were:

- to develop a practical methodological framework for assessing the risk to building integrity presented by natural hazards, using flood and geological hazards as test cases;
- to introduce the characteristic of building vulnerability into the methodology;
- to limit the input data needed for assessment to that which already exists or can be observed non-invasively;
- to point the way to further development of the methodology so that the scale at which assessment is conducted can be increased from individual buildings to larger sectors.

Theory and Methodology

In this research, risk is expressed in terms of the cost of damage over a period. A starting point for the research was a method due to Blong[2] of evaluating historical damage to any type of building caused by any hazard. It measures damage as the cost of reinstatement:

Damage = Replacement Ratio (RR) x Damage Value (DV)

where RR is a measure of the value of the building in multiples of the value of an average family house (measured in "house equivalents") and DV is the fraction of the building cost lost in the hazardous event, measured from 0 (no damage, full resilience) to 1 (total collapse, complete vulnerability). Through review of existing studies of damage caused by natural hazards, Blong has produced five "damage classes", light, moderate, heavy, severe, and collapse, each with a range of damage values as well as a "central damage value" to be used in the above formula. This methodology is a simple and clear approach to damage estimation allowing damage due to several hazards to be compared and summed.

[2] Blong, R., 2003. A new damage index. Natural Hazards, 20:1-23. 2003. Kluwer Academic Publishers.

An overarching framework shared by the ASCCUE work packages was the definition of risk as a function of three elements[3] (the risk function):

Risk (R)= f { Exposure, Hazard, Vulnerability }

where: **Risk** is the periodic cost of damage caused by the hazard being considered; **Exposure** is the extent and value of land or buildings that would be affected were the hazard to occur; **Hazard** is the extent, severity and probability of the hazard; and **Vulnerability** is the susceptibility of the land or buildings to the hazard. The presence of vulnerability in this function is of particular significance for WP3.

By re-interpreting RR and DV in the light of this definition of risk, Blong's measure could be redefined to include vulnerability. As RR is the value of the building at risk, it was interpreted as a measure of exposure. As DV is the proportion of the building damaged by the hazard, it could be interpreted for any particular hazard in the following "damage function":

Damage Value = f { Hazard severity, Building vulnerability }

Through the assessment of Exposure, Hazard, and Vulnerability and their application within this function the damage likely to individual buildings can be assessed in terms of periodic reinstatement cost, measured in housing equivalents. Through addition of these values damage estimation can then be achieved for larger sectors such as postcodes, towns or flood catchment areas and WP2's UMU (Urban Morphology Units). A more complete explanation of this process is given in Fedeski & Gwilliam[4].

This methodology was developed to enable neighbourhood scale risk assessment through a focus on individual building vulnerability. It considers each factor of the risk function independently, and combines them in a GIS-based overlay process. Stages in this methodology for a single hazard are summarised below.

i: Exposure Assessment: Secondary data is analysed to identify buildings likely to be affected by the hazard and estimate their value. GIS layers representing the distribution of built form and the extent of the hazard are overlaid to establish where spatial coincidence occurs (the study population). The value of buildings in the study population is assessed from ground floor areas given by the Ordnance Survey's "Mastermap", information on building

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[3] Crichton D., The Implications of Climate Change for the Insurance Industry – An Update and Outlook to 2020, BRE, Watford, 2001

[4] Fedeski M. H., and Gwilliam J. A., Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology, Planning and Landscape J., Submitted 2006

types and numbers of storeys collected during the vulnerability survey described below, and average building costs derived from Spon[5]. From these, Replacement Ratios for each property are calculated by dividing by an average house cost.

ii. Hazard Assessment: Employing the GIS hazard datasets, the event projected for each building is placed into a class of severity, to which a "Severity Index" has been allocated. Classes of hazard severity and corresponding indexes have been established as a tool for flood and geohazard assessment.

iii: Vulnerability Assessment: The vulnerability of each building in the population is established by a survey of "vulnerability factors" using both visual inspection in the field and a study of secondary data, and their combination in a singular measure of the building's vulnerability to the hazard, the "Vulnerability Index". The factors that can be recorded in the field are limited to those visible from the public realm, ensuring an appropriately rapid and non-intrusive data collection process. A set of factors that influence vulnerability to flood and geological hazards has been established and a tool has been developed to combine them into a single Vulnerability Index from a look-up table. The Index is dimensionless and varies from 0, indicating resilience to hazard, through to 1, indicating greatest vulnerability to the hazard. A separate tool has to be developed for each new type of hazard considered, and the method tested uses an Analytical Hierarchy Process developed by Saaty[6], which is a well-established decision-making procedure.

iv. Risk Assessment: A Damage Value is established from the Severity and Vulnerability Indexes. This requires a further tool in the form of a look-up table or a damage function, which has to be developed for each type of hazard either from historical data or by expert judgement. Some simple proxy functions were used to demonstrate and test the method. The risk, which is the periodic cost of damage expected from the hazard, is then assessed by multiplying the Replacement Ratio and the Damage Value as already explained. The cost of damage to a neighbourhood, or to a UMU from WP2, is simply the arithmetic sum of the damage to its constituent buildings. The resulting risks can then be mapped using the periodic damage costs.

Validation: Applying the methodology in Lewes tested the practicality of gathering the data necessary for its execution and the feasibility of establishing a useable Vulnerability Index.

[5] Spon, Spon's architects' and builders' price book, London, 2000, Spon.
[6] Dai, F.C., Lee, C.F., Zhang, X.H., GIS based geo-environmental evaluation for urban land-use planning: a case study. *Engineering Geology,* 2001, 61, 257 – 271

There are existing methods of estimating building by building the cost of flood damage for a given depth of flood, which could be used as comparators. The results for the damage costs of all buildings and of all UMUs in the study area as assessed by the various methods were compared. Results from the new methodology for flood hazard, using two proxy damage functions, were found to correlate highly with results obtained using these existing methods at UMU scale. There was disagreement between the existing methods about the total cost of the damage. The assessment of the total using the new methodology was nevertheless in the same range. This outcome gave confidence in the methodology.

WP3 has a number of links with other ASCCUE work packages. In consultation with WP1 the potential impact of climate change on the flood hazard was explored. The UMUs developed by WP2 for Lewes have formed the basis for the neighbourhood scale risk assessment process of Lewes. Work in collaboration with WP2 on the interaction between the conurbation and neighbourhood scale risk assessment methodologies has been published[7]. Other potential areas of collaboration could not be exploited. Results from WP1 models of flood risk at Lewes could not be available until the end of the project. Interaction between planting in greenspace and geologically based hazards was considered in collaboration with WP5, but further data collection was needed to pursue it.

WP3 has established potential links with two other BKCC projects:

Engineering Historic Futures: As flooding is a significant area of concern for historic building, future joint projects have been discussed on the subjects of remedial action and socio-economic adaptation.

Bionics: Incorporation of findings from the Bionics project has been discussed should the transport infrastructure be included in future developments of the WP3 methodology.

Engagement was undertaken in Lewes with the East Sussex Highways, Lewes District Council: Planning Department and Network Rail. This was undertaken individually as no formal stakeholder group was set up for the Lewes case study due to the sensitivity of the local population at the time to the issue of flooding. Consultation has also been undertaken

[7] Gwilliam, J., Fedeski, M., Theuray, N., Lindley, S., and Handley, J., (2006). Methods for assessing risk from climate hazards in urban areas. Municipal Engineer, Forthcoming.

with the BGS in relation to geological hazards, as mapped within their GeoHazard Dataset and their application within WP3's work.

Key research findings

The methodological framework proposed here uses GIS to estimate the combined risk to buildings from several natural hazards. It would be able to evaluate the risk of damage under current conditions as well as potential changes in risk in the light of climate change. It employs non-invasive survey techniques, and it allows city sectors to be differentiated according to their vulnerability. Furthermore, the framework of this methodology has been developed sufficiently for it to be tested in principle using flood and geohazard in Lewes as examples. The success of the tests justifies further work in the future to develop the quantitative relationship between hazard and damage to the point where it could be used for prediction.

This work has been directed towards estimating the potential overall cost of climate change due to a number of hazards. The procedure in outline would be to estimate the total cost of damage due to combined hazards occurring at their present rate, to repeat the estimation for a revised rate following climate change, and to take the difference between them. This is the cost if there were no adaptation. The main application of the methodology is in the assessment and evaluation of adaptive strategies: the benefit of proposed strategies would be estimated in a similar way and compared with the cost of making them.

WP2's conurbation scale methodology and WP3's neighbourhood risk assessment methodology present planners with a phased approach to decision-making. The former enables planners to decide on the priority to be given to different places within an overall plan for the future of the city. The latter enables them to focus attention on individual neighbourhoods and gives more assistance in deciding what action should be taken with respect to current property. This combination provides a firmer foundation for the development of appropriate adaptation strategies, the ultimate aim of the project as a whole.

The research has undertaken proof of concept. To supply a functioning tool that can be applied in cities to estimate risk, it has to be taken to the next stage of developing the appropriate damage functions. A drawback in this respect, although not insurmountable, is the lack of data on historical damage that includes information on building vulnerability, from which these functions can be drawn.

In its present state, the methodology requires considerable fieldwork to establish a local database on vulnerability, and this would discourage its adoption by city authorities. To overcome this drawback, it is anticipated that a reduced survey procedure could be developed in future research, which relies less on primary data. However, dependence on secondary hazard and exposure data carries the disadvantage that the accuracy of the risk assessments is constrained by their availability, validity and reliability. With commercial data, the process by which it has been created can be commercially sensitive and therefore unavailable for analysis or scrutiny, as is the case with the BGS Geohazard dataset. Nevertheless, the work on geohazards demonstrated how progress could be made in dealing with limited information by drawing on the literature and expert judgement, in this case to judge the severity and probability of mapped geohazards, and to create a tool for measuring a Vulnerability Index.

Assessment of future hydrodynamic risk is limited by the accuracy of future climate change scenarios, and at present predictions of future rainfall intensity are very uncertain. Building fabric is damaged not only by contact with flood water, but also through the movement of water and floating debris. Current estimations of flood risk refer to water levels but not water flow.

Recommendations from WP3 are for further work on:

- collection and analysis of historical data from, for example, insurance claims and on building damage in response to hazard, especially in the area of geological risk;
- estimating the cost of damage in response to hazards by analysis of the damage and the remediation processes;
- implementation of expert judgement to establish further vulnerability indexes and damage functions;
- the scope for remote assessment of building vulnerability;
- associating vulnerability with building types that can be identified at neighbourhood scale;
- incorporating other parts of the urban infrastructure, such as roads, railways, bridges, paving, street furniture, planting, and services into the vulnerability methodology;
- taking into account socio-economic impacts, especially those associated with changes to the future development regime.

Implications for policy and practice

The WP3 methodology may influence urban development policy. For example, its availability may help to create wider control on development of land exposed to geological and flood hazards. Results from its application in particular cities to the assessment of their adaptation strategies in the face of flood and geological hazards may generate more general guidelines.

The methodology will assist urban planners in identifying areas currently at high risk and in implementing appropriate controls in relation to both new and existing buildings and development. For example it could be used to inform the development of supplementary planning guidance. It could also help strengthen control over further development of sites where hazards are present, thus minimising risk and, perhaps through the removal of certain permitted development rights in the presence of hazards, removing the potential for increased risk to occupiers in the presence of hazard. The method could expand on the application of EA flood mapping already in use.

Through consultation with stakeholders it was perceived that the value of the information derived from the methodology would rise as climate change begins to climb the political agenda. Its principal application is for identifying appropriate adaptation to change through the assessment and evaluation of alternative strategies. The general cost-benefit procedure has already been outlined. Such a methodology could be applied to plans for adapting the existing building stock as well as strategic planning for future development.

The separate mapping of exposure, hazard, and vulnerability factors clarifies the assessment. For example, the influence of flood defences will be seen on the hazard layer, future building proposals on the exposure layer, and improvements in the resilience of buildings on the vulnerability layer. The databases built in developing the tools, particularly the GIS database on the vulnerability of city structures to natural hazards, will be valuable resources for planners. It should be realised, however, that the methodology is not designed to yield reliable information on the risk to individual buildings, as the figures collected at this scale have to be aggregated to even out inaccuracies due to the use of averages.

Adoption of the methodology involves separating the concepts of exposure, hazard, and vulnerability and implementing techniques for mapping them as separate layers. This way of thinking should assist urban designers as they plan for the balance between these elements needed for a future in which the risk of flood, geological, and other natural hazards has increased significantly in cities because of climate change. The most straightforward strategy is to separate exposure from the hazard (build outside the flood plain), but a more realistic approach will involve adapting vulnerability to the level of hazard.

Consultation with stakeholder groups shows that the WP3 methodology, particularly its techniques for assessing vulnerability, is likely to have application in the insurance industry. The GIS-based hazard information is likely to find direct application in building control, especially in relation to specific known local hazards. Finally locally householders and building professionals are likely to be interested in learning about appropriate adaptation in the light of existing and future hazards, perhaps through the production of locally appropriate advice sheets.

Work Package 4 Summary: External Human Thermal Comfort

Context

The provision and use of open space, both public and private, is an important element in the way in which urban areas and urban populations respond to climate change. The raft of policies to promote the regeneration and renaissance of urban areas, to revive public open space, and to promote the "safer, cleaner, greener" agenda, all need to consider the capacity to adapt to unavoidable and projected climate change.

There is already evidence (from organisations such as National Trust and RHS) that people's use of open space is changing in response to climatic change, especially warmer springs and autumns. However, while there is much research on people's levels of comfort in internal spaces, there is less understanding of people's experience of outdoor spaces, particularly within urban areas. It is likely that, with warmer average temperatures and higher extreme temperatures, people's need for, use of, and experience of open space will change.

Socio-economic drivers are as important as climatic conditions in influencing behaviour, and it is important that the research considers the different needs of users of open space, and possible changes in the factors affecting the provision of such space over the coming century.

This Work Package therefore seeks to bring together some of the work on thermal comfort and the sociology of comfort, and the UKCIP02 climate change and socio-economic scenarios, in order to make recommendations for the planning and design of open space in 21st century.

Aims and objectives

WP4 aimed to explore the implications of climate change for the use of urban open space taking account of socio-economic change, at conurbation and site-scale; and to assess the opportunities for increasing adaptive capacity.

Its objectives were to:

- undertake meteorological measurements (air temperature, wind speed etc) and comfort surveys (comfort votes and preferences) amongst users of selected open spaces in different seasons
- assess the findings in the light of UKCIP02 climate change scenarios and socio-economic scenarios
- compare the findings with the results of similar European studies
- assess the options for promoting adaptive opportunities in external environments
- draw out the implications for spatial planning and urban policy

Theory and Methodology

WP4 draws on three distinct theories. Although human thermal comfort has been the subject of scientific study since early C20, previous research concentrated on indoor thermal comfort (such as in determining standards for building occupancy). However, field studies both indoors (Humphreys and Nicol 1998, deDear and Brager 2002) and out (Hoppe, 2002; Nikolopoulou & Steemers, 2003; Nikolopoulou & Lykoudis, 2006) have shown that the behavioural response to any environment has a major impact on comfort. Outdoor environments differ from indoors (there is less human control; the climatic conditions vary more; there is greater diversity of space and use (for instance, for leisure, work, circulation, break from work etc); previous experience of space may differ), yet the level of discomfort actually measured in outdoor spaces is much smaller than that predicted by the standard index designed for indoor spaces. This suggests that people may be more tolerant of outdoor conditions and that the key to comfort in outdoor spaces is the adaptive opportunity afforded by those spaces to the people in them, allowing them to choose among the local micro-climates to suit themselves.

This perspective on adaptive capacity is reinforced by theories in the sociology of comfort (Chappell and Shove, 2005) which suggest that “comfort” is a socio-cultural construct, and that in the indoor environment there is concern that, under conditions of climate change, we might experience loss of adaptive capacity through “lock-in” to technical trajectories such as the promotion and increased use of mechanical air-conditioning.

A third underpinning theory is that explaining the UHI effect (Mayor of London, 2006) which suggests that higher temperatures expected under climate change may be exacerbated in urban areas which can already experience temperatures up to 9ºC higher than the surrounding countryside, with a peak in city centres at night. Part of the solution to this is the provision of planted open areas. In their analysis of the causes of excess deaths in France during the 2003 heat wave, Riberon et al (2006) found that the presence of significant vegetation within 300m of the house reduced the risk of death.

Case-studies: selection and survey 2004-2005: An initial literature review of research in thermal comfort was conducted in early 2004. Case studies were then selected. The methodology adopted was where possible consistent with the rest of the ASCCUE project: it selected broad regional areas of study to reflect the NW-SE climate gradient, and within those identified case-studies in Greater Manchester and Lewes, E. Sussex, which enabled consistency between the WPs.

Four case-study sites (three in Manchester, one in Lewes) were selected to reflect a range of design, location, features and users. WP2 mapped the UMTs in Greater Manchester, and ideally WP4 would have selected open spaces across a range of UMTs, but the constraints of time and the need to carry out the surveys at different seasons meant it focused only on city centre sites. A questionnaire was designed to establish people's perceptions of comfort using a seven-point scale and other details about the subject and his/her perception of the environment. A portable weather station was constructed to measure ground-based meteorological conditions at the time of the interviews. The survey methodology drew on that of the EU-funded RUROS (Rediscovering the Urban Realm and Open Spaces) project, which surveyed seven cities in five countries. This helped to ensure a wider application and to allow the ASCCUE results to be generalised through comparison with the RUROS database which was kindly made available to us.

Climate change scenarios: The outputs of BETWIXT and WP2 were used to generate daily weather sequences for Greater Manchester under the UKCIP02 climate change scenarios, and to display these on maps based on the UMTs. This enabled identification of those UMTs – particularly the city centre - which might experience significant increases in temperature for 2050s and 2080s. The later (2006) CRANIUM outputs (probabilistic data-sets) were also used to explore the likelihood of periods of extreme weather (such as heat waves).

Socio-economic scenarios: As important as the physical production of adaptive capacity is the social and cultural capital required to adapt to a changing climate. Climate change will occur in a possibly very different socio-economic and cultural context by the middle or end of this century, and this will affect the capacity and willingness of individuals and institutions to adapt. Socio-economic scenarios are useful in providing consistent storylines to envision a range of possible futures. WP4 made use initially of the generic BKCC BESEECH socio-economic scenarios in combination with the climate change scenarios, and later used the ASCCUE-specific BESEECH scenarios for North West and South East regions.

Assessment of design options: The findings of the survey suggested that relevant design options in the outdoor environment will include (i) adaptive opportunities in the provision of shade in the summer and wind-shelter in the winter (ii) open-space planning policy to enable the increased use of open space for recreation and provision of, for example, open-air cafes, markets etc to reflect weather-related changes in social patterns, and (iii) careful choice of plant species which are compatible with climate change scenarios. WP4 assessed such measures qualitatively, using evidence from comparable studies of the effects of altering physical design parameters, and developing the spatial storylines from BESEECH under different climate change scenarios to bring out the implications for physical and socio-cultural adaptive capacity.

Use of BKCC feeder information: WP4 made use of the BETWIXT and CRANIUM data-sets, and the BESEECH socio-economic scenarios.

Interaction with other ASCCUE WPs: Strong links were maintained with all the other work packages. One of the case-studies was in Lewes which was also the focus of WP1 on combined (fluvial, tidal and storm-surge) flood-risk, and WP3, on building integrity. The work of WP5 on urban greenspace was most relevant in identifying the multi-functional role of greenspace in evapo-transpiration to moderate temperature increases, and its rainfall-attenuation functions, and hence the need for open space to assist these functions. WP6, 7 and 8 will draw on the findings of the substantive WPs including WP4.

Linkages with other BKCC projects: In addition to those mentioned, WP4 made links with the PII project on Internal Thermal Comfort (Hacker et al, 2005), and the DEFRA Cross-Regional Adapting to Climate Change programme, especially the project on Adapting to Climate Change in the government's Sustainable Communities Growth Areas http://www2.defra.gov.uk/research/project_data/projects.asp?M=KWS&V=cross+regional&SUBMIT1=Search&SCOPE=0

Stakeholder engagement: The input of stakeholders has been an invaluable part of the research process. In addition to the stakeholders represented on the National Steering Group, regional and local stakeholders were engaged in a number of workshops organised for the whole ASCCUE project. The Lewes workshop was geared primarily at issues of flood-risk and building integrity, but was used to identify a case-study location for WP4 survey. A workshop in Greater Manchester identified human health as a major concern for stakeholders, which led to further emphasis on health in mapping risks in WP2, with obvious links to thermal comfort. A major dissemination workshop in Manchester early in 2006 provided useful input on the policy context for the urban renaissance in Manchester city centre, the current provision of public open space and the scope for enhancing adaptive capacity. Findings from WP4 about city centre issues were also fed into the stakeholder-led DEFRA-funded study Climate Change and the Visitor Economy. Finally, a valuable workshop was held jointly with the DEFRA project on Adaptation in the Growth Areas, to explore some of the findings of ASCCUE in relation to new areas of development such as the Thames Gateway. The workshop included stakeholders from the Three Regions Climate Change Partnership (SE, London and East of England), the Environment Agency, and development and policy interests in Bedford, Wood Wharf, London, and Queenborough & Rushenden (North Kent). Useful messages about the importance of London's urban heat island, and lessons from experience overseas in addressing urban over-heating, were conveyed.

Key research findings

Comfort surveys of 485 respondents were completed in summer-autumn 2004, winter 2004/05, spring 2005 and summer 2005, at different times and at different locations within the case-study sites. Climate variables of air temperature varied from a minimum of 4ºC to a maximum of 30ºC. In brief, the findings were that, as expected, people outdoors respond to season and to weather. While there is considerable adaptation to different conditions and temperatures, such as changes in clothing, in activity and in location, the adaptation is incomplete. This is in line with the findings of the Eurowinter Group, (1997). Adaptation takes time. So, in spring, people are comfortable in cooler temperatures than in the autumn when they have recent experience of summer conditions. Clothing levels are heavier in winter and help to compensate for lower temperatures. Activity changes with season and temperature; few people “sit about” below 17ºC. While comfort votes vary continuously with air temperature, the most “comfortable” air temperature (with no votes that it was much too warm or much too cool) was around 20 ºC. Access to solar radiation can be equivalent to an increase of about one vote, and exposure to wind is equivalent to a decrease in one vote. Generally, there was a desire for less air movement, except in hot, still weather. There is some suggestion that people will choose sites which will optimise access to air movement. While more people expressed a view that they were “much too uncomfortable” at temperatures above 24.5 ºC, the survey showed that at these temperatures more people choose to sit in the shade. They also expressed a preference for “more greenery”, although this varied with location.

The conclusion is, as with the RUROS results, that people feel comfortable across a wide range of outdoor conditions. It was expected that people’s sense of personal choice would play a role in their experience of comfort, and that different responses might be received from, for instance, outdoor workers such as market traders or those who had to wear a uniform such as street wardens. However, although a good number of outdoor workers was interviewed, the survey did not find a noticeable difference in their comfort votes. It did find that people in the oldest age band (>50years) were significantly warmer at temperatures below about 15 ºC, which appears to be explained by their wearing significantly heavier clothing in winter. There were no significant differences between those who described themselves as familiar with the British weather, and those who did not, nor between genders.

Climate change will bring significantly higher temperatures. For instance, the maximum mean surface temperature in Manchester city centre is currently 31.2 ºC. Using the BETWIXT data, WP5 estimates that this might increase to 33.2 ºC by the 2080s for the Low emissions scenario, and to 33.5 ºC for the High emissions scenario. Findings from WP2, which mapped the risk to sensitive receptors in summer for the High emissions scenario up to 2080s, showed that city centre populations might be particularly exposed to these higher temperatures. Moreover, the CRANIUM study has provided probabilistic scenarios which show that even under a Medium-high scenario for Ringway (Manchester Airport), the number of hot days (ie days with maximum temperatures greater than 24.3 ºC) in summer will increase from around 5 days in the reference period of 1961-1990 to about 45 days in the 2080s. The cumulative probability of an increase of up to 50 days in hot summers is 80%. Similarly, the number of warm summer nights might increase from 7 to 44. In Lewes in the south east region, even higher temperature increases are expected.

Under these conditions, it is expected that the demand for open space will increase for a number of reasons: to enjoy the warmer conditions over a longer season (with warmer springs and autumns) and a longer day into evening (with more moves towards a 24-hour city); to have access to open air, wind and shade from uncomfortably hot, poorly ventilated offices, shops and public buildings during the day, or from over-cooled buildings; and to have access to the open-air for cooling from uncomfortably warm, naturally-ventilated residential properties in the evening or at night.

It is essential that we give consideration to the provision of adaptive capacity to enable people to adapt to these different conditions. Adaptation can be planned or spontaneous, but the planning, design and maintenance of public open spaces can offer significant adaptive opportunities. The implications for central Manchester are significant. The Manchester stakeholder workshop confirmed that it is characterised by having few green open spaces or parks (although more open spaces have been created recently such as Exchange Square), and little blue infrastructure, lacking a river focus. There are limited pedestrian connections between open spaces. Adaptive capacity can be physically enhanced through non-trivial methods of greening open spaces, through trees and vegetation, using a variety of building and other structures height and density, altering street layouts, and using different materials.

However, as important as the physical production of adaptive capacity is the social and cultural context which allows adaptation. The BESEECH scenarios suggest significantly different story-lines for public open spaces in urban centres. To illustrate these: under the National Enterprise scenario, there may be a neglect of public open space, with a lack of investment, accompanied by an increase in social polarisation, and a risk of reduced adaptive capacity for poor, vulnerable groups. Under Local Stewardship, there might be active management of the public realm and commitment to public access; high densities will mean a demand for public open space, but adaptive capacity will be shared equitably. Under World Markets, while there are high levels of GDP growth, there are few regulatory controls: there may be a flight from the city centre (and a reversal of recent trends to city centre living) if it experiences over-heating and discomfort. There will be polarisation and an increase in exclusive (gated or privately-controlled) spaces. Under Global Sustainability, fairly high GDP and population growth lead to public investment in low-tech solutions to adaptive capacity, with cross-national learning from experience overseas in managing open spaces in hotter urban areas.

There are already concerns that public open space is being “over-managed”, with an increase in public-private partnerships in city centres leading to polarisation and homogenisation of outdoor spaces, with consequent limitations on freedom of access to all (Minton, 2006).The implications of WP4 are that the increase in average and extreme temperatures and periods of hot weather under climate change is likely to increase pressure on open areas both public and private. The planning, provision, design and maintenance of public open spaces is therefore critical in offering adaptive capacity to all citizens and users of spaces to maintain levels of thermal comfort under all the climate change scenarios and the socio-economic scenarios.

Implications for the wider ASCCUE research: WP4 therefore has important implications for the provision of adaptive capacity in urban areas. Under all socio-economic scenarios considered by BESEECH, the UK is likely to remain a predominantly urban society. Within this context, climate change is likely to alter both the demand for, and the use of, open space, but also its characteristics and hence functionality. The spatial planning system and urban policy at all levels of intervention need to consider the provision and design of open space, and the needs of those likely to be living, working, studying in or visiting cities in the future. They also need to acknowledge the multi-functional role of open space identified by WP5 in cooling urban areas and moderating heat island effects, and in offering opportunities for users to adapt to the impacts of climate change. In policy terms, this reinforces the need to retain existing public open space, and to adjust the current concern for the enhancement of open space, to meet sustainability objectives of equity, inclusion and accessibility. This can be done through planning policies for improvement or re-structuring of city centres and inner urban areas, and for densifying suburbs, urban extensions and new settlements

It is important to integrate the understanding of the impacts of climate change on thermal comfort with the impacts on public and personal health in urban areas. There are also important links to policies for creating blue and green infrastructure, for promoting water-side or water-front developments, and for managing the increase in impermeable surfaces and “urban creep”.

Limitations of the research: While WP2 took a risk-based approach in mapping exposure units such as the health or flooding impacts on vulnerable populations, the human comfort exposure unit WP4 acknowledged that climate change brings opportunities as well as risks, such as the opportunity for enjoyment of warmer temperatures, and greater use of the outdoor spaces. It proved difficult to map these opportunities for adaptive capacity at the conurbation scale using the UMTs.

While the survey work enabled results to be mapped by location of the sites, the WP was unable to gain access to the 3-D modelling software which had been promised, and no contingency plan was in place to acquire or train within another package. While the WP had not originally set out to model spaces, this appeared to be a possibility during the course of the research, and would have allowed us the testing of interventions such as increasing green cover for shade, altering the disposition of solid features for wind-breaks, or shelter, or modelling the different allocation of space within streets to different users (such as increasing pavement widths).

There were some issues in undertaking surveys at a distance, to have the flexibility to target days which provided “extreme” conditions (such as the rare hot days in summer 2004); and there were limitations of climate change scenario data-sets for urban environments and morphologies. While it was very useful to have quantitative characterisation of the socio-economic scenarios, this was only available for 2050s, and so there were some issues in pairing the climate change scenarios and the socio-economic scenarios for comparison and consistency.

Recommendations for future research: This research has broken new ground in trying to link external thermal comfort surveys with climate change models. Future research could profitably explore the better understanding of people’s experience of outdoor climatic conditions, or climate change models for urban areas, or the interface between these.

For instance, it would be desirable to survey areas of transition between indoor and outdoor spaces. The experience of those who have just come out of internal environments (such as centrally-heated or mechanically-cooled buildings) may differ from those who have been outdoors for some time. Transitional spaces may reduce the impact. More measurements of physical parameters such as building and surface materials properties (such as emissivity and reflectivity), or wider choice of locations (perhaps to include water-side areas), would increase understanding of complex urban environments. They could allow better modelling such as using Space Syntax of Ray Man packages, and link directly to urban heat island studies taking climate change into account. Outdoor social surveys could be extended to include longer periods (especially evenings), and wider groups of users (especially the construction work-force).

A meta-study across Europe would build on the ASCCUE work and the RUROS cases. While there is debate over the transferability of design lessons from one country to another, because of their different historical, cultural, social and political contexts which have given rise to particular built forms, there is value to be gained from cross-national studies. As climatic zones broadly shift northwards, there is scope for learning of lessons (as in the recent London study) and for public awareness-raising. Further spatial elaboration of the socio-economic scenarios specifically for urban areas would also prove fruitful.

Implications for policy and practice

High level strategic issues for policy-makers: The external environment is likely to be crucially affected by climate change. Decision-makers need seriously to consider the use and functions of open space (public and private), and the needs of the users of that space over the next 20-50 years, in order to take advantage of positive opportunities as well as to maximise adaptive capacity and to meet sustainability objectives of equity, inclusiveness and accessibility.

There are three reasons for this: climate change scenarios suggest that, with higher average and extreme temperatures, there will be an extended and increased demand for the use of open space. Secondly, socio-economic scenarios suggest that a number of factors might prevent or inhibit the provision and maintenance of public open space, with consequent risks for equality of access. Thirdly, while this research has shown that people in Britain adapt well to a wide range of temperatures, this adaptation is incomplete; if temperatures change rapidly, people will need a physical environment which allows them to maximise their opportunities to adapt and to build adaptive capacity and an effective early-warning system to warn of dangerous conditions.

Public open space has a vital role in offering scope directly for individuals to choose locations and activities to aid adaptation, and indirectly through cooling ambient surface temperatures which can moderate the urban heat island effect. But both require attention to the principles of bio-climatic design.

It is also important that adaptation is integrated with mitigation of climate change. Carbon emissions may be reduced from transport by designing and planning for compact cities at higher densities, and from buildings by promoting more energy-efficient designs such as terrace houses or apartments. The form of the city can also allow it to make use of mutual shading by buildings from both wind and sun. Both these approaches might entail urban intensification and hence risk reducing the provision of open space, or increasing the demand for it. It is therefore important that the two are planned together, and not in conflict.

Implications for planning: There are 6 key messages for spatial planning: it needs to

- give consideration to the lifetime of the built environment, and to acknowledge the possible changes to the climatic and social conditions which will be experienced over the longer-term
- recognise that demand for public open space will increase under climate change, and to ensure that open access to public open space is an essential element of any polices for urban restructuring (whether in city centres, inner areas or densifying suburbs) and urban extensions
- consider the socio-economic implications under future conditions of climate change of developments (such as BIDS, public-private partnerships, and city-centre management companies)
- ensure the design and management of public open space maximises the opportunities for climate change adaptive capacity, and that planting policies take account of the likely changes.
- ensure no net loss of existing areas of public open space
- urban greening and blue infrastructure initiatives include public open space and access routes such as streets, pedestrian routes and linkages

Implications for urban design: Urban designers need to consider the implications of climate change for human thermal comfort in the provision, availability and design of private and (especially) public open space. This includes specifically designated open space and circulation space. Suitable tools include 3-D modelling of spaces for access to solar radiation or shade, exposure to or shelter from wind, trees and vegetation, and water features.

Issues for other practitioners/stakeholders: The multi-functional design and role of public and private open space should be enhanced. Building and transport operators and designers for standard groups (such as commuters, office-workers and householders) and for vulnerable groups (such as school children at play-time, the elderly or those in residential institutions, and outdoor workers such as street cleansing, market traders, community policing and the construction work-force) should consider climate change adaptive capacity.

References

Chappells H and Shove E. (2005) Debating the future of comfort; environmental sustainability, energy consumption and the indoor environment, *Building Research & Information* 33(1), 32-40

deDear, R.J. and Brager, G.S. (2002) Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard *55 Energy and Buildings,* Volume 34,(6),pp 549-561

Eurowinter Group: Keatinge WR, Donaldson GC, Bucher K, Cordioli E, Dardanoni L, Jendritzky G, Katsouyanni K, Kunst AE, Mackenbach JP, Martinelli M, McDonald C, Nayha S, Vuori I (1997) Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. *The Lancet,* 349: 1341-1346

Hacker J. et al (2005) *Beating the Heat: Keeping UK Buildings Cool in a Warming Climate* Oxford: UKCIP

Hoppe P. (2002) Different aspects of assessing indoor and outdoor thermal comfort, *Energy and Buildings* 34(6), 661-665

Humphreys, M.A. and Nicol, J.F. (1998) Understanding the Adaptive Approach to Thermal Comfort, *ASHRAE Transactions* 104 (1) pp 991-1004)

Mayor of London (2006) *London's Urban Heat island: a Summary for Decision-makers*, London: GLA

Minton A. (2006) *The privatisation of public open space*, London: RICS

Nikolopoulou M & Lykoudis S. (2006) Thermal comfort in outdoor spaces: analysis across different European countries, *Buildings and Environment* 41(11), 1455-1470

Nikolopoulou M. and Steemers K. (2003) Thermal comfort and psychological adaptation as a guide for designing urban spaces, *Energy and Buildings* 35(1), 95-101

Ribéron, J, Vandentorren, S., Bretin, P., Zeghnoun, A., Salines, G., Cochet, C., Thibault, C., Hénin, M. and Ledrans, M (2006) Building and urban factors in heat related deaths during the 2003 heat wave in France, *Proceedings of Healthy Buildings 2006 Conference, Lisbon.*

Work Package 5 Summary: Urban Greenspace

Context

Much of the emphasis in planning for climate change is focused on reducing greenhouse gas emissions, as present day emissions impact on the severity of future changes. However, climate change is already with us. Due to the long shelf-life of carbon dioxide in the atmosphere, much of the climate change over the next 40 years has been determined by historic emissions (Hulme et al., 2002). Thus, there is a need to prepare for climate change that will occur whatever the trajectory of future greenhouse gas emissions.

Urban areas have distinctive biophysical features in comparison to surrounding rural areas. For example, urbanisation replaces evapotranspiring vegetated surfaces with built surfaces which store heat. This modifies energy exchanges and contributes to the urban heat island effect, where air temperatures can be up to 12°C warmer than in the countryside (Oke, 1987). The hydrological regime is also altered by urbanisation, with impervious surfaces increasing the volume and rate of surface water runoff. Urban greenspace moderates the urban heat island effect through providing shade and evaporative cooling, and decreases runoff through the interception, storage and infiltration of rainwater (Whitford et al., 2001).

Climate change scenarios suggest that the UK will experience warmer wetter winters with increased precipitation intensity, and hotter drier summers. There is likely to be significant urban warming over and above that expected for rural areas (Betts and Best, 2004). Most of the UK population live in urban areas, and it is here that much of the impact of climate change will be felt. For example, it is estimated that the 2003 European summer heatwave claimed 35,000 lives (Larsen, 2003). In addition, intense rainfall can result in riverine and sewer flooding, causing physical and psychological illnesses to those involved and damaging the built infrastructure. Flooding in the UK in autumn 2000 resulted in an estimated insured loss of £500 million (Austin et al., 2000).

Urban greenspace offers significant potential in adapting cities for climate change, through its role in ameliorating the urban climate and reducing surface runoff. However, this potential has not been explored. In addition, little is known about the impact of climate change on urban greenspace, and how this may impact back on its functionality. This knowledge will be critical for the creation of adaptation strategies through urban greenspace planning, design and management.

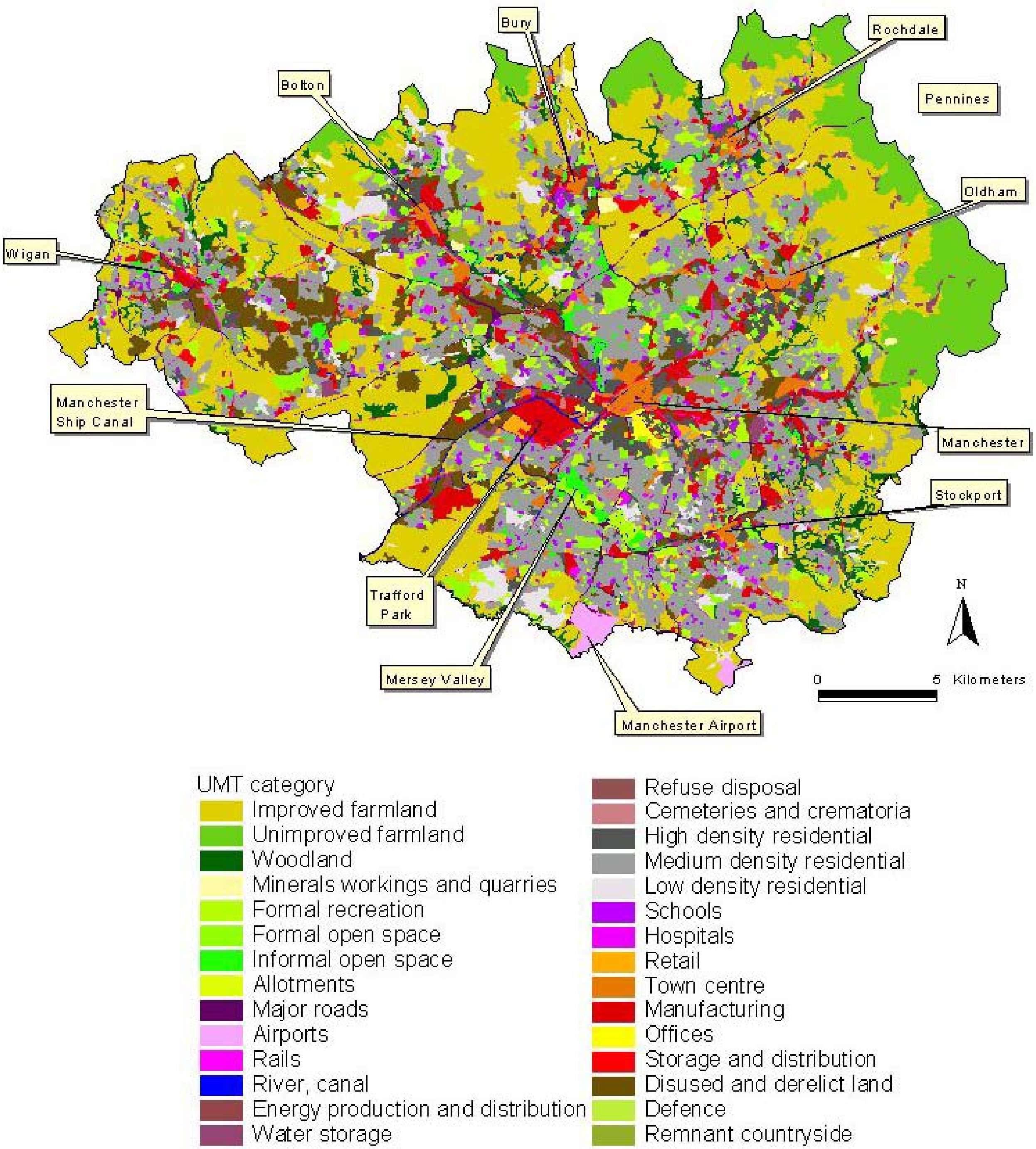
Aims and objectives

The aims of this work package are: to assess the vulnerability of urban greenspace to climate change at the city and neighbourhood level; and to investigate the potential of greenspace to adapt cities to climate change. The objectives are: to determine the extent, spatial patterning and attributes of greenspace in the case study area; to develop a GIS-based approach providing quantitative estimates of surface temperatures and surface runoff in relation to greenspace pattern and attributes; to clarify the vulnerability of urban greenspace to climate change; and to test options for soft engineering to utilise the moderating influence of greenspace to reduce climate change impacts on people and buildings.

Theory and Methodology

WP5 focused on the Greater Manchester (GM) case study. The first stage was to characterise the urban environment. The urban morphology type (UMT) map created by WP2 was used as the spatial basis (Figure 1). The surface cover of each UMT category was estimated by aerial photograph interpretation of random points (400 within each category). This is very important as the surface cover affects the environmental performance of the conurbation and is a vital input into models of surface temperature and surface runoff (Whitford et al., 2001).

Figure 1. UMT map of GM (from 1997 aerial photographs, source: Cities Revealed)



The next stage explored the impacts of climate change on urban greenspace. This was undertaken by mapping the spatial and temporal occurrence of drought conditions for grassland under current and future climate scenarios. The available water in the soil profile for grass (source: NSRI, Cranfield University) was combined with monthly precipitation (source:

Met Office and UKCIP02 5km data) and potential evapotranspiration (source: BETWIXT output for Ringway). The soil water deficit was estimated for each quarter month and the number of months when the grass would be water stressed was calculated. Drought conditions impact on the functionality of urban greenspace, in particular, in terms of reducing its evaporative cooling which could then impact on human comfort (WP4). Drier soils could also affect building integrity (WP3) as shrink-swell soils can damage foundations and may be exacerbated by the proximity of trees.

Modelling was then undertaken of maximum surface temperatures and surface runoff (Whitford et al., 2001). The surface temperature model is based upon an energy balance equation and requires input of proportional surface cover, building mass per unit of land, and various meteorological parameters (some calculated from BETWIXT output for Ringway). The surface runoff model uses the curve number approach of the US Soil Conservation Service. Model inputs are surface cover, precipitation (calculated from BETWIXT output for Ringway), antecedent moisture conditions, and hydrologic soil type.

The surface temperature model was run for the 98th percentile summer day, a day expected twice per summer on average; the surface runoff model used the 99th percentile winter precipitation event, expected one day per winter on average. Model runs were undertaken for the baseline 1961-1990 climate, as well as for UKCIP02 Low and High emissions scenarios for the 2020s, 2050s, and 2080s. Model runs were completed for the UMT categories with their current form, i.e. using proportional surface covers from the urban characterisation, as well as for a series of ‘development scenarios’ exploring the impact of adding and taking away green cover. The ‘development scenarios’ were intended both to help understand the effects of current development trends (e.g. Duckworth, 2005 for ASCCUE/AUDACIOUS), as well as to explore the potential of greening in adapting for climate change. They included: residential and town centres plus or minus 10% green or tree cover, greening roofs in selected UMTs, high density residential development on previously developed land, increasing tree cover by 10-60% on previously developed land, residential development on improved farmland, and permeable paving in selected UMTs. In addition, for the surface temperature model, runs were completed where grass was excluded from the evapotranspiring proportion. This was intended to model the impact of a drought, when the water supply is limited and plants evapotranspire less, and hence their cooling effect is lost.

Key research findings

The urban characterisation results show that on average 72% of GM, or 59% of 'urbanised' GM, consists of evapotranspiring (i.e. vegetated and water) surfaces (Figure 2). All UMT categories have, on average, more than 20% evapotranspiring surfaces, however there is considerable variation. Town centres have the lowest evapotranspiring cover of 20%; woodlands have the highest cover of 98%. Tree cover is fairly low, covering on average 12% over GM and 16% in 'urbanised' GM. Whilst woodland has 70% trees, all other UMTs have below 30% cover (Figure 3). Town centres have a tree cover of 5%. Residential surface cover is particularly important as it accounts for almost half of 'urbanised' GM and therefore has a great impact on the environmental performance of the conurbation. Approximately 40% of all evapotranspiring surfaces in 'urbanised' GM occur in residential areas, with medium density residential accounting for the majority of such surfaces. Two thirds of high density residential areas are covered by built surfaces, compared to half in medium density and one third in low density areas. Tree cover is 26%, 13%, and 7% in low, medium and high density areas, respectively.

Figure 2. Evapotranspiring (i.e. vegetated and water) surfaces over GM

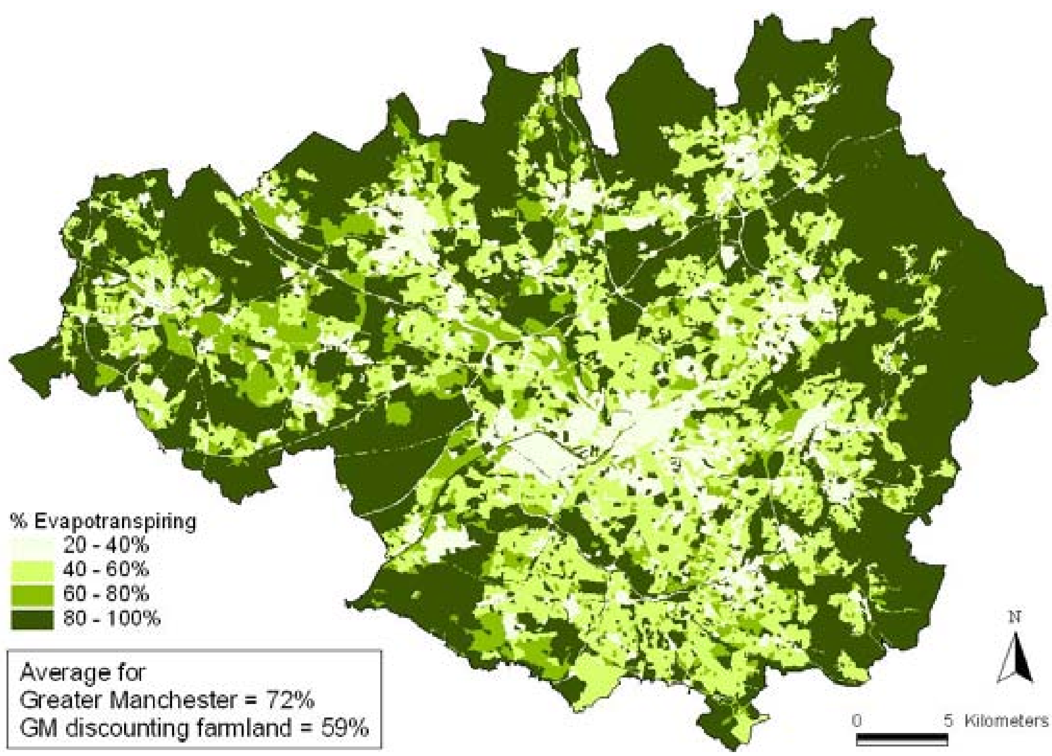
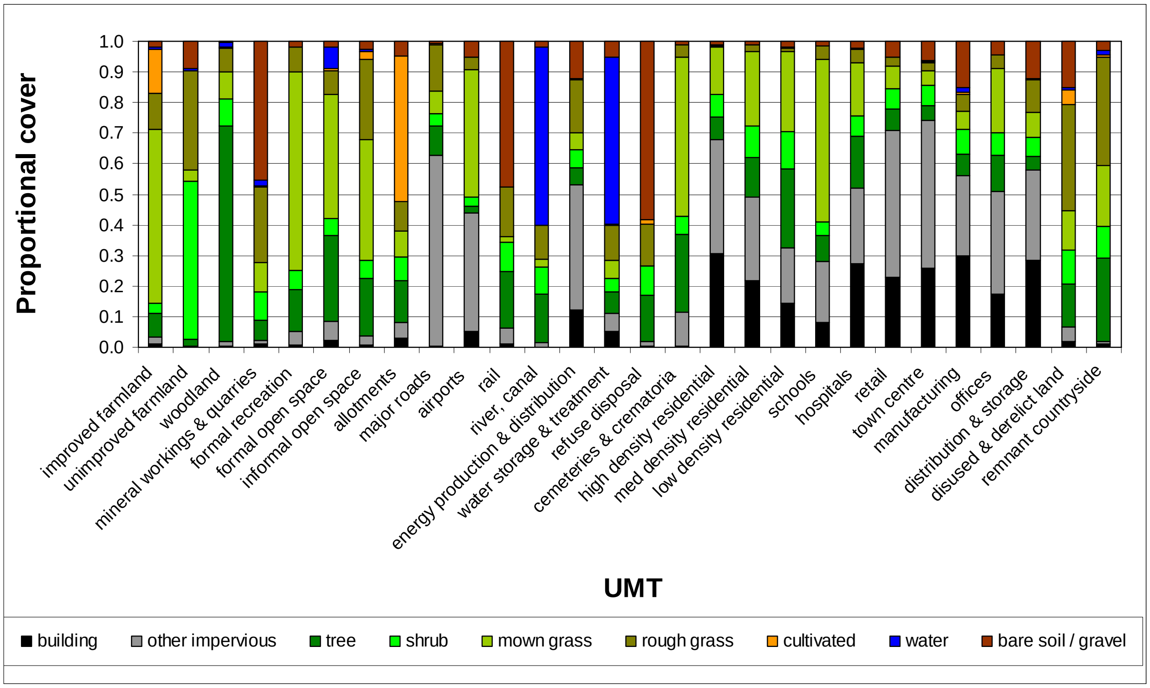
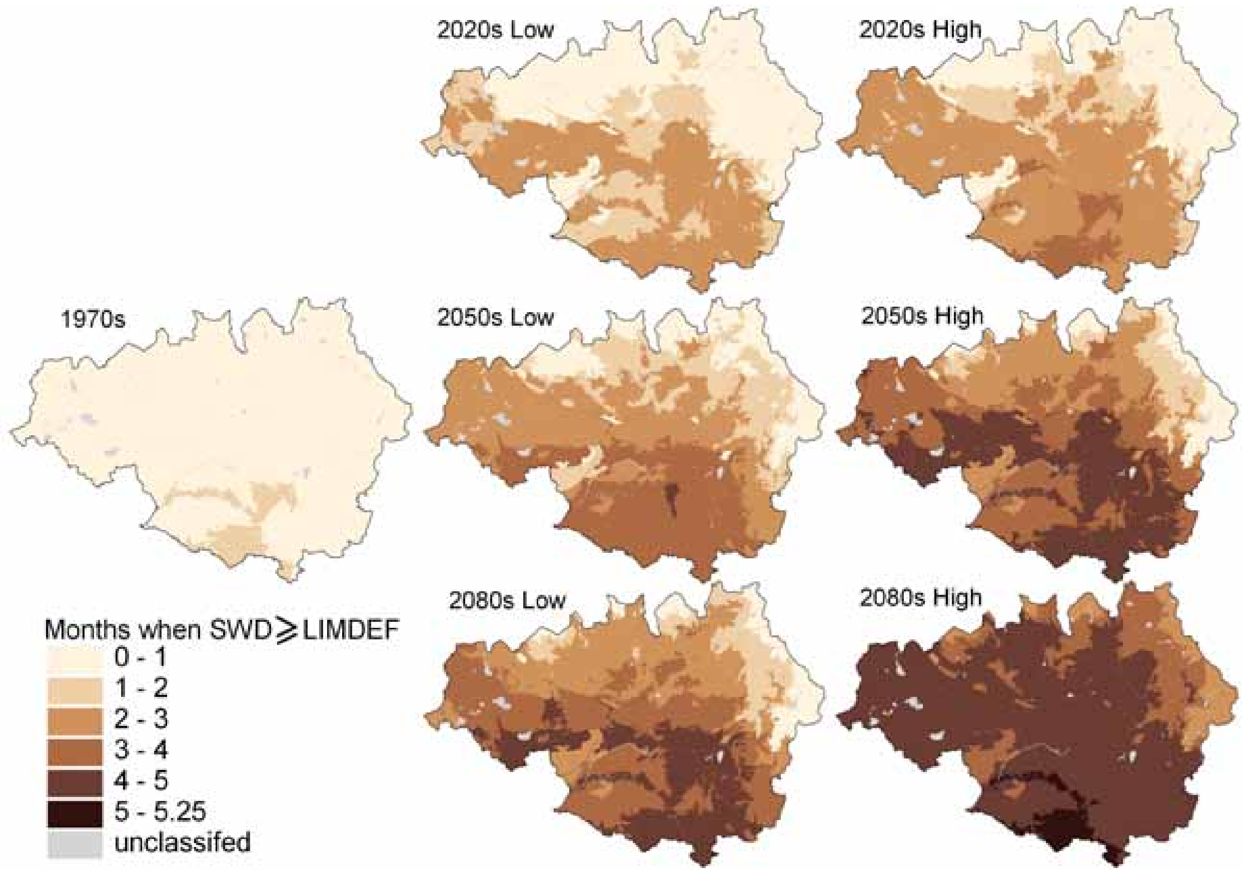


Figure 3. Proportional surface cover in the UMTs



The drought mapping suggests that, with climate change, grass will experience longer periods of water shortages affecting more of the conurbation (Figure 4). In 1961-1990 all UMT units in GM experienced less than 2 months of water stress in the average year; by the 2080s High they experience between 2½ and 5¼ months of stress. The cooling effect of grass is also reduced by more than 50% for up to 2 months of the year by the 2050s High in certain UMT units, and between ½ and 3¾ months in all units by the 2080s High. Full soil water recharge occurs across the conurbation but takes place later in the year. In 1961-1990, the majority of soils in GM were recharged by the end of September; by the 2080s this is achieved by the end of November.

Figure 4. Number of months when water supply to grass is limited



The surface temperature modelling highlights the major role that urban greenspace plays in moderating surface temperatures. The coolest parts of the conurbation are those with the highest greenspace cover, for example woodlands, whilst the warmest have the least evaporating cover, for example town centres (Figure 5). The modelling work suggests that greenspace can be used to reduce or even remove the effects of climate change on increasing surface temperatures. For example, adding 10% green cover keeps maximum surface temperatures (for the 98th percentile summer day) in high density residential areas and town centres at or below the 1961-1990 current form case up until the 2080s High (Figure 6). The addition of green roofs in town centres and high density residential areas is also shown to be an effective way to moderate surface temperature increases with climate change. On the other hand, removing 10% green cover from these areas results in increased maximum surface temperatures by up to 8.2°C by the 2080s High, compared to the 1961-1990 current form case. A caveat to the use of greenspace to moderate surface temperatures is the case of a drought when plants may experience water stress and reduce their evapotranspiration. In such a case the role of water bodies, for their evaporative cooling, and mature trees, for the shade they provide, become increasingly important.

Figure 5. Maximum surface temperature (98th percentile summer day)

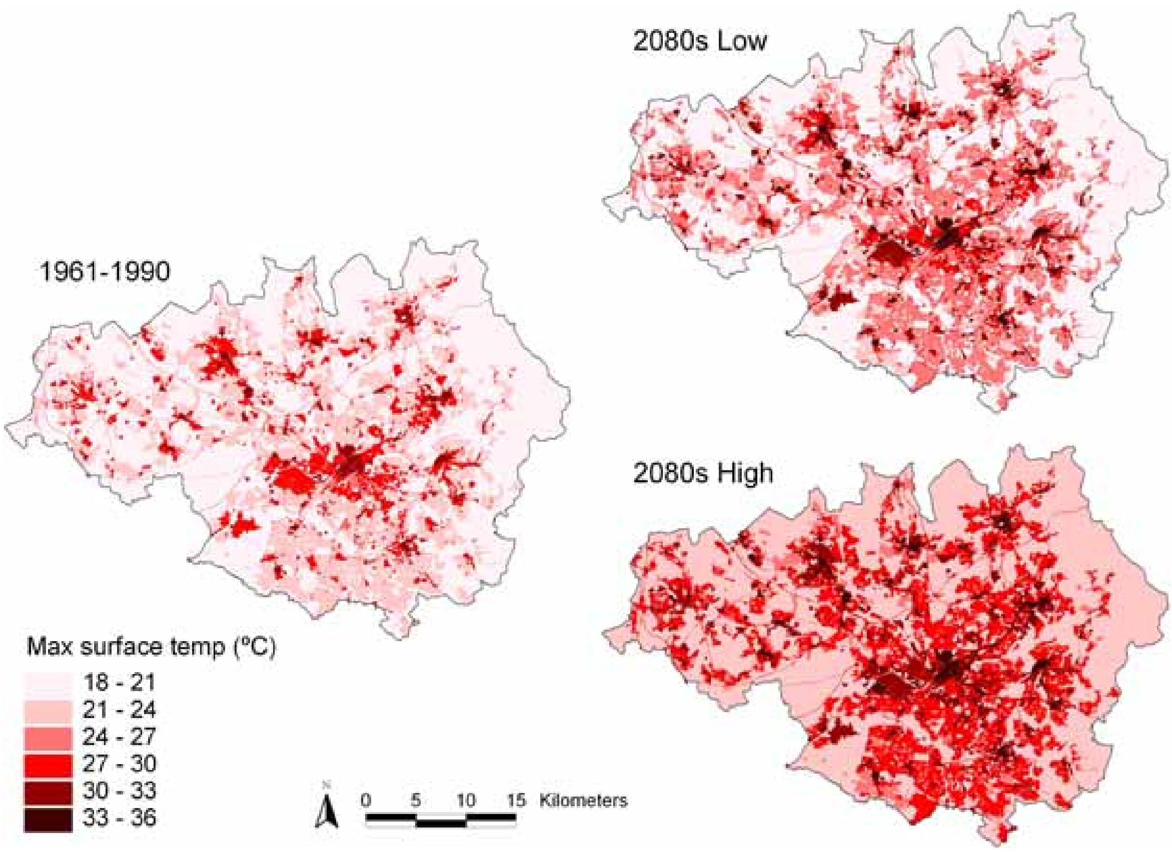
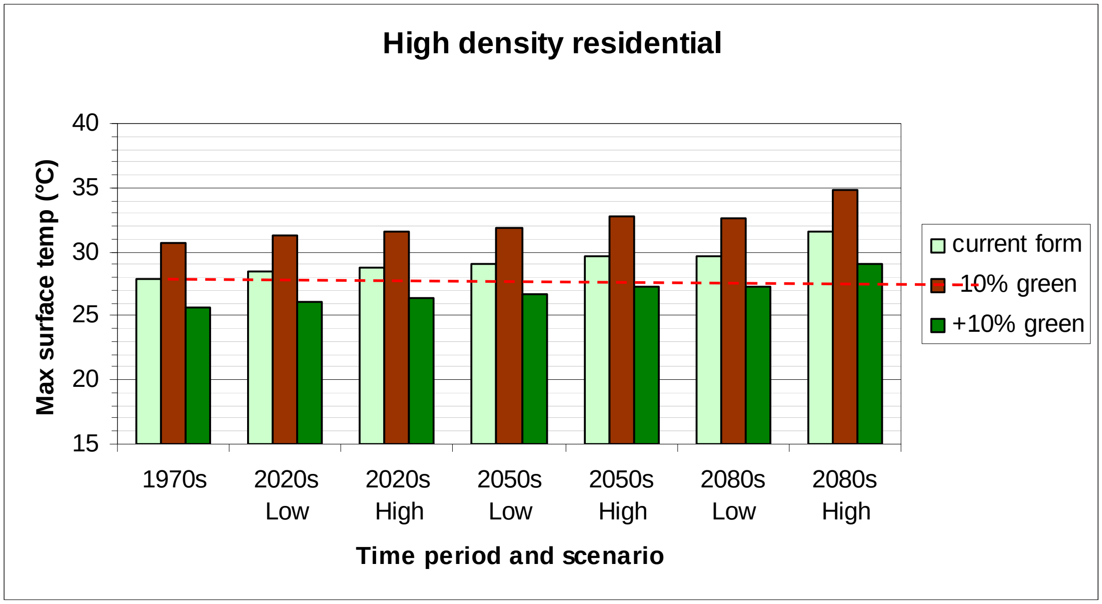


Figure 6. Maximum surface temperature (98th percentile summer day) in high density residential with plus or minus 10% green cover



The surface runoff modelling shows that, in general, the more built up a UMT category is the more surface runoff there will be (Figure 7). Additionally, soil type is very important. Faster infiltrating soils, such as sandy soils, have lower runoff coefficients than slower infiltrating soils, such as clays. The runoff coefficients display the largest range between the UMTs on high infiltration soils and the smallest range on low infiltration soils. For example, for an 18 mm precipitation event (the 99th percentile winter event in 1961-1990) with normal antecedent moisture conditions on sandy soil, low density residential UMTs have 32% runoff compared with 74% from the more built up town centres, which have the highest runoff coefficients of all the UMTs. On a clay soil this changes to 76% and 90% respectively, much higher values and with a smaller difference between them. Thus, surface sealing has a more significant impact on runoff on a sandy soil with a high infiltration rate than on a clay soil with a low infiltration rate. By the 2080s High, the 99th percentile winter precipitation event has 56% more rain than the 1961-1990 baseline, at 28 mm. This results in an 82% increase in runoff from GM. Whilst adding green cover can reduce runoff significantly locally, for example, by up to 20% when green roofs are added to high density residential areas in 1961-1990 and 14% by the 2080s High, this effect is not sufficient to counter the extra precipitation resulting from climate change (Figure 8). Additionally, at the conurbation level, the most effective 'development scenario', adding 10% trees to residential areas, reduces runoff by 2% by the 2080s High. There is thus a need to explore the use of storage, in combination with green surfaces, in order to counter the increased runoff resulting from climate change.

Figure 7. Surface runoff coefficients for 99th percentile winter daily precipitation event

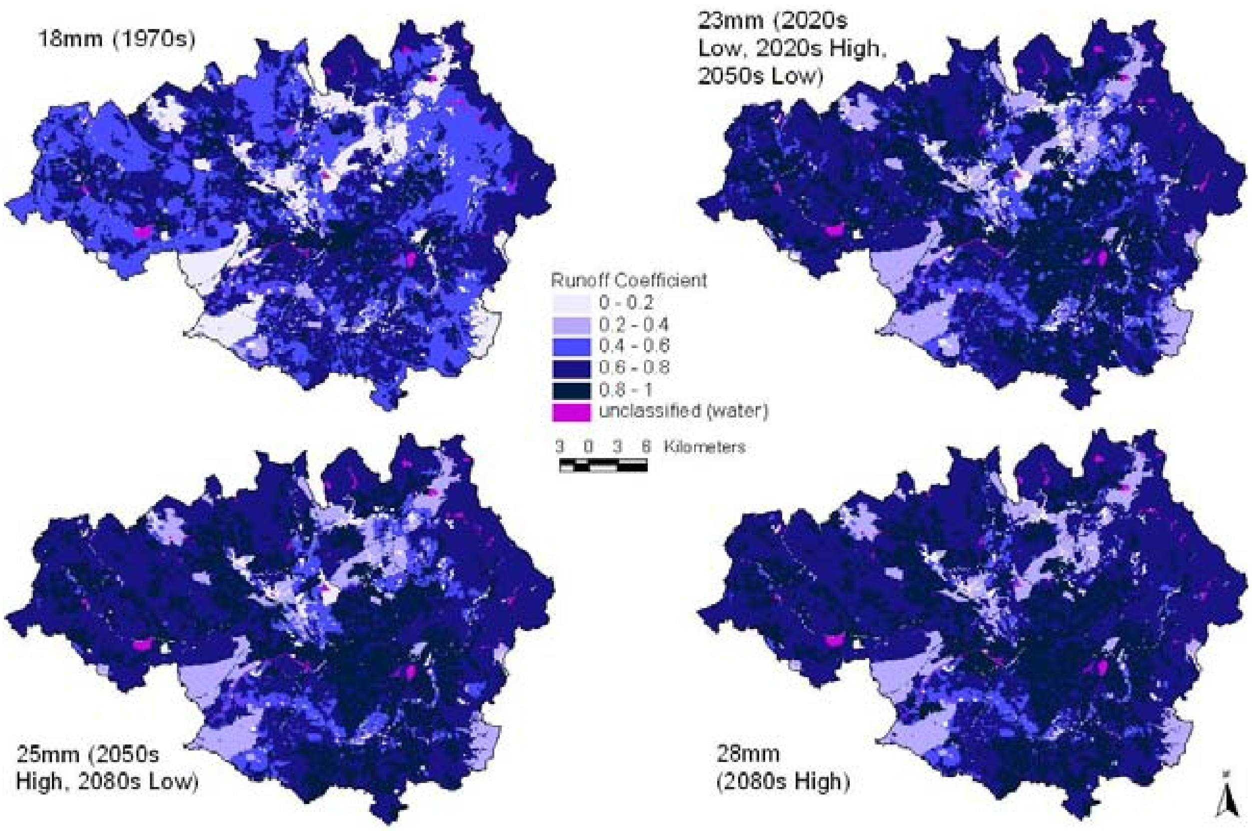
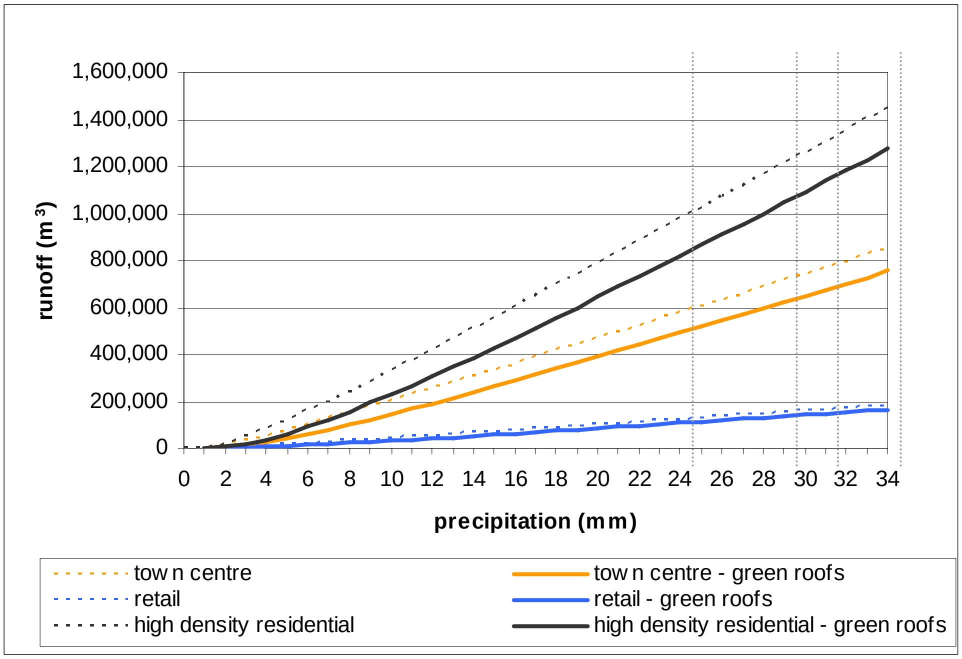


Figure 8. Total surface runoff (m^3) for selected UMTs with green roofs

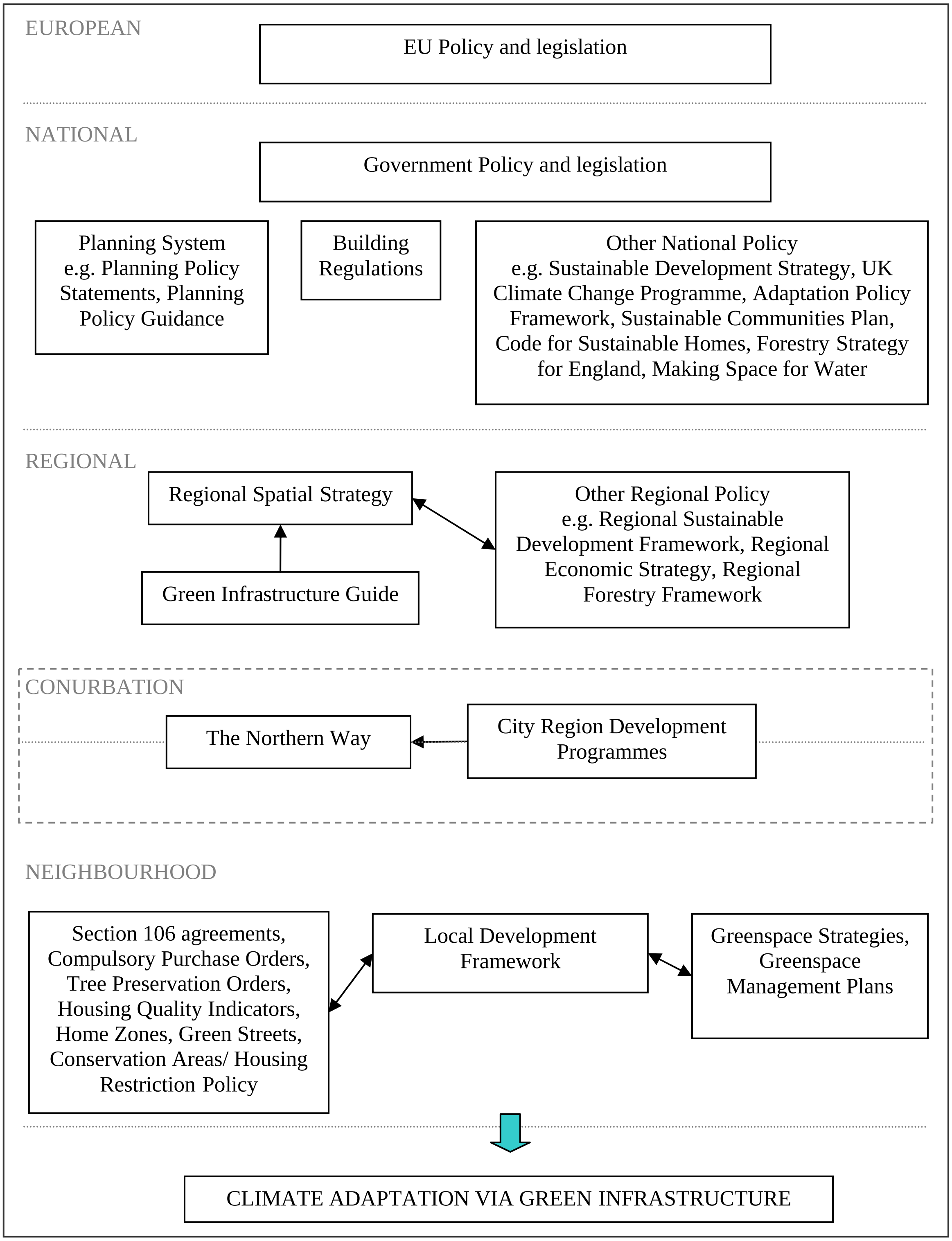


Future research could: explore intra-UMT variations in surface cover; consider automatic classification methods for urban characterisation; investigate the impacts of climate change on urban greenspace; assess drought risk for different greenspace types; determine irrigation requirements of greenspace and investigate ways of sustaining it; examine the relationship between shrink-swell soils, building foundations and trees; validate the models in the context of GM; investigate the linkages between surface, globe and air temperature and their relevance for human comfort; produce guidelines about the optimum size, type and configuration of greenspace; model the interaction between urban greenspace and the internal environment; model greenspace functionality in relation to air quality with climate change; investigate the economic implications of this modelling work; explore design options at the neighbourhood scale; investigate the impact of adaptation strategies on the wider functionality of the green infrastructure; undertake climate analogue studies considering best practice in greenspace provision and management.

Implications for policy and practice

Urban greenspace, from street trees, to private gardens, to city parks, provides vital ecosystem services which become even more critical under climate change. The creative use of the green infrastructure is one of the most promising opportunities for adaptation as it provides other social, economic and environmental benefits. It is essential that the green infrastructure is strategically planned. This needs to be reflected in relevant policies and practice from the national to the local and neighbourhood level. The planning system is crucial in ensuring adaptation to climate change via the green infrastructure, but other policies, plans and programmes are also important (Figure 9).

Figure 9. Some policies, plans and programmes to deliver climate adaptation via the green infrastructure (adapted from TCPA and FoE, 2006)



Within the planning system, national policy tends to favour urban densification and the use of brownfield land for new housing developments. A greater emphasis should be placed on the role of the green infrastructure in adapting for climate change within Planning Policy Statements (PPS). In particular, the proposed PPS on climate change should have a strong reference to this. Regional Spatial Strategies and Local Development Frameworks should also be explicit about the potential of the green infrastructure in adapting for climate change. Development control at the neighbourhood level will be crucial and may vary for different urban neighbourhood types. For example, in densifying suburbs, the creation of Conservation Areas could help to restrict infill development in gardens and thereby maintain the high environmental functionality found in such areas. Changes to Building Regulations to include paving over of gardens would also be useful. In other areas, section 106 agreements can be used to require developers to support and maintain tree planting and greenspace provision.

Whilst much of the emphasis within the planning system is placed on the regional and local levels, the conurbation level has been highlighted by this research as crucial for climate adaptation via the green infrastructure. Spatial greenspace, or green infrastructure, strategies should be developed at this level to preserve existing greenspace and create new greenspace such that a functional network that crosses local authority boundaries is formed. The Association of Greater Manchester Authorities could be a useful vehicle in GM for the development of such strategies.

Strategies firstly need to understand the environmental functionality of greenspace under present and future climate scenarios. This should include the role of private gardens. Next, greenspace strategies should take into account the impacts of climate change. For example, tree planting should include species which will have a large canopy and an ability to withstand hotter drier summers. The provision of an adequate water supply for irrigating greenspace in times of drought is crucial, recognising that they provide benefits beyond amenity. Options could include rainwater storage and distribution (potentially as SUDS within greenspaces), using water from sources which are not fit for human consumption such as aquifers with a low water quality and canals, and reductions in water consumption.

Greenspace strategies should then attempt to conserve or preserve existing greenspace and to enhance it where possible, especially where it provides a high functionality such as on high infiltrating soils and in river corridors. Different approaches to this will be required in different urban neighbourhoods. Within urban centres, greenspaces constitute critical natural capital that, once developed, is difficult to replace. The built fabric of these areas is largely established and there will be few opportunities to create significant new greenspaces. Programmes such as Green Streets of the Red Rose Forest are very important in securing street tree planting. Mature trees will be very important for the roles they play in providing shade and intercepting rainfall. Other key areas for the introduction of shade trees are schools, hospitals and in high density residential areas, which often suffer from socio-economic disadvantages and a low tree cover. In addition, key streets within city centres could be pedestrianised and greened, and opportunities for greening must be taken on building roofs and facades. Maximum use should be made of any water bodies and features, for example, in Manchester city centre through the 'daylighting' of culverted rivers and canals. Opportunities to enhance the green cover should also be taken where structural change is occurring, for example, in urban regeneration projects and new development. Within the Government's Sustainable Communities Programme it is crucial to take the opportunity to 'climate proof' new developments in the Growth Areas and to reintroduce functional green infrastructure during the redevelopment process in areas subject to Housing Market Renewal.

References

Austin, B., Cheesman, P. and Maggs, C. (2000). *United Kingdom Floods: 2000*. Guy Carpenter, Instrat UK, London. Available: http://www.guycarp.com/portal/extranet/pdf/ukflood.pdf.

Betts, R. and Best, M. (2004). *Simulating Climate Change in Urban Areas: Interactions Between Radiative Forcing, Landscape Effects and Heat Sources*. BETWIXT Technical Briefing Note 3, Version 2. Met Office, Exeter and Wallingford.

Duckworth, C. (2005). *Assessment of urban creep rates for house types in Keighley and the capacity for future urban creep*. Unpublished thesis (MA), School of Environment and Development, University of Manchester, Manchester.

EEA (2006). *Green urban areas within urban morphological zones (2000) - version 12/2005*. European Environment Agency, Copenhagen. Available: http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=912 (accessed 8th August 2006).

Hulme, M., Jenkins, G., Lu, X., Turnpenny, J., Mitchell, T., Jones, R., Lowe, J., Murphy, J., Hassell, D., Boorman, P., McDonald, R. and Hill, S. (2002). *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich. Available: http://www.ukcip.org.uk.

Larsen, J. (2003). Record heat wave in Europe takes 35,000 lives. *Earth Policy Institute,* October 9th 2003. Available: http://www.earth-policy.org/Updates/Update29.htm.

Oke, T. R. (1987). *Boundary Layer Climates* (2nd edition). Routledge, London.

Whitford, V., Ennos, A. R. and Handley, J. F. (2001). "City form and natural process" - indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning,* 57 (2), 91-103.

Work package 6 Summary: Climate risk - the socio-economic dimension

Climate change has become a mainstream issue in recent years. It is no longer seen as merely an environmental or 'green' issue but rather one that is likely to have serious economic and social repercussions for society in future decades. The Stern Review[8], which focused on the economics of climate change and called for urgent international action, is the most recent illustration of this important shift in our perception of the risks associated with climate change.

ASCCUE identified flooding (fluvial and coastal), heat stress, geohazards, and an increase in the frequency of extreme events as the impacts likely to be of greatest concern within the urban environment. Flooding, for example, can result in deaths, injuries and a variety of health problems (not only physical illness but also psychological distress, as was reported for the Lewes flood event in 2000). There are also considerable economic implications, highlighted by costs of over £1 billion to the insurance industry following widespread flooding in the UK in Autumn 2000 (source: ABI). At the forefront of managing the risks associated with a changing climate, the insurance industry has had to re-think its traditional policy on property insurance, with any future restrictions in geographical coverage having important implications for homeowners. For instance, access to affordable insurance can lead to forms of economic exclusion, often affecting those already at a disadvantage in society. As a consequence property values may also be adversely affected (the potential danger of blighting housing was a sensitive issue that needed careful consideration during the research process). What has come through strongly from the ASCCUE programme of research is that climate change is likely to exaggerate existing vulnerabilities. The issue of heat stress (with the most vulnerable being the elderly, the poor, those in ill health, and the very young) clearly illustrates this. Evidence from the 2003 heat wave that killed tens of thousands across Europe indicates that it was the elderly in our society that were worst affected. Climate change is likely to increase both the frequency and intensity of such events, and therefore maintaining human comfort, and safeguarding the health of the most vulnerable in society, will become increasingly important in our towns and cities in the future.

It is important to recognise that climate change will impact on towns and cities that may be very different from what we know today, and we need to consider how society is likely to evolve if we are understand the nature of the impacts, and hence devise appropriate

[8] http://www.hm-treasury.gov.uk/media/8AC/F7/Executive_Summary.pdf

adaptation strategies. Drawing on the UKCIP socio-economic scenarios, analysis conducted as part of the BESEECH project (Dählstrom and Salmons, 2005) produced four 'enhanced' scenarios for use by the Greater Manchester case study (national enterprise, local stewardship, world markets, and global responsibility), with consideration of differing social values and governance structures shaping these alternative 'futures'. This information, in both quantitative and qualitative format, benefited the ASCCUE project by highlighting possible changes in key socio-economic variables as well as characterising the capacity and ability of different societies and groups to adapt to climate change under the different scenarios.

It is also important to recognise that in many cases climate change may not be the most important factor in determining impact in the built environment, with changes to our climate interacting with urbanisation processes to either amplify or moderate the degree of impact. Urban form, and the role of spatial planning, is particularly influential. For instance, the densification of cities (promoted by land use policy in England since the late 1990s) can act to intensify the urban heat island effect by increasing the building mass, as well as posing problems for urban drainage by increasing the proportion of impermeable surfaces within the urban system (*insert Duckworth reference*). As promoted by the ASCCUE findings, adequate greenspace provision is considered a particularly important adaptation option, however this valuable natural resource is often the loser in development processes. The greenspace issue is further complicated by questions of ownership. An increase in the involvement of private companies in city-centre redevelopment schemes has been accompanied by a trend towards the 'privatisation' of associated public space, raising issues of social and environmental equity in our larger cities. Even in the suburbs much of the greenspace fabric is also privately owned. Here, the 'paving over' of gardens, and subsequent loss of infiltration capacity, is a contemporary issue that has been the focus of recent media interest. In response, it was suggested by several stakeholders at an ASCCUE workshop that the use of similar designations to existing 'conservation areas' would enable some degree of planning control in this regard.

Demographic change is yet another factor influencing overall climate risk. With the UK experiencing an ageing population, the greater number of elderly people will increase societal vulnerability to climate change, particularly in relation to extreme events (as part of the ASCCUE project, a Masters dissertation project analysed future vulnerability to the hazard of heat stress in Greater Manchester - Peet, 2005). The combination of this growth in the older population with other social variables is also fuelling a rapid increase in the number of single person households (Government figures suggest that 38% of households will be single person by 2016), hence stimulating significant demand for new, and different types of, housing. The difficult question facing the Government, and others, is where all this housing will go. In the Greater Manchester case, there has been a rapid rise in city centre living (driven by cultural influences and lifestyle choice), there are significant areas of regeneration activity in the east of the city as a result of the national 'pathfinder' initiative, and many of the more desirable suburbs, particularly to the south of the city, are increasingly subject to densification. Obviously, careful consideration of the location of any new development can reduce exposure to climate-related hazards e.g. avoiding areas at risk of flooding where possible. As identified in the ASCCUE risk workshops, each of these neighbourhood types will be subject to different development pressure, interacting with a range of different climate change impacts. As a result of this diverse challenge, adaptation responses will need to be tailored to locally specific circumstances.

As alluded to in the previous paragraph, changing lifestyles is another socio-economic ingredient in the mix. Although more commonly shaped by a mixture of social, economic and cultural factors, lifestyle choice may be increasingly influenced by climate change. For instance, the onset of warmer summers and more comfortable evenings will act to reinforce the move towards a café culture and increase the demand for public open space, consequently adding to the pressure on existing urban greenspace. There may also be negative feedbacks, with an increased use of outdoor heaters, for example, contributing to the climate change problem.

All systems have the capacity for self-adjustment, however findings from the ASCCUE project have shown that the urban environment would benefit from planned adaptation to climate change in order to reduce the exposure and vulnerability of the main elements at risk – people, buildings and infrastructure, and even the spaces in between (addressed by the three ASCCUE work packages – human comfort, integrity of the built environment, and urban greenspace). There will obviously be cost implications to building resilience, or 'climate headroom', into the urban system, however authoritative studies such as the Stern Review are beginning to compile a substantial evidence-base that the costs of doing nothing will be much greater in the longer run. That said, the positive dimensions of adaptation should not be under-estimated. Having a better understanding of climate risks and ensuring the integrity of the built environment can sustain the lifetime of urban infrastructure. Addressing adaptation issues can also make cities more attractive places in which to live and work, ensuring their economic viability in the longer term, and even at the street scale there is the potential for local business opportunities resulting from pedestrianisation and the creation of an amenable micro-climate i.e. ensuring shading / shelter for customers (as is common in many continental cities).

ASCCUE research has shown that designing, planning and retrofitting our towns and cities for changing climatic conditions can also reinforce wider sustainable development objectives and contribute to crosscutting social and economic agendas. The importance of greenspace to the functioning of our cities was a key finding of the research – not only does it provide cooling and rainwater infiltration capacity, but its promotion as a multi-functional resource can enhance environmental equity by ensuring access to open space for all city dwellers, ultimately contributing to quality of life in the urban realm (engagement with ASCCUE stakeholders also highlighted the potential for greater exploitation of our rivers, canals and the use of water features in our urban areas). As such, there is obvious synergy between adaptation objectives and the activity of those, such as Cabe Space, seeking to promote the management and improvement of our public spaces. Indeed these open spaces have the potential to act as green ‘gyms’, thereby also having a positive contribution to the health agenda. Furthermore, maintaining human comfort in city centres has important social and economic dimensions, not only for those who need to work outdoors but also for office workers wishing to leave air-conditioned buildings to relax outdoors during their lunch breaks. This implies the need to design and manage open space in a way that maximises the adaptive capacity of our urban centres.

Due to the complexity of the climate change issue, adaptation responses will interact with many other policy agendas and engage with a range of different stakeholders. In the built environment, there are obviously implications for strategic planning and urban design, however linkages also exist with multi-level policies, including sustainable communities, regeneration, health, public space, green infrastructure, flood risk management, SUDS, water resources, tourism, to name but a few. Making these interactions explicit, and identifying whether they are positive or conflicting, would contribute to more effective decision-making. Addressing adaptation at a strategic level, we need to be ensuring that all development is climate 'proofed', simply meaning that we need to ensure that there is adequate flexibility in the urban system to deal with the uncertainties posed by a changing climate. Part of the solution is to seek to increase our adaptive capacity. This will ultimately require a reduction in existing social and economic inequalities – a 'win-win' solution for future society.

Dissemination:

Dahlstrom K. & R. Salmons (2005) *BESEECH: Building Economic and Social information for Examining the Effects of Climate change* Policy Studies Institute, London.

Duckworth, C. (2005) Assessment of urban creep rates for house types in Keighley and the capacity for future urban creep, Unpublished thesis (MA), University of Manchester.

Peet M. E. J. (2005) *Future Vulnerability to the Hazard of Heat Stress in Greater Manchester* Unpublished MSc dissertation, University of Manchester, Manchester.

Work package 7 Summary: Strategies for development and testing

Workshop reports are available for this work package.

- Workshop on development of risk assessment methodologies, Manchester, July 8th, 2006.
- Workshop on adaptive management and climate conscious deign for urban neighbourhoods, Manchester, January 18th, 2006.
- Joint workshop with DEFRA Cross Regional Project on climate change implications for new development in the growth areas, London, March 20th, 2006.
- Special meeting of ASCCUE National Steering Group in workshop mode to consider research findings of Lewes case study, London, 21st September, 2006.

Work package 8 Summary: Understanding the relationship between adaptation and mitigation

Part of the original ASCCUE remit was to undertake an initial ‘scoping’ study of the linkages between the mitigation and adaptation agendas. This was considered an important endeavour, as a better understanding of the conflicts, synergies and trade-offs between the two sets of measures would make a valuable contribution to the development of a more integrated climate change strategy.

It is important to clarify what each of these agendas entails up-front. In summary, both are deliberate human responses to climate risk; mitigation seeking to reduce risk by addressing the drivers of climate-related hazards (by reducing greenhouse gas emissions and enhancing carbon ‘sinks’), whilst adaptation targets vulnerability and exposure to these hazards (planned adjustment to either restrict potential harm, or exploit opportunities, from change that cannot be avoided). Traditionally, climate change action in the UK has tended to be dichotomised between the two different ‘camps’. From its introduction in the early 1990s, the main focus of the first national Climate Change Programme has been one of mitigation, in particular moving towards a low carbon economy (reinforced by the recent Climate Change Bill in November 2006 which sets a national 60% reduction target for the UK by 2050). As such, reducing greenhouse gas emissions was the primary focus of policy setting (and hence research funding) in the UK, with little consideration of adaptation objectives and minimal integration of specific issues and possible solutions.

However, more recently there has been a shift in emphasis, with increasing recognition that we need to be planning for adaptation, as well as continuing mitigation efforts. This is reflected by acknowledgement in both policy and research communities that we need to adopt a wider approach to climate risk, including the consideration of both types of response as part of a more coherent climate change programme. In the UK, the revised Climate Change Programme (2006) explicitly considers adaptation for the first time, and the forthcoming Planning Policy Statement on Climate Change (PPS 26) will also be an influential document for the ‘climate-conscious’ planning and design of our towns and cities. Research carried out by the ASCCUE project and the wider Building Knowledge for a Changing Climate programme will be used to provide state-of-the-art scientific support for these new policy developments. At the European scale, it is also intended that adaptation will feature more strongly in the second

European Climate Change programme (currently under consultation), and in research terms both mitigation and adaptation (and their trade-offs) are being considered as part of the ADAM project[9].

Although there is an obvious political desire to exploit the interdependencies between mitigation and adaptation, aiming to achieve ‘win-win’ solutions where possible, there has been little detailed analysis of what this actually means in practice i.e. whether synergies exist in reality or whether conflict and trade-offs may actually be more prevalent. Indeed, some in the academic community argue that mitigation and adaptation are, in effect, substitutes for each other and may actually compete for resources. In broad terms there are obvious linkages between the two approaches. Both are deliberate responses to climate change, with successful implementation dependent on similar determinants: technology, economic resources, human and social capital, political will, public acceptance, issues of governance etc. In the context of the built environment, they are also both driven (and influenced by) urban development pressures. However, although there are discernible synergies between mitigation and adaptation, there are also very important conceptual differences which need to be appreciated.

Firstly, there is a mismatch in terms of scale, both spatially and temporally. For example, mitigation efforts are typically driven by national initiatives, operating within the context of international obligations, and (due to greenhouse gases having long residence periods in the atmosphere) the results will only become evident in decades to come. Being action targeted at the longer term, mitigation therefore attaches importance to the interests of future generations and hence can be considered an altruistic response by society. On the other hand, adaptation to climate change and variability tends to be much more local in nature, often in the realm of local / regional economies and land managers. Adapting to the impacts of climate change therefore has a stronger element of immediacy and is typically seen more in terms of every-day ‘self interest’.

These differences lead us to a consideration of environmental equity, in particular who pays and who benefits. For example, those responsible for the majority of emissions also tend to have the highest adaptive capacity (hence influencing the urgency attached to any mitigation

[9] http://www.adamproject.eu

response). This not only applies in an international context, with developing countries considered the most vulnerable to the impacts of a changing climate, but also within national territories as well. Even within the UK, those most vulnerable to climate change are often those already at a socio-economic disadvantage in society (for example, relatively immobile populations living in poor quality accommodation).

A final but important difference relates to the actors involved. Not only are decisions taken in different policy domains, they also engage with different stakeholder communities. Mitigation policy is primarily focused on decarbonisation and therefore tends to interact with the large 'emitting' sectors such as energy and transport etc. The limited number of key actors, and their experience of dealing with long-term investment decisions, means that the mitigation agenda is more sharply defined. In contrast, actors involved with the adaptation agenda come from a wide variety of sectors, operating at a range of spatial scales from national planning authorities down to individual building owners. As a result, the implementation of adaptation measures is likely to encounter greater institutional complexity.

So what do these differences actually mean for policy and practice in our urban areas? At the city (or strategic planning) scale, the interaction between the two approaches would appear to be predominantly one of conflicts, ultimately requiring consideration of policy trade-offs. Mitigation efforts in urban areas, based largely on energy efficiency measures and the decarbonisation of energy supply, are strongly influenced by urban form e.g. the greater the density of development the less the need to travel and the greater the viability of community heating systems etc. The consolidation of our cities, including the development of brownfield land, has been central to the urban renaissance agenda since the late 1990s. However, results from the ASCCUE project show that urban densification can be in sharp conflict with adaptation measures, as well as wider sustainable development objectives (particularly in relation to the social domain). Increasing the built mass of urban areas conflicts with the adaptation agenda in two main ways. It not only acts to intensify the urban heat island effect, but through a process of 'urban creep' can also pose problems for urban drainage. These issues are especially important within our towns and cities, with complicated feedback processes acting to amplify the impact on the built environment (for instance, riverine flooding may combine with flooding from overwhelmed storm drains and sewers to heighten the seriousness of an urban flooding episode). In response, adapting our cities for climate change would benefit from greater consideration of ecological principles, in particular the use of green and blue spaces to produce cooling and water storage capacity, as well as enabling infiltration. From recent experience however, it is evident that greenspace is often the loser in urban development processes, and it is clear that a more balanced approach to the densification process is needed – for example, some land classified as 'brownfield' may actually have useful multi-functional attributes. Furthermore, cities that are poorly designed for the predicted hotter summers of the future are likely to become uncomfortably hot, leading to increased use of air conditioning and a consequent reinforcement of climate change. Planners therefore need to be aware of the trade-offs involved and strive to ensure that a balance is struck between promoting mitigation attributes and the need to retain and promote land uses which moderate adverse climate change impacts.

From the scoping exercise, there would appear to be more opportunity for synergy and 'win-win' solutions at the neighbourhood or building scale. A range of climate-related factors can compromise the integrity of buildings and other infrastructure, with the most critical identified as flooding, wind and driving rain, subsidence and soil movement. Through informed urban design it would be possible to address the resilience of building stock to the impacts of changing climate, whilst simultaneously considering the integration of energy efficiency and renewable options. Building height, location and layout of new development, spacing, even the materials used, are all important considerations for mitigation and adaptation efforts. The explicit consideration of where win-win, or at least low regrets, solutions exist, combined with the identification of examples of mal-adaptation, would be of considerable benefit to best practice guidelines. This knowledge could then be used to improve the long-term sustainability of our buildings and other infrastructure through legislation and guidance, whilst simultaneously contributing to the mitigation agenda.

In reality, for many high-density cities in the UK it is likely that retrofitting and other innovative initiatives (green roofs can reduce energy requirements as well as performing important adaptation functions) may be required, however there are also significant opportunities for the uptake of adaptation measures associated with major programmes of urban restructuring and regeneration. However, the ASCCUE research findings indicate that the type and severity of impact varies according to neighbourhood type – city centre, restructuring, densifying suburb, new build etc – and as such adaptation strategies will need to be evidence-based where possible with location specific, or ‘place-based’, integrated assessments holding greatest potential for exploiting the synergies between mitigation and adaptation that do exist.

Ultimately, the challenge is not only to better understand the synergies and conflicts between the two approaches, but to ensure that any response to climate change, whether mitigation or adaptation, is embedded within the wider context of sustainable development, contributing to a combination of economic, environmental and social well-being within our towns and cities.

Dissemination:

McEvoy D., Lindley S. and Handley J. (2006) Adaptation and mitigation in urban areas: synergies and conflicts. Proceedings of the Institution of Civil Engineers, Municipal Engineer, 59, No. 4, 185-191.

McEvoy D. (2006) Climate goals need balance, Planning magazine, 17th Nov 2006.