Community Resilience to Extreme Weather – the CREW Project

Final Report

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EPSRC Engineering and Physical Sciences Research Council

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Funded by EPSRC within the Adaptation and Resilience to a Changing Climate Coordination Network (ARCC CN), the CREW project represents an ambitious, interdisciplinary programme of research providing a transferable template to provide guidance in planning for adaptation and community resilience to extreme weather events in the metropolitan regions of the UK.

Engineering and Physical Sciences Research Council

EPSRC Projects reported

This report constitutes the final project report for the following six interlinked Programme Packages (PPs), together comprising the CREW project.

Research Project Title	Principal Contact	PP	EPSRC Grant Ref. Number
Identification and assessment of coping measures for dealing with extreme weather events	Prof L Shao	PP1	EP/F036442/1
Community Resilience to Extreme Weather events through improved local decision making	Prof K Jones	PP2	EP/F035861/1
EWESEM — Socio-economic model and community impact simulators	Prof G Pryce	PP3	EP/F037716/1
SWERVE — Severe Weather Events Risk and Vulnerability Estimator	Prof H Fowler / Dr S.Blenkinsop	PP4	EP/F037422/1
WISP — Weather impact 'What-If' Scenario Portal	Dr S Hallett	PP5	EP/F036817/1
CREW Project Co-ordination and Management	Dr S Hallett	PP6	EP/F036795/1

Report edition 2.0

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Contents

Glossary of Abbreviations

The following useful abbreviations are adopted:

Abbreviation	Definition
API	Application Programming Interface
CEC	Commission of the European Communities
CESP	Community Energy Savings Programme
CMS	Content Management System
CREW	Community Resilience to Extreme Weather
CSV	Comma-Separated Variable
EAC	Environmental Audit Committee (House of Commons)
ED	Enumeration District
EDINA	A JISC National Data Centre based at the University of Edinburgh
EPSRC	Engineering and Physical Sciences Research Council
EWE	Extreme Weather Event
EWESEM	Extreme Weather Event Socio-Economic Model
GDAL	Geospatial Data Abstraction Library
GHG	Greenhouse Gas
GIS	Geographical Information System
GLA	Greater London Authority
GOR	Government Office Region
IBH	Inter-Borough Hotspot
IDW	Inverse Distance Weighting
IMD	Index of Multiple Deprivation
IPCC	Intergovernmental Panel on Climate Change
JISC	Joint Information Systems Committee
KDE	Kernel Density Estimation
LCCP	London Climate Change Partnership
LCLIP	Local Climate Impacts Profile
LSOA	Lower level Super Output Area
MAUP	Modifiable Areal Unit Problem
NI	National Indicator
NPD	Natural Perils Directory
NSRI	National Soil Resources Institute
PSMD	Potential Soil Moisture Deficit
SELRZ	South-East London Resilience Zone
SIMV	Single Index of Multiple Vulnerability
SME	Small and Medium-Sized Enterprise
SSWELL	Shrink and Swell
SWERVE	Severe Weather Events Risk and Vulnerability Estimator
UFS	Underground Foundation Stability
UHI	Urban Heat Island
UKCIP	UK Climate Impacts Programme
UKCP09	UK Climate Projections (2009)
UNFCCC	United Nations Framework Convention on Climate Change
WISP	'What-If' Scenario Portal

Further definitions and terms are presented in Appendix One.

Executive Summary

Community Resilience to Extreme Weather (CREW) was an Engineering and Physical Sciences Research Council (EPSRC)-funded research project which stretched for four years from 2008 to the final general assembly in November 2011, and was established to develop a set of tools for improving the capacity for resilience of local communities to the impacts of current and future extreme weather events. Taking a case study of five southeast-London boroughs, CREW investigated local-level impacts on householders, small and medium-sized enterprises (SMEs) and local policy/decision makers from a range of hazards associated with extreme weather events (EWEs), including flooding, subsidence, heat waves, wind storms and drought. The CREW research investigated the potential future changes in these hazards, the impediments to and drivers of change and the consequent opportunities and limitations for local communities' adaptive capacity. This was undertaken through consideration of decision making processes across five local authority areas in London, to the south of the River Thames, namely Croydon, Bromley, Lewisham, Greenwich, and Bexley. As a study area, these boroughs comprise the 'South-East London Resilience Zone' (SELRZ). The SELRZ area is of economic significance and part of the strategic London Plan, which states that the effects of climate change should be incorporated into the development of the 55,000 additional homes and 100,000 new jobs planned up to 2026. A set of web-based mapping and information tools were developed during CREW's lifespan using state-of-the-art EWE and hazard modelling methods to present current and potential future hazards for a range of future scenarios from the UK Climate Projections (UKCP09). Further to these, a tool for the evaluation of coping/adaptation mechanisms was also provided.

CREW comprised a consortium of researchers drawn from 14 Universities and was established to:

- gain a better understanding of the impacts of extreme weather events (current and future) on local communities, based on three community groups: householders, SMEs and decision makers;
- integrate social and physical research to develop an improved understanding of risk from EWEs at the community level;
- study the complex inter-relationships between community groups in order to improve the understanding of risks, vulnerabilities, barriers and drivers that affect the resilience of a local community to extreme weather events;
- quantify and rank a number of technical and adaptive coping measures for reducing vulnerability to the extreme weather effects of heat waves;
- develop web-based information dissemination tools for integrating the project outputs, delivering maps, reports and guidance on impacts and resilience measures for extreme weather.

CREW focussed on understanding the frequency and magnitude of current and future hazards and their likely socio-economic impacts. Initiatives, such as the Stern Review[1], had previously provided high-level socio-economic impacts, but had not provided sub-regional or local estimates pertinent at the community and individual scale. Therefore, the CREW consortium sought to investigate these impacts at the local level on householders, SMEs and local policy/decision makers, considering the opportunities and limitations for local communities' adaptive capacity. Within the case study area,

[1] Stern, N. (2006). Stern Review on The Economics of Climate Change. HM Treasury, London. ISBN 0-521-70080-9.

CREW sought to consider the community-scale decision making processes at play, including the impediments and drivers of change. The CREW web-based portal was designed to support decision making processes by providing a facility with which to explore the potential hazards for a range of future climates, and to evaluate different coping mechanisms in building design to address one specific hazard, that of heat waves.

The CREW project has represented a significant body of academic research, drawn across a number of collaborating research teams. The project was organised into a series of 'programme packages' which are reported here, together with their specific research outcomes and conclusions.

This report is submitted as the final project and stakeholder report of the EPSRC-funded research programme 'Community Resilience to Extreme Weather – CREW Project'. Crew was part of the Adaptation and Resilience to a Changing Climate Coordination Network (ARCC CN).

CREW Researchers

The following researchers and persons were involved in the CREW project:

Coordinator: Hallett, S.H.

Principal Investigators: Shao, L., Jones, K., Pryce, G., Blenkinsop, S., Fowler, H., Hallett, S.H.

Core research team: Ali, F.M.M, Baker, C., Barr, S., Berryman, F., BinguIngirige, Bovolo, I., Burton, A., Chen, A., Chen, Y., Cotton, I., Davies, M., Djordjević, S., Eastwick, C., Emberson, C., Few, R., Ford, A., Goodier, C., Harvey, H., Mullins, A., Porritt, S., Proverbs, D., Quinn, J., Rayner, A., Rose, C.B., Simms, D., Soetanto, R., Thomas, D., Thornes, J., Truckell, I., VanHoek, M., Walsh, C., Wedawatta, G., Wood, G., and Zhao, S.

Project Administrators: Carter, M., Colclough, A., Stephens, M., Payne, Z.

The research team would like to pay especial thanks to Dr G.Wood, whose original insight was instrumental to the success of the CREW project.

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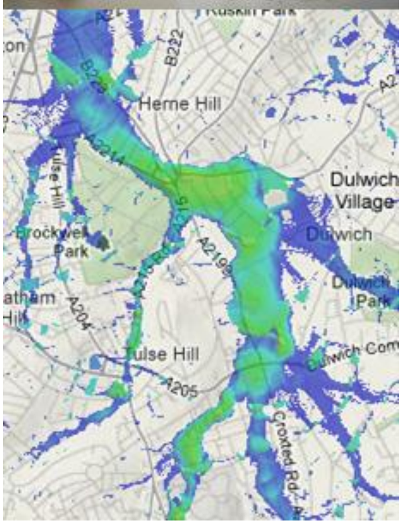
Chapter One. Introduction

Community Resilience to Extreme Weather (CREW) was an EPSRC-funded research project, established in 2008 to develop a set of tools for improving the capacity for resilience of local communities to the impacts of future and future extreme weather events. It comprises a series of linked projects forming a broad consortium of some 40 researchers, drawn across 14 Universities. The research focussed upon a case study area of five local authorities in London, to the south of the River Thames, namely Croydon, Bromley, Lewisham, Greenwich, and Bexley. As a study area, these boroughs comprise the 'South-East London Resilience Zone' (SELRZ). The SELRZ area is of economic significance and part of the strategic London Plan (Mayor of London, 2008), which states that the effects of climate change should be incorporated into the development of the 55,000 additional homes and 100,000 new jobs planned up to 2026. CREW was established to gain a better understanding of the effects of future climate change on extreme weather events and associated hazards, and to develop a range of tools for improving local-community resilience. Previous initiatives, such as the Stern Review (Stern, 2006), had considered high-level socio-economic impacts, but had not addressed sub-regional or local estimates pertinent at the community and individual scale.



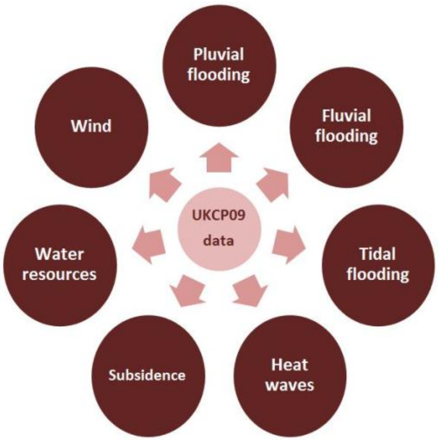
The CREW research therefore sought to address the needs of a range of key beneficiaries and stakeholders including: (1) decision makers for community resilience; (2) property owners and householders, insurance companies and the building industry; (3) small to medium sized business enterprises (SMEs) such as housing associations, and (4) the research community.

CREW consequently investigated observed and potential local-level impacts on householders, SMEs and local policy/decision makers from a range of extreme weather-related hazards including flooding, subsidence, heat waves, wind storms and drought. The research has sought to investigate opportunities and limitations for local communities' adaptive capacity, considering the decision making processes across communities and the impediments and drivers of societal change. A web-portal, www.extreme-weather-impacts.net, provides projections of potential hazard occurrence for a range of future scenarios from UK Climate Projections (UKCP09) for the near- to mid-21st century, together with evaluations of coping mechanisms for building design in addressing the adverse effects of heat waves.

Specifically, CREW has sought to follow an interdisciplinary approach, seeking to:

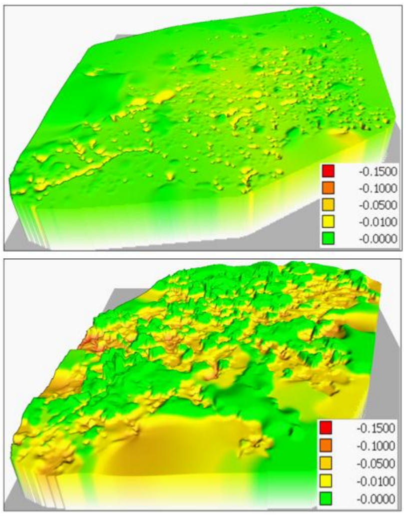
a) develop and apply new implementations of the UKCP09 weather generator to produce spatially-consistent, high-resolution, catchment and city-scale time series of current and future climate for the SE London Resilience Zone (SELRZ) study area;
b) gain a better understanding of the impacts of EWEs (current and future) on local communities, based on three community group: householders, SMEs and decision makers;
c) integrate social and physical research to develop an improved understanding of risk from EWEs at the community level;
d) study the complex inter-relationships between community groups in order to improve the understanding of risks, vulnerabilities, barriers and drivers that affect the resilience of a local community to extreme weather events;
e) quantify and rank a number of technical and adaptive coping measures for reducing vulnerability to the extreme weather effects of heat waves;
f) develop web-based information dissemination tools for integrating the project outputs. These deliver maps, reports and guidance on impacts and resilience measures for extreme weather.

The CREW research programme has been broad ranging and as such has secured achievements and impacts across many disciplines with over 50 publications and presentations (see Appendix Two) secured together with representations made to several influential committees and agencies. A wide engagement with industry, health practitioners, and policy makers at local, as well as national levels has benefited both the research team and the stakeholders alike.

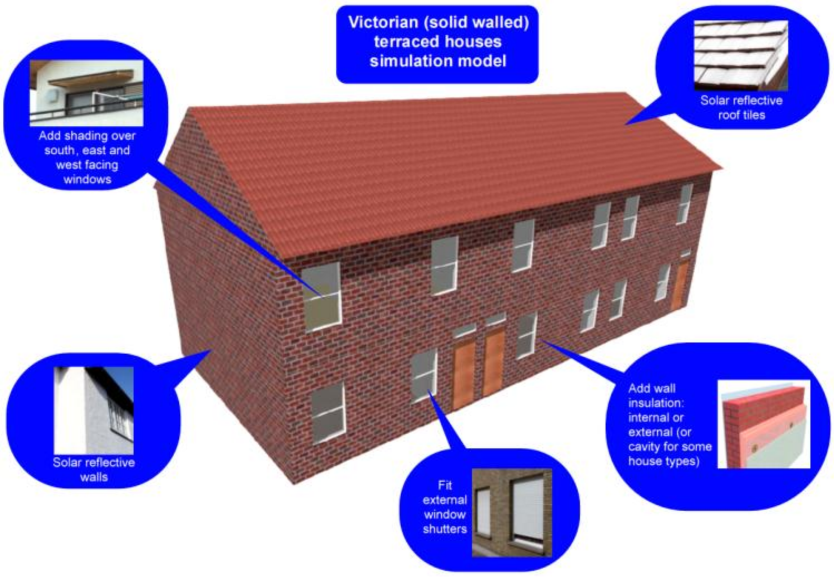


A key outcome of CREW has been the development of the UKCP09 weather generator approach to produce spatially consistent high-resolution catchment and city-scale simulations of current and future climate for the SELRZ (Chapter Two). This work has underpinned the development of a series of hazard models exploring projections for periods centred on the 2020's and 2050's, compared to the current time. This has included, for example, the development of detailed models for pluvial/fluvial flood at the local scale. Soil subsidence models were prepared to show the likely impacts of clay-related subsidence, whilst heat wave models have drawn on land use information as well as other factors to produce future estimates of heat events across London and producing mapped vulnerability and risk indices as outputs. Model simulations for exploring water resource drought have been produced that provide projections of water saving measures, such as the implementation of hosepipe bans, considering the effects of both water supply (climate and hydrology) and demands (population change). UKCP09 climate projections with particular probabilities were used to generate corresponding hazard projections, identified using a range of user-relevant thresholds. A notable achievement has been in how uncertainty in future hazards has been captured and represented to the various stakeholder groups.

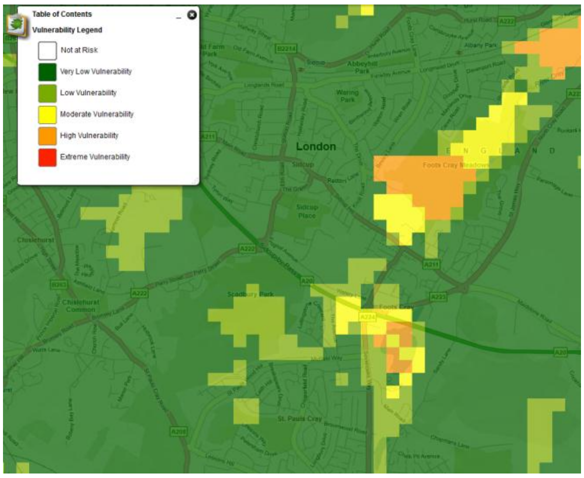
The research has facilitated the development of a risk assessment framework for improved community scale decision-making and has led to a greater understanding of the issues faced by SMEs in interpreting extreme weather scenarios and in developing contingency plans to reduce their vulnerability, improving resilience and adaptive capacity (Chapter Three). The risk assessment framework developed was supported by technical evidence of coping strategies as well as related field work drawing upon these inputs. The research has allowed for a greater understanding of the issues faced by local policy planners in preparing community level assessment plans for extreme weather events and has further led to a greater understanding of the inter-relationships between households, SMEs and local authority policy makers. For example, we have helped develop the first empirical model to quantify the negative effect that flood risk has on employment, and how this relationship will vary depending on the spatial concentration of employment (Chapter Four). This work has been facilitated through the integration of climate model output with high-resolution hazard models and the portrayal of these outputs utilising a web mapping geographical information system (GIS) interface.



The CREW research has led to a fruitful critical literature review being published concerning the shortcomings in existing theoretical and methodological frameworks as identified when applied to a world characterised by global climate change. This work has further led to the development of a published theoretical framework, grounded in the economic psychology and sociology of risk literatures that draws together the links between risk-adjusted house prices, observed house prices and flood risk, and posits how these relationships are likely to change in the context of climate change (Chapter Four). The research has also led to an estimation of the first models of the effect of flood risk on house prices and employment, taking into account feedback effects from and to each sector. We also take into account spatial spill-overs - how changes in house prices and employment in one area can have knock on effects on surrounding areas not directly affected by flood risk.

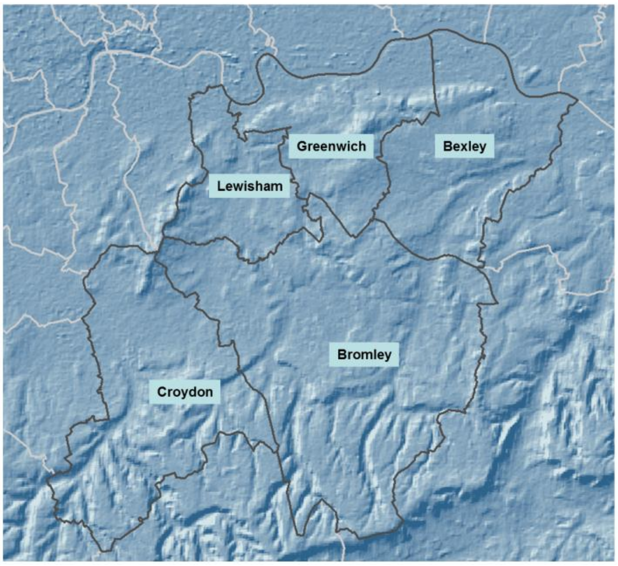


Considering the development of coping measures for community adaptation, for the first time CREW has offered a systematic and quantitative assessment of passive coping measures for heat waves which will vastly improve building adaptation/retrofit decisions (Chapter Five). Taking human factors into consideration, the CREW research has revealed the major importance of occupancy for building adaptation design options and has revealed the interaction between mitigation and adaptation – some mitigation measures would undermine adaptation, and *vice versa*. It has been shown how this could be prevented with minimum cost and disruption where mitigation and adaptation are both considered together.



Lastly, the CREW research programme has allowed the deployment of an interdisciplinary web-based portal designed to integrate information, model results and qualitative information summaries from the research outputs from the other programme packages (Chapter Six). Key achievements include not only the use of the web-portal toolkit to represent phenomena indicative of the conditions prevailing under a range of uncertain future climates, but also the successful drawing together of coherent information representing the social sciences, atmospheric sciences, earth sciences, hydrological sciences and engineering disciplines. Use of the web-portal toolkits to support the project's stakeholder engagement activities has also represented an important achievement, where decision makers, SMEs and householders were able to utilise the functionality of the WISP tools to aid communication and understanding, guided by the project facilitator. Further to this, the engagement with user groups in CREW meetings and general assemblies have allowed the researchers to take on board and reflect stakeholder viewpoints. CREW has thus led to the development of 'real-world' tools that communicate effectively the many scientific outputs to affected parties.

Throughout this report, certain terminology has been adopted extending the literature of resilience and adaptation to climate change. Appendix One presents an extended glossary of terms, together with definitions adopted by the project partners.



Overall, CREW represents an ambitious, interdisciplinary programme of research focussing on the issues of community responses to extreme weather events in the SELRZ study area, coordinated to draw together the inter-disciplinary research undertaken (Chapter Seven). The research has also produced a transformative template which, looking forward, can now equally be applied in and transferred to other metropolitan regions of the UK to provide guidance in planning for adaptation and community resilience to extreme weather events.

References

Mayor of London. (2008) *The London Plan. Spatial development strategy for greater London. Technical report*, Greater London Authority, 2008.

Stern, N. (2006). *Stern Review on the Economics of Climate Change*. HM Treasury, London. ISBN 0-521-70080-9.

CREW report structure

The CREW project final report draws from each of the six core, interlinked programme packages which, together with the stakeholder report, are ordered into chapters as below.

Chapter Two. SWERVE — Severe Weather Events Risk and Vulnerability Estimator – the development of computer models that estimate extreme weather events and associated hazards for current and future climates at the community-scale – these will be founded on the UKCP09 climate projections for the study area, medium emissions scenario. *(Programme Package 4)*

Chapter Three. Community Resilience to Extreme Weather events through improved local decision making – stakeholder-led research to understand better how community groups (policy makers, householders and SMEs) respond to extreme weather events and to study the complex relationships between them. *(Programme Package 2)*

Chapter Four. EWESEM – Extreme Weather Event Socio-Economic Simulator. Socio-economic model and community impact simulators – the development of a 'What if?' scenario model for quantifying and understanding the socio-economic impacts of extreme weather events. *(Programme Package 3)*

Chapter Five. Identification and assessment of coping measures for dealing with extreme weather events – identification and assessment of existing coping measures, from simple personal options through to hard engineering solutions, for dealing with overheating extreme weather events. *(Programme Package 1)*

Chapter Six. WISP — Weather impact 'What-If' Scenario Portal – the integration of all Programme Packages into a community-focussed toolkit for mapping likely future extreme weather events, for assessing their impacts under a range of scenarios, and for evaluating and offering a range of coping measures. This will be delivered using web-based mapping services. *(Programme Package 5)*

Chapter Seven. CREW Project Co-ordination and Management – Coordination and management of the CREW research effort and dissemination events. *(Programme Package 6)*

Chapter Eight. Stakeholder report – Responses from key stakeholders.

The CREW project is described in full online at the project web portal www.extreme-weather-impacts.net.

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Chapter Two. A Severe Weather Events Risk and Vulnerability Estimator (SWERVE)

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Overview

SWERVE used the latest probabilistic climate model output and climate downscaling tools to project the frequency and severity of future extreme weather for the South East London Resilience Zone (SELRZ) for two periods centred on the 2020s and 2050s assuming medium greenhouse gas emissions. The historical period of 1961-1990 was also used as a reference baseline indicative of 'current' conditions. This output was then applied to models of weather-related hazards comprising flooding, heat waves, subsidence, drought and wind. High resolution maps and charts of current and future hazards have been produced based on location specific and user-relevant thresholds. This has resulted in one of the broadest assessments to date of different weather-related hazards impacting on the city scale.

What are the issues that SWERVE has addressed?

A key component of the CREW project was the development of a 'Severe Weather Events Risk and Vulnerability Estimator' (SWERVE). This sought to generate state-of-the-art simulations of weather-related hazards for the South East London Resilience Zone (SELRZ). The aim was to produce information that may be mapped and used to support climate-change adaptation related decision-making by local community stakeholders including residents, local businesses and planners. The output of SWERVE has therefore sought to quantify:

- current hazards (adopting the 1961-90 climatological baseline for this purpose);
- future hazards for two periods (the 2020s and 2050s). In particular, stakeholders told us that projections for the near-future were the most useful; however, projections for later decades provide challenges to stakeholders who have insufficient planning in place for the medium- to long-term impacts of change in hazards. Later periods also and also allow us to more clearly determine any trend or 'signal' of future climate change.

To provide the best possible climate information SWERVE applied the UK Climate Projections (UKCP09; Murphy *et al.*, 2009). All projections were obtained assuming the medium future greenhouse gas emissions scenario from UKCP09.

How does this study relate to previous city-scale assessments?

Climate change impacts assessments on the city scale have tended to focus primarily on flooding and increased heat. SWERVE has therefore provided a more extensive assessment of hazards than has previously been undertaken at the city-scale (Figure 1), representing a testing ground for a broader-based assessment of potential climate change impacts and vulnerability and their integration in the adaptation decision-making process.

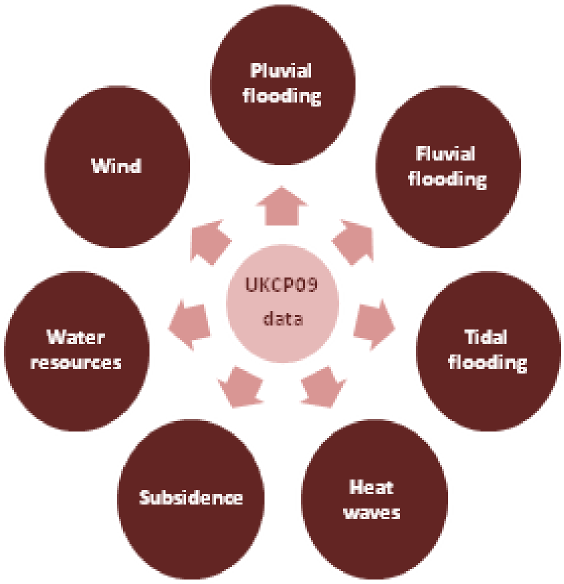

Figure 1: The full range of SWERVE hazard types.

How detailed is the hazard information provided by SWERVE?

UKCP09 provides climate model baseline simulations and future projections of climate at a resolution of 25 km but this is not sufficient to reproduce the local scale variations in climate that are important to the hazards shown in Figure 1. SWERVE has therefore built upon the functionality of the UKCP09 weather generator (Jones *et al.*, 2009), which provides downscaled weather simulations at a resolution of 5 km, in unique and innovative ways to generate the high resolution climate information required for hazard modelling. For example, rainfall simulations have been generated at 2 km and 15 minute resolutions to provide the detail required for realistic simulations of urban flooding (Burton et al, 2010). Further, since a spatial rainfall model was used, the rainfall simulations developed in SWERVE have a coherent spatial extent rather than providing information for individual 5 km grid cells only as in the UKCP09 weather generator.

How has SWERVE dealt with the uncertainty information provided by UKCP09?

UKCP09 reflects the uncertainty in climate modelling by providing probabilistic projections of climate change. This means that it is possible to assign probabilities to given magnitudes of change. For most of the hazards examined by SWERVE it was practicable to apply a large number of UKCP09 climate projections to the relevant hazard model to obtain a sufficient data sample to generate probabilistic hazard projections. However, one of the challenges met by SWERVE was to develop methods for the application of these climate projections to computationally intense hazard models which cannot feasibly apply a large sample from the UKCP09 climate projections, such as the pluvial/urban flood modelling (Burton *et al*., 2010). This was achieved by developing statistical sampling methods – for example the procedure developed for applying the probabilistic projections of future rainfall to urban flood modelling is shown in Figure 2.

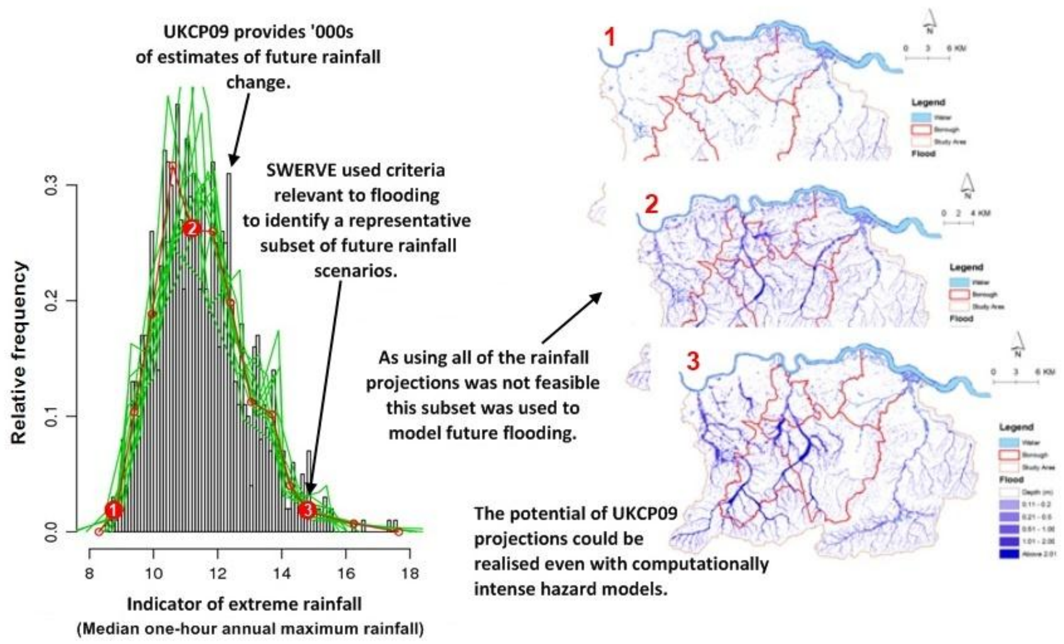

Figure 2: A simplified scheme for sampling UKCP09 projections for application in the Urban Inundation Model.

Note: See Burton et al. (2010).

What specific hazards has SWERVE considered?

SWERVE invited representatives from the three stakeholder groups to identify the sort of information they considered to be of use and to indicate relevant thresholds for specific hazards. Whilst it was not possible within the scope of this research project to provide results for every hazard identified, the methodology is readily applicable to many more hazards. Some examples of the hazards that were examined in SWERVE and the associated interested sectors are shown in Table 1.

Table 1: A summary of hazards examined in SWERVE.

Impact Type	Hazard	Definition	Sectors
Temperature/heat	High temperatures	Summer maximum temperature	Urban planners, architects, construction, health
	Heat waves	Heat wave frequency based on London specific temperature thresholds	
	Risk indices	The above measures incorporating current and future population	

		projections	
Flooding	Urban flooding	Flood depth and frequency based on critical thresholds and a new hazard number index combining information on maximum and average flood depth and flood extent.	Householders, insurers, business, urban planners, architects, construction, local contingency organisations
Water resources	Disruption to water supply	Frequencies of a range of interventions from public awareness campaigns to hosepipe bans and rationing	Water companies, local contingency organisations
Subsidence	Clay-related soil subsidence	A 9-point vulnerability score based on the combination of soil and climate data, ranging from 'Extremely Low' to 'Extremely High'	Householders, insurers, urban planners
Wind	Risk of damage to buildings Danger to pedestrian comfort or safety	Maximum gust speeds of at least 35 ms^{-1} Maximum gust speeds of at least 20 ms^{-1}	Insurers, urban planners, engineers

Stakeholders indicated that they did not require detailed information representing the full range of possible future climate scenarios provided by UKCP09. SWERVE therefore limited future hazard projections to representative "low", "medium" or "high" projections (corresponding to the 10th, 50th and 90th percentiles) for each hazard (see example in Figure 3).

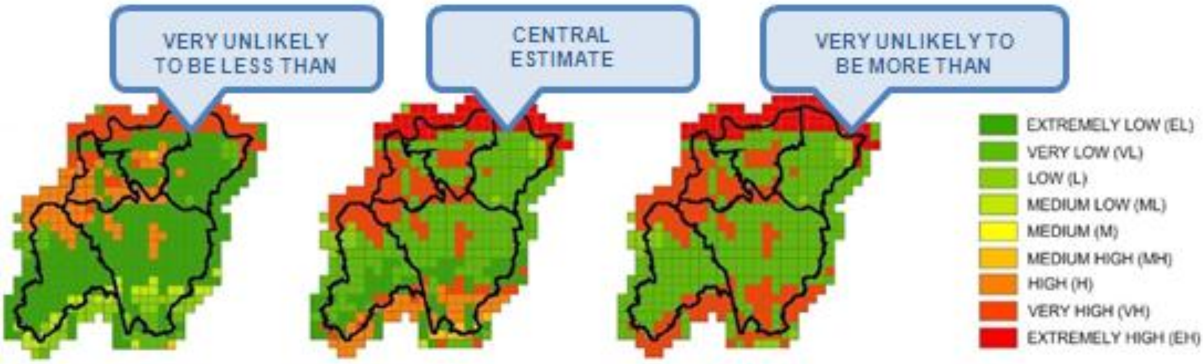

Figure 3: Representative projections of soil vulnerability to clay related subsidence for the 2020s.

Results are provided to users as 'low' (very unlikely to be less than), 'medium' (central estimate) and 'high' (very unlikely to be more than) projections of future hazard (Blenkinsop *et al.*, 2010).

This presents the probabilistic hazard information derived from UKCP09 projections to those engaged in the decision-making process in a more readily interpretable format.

Headline changes

SWERVE generated a vast amount of data covering the baseline and two future time periods for a number of different hazards and so the SWERVE database provides a wealth of local hazard information, analysis of which is beyond the scope of this report. Therefore, only headline changes are summarised here. For each of the impact types shown in Table 1, an example of a typical question that may be addressed using the SWERVE outputs is provided.

> Temperature/heat
>
> *"As a registered social landlord how can I identify which of my existing housing stock will be most exposed to heat waves as a consequence of climate change in order that I might prioritise which parts of my portfolio to adapt?"*

New methods have been developed in CREW to assess future exposure to hazards associated with high temperatures in cities. Satellite imagery was used to increase the resolution of the information provided by UKCP09. The work also identified the need to move from measures of exposure to hazards to measures of vulnerability – in other words how to factor in other drivers such as population density and growth to determine future risk exposure. This work can play an important role in increasing the awareness of heat waves as a major community issue.

- Potentially large increases in average maximum summer temperatures are projected across London (Figure 4) with an increase of ~3.7°C projected as a central estimate (50th percentile) for the 2050s. However, there is considerable spatial variability and for many areas in central London, to the west around Heathrow, and along the Eastern Thames corridor, the high estimate of change (90th percentile) projects temperature increases of around 8°C.

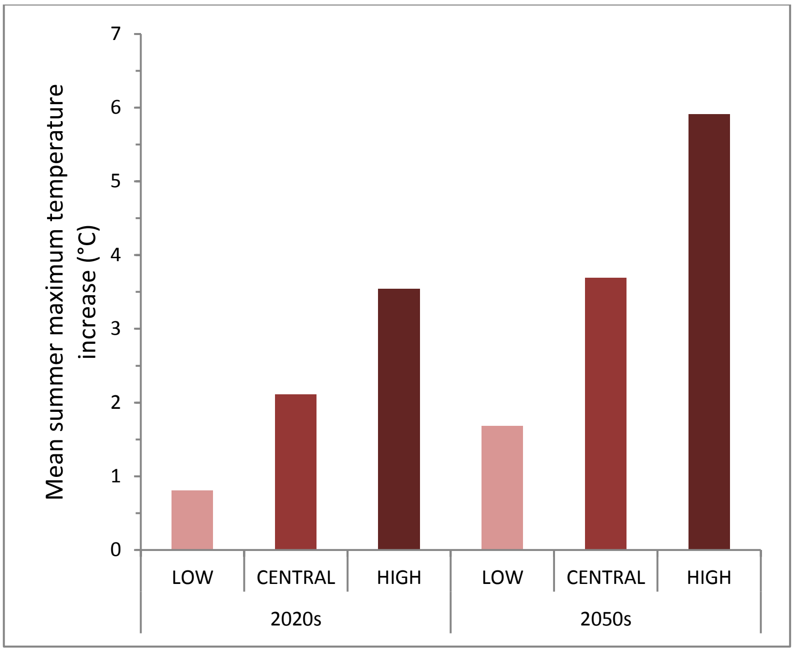

Figure 4: Projected increase in London average summer (June – September) maximum temperature for the 2020s and 2050s relative to the baseline.

Changes are shown for "low", "medium" and "high" probabilistic projections of change.

- Heat waves were considered by identifying areas in the UKCP09 climate projections with temperatures in excess of 32°C - 18°C - 32°C for sequences of daily maximum, minimum and next-day maximum temperature as defined in the NHS heat wave plan for England (Department of Health, 2010). High resolution temperature information was incorporated in the projections using innovative methods examining data derived from satellite measurements.
- These detailed future temperature projections were then combined with those for population to identify areas where future risk might be greatest (Figure 5). These potentially provide a first order targeting approach for adaption and planning for heat wave event response into the future.

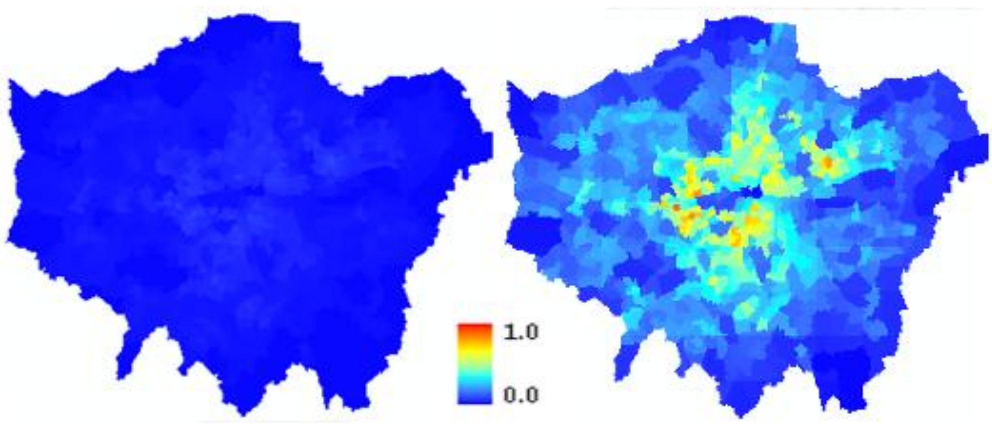

Figure 5: Heat wave risk for the baseline (left map) and 2050s high projection (90th percentile, right map).

Here the main population risk was identified as high-density residential areas in the centre and the east of London rather than in the SELRZ.

Flooding

"As a medium sized retail business how can I identify which of my outlets are most vulnerable to closure due to flooding? Are my key suppliers located in areas that are at a high risk of flooding?"

A rainfall model (Burton *et al.*, 2010) was used to obtain rainfall simulations and future projections based on UKCP09 at resolutions of up to 2 km and 15 minutes. This resolution is higher than that provided by UKCP09 and the model was also able to simulate spatial rainfall patterns – two essential characteristics for assessing flood risk in urban areas. This data was used as input to a hydrological/hydraulic model (Urban Inundation Model) enabling the combined assessment of both pluvial flooding (arising directly from rainfall accumulating on the surface) and fluvial flooding (arising when rivers overtop their banks) across the SELRZ for present and future climates.

- In addition to flood depth information (Figure 6) a "Hazard Number" index has been developed to measure flood hazard. This comprises the maximum and average flood depths and the proportion of the area flooded to provide a simple, readily understandable measure of the flood hazard in an area. Both the 2020s and 2050s project an increased flooding hazard when compared with the baseline.

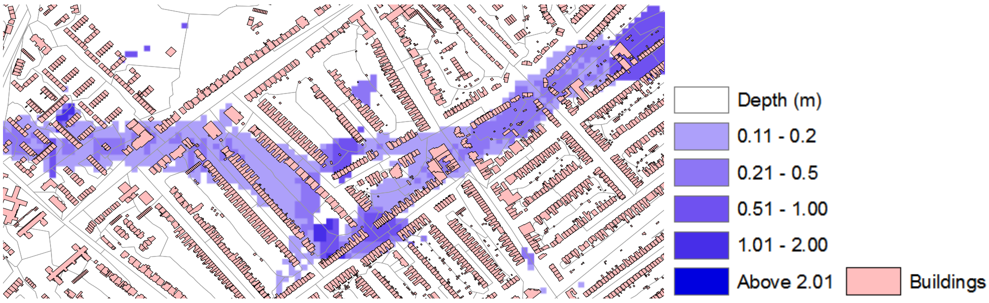

Figure 6: Illustration of flood mapping, showing maximum flood depth mapped for a particular locality.

By combining the hazard information with additional map layers a user could identify which retail outlets are in areas at greatest risk of flooding. Appropriate action could then be considered to reduce vulnerability to closure.

- The modelling approach is reproducible in other areas and with new computing technologies the computational load involved in running such high resolution models could be reduced. An improved event filter which only models rainfall events likely to cause flooding should also lead to improved efficiency.

- Additional modelling work indicated that the River Thames' defences have a design Standard of Protection (SoP) to contain a tidal surge with a 0.1% probability of exceedance in a given year (the "thousand year event"). When the defences were constructed, considerable extra height was added and so it is generally believed that the defences provide an actual SoP in the region of 1 in 2,000 years. Work undertaken in SWERVE indicates that the actual SoP afforded by the current defence system provides protection against the thousand year event with a (very) comfortable margin after 50 years of worst-case sea level rise (~400mm) from the IPCC 4th Assessment report (2007).

> Water resources
>
> *"As a local authority are we likely to face an increased requirement to assist in implementing emergency drought measures in the future?"*

The assessment of future drought occurrence used a sophisticated multi-model approach combining the UKCP09 climate projections with a rainfall model capable of simulating spatial rainfall patterns. The resulting rainfall projections were used within a hydrological model and the Environment Agency's water resource model for London (AQUATOR).

- Climate change and population increases will put further pressure on the limited resources of the London Water Resource Zone. Changes in the climate alone will increase the need for demand saving activities (Figure 7).

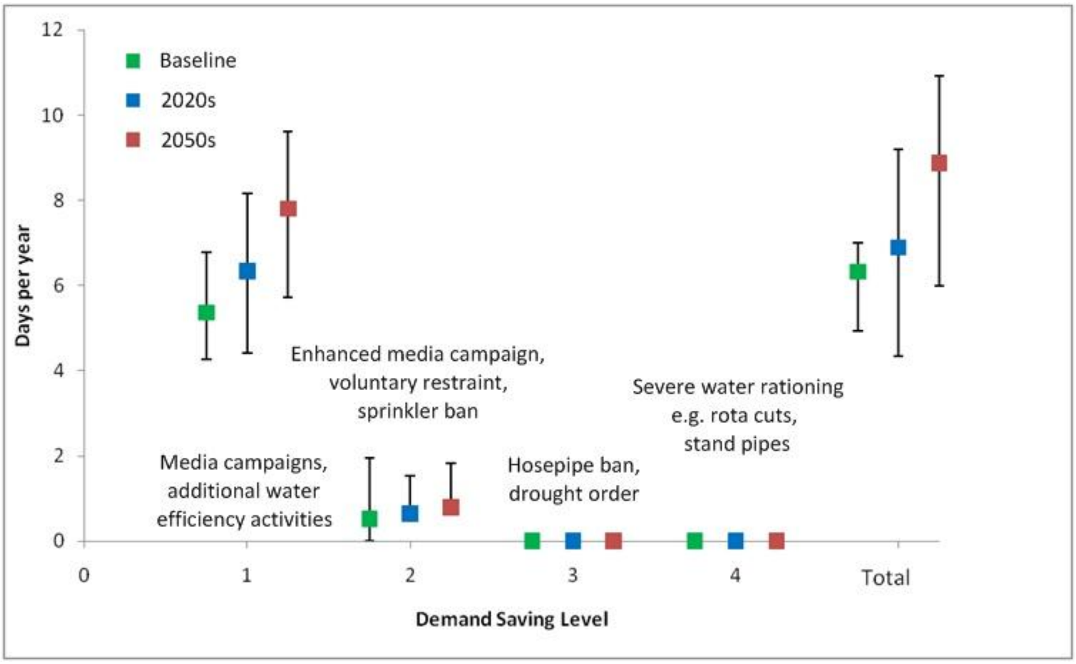

Figure 7: Annual demand saving days for the baseline and future scenarios based on current demand.

Note: Typical activities associated with different demand saving levels are shown. Boxes show the central estimate and the bars show the low and high ranges (10th and 90th percentiles).

- However, even assuming no effect from climate change, by the 2020s total demand saving days may still increase by nearly 50% compared to the baseline period due to projected population change, and if considering the projected 9% demand increase alongside the central estimate climate scenario, total demand saving days could increase by 175%.
- In order to offset demand increases coupled with the effect of climate projections, a combination of demand management e.g. reduction in water use per capita, more water efficient household appliances and new supply options e.g. desalination plant, new reservoirs, are required.

Subsidence

"As a house buyer in the Croydon area how might I learn about future subsidence risk and factor that in to my buying decision?"

Clay-related soil subsidence projections were calculated using a combination of climate and soil characteristics data and were presented to users via an easy to understand 9-point vulnerability score ranging from "Extremely Low" to "Extremely High" (Blenkinsop *et al.*, 2010).

- According to the central estimate there will be no change in vulnerability to clay-related subsidence across most of the SELRZ by the 2020s but it will increase across the North Downs and parts of Croydon. By the 2050s the central and high estimates both suggest that vulnerability will increase across the southern half of the SELRZ.
- Vulnerability across the SELRZ for the 2020s is shown in Figure 3 and could be compared with current vulnerability to assess the degree of change. This information could then be used by a potential house buyer as part of their decision making process.

Wind

"Is my house likely to experience more storm damage in the future?"

Average daily wind speed information is provided from UKCP09 climate modelling experiments but this is relatively coarse, at a resolution of 25 km. SWERVE used a method which has previously been used in the engineering community to estimate structural loading on new buildings to statistically derive hourly maximum wind speeds and gust speeds at a resolution of 1 km (Blenkinsop et al., 2012).

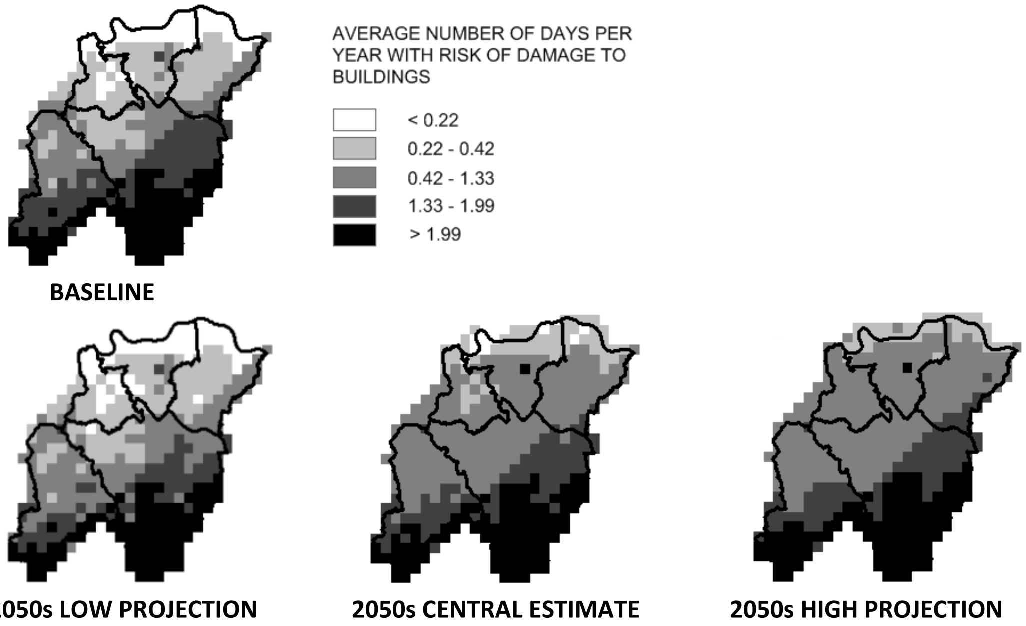

Figure 8: Simulated current (baseline) and projected future (2050s; low, central and high) projections of average annual frequencies of wind gusts which provide a risk of damage to buildings.

- By the 2050s changes in mean daily wind speed over the SELRZ are likely to be small and not significantly different to those for the baseline period. Averaged over the whole SELRZ this means there is a relatively small increase in the frequency of events posing a risk of damage to buildings.
- Using the central estimate projection indicates that the frequency of events posing a risk of damage to buildings remains at less than one event per year over the more densely populated northern areas of Lewisham, Greenwich and Bexley (Figure 8).
- It should be noted that there remain considerable uncertainties associated with climate model simulations of wind climate and confidence in local-scale projections is low.

Summary

The methods developed and information provided by SWERVE can be used in conjunction with tools developed elsewhere in CREW to provide opportunities to:

- target resources on “hotspot” areas (areas where more than one hazard is, or is projected to be, a problem) for mitigation and adaptation. The provision of information on local-scale variability in hazard occurrence could be incorporated into more effective policy-making;
- form a vital source of information to assist in changing community actions through various mediums such as increasing awareness and personal resilience;
- act as a framework to use identical approaches for city-wide studies in other regions.

SWERVE has provided projections for a wide range of potential hazards affecting south east London:

- there are potentially large increases in future heat wave risk arising as a result of increases in temperature, future urban development and population growth. Future risk is projected to be greatest in parts of London outside the SELRZ;

- detailed flood projections have been provided using a range of different metrics;
- water saving measures are likely to be required more frequently in the future in response to a combination of climate change and increased demand;
- vulnerability to clay-related soil subsidence is projected to increase in the southern part of the SELRZ;
- small changes in the occurrence of damaging winds are projected although uncertainties in the modelling of wind speeds are currently relatively high and so confidence in these estimates is low.

Accessing the SWERVE data

The SWERVE outputs have been integrated within a hazard/vulnerability mapping tool called the "What-if? Scenario Portal (WISP). This is a web-based geographical information system (GIS) presented at www.extreme-weather-impacts.net, that has a user-friendly interface providing the opportunity to inform climate change planning and decision-making. The tools are described in full in Chapter Six.

Acknowledgements

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Chapter Three. Community Resilience to Extreme Weather events through improved local decision-making

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Introduction

The 'Community Coping' project package investigated community resilience through social investigation. Led by the University of Greenwich, it brought together built environment disciplines, geography and psychology, to:

- Understand decision-making processes and perceptions of Extreme Weather Events (EWEs) amongst stakeholders;
- Examine the interrelations and interdependencies between stakeholders and their effects on community resilience;
- Learn lessons from history;
- Gauge stakeholder responses to local modelling outputs from other CREW projects;
- Develop tools and an integrated decision-making framework for resilience-building.

Here, stakeholders comprise interacting policy makers, SMEs and householders, shown in Figure 1. Each stakeholder group was viewed to have a dynamic internal structure and characteristic vulnerability, resilience and adaptive capacity, and group interrelations seen to condition the community resilience.

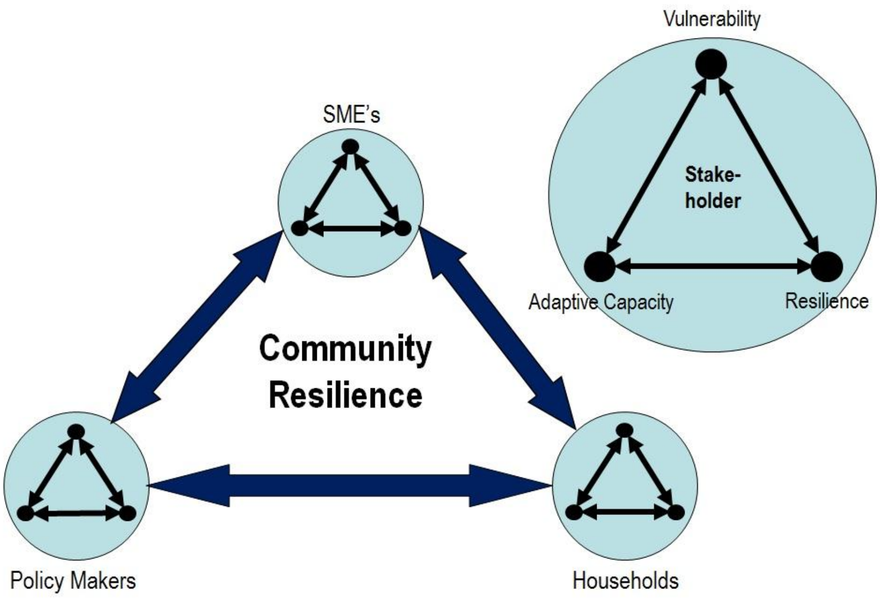

Figure 1: The CREW community stakeholder model

In the following chapter we ground the study in the legal, policy and historical context of extreme weather, and present findings from our study for lay, policy, practice and research audiences.

Legislative Entanglements and Moving Policy Frameworks

Extreme weather events in the UK are governed by four major entangled legislated themes. These comprise: Civil Contingencies, Climate Change, Planning, as well as Flood and Water Management.

There is nothing like actual experience of events and losses to trigger institutional performance review and adjustment. The Flood and Water Management Act 2010 in particular was informed and motivated by the Pitt Review following the major floods of 2007. The CREW research found the resilience of local and regional public institutions to be 'snow tuned' due to successive cold periods over the winters of 2009-11, which enabled implementation and feedback on recommendations made by the Quarmby Review (2010).

The research period extended over a period of national governance regime transition. The national policy of localism as well as its strategy for deficit reduction continues to transform the language, resourcing and relations between, central, regional and local levels of governance. The deletion of National Indicator 188 was emblematic of this shift from centrally policed to locally-led adaptation activity. New local authority responsibilities over pluvial flood and those forthcoming in health will continue to modify the institutional participants in local adaptation work.

Lessons from History

Six extreme events, some weather-related, others with different origins, were selected from the UK and globally to draw common and lasting lessons on resilience for this research. The events selected were; the 1953 storm/surge flood in the east of England, the European heat wave of 2003, the 2007 UK summer floods, the BSE crisis in the UK, as well as Hurricane Katrina of 2005 and the 2001 World Trade Centre attacks in the USA.

Several lessons were shared across quite different types of events - summarised below they revolve around knowledge, responsibility and false perceptions of security.

A lack of clarity concerning the responsibility of different agencies decreases resilience by leading to confusion and false expectations.

Inadequate or misleading information decreases resilience by creating confusion, lack of trust, and inhibiting timely action.

A false sense of security decreases resilience through reducing the perceived need to take action, whether in anticipation of or during an event. Inadequate warning systems increase vulnerability by not providing sufficient time for action. However, often warnings are accurate but appropriate action is still not taken. Inadequate protection from impacts increases vulnerability and exposure, creating a false security and disincentive to taking other protective measures.

A lack of preparation and sense of responsibility at policy and individual levels lowers resilience due to uncertainty over appropriate action, reliance upon action of others and being unprepared for the impacts.

Vulnerable critical infrastructure decreases resilience if extreme events renders them unusable, exacerbating the impacts on society and services.

Community cohesion increases resilience by providing trusted information and assistance before and after official intervention, by using local knowledge and networks and ensuring the vulnerable are cared for.

With extreme weather and climate risks, knowledge and the distribution of responsibility are uncertain and vary with time and location. The following sections provide tools for thinking through the implications of this.

The Local Authority Adaptation Ecology

Figure 2 presents the governed arenas brought together in adaptation work.

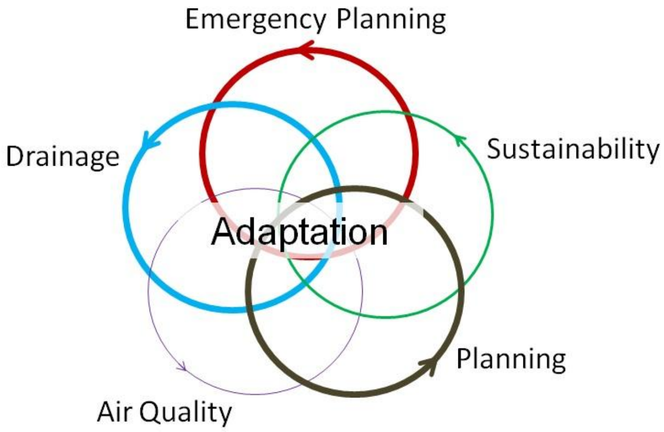

Figure 2: The Local Authority Ecology of Adaptation, thickness denotes relative power

The kinds of knowledge available to these sub-stakeholders vary unevenly, as does the aspect of the adaptation scenario (and resilience) that concerns them. Planning, Emergency Planning and Drainage are well established professions, with Sustainability eclipsing Air Quality in recent years as its political value has mushroomed in relative terms.

Adaptation is inherently interdisciplinary and with foreknowledge of working flows, purviews and scientific characteristics of actors involves, better decisions and time allocations can be expected. To the Emergency Planner, extreme weather is one set of risks to be managed at the earliest. Whereas to Sustainability it is a consequence of human actions, and part of long-term climate change work. Drainage engineers were found rich in a fine grained experiential knowledge of their boroughs, of topography, hydrology and recently flooded areas, in contrast with planner's more highly regarded bird's eye forward-looking toolkit.

Figure 3 incorporates legislation and policy into the decision-making ecology to give an idea of the complexity of competing demands into which resilience policy speaks.

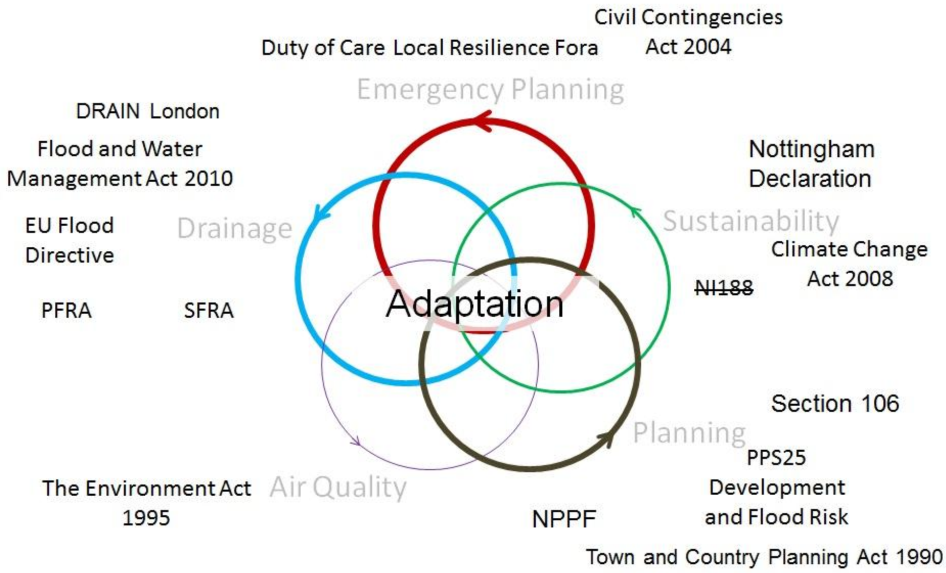

Figure 3: Policy drivers operating in the adaptation ecology

Adaptation and Time

The competing demands within the ecology of decision makers shape their collaboration and the points at which they can interact seriously with extreme weather issues. Perceived importance is also affected by political values and by mundane bureaucratic rhythms as depicted in Figure 4. Here perceived importance and time provide the axes across which we might see the rapid emergence and fading of a 'hot' issue, or the slow burn amplification of a longer term political realisation.

The future unfolds as a function of both continuous and discontinuous change, where public, political and policy decisions feature in addition to EWEs. Along the time axis is a series of institutional times scales by which modern public sector organisations are structured. The bias towards hot issues is clear, current democratic practices tend to focus on issues with short timescales, a major challenge for adaptation.

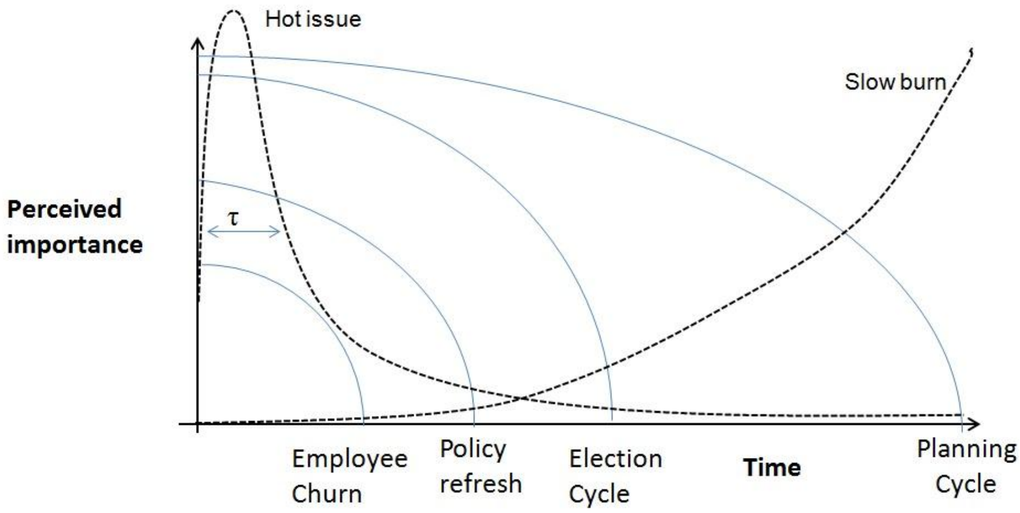

Figure 4: A plot to show the dynamic importance of issues along with organisational rhythms
Note: τ can be considered the duration of policy importance.

Dialogical Adaptation

Up to now, adaptation work from local authorities has been largely an internal affair, external relations and engagement are in their infancy, often curtailed for lack of will or perceived public interest.

With the maturation of flood management, mapping information, particularly for surface water flood is becoming more widely spread. Yet often, public officials were found to reticent to release maps, citing: the costs of engagement, 'flood-blight', the risk of alarming the older population, and the consequences of having to deal with public response, if not the insufficiency of awareness-raising.

However, community-based respondents responded well to prototype flood maps from the CREW project. Given the expiry of the Statement of Principles (ABI, 2008) in July 2013 and the changing flood insurance regime it is important that public agencies inform the public of flood risks.

Stakeholder Interrelations: The idealised and the actual

One of the causes of bad policy is in the mis-idealisation of the problem and the people involved. By comparing idealised and actual perceptions between stakeholders, our research was able to distinguish mismatches as shown on Figures 5 and 6. The implications of these findings could be in the maturing of relatively open public engagement and dialogue between stakeholder groups.

Figure 5: Idealised perceptions between stakeholder groups

Note: DM refers to decision-makers, SME to small and medium sized enterprises, HH to householders

Figure 6: A fieldwork-grounded snapshot of perceptions between stakeholder groups

The SME Impact

The local business stakeholder is seen of strategic importance due to its depth of interaction with the economy and population at large. It was a particularly difficult to engage in formal research, and was often in competition within itself. We conducted London-wide survey data collection and in-depth interviewing in South East London.

Maturity and sector were found to be a particularly important characteristic for business resilience. At their formative stage, businesses are least aware of the local flood history and have less developed relationships with suppliers and customers. Sector of industry was particularly determining of hazard exposure, with retail's stocks and construction's wide supply chains particularly notable.

The survey of SMEs registered a wide range of cumulatively experienced impacts which are organised and connected in Figure 7. The precise distribution and interaction between impacts will vary according to the type and extent of hazard, as well as the businesses own characteristics and sector. The diagram allows a business to overlay their own situation, with respect to the hazards, and then evaluate the relevance of adaptation and coping measures to their context.

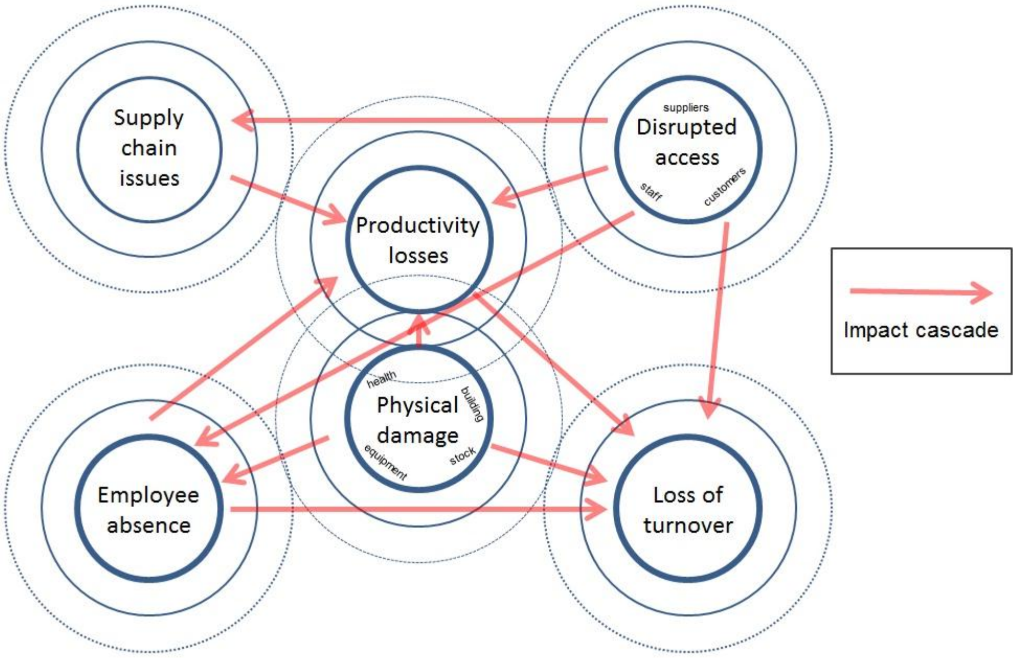

Figure 7 Connecting EWE impacts reported by SMEs

A few examples are worth demonstrating. Construction sector businesses, with large supply chains can diversify them to mitigate EWE impacts on any single one of them and maintain productivity. A retail outlet with vulnerable stores would be advised to explore their location and offsite office working can be facilitated with work-from-home arrangements. Establishing the relative strengths of interconnected impacts is also useful for assessing different insurance policies.

Existing risk and resilience perceptions

Flooding was recognised as a critical business threat, though seldom sufficiently prioritised for developing a coping strategy. It was perceived as an unavoidable risk that required community level engagement (structural protection, better drainage system, proper drainage maintenance). Nearly half of the SMEs had neither considered the risks nor implemented coping, those that had usually extended generic business risk strategies to deal with immediate impacts of EWEs. Supply chain impact potential was often unrecognised.

Participants interviewed believed that the strength, experience and determination of business owners and partners would help them cope and recover from extreme weather impacts. The local authority was perceived as a reliable source of information, but many flood-experienced businesses considered them unsympathetic to their previous extreme weather difficulties.

Coping measures

Coping measures, technical or procedural can prevent, reduce and manage disruptions to business organisations. Table 1 shows the relative prevalence of measures that were found.

Table 1: Coping measures reported in London-wide SME survey (N=140)

Property level coping measures		Other coping measures	
Premises improvements	19%	Business data backup system	23%
Stock / equipment relocation	7%	Business continuity plan	17%
Flood defenses	3%	Reviewing property insurance for EWEs	14%
Relocation of business premises	1%	Business interruption insurance	9%
		Planning for supply chain disruptions	6%

Coping needs to fit a business's context. A case study is featured in Figure 8 depicting the resilience measures taken by a new business in response to a 2007 flooding event, and how the measures would be expected to reduce impacts from future events. The business was a few months old at the time of impact and was still in recovery from it at the time of interview. However, despite taking measures, its insurance premium had increased. One way of incentivising business to invest in installing adaptation measures is for the insurance sector to respond to their uptake.

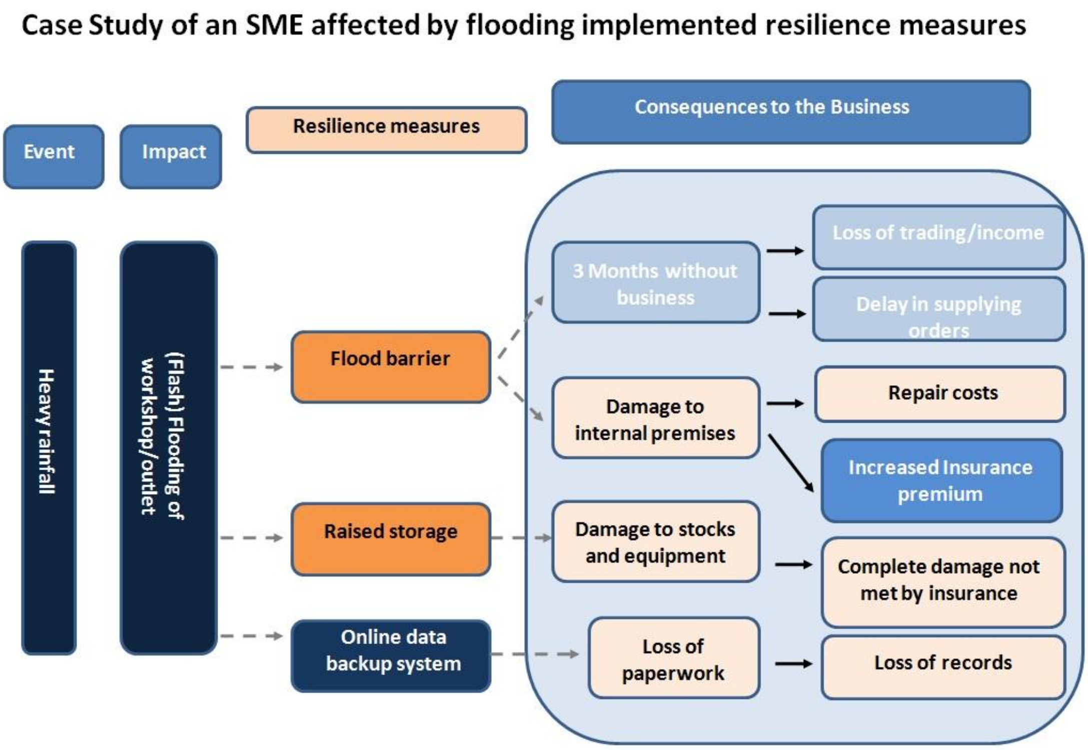

Figure 8: Analysis of impacts of EWE and resilience measures on a new internal decorations business

Households

Raising awareness of a hazard does not, of itself, engender action in the affected communities. An understanding of the psychological underpinnings of human behaviour including decision-making processes, can explain some of the adaptation strategies employed in the face of natural hazards, including flooding.

Policy-making bodies frequently adopt a ‘technical fix’ approach to reducing flood risk, and policy failures have historically been attributed to public ignorance or irrationality. For example, neither lack of information nor financial pressures can explain the low uptake of adequate property-level flood protection. Experience of past flooding is the critical factor.

Adoption of practical coping strategies is not a simple purchasing decision amenable to marketing techniques and involves complex psychological and sociological aspects. The uncertainty in probabilistic climate projections are perceived by the at-risk population differentially, depending on; their familiarity with the hazard, how ‘controllable’ the threat appears as well as personality types and belief systems. By understanding and acknowledging such factors, the policy-making sector can overcome some of the barriers to preparedness.

At a societal level, each community needs to identify its own determinants of vulnerability and adaptive capacity. This is a more effective approach than reliance on generic assessments and ‘preferred solutions’. This requires more active engagement with the community by the policy-making sector, and a transition from a ‘top-down’ to an inclusive approach.

Interconnections and Interdependencies

We explored perceptions and interrelations within and between different stakeholder and identity groups. This is significant given high expectations of ‘interconnectedness’ within modern societies. Resilience measures are limited when they do not take into account the way in which humans behave and relate as individuals and communities.

The study of historical lessons highlighted the issue of responsibility for community resilience. Qualitative and quantitative methods were deployed here to explore perceptions of social responsibility in relation to extreme flooding within local communities.

A community social responsibility framework is given in Figure 9. Its advantage over a public relations process model lies in its greater scope for community depth and comparison.

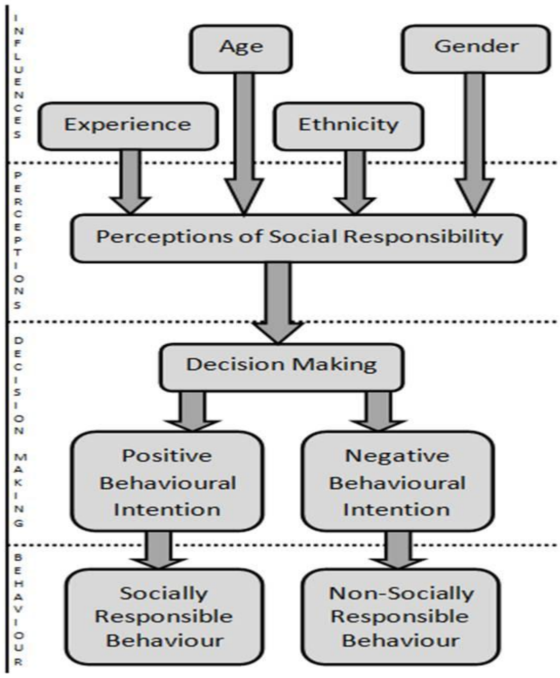

Figure 9: Community Social Responsibility model

Findings

Each stakeholder community group believed themselves more socially responsible than the other two groups perceive them. Policy makers believed they were most socially responsible while SMEs believed themselves to be more socially responsible than householders.

Generally the older participants reported higher levels of social responsibility. They are also more vulnerable to extreme events and display greater interest in hazards, acceptance of risk and the uptake of coping measures.

Recent flood experience was found to create experiential learning and raise reported levels of social responsibility, though not uniformly over location. It also brought out ethnic difference.

Ethnicity was found to matter amongst the flood experienced. Householder and SME stakeholders within the Asian group reported higher levels of social responsibility than the White group, who in turn reported higher levels of social responsibility than the Black group. Asians were found more aware and accepting of flood risk and more likely to adopt resilience measures.

This finding is in contrast to previous research which suggests majority groups estimate risks more precisely. The effect of ethnic difference is not consistent between countries and in this research a policy maker identity was found to override differences in policy maker ethnicity and experience.

Community Resilience Risk Assessment

Figure 10 depicts a new risk assessment method. It was developed with a social housing SME to appraise current and future risks, as well as adaptation options, with respect to extreme weather. It reads from top to bottom and operates at both component and whole system levels.

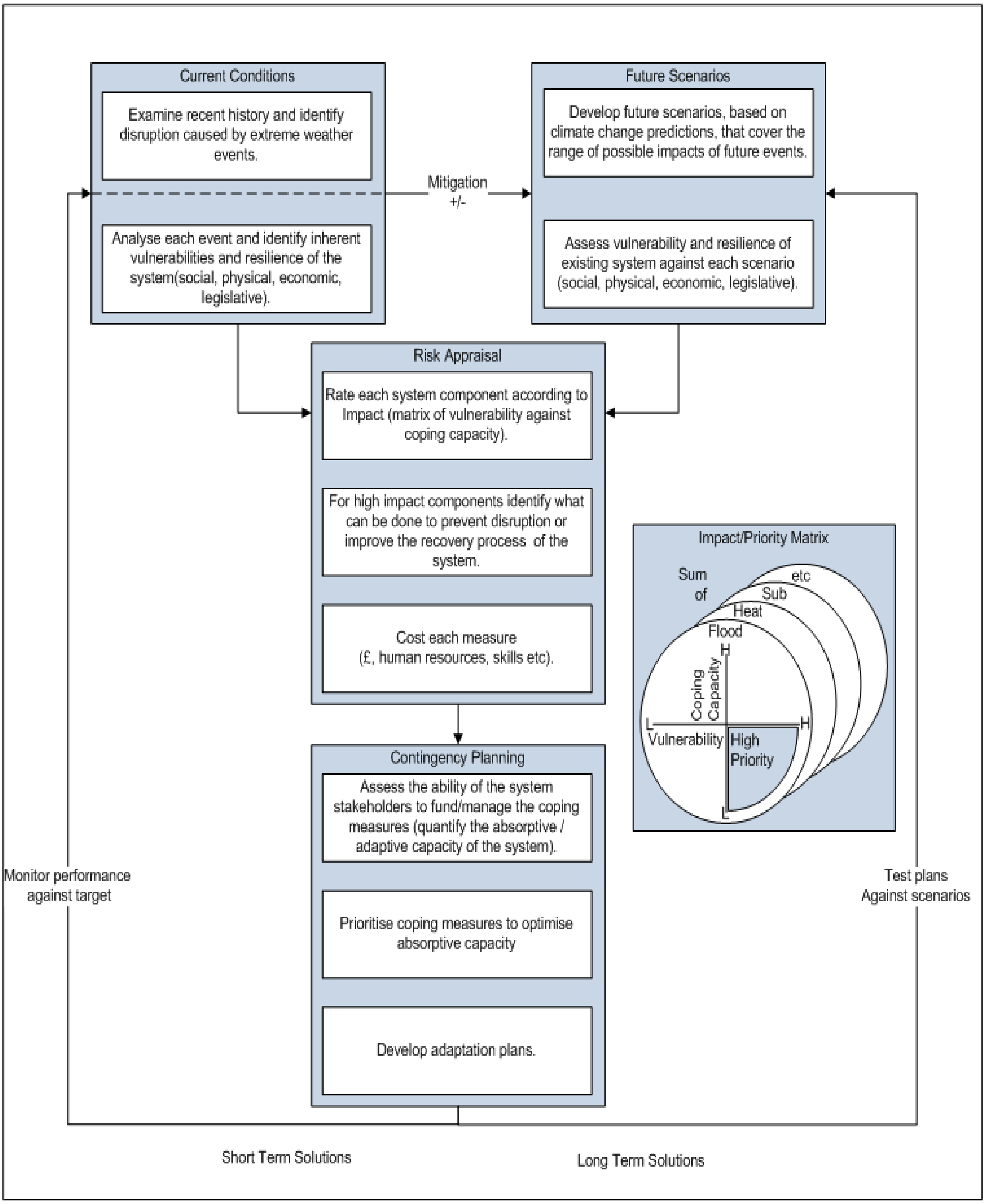

Figure 10: An Organisational Risk Assessment Framework for Community Resilience to Extreme Weather Events

The first phase in assessing resilience is to (a) establish the boundaries of the organisational system, and (b) assess its current *vulnerability* and resilience to EWEs. The latter may be achieved through a survey of local newspapers, conversations inside the local community and scanning of relevant policy documentation. At this point it is possible for stakeholders to test their existing emergency response plans.

The second stage involves repeating the initial phase but substituting the current climate with modified climate projections, such as those from the UK Climate Impacts Programme (UKCP09). Comparing the impacts between current conditions and future scenarios in relative terms provides a means for stakeholders to assess the significance of climate modified impacts against a familiar situation.

The third level of refinement is to (a) distinguish particular system components that are highly vulnerable to EWE impacts that presently have low coping capacity, and (b) develop interventions that reduce vulnerability and increase coping capacity. These interventions, their costs and expected impacts are assessed with stakeholders and plotted on an Impact-Priority Matrix (see inset on Figure 10).

Finally, having established and prioritised each resilience measure, high priority interventions within the adaptive capacity of the organisation are incorporated into a short- or long-term adaptation plan, and their performance monitored with time and risk reappraisal.

Acknowledgements

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Chapter Four. An Extreme Weather Event Socio-Economic Model (EWSEM) to identify the Social and Economic Impacts of Climate Change

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Overview

EWESEM has sought to advance the nascent socio-economic literature on the long-term local impacts of extreme weather events (particularly flooding). It has sought to identify practical ways forward, particularly in terms of quantitative socio-economic modelling and the development of methodological prototypes in the context of a changing climate.

Because the literature in this area is relatively undeveloped, at almost every turn we encounter significant boundaries to scientific knowledge that need to be overcome if the literature is to progress. We identified four major challenges for research in this area:

Challenge 1: Understanding the Effects of Long Term Increases in Flood Risk (as opposed to the impacts of particular flood events);

Challenge 2: Accounting for Agglomeration Economies and Other Spatial Spillovers;

Challenge 3: Modelling Interactions Between Sectors;

Challenge 4: Understanding the Behavioural Response to Flood Risk.

These four challenges formed the pillars upon which the EWESEM research developed. Our goal was not just to offer a theoretical critique but to propose and demonstrate creative solutions to these challenges, providing a ground-plan for how the literature might progress. Where possible, our ideas are illustrated using workable methodologies developed using real data. Where this was not possible, we developed conceptual frameworks to guide future development.

The key achievements and results of the EWESEM project are as follows:

- We developed what we believe is the first spatial econometric model of the impact of flood risk (as opposed to particular flood events) on the location of employment. Our results showed a significant negative effect of flood risk on employment location.
- We estimated what we believe is the first model of flood risk impacts to incorporate the impact of agglomeration economies: a major omission in the literature on the socio-economic impacts of flood risk is the failure to explore the mitigating effects of proximity to

other firms in the wider urban area. Our results showed that agglomeration economies play a significant role in mitigating the impacts of flood risk. This is important because it suggests that flood risk may have a more deleterious effect on employment in areas where economic agglomeration is weak.

- We sought to base these models on a high-resolution measure of employment location that would allow us to capture the local effects of flood risk—most previous studies consider employment patterns at much higher levels of geographical aggregation.
- We also developed what we believe to be the first model of flood risk impacts to allow for connections between employment and house prices (achieved by developing a GMM two-stage least squares spatial econometric model). Our results suggested that the feedback effects from house prices to employment were weak.
- We also estimated a number of models of house prices which took into account feedback effects from employment and deprivation. Our results showed that these feedback effects significantly increased the overall impact on house prices of increases in flood risk.
- Drawing on insights from the economic psychology and sociology of risk literatures, we developed a theoretical framework to help clarify the interpretation of flood risk/flood event impacts on socio-economic variables. One of the important corollaries of this conceptual model was that the responsiveness of house prices and employment to changes in flood risk are likely to increase over time (because the drivers of inertia—"amnesia" and "myopia"—are likely to diminish as floods become more frequent).

What is the Purpose of the EWESEM Models?

The EWESEM models are not intended as forecasting tools. Climate forecasting inevitably entails huge prediction errors over long time-scales and the socio-economic models we have developed only bring further layers of statistical uncertainty. Instead, the EWESEM tools are intended to help with *scenario planning*—being able to simulate, with a degree of realism, plausible effects of climate and flood risk scenarios, for a given set of background social and economic conditions. Simulation tools are not a substitute for sound judgement, but they can help policy-makers think through a wide range of effects in more detail and identify potential unintended consequences of policy intervention. In this respect, toolkits like EWESEM could have an important role to play in helping society adjust to climate change by directing policy-makers and regional planners towards the optimal location of mitigation strategies and also help inform long-term decisions regarding transport infrastructure and land-use.

Why House Prices and Employment?

We focussed on modelling the effects of flood risk on house prices and employment because of the key roles these variables play in determining socio-economic outcomes. *House prices* are important because:

1) Spatial variation in the price of a unit of housing services can, in principle, reveal the money value of the welfare loss associated with vulnerability to flooding and other risks and amenities. Given that the cost of insurance claims may understate the total impact of floods on human wellbeing (e.g. the cost of floods to the uninsured are overlooked) there is a potentially important role for housing economics in weighing up the costs and benefits of potential interventions.

2) Housing is a major source of collateral for the financial system. Being able to simulate house price impacts may help reveal the true exposure of financial institutions to future flood risk. The US subprime crisis has illustrated the vulnerability of the world financial system to the changes in the value of real estate in specific locations, and so an important implication of growing flood dangers is the wider destabilising effect that unanticipated house price declines could have.

3) Fragility and poor performance of pension funds has encouraged many households to make housing their major source of saving for retirement. Spatial variations in housing wealth are a potentially important source of economic inequality (Levin and Pryce, 2011; Pryce 2012). The potential for floods to wipe-out housing wealth accumulated over a person's lifetime is of particular concern in societies where there are high rates of homeownership and of households with undiversified portfolios.

4) House prices have an important role in sorting households across space according to their ability to pay. As prices fall in high flood risk areas and rise in low risk areas, the geographical dispersion of low income households is likely to shift accordingly. Such changes to the geographical distribution of low income households will change the relative proximity of low and high income households to flood risk, with corresponding implications for social justice.

Employment location is important because:

1) One firm's location decision affects the location decision of others due to "Agglomeration Economies". Agglomeration Economies refer to the benefits of locating near other firms. Such benefits arise due to reduced transport costs, access to pools of skilled labour, and the social interactions that foster the sharing of ideas and the development of initiatives. It is because of Agglomeration Economies that cities emerge. Agglomeration Economies may also have important implications for local economic resilience to flood risk and flood events.

2) Employment is a major source of human wellbeing as it provides meaningful occupation and the financial resources to improve living standards and fund public services.

3) Employment location has a major effect on the geography of house prices (Osland and Pryce, 2012) and the pattern of residential location.

4) The relocation of employment (e.g. due to flood risk) could lead to mismatches between the location of workers and the location of jobs (e.g. consider the concentration of long term structural unemployment in former industrial areas of the UK due to the relocation of manufacturing to emerging economies).

Challenge 1: Understanding the Effects of Long Term Increases in Flood Risk

Existing research (particularly in the employment literature) has tended to focus on the effects of a particular flood event rather than the long term consequences of flood risk. Such studies tend to show that flood events and other natural disasters have only a temporary impact on house prices and employment. The local economy may dip initially but will then tend to recover (Figure 1).

Note, however, that the effect of a particular natural disaster is only one part of a much bigger picture. We also need to understand the effects of long-term increases in *flood risk*, which may have very different implications to those of a particular *flood event*. A single flood may be regarded by the market as a one-off disaster and therefore of limited consequence for long-term quality of life or employment location. In contrast, an anticipated inexorable rise in flood risk in particular locations could cause firms to relocate and house prices to fall significantly as the prospects for resale value and local economic activity decline and the costs of insurance rise.

The shortage of research on the impacts of secular changes to flood risk at the local level is made especially important by the fact that changes in the geography of flood risk is a predicted outcome of climate models for many areas. This research deficit is particularly acute in the context of employment location—prior to the EWESEM project, there was not a single empirical study (as far as we are aware) of the employment effects of flood *risk*.

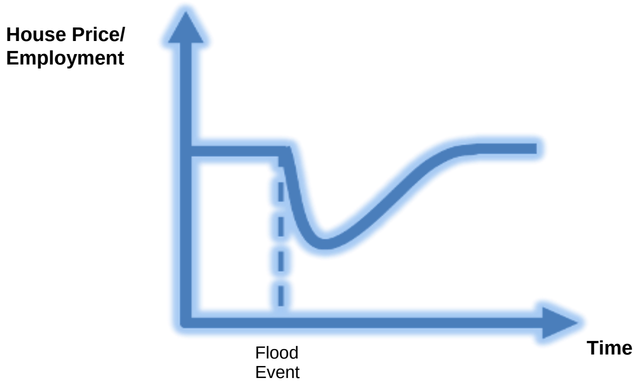


Figure 1 The Bounce-Back Effect

One of the challenges to advancing knowledge in this area is obtaining reliable measures of flood risk, both with regard to present risks but also estimates of flood risk at future time points. Unlike the employment location literature, the housing literature does include studies of flood risk, but these tend to rely on crude measures of flood risk, either a binary measure—indicating, for example, whether a dwelling is located on a flood plain—or a simple categorisation of flood risk, with no indication of variation in potential flood severity. Note also that usually these measures relate to fluvial or coastal flood risk, taking no account of pluvial flooding,[2] and are generally spatially imprecise.

One of the goals of the CREW project was to build models of employment location and house prices that estimate the effect of flood risk using measures that (a) are of high spatial resolution; (b) include both fluvial and pluvial flood risk; and (c) capture not only frequency of flooding, but severity also.

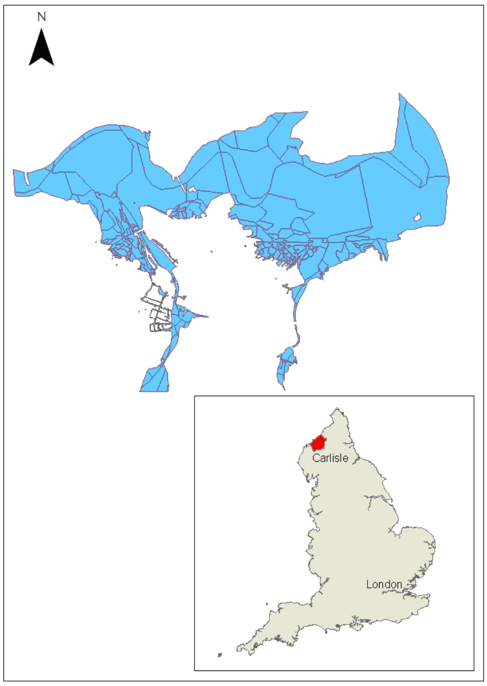
We estimated spatial econometric models of house prices and employment for the 5 boroughs of the SE London SELRZ study area using a high-resolution measure of flood risk provided by Programme Package 4 (PP4) that captured both flood frequency and flood severity using a “hazard number” approach. We found that that in both house price and employment models, flood risk had

[2] See Chen, Pryce and Mackay (2011) for a more detailed survey of the housing economics literature on flood risk and climate change.

a statistically significant negative effect on employment density and house price. Based on these models, we then simulated the impacts on house prices and employment in the future using data on flood risks in the 2020's and 2050's.

Challenge 2: Accounting for Agglomeration Economies and Other Spatial Spillovers

The effects of flood events and flood risk are complex, not least because they affect neighbouring houses and firms. Consider, for example, our estimates (Chen *et al*. 2009) of the house price effects of the Carlisle floods of 2005 (an outline of the flooded areas is provided in Figure 2).



Source: Environment Agency (2005).

Figure 2 Outline of Flooded Areas in Carlisle

We estimated the relationship between the distance to flooded properties and house price change and then used these estimates (calibrated on the basis of the Carlisle floods) to simulate what would happen if a similar flood were to occur in the London case study area.[3] The results are plotted in Figure 3.The graph shows that the risk adjusted price would be around 10.7% lower than current market prices in the flooded postcodes. Surrounding neighbourhoods would also be effected. Houses located 100 metres of the flood would fall in value by approximately 10% and those half a kilometre away would experience a price fall of around 5%.

[3] We assumed, for purposes of illustration, that a flood occurs in the Postcodes indicated as having a "major flood risk" in the LandIS data (Keay *et al*, 2009), which was provided by Cranfield University, and labelled this hypothetical disaster, the "LandIS Flood".

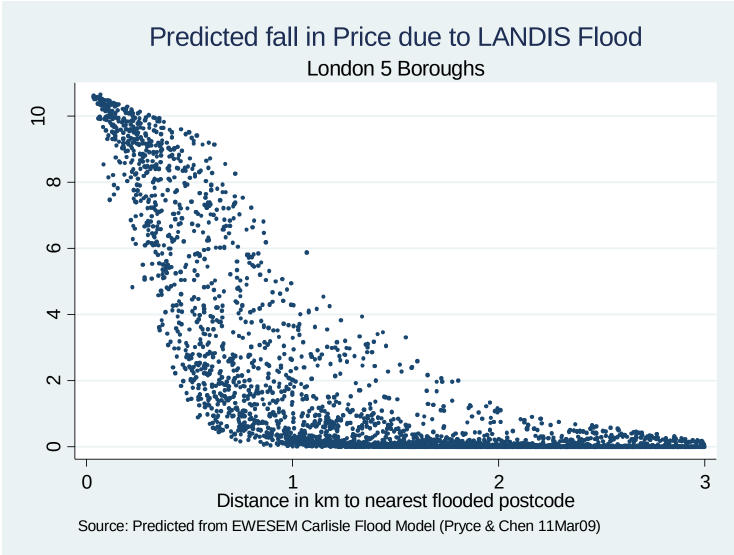


Figure 3 Spatial Spillover Effects on House Prices from a Flood Event

These "spatial spillovers" occur because dwellings in neighbourhoods surrounding flooded areas can experience upheaval due to the impacts on infrastructure, supply chains and access to amenities. Spatial spillovers may also arise due to households updating their prior beliefs about flood risks in the aftermath of nearby floods.

Spatial dependencies can lead to estimation errors if they are not accounted for when comparing the prices of houses that were flooded with those that were not. If dwellings that were not flooded were nevertheless subject to a negative price impact of the flood due to spatial spillovers, then the house price impact of the flood computed from such a comparison could underestimate the true impact. This is essentially a failure to establish the counterfactual. In order to gauge the true impact of a flood, the trajectory of prices for flooded houses has to be compared with the trajectory that would have occurred if there had been no flood. Unfortunately, neighbouring houses that were not flooded cannot be assumed to provide a reliable guide to the latter trajectory.

Another important implication of spatial spillover effects is that they could potentially overlap, especially when floods occur simultaneously in different locations in the same region. While the likelihood of simultaneous disasters may have been remote in the past, the probability may rise in future due to the combined effect of rising sea levels, more potent and frequent extreme weather events and storm surges. Overlapping spillover effects from multiple hot-spots of risk could imply spatial tipping-points in areas caught at the intersection of concentric house price ripples. Understanding these spillover effects and their interactions could be vital to our understanding of the effect of climate change on the house price map of countries like the UK where many major cities are located on coastlines or in flood-prone areas.

Similar spatial spillovers are likely to occur for firms. Note, however, that spatial interactions between firms could actually be a source of resilience (Chen *et al*. 2012). This is because firms benefit from locating near other firms—the "agglomeration economies" referred to earlier. While agglomeration effects have been explored at length in urban economics and regional science, there do not appear to be any studies that examine the interaction between agglomeration and flood risks. According to urban economic theory, industrial concentration offers positive externalities for firms to reduce costs and improve productivities, through labour market pooling, input sharing and knowledge spillovers. A thick and tight labour market assists firms to find suitable workers, and the concentration of firms enables them to share input suppliers, knowledge and ideas. Where network effects between firms are strong, there may be a greater collective potential to adapt to flood events, and these effects may be non-linear. For example, if there are only two suppliers of a particular input to firm A, even a geographically limited flood event might sever all supply links to A. However, if there are 200 potential suppliers of that input, the probability of all lines of supply being affected by a particular weather event will be disproportionately lower. The greater the agglomeration economies at a particular location, the stronger the attraction for a firm to remain at that location and the more severe the degree of flood risk would have to be to induce relocation. This has self-reinforcing effects across the urban agglomeration network because if firms know that other firms are unlikely to move, this reinforces the benefits to them of staying.

When we tested the hypothesis (see Chen *et al.* 2012) that there is likely to be a positive interaction effect between flood risk and agglomeration, we found that agglomeration economies do indeed have a significant effect in mitigating the impact of flood risk. These results imply that flood risk may have a more negative effect on employment in areas where economic agglomeration is weak. This is important because it changes how we assess the costs and benefits of flood intervention schemes at competing locations, implying an additional layer of complexity dependent on pre- and post-intervention agglomeration economies. Crucially, policy-makers and planners cannot assume a uniform effect across space from increases to flood risk, even if those increases are the same for all areas being considered—i.e. two areas could experience identical increases in flood risk but very different economic consequences if the agglomeration economies are different.

Challenge 3: Modelling Interactions Between Sectors

While the primary effects of floods (insurance costs, clean up, repairs, working days lost etc.) are well understood, the secondary effects on the location of jobs, house prices and deprivation remain poorly researched. These longer term impacts could be profound, made all the more potent by interconnections between sectors (Figure 4).

An important connection between house prices and employment arises from the spatial competition between firms and households for land which is a crucial driver of urban economic geography. The implication is that house prices are likely to be dependent on employment location and vice versa. So, while one would expect firms to avoid flood hazards due to the disruption and damage that flood events cause to the physical capital stock, supply chains and infrastructure, they have to weigh up such costs against the benefits of potentially lower rents associated with high flood-risk areas, rents that are determined by the competition for land between firms and households. If the marginal loss associated with flood risk is higher for households than firms, then firms will tend to locate in high flood-risk areas (and *vice versa*). Firm location affects employment, and this in turn affects the demand for housing and social deprivation, which are likely to have feedback effects on the attractiveness of an area to employers, all of which can have spillover effects on surrounding areas.

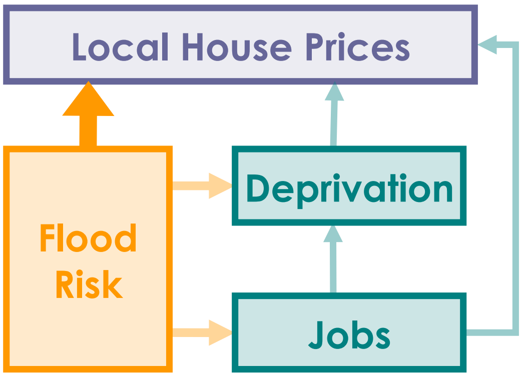


Figure 4 Interdependencies between house prices, jobs and deprivation

Clearly, how firms respond to flood risk signals will be crucial to the economic impact of anticipated climate change. If firms are drawn to high flood risk areas because of lower land prices, then areas with increased flood risk will attract employment, and future flood events could affect many more firms. If, instead, firms tend, on balance, to be repelled by flood risk, then we might conclude that those areas predicted to have increases in flood risk will gradually lose employment over time, with associated falls in house prices and increases in deprivation.

The net effect of these mutually-reinforcing secondary effects of flood risk could dwarf the immediate effects. For example, our estimates of the impact of doubling flood risk on house prices was far greater when employment and deprivation feedback effects were included (Figure 5), plotted for the 5 London boroughs of the CREW project study area.

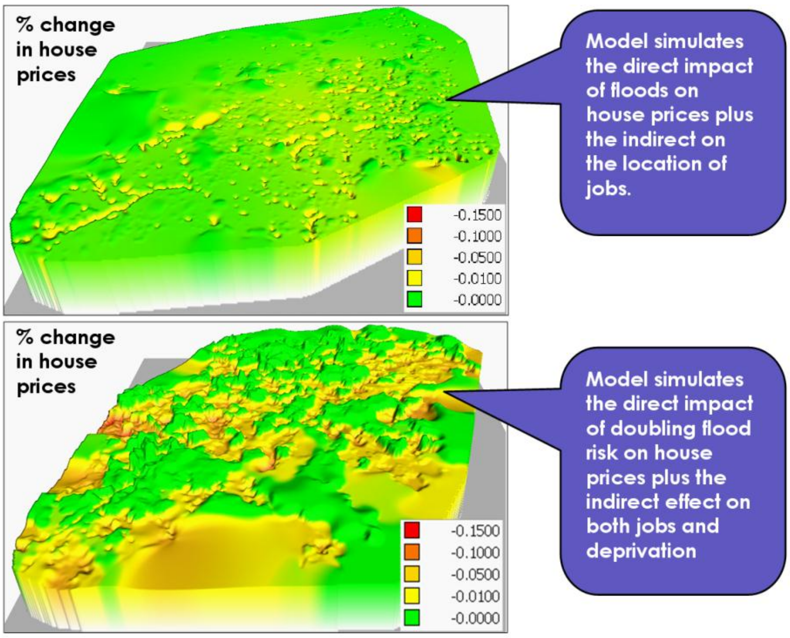


Figure 5 Mapping the Impact of a Hypothetical Doubling of Flood Risk

However, the feedback effects from house prices to employment appear to be more modest - using cutting-edge techniques that allow us to estimate the two-way causation between house prices and employment density, we found a modest and statistically insignificant house price feedback effect (this model was also novel in that it utilised a high resolution measure of flood risk that accounted for both expected severity and frequency of floods in SE London).

Challenge 4: Understanding the Behavioural Response to Flood Risk

The negligible feedback effect from house prices on employment may in fact be an important finding as it could signal a degree of inertia in house price response to flood risk. This is perhaps not surprising given the relatively flat rates of insurance premiums on the market at the time of the study arising from the longstanding "gentleman's agreement" between insurance firms and the UK government. This agreement, formally embodied the "Statement of Principles", is due to expire on 1st July 2013 (ABI, 2011, p.1).

In recent years, insurers have expressed concerns about the degree of under-pricing in flood insurance that the Statement of Principles perpetuates: "On average, home insurance for those at significant risk of flood is under-priced by 165% (£430) … with insurance under-priced by 500% or more in some cases" (ABI, 2011, p.1). Given these misgivings, and insurer's further concerns about the likely increases in future risk exposure due to climate change, it is probable that any future agreement will reduce the degree of cross-subsidy offered to high-risk households. The implication is that future risk premiums will more closely reflect variation in flood risk, and because the variation of risk is likely to increase due to global warming, the variation of premiums across households is also likely to increase. Moreover, awareness of flood risk among house buyers and firms is also likely to rise over time as the frequency and severity of floods rises. The combined effect of all this is that house prices and employment will become increasingly sensitive to flood risk and we would expect the feedback effects of house prices on employment also to increase.

To help us think through these processes in a more rigorous and coherent way we developed a detailed conceptual framework (Pryce, Chen and Galster, 2011), integrating insights from sociology of risk and economic psychology literatures (Levin and Pryce, 2008). We sought, in particular, to address the rather insular and atheoretical development of the housing economics literature with respect to flood risk which has led, at times, to a confused interpretation of the impact on house prices and a failure to distinguish between prices observed in actual transactions and those that would exist in perfectly-informed risk-adjusted market valuations. This has resulted in a failure to fully understand the ramifications of climate change for housing market adjustment.

The confusion arises partly because households may respond in non-rational ways to major risks, particularly when those risks seem remote, catastrophic, or highly uncertain; or when information about those risks is produced by institutions associated with government or with centres of power. All of these feature in human responses to the risks associated with climate change generally, and the effect of climate change on flood risk specifically. We developed a theoretical model of flood risk which incorporates the following behavioural traits:

(a) Myopia—individual homeowners will tend to discount information from anticipated future events (Pryce, 2012), with the discount rising progressively as the event becomes less imminent.

(b) Amnesia—individual homeowners will tend to discount information from past events, with the discount rising progressively as time elapses.

Myopia and amnesia mean that perceived risk could diverge considerably from actual risk, particularly if a long period has elapsed since a local flood has occurred. This in turn means that observed home prices may diverge from zero-risk prices and truly risk-adjusted prices for an extended time, concepts that have not previously been incorporated into housing economic models in a systematic or coherent way.

(c) Contingency—myopia and amnesia are likely to diminish in housing market importance as floods become more frequent and information and communication technologies improve, thereby leading to a (non-linear) convergence of observed and risk-adjusted home prices.

(d) Path Dependency—the convergence path of observed home prices towards risk-adjusted prices will tend to be idiosyncratic, contingent on the sequence of flood experiences in each area.

The implication of this framework is that it suggests a need to reinterpret apparent market inertia and the "bounceback effect". Sluggish price-responsiveness to rising flood risk, and regenerative market responses to flood events, may suggest the existence of tipping points in how markets will respond to flood risk in future. The historical non-response may reflect persistent ambivalence towards environmental risks (Anderson *et al.* 2011), lack of foresight ("myopia"), short memories about past floods ("amnesia"), misplaced assumptions about the ability of governments to provide support, or unsustainable reliance on insurance companies offering inexpensive comprehensive cover (Pryce, Chen and Galster, 2011). Historically benign market responses to flood events and flood risks may therefore have given us a false sense of security.

A further implication of our framework is that, whilst post-flood price declines may tell us little about the likely impacts of climate change, they may reveal the extent of drift from risk-adjusted prices, which in itself may offer a useful avenue of research into the behavioural economics of perceived versus actual risk pricing. How the relationship between observed house prices and flood risk changes following a flood is also of interest as the aftermath of a flood offers a temporary window in which the market is relatively well informed and may provide opportunities to gauge the true relationship between risk-adjusted house prices and flood risk.

Most importantly, our model suggests that important changes are needed in how housing economists think about climate change, the ramifications of which are likely to become increasingly potent as natural hazards become more widespread, severe and frequent.

Conclusion and Policy Implications

Challenges and Achievements

EWESEM has sought to advance the analysis of local socio-economic impacts of flood risk in the context of a changing climate. We attempted to address four major challenges facing this nascent field: (1) understanding the effects of long term increases in flood risk (as opposed to the impacts of particular flood events); (2) accounting for agglomeration economies and other spatial spillovers; (3) modelling interactions between sectors; and (4) understanding the behavioural response to flood risk.

While there remain major areas for development with respect to each of these challenges, EWESEM made a number of notable contributions, including the development of the first spatial econometric model of the impact of flood risk on the location of employment, utilising a high resolution measure of flood risk that accounts for both severity and frequency of flooding, and the first model of flood risk impacts to incorporate the impact of agglomeration economies and feedback effects from house prices. We also estimated a number of models of house prices which took into account feedback effects from employment and deprivation. Finally, we developed a new theoretical framework to help clarify the interpretation of flood risk/flood event impacts on socio-economic variables.

Results from our empirical models revealed a significant negative effect of flood risk on employment location, and a significant mitigating role from agglomeration economies. We also found that feedback effects from employment and deprivation significantly increased the overall impact on house prices of increases in flood risk.

Policy Implications

These models have important implications for government in terms of reductions in tax raising potential of the worst affected areas (due to firms moving away and high income households relocating to safer areas) and hence the future provision of local health and social services. There are further implications for long term infrastructure decisions—if the optimal location of firms is likely to change due to flood risk, so will the optimal location of transport links and nodes to service those firms. Note also that as well as quantifying the impact of anticipated flood risk at particular locations, these models could be used to simulate the effects of particular flood interventions that reduce flood risk, such as flood barriers. So EWESEM offers a simulation tool that could assist decision making.

Our finding that agglomeration economies have a significant mitigating effect on flood risk is also of potential interest to government at various levels because it suggests that flood risk may have a more deleterious effect on employment in areas where economic agglomeration is weak. Policy makers and planners cannot therefore assume a uniform effect of future changes to flood risk as a result of climate change, and this needs to be taken into account when estimating the costs and benefits of interventions to reduce flood risk at particular locations.

Government should also be concerned about whether housing and employment markets respond gradually and smoothly to changing flood risk, or whether adjustment will be delayed, sudden and disruptive. Existing evidence suggests that house prices, for example, remain relatively insensitive to flood risks and this may be due to cross-subsidisation of insurance premiums (i.e. premiums and availability of cover do not currently reflect the true risks of floods). This setup is unlikely to continue indefinitely, however, and there is a danger that unforeseen withdrawal of insurance could tip areas into decline. Note that availability of mortgage finance is usually dependent on a property being insurable. Other sources of market myopia include misplaced confidence in the responsibility and ability of the state to provide flood defences and/or provide public funds for the restoration and regeneration in the aftermath of a major flood.

To avoid the destabilising effects of sudden price adjustment there is an imperative for governments to reduce the magnitude of the price drift illusion, and hence defuse the implosive potential of tipping-points in house price adjustment. A key policy aim should be to facilitate a gradual adjustment path through improved information dissemination and regulatory and institutional reform.

There are also implications for local and regional planning bodies. Land planning has an important role to play in flood risk management. As dwellings, offices, roads and railways constructed now are likely to remain in place for a long time, there is an imperative for planners to rise above the myopia and sluggishness that plagues individual decision-making (Pryce *et al*, 2011), and design planning systems and incentives that will encourage the right sort of development in the right places, long into the future.

Land planning needs firstly to have the right regulatory framework, one that discourages development that exacerbates the risks and impacts of flooding (Pryce and Chen 2011). Second, planning needs to anticipate, and respond to, market signals. Planners have the difficult task of divining how changes to flood risk will shape the optimal location of firms and households in the long-term. Some industrial areas that are safe from flooding may, in future, be put to better use as residential areas, and so planners may have the important but challenging role of managing the transition to new patterns of land use.

While governments can discourage further development on floodplains using regulatory frameworks to promote sensible land-use zoning and well-enforced building codes, this response alone will be inadequate because new-build forms a tiny proportion of the total housing stock. The bigger problem is what to do about existing patterns of residential and employment location. Ultimately, market signals have to reflect the long-term risks associated with locating in areas likely to be worst affected by flood risk, otherwise households will continue to make ill-informed house purchase decisions which could have major implications for their long-term financial security. If limits to government finance imply that it will be impractical to maintain flood defences in particular areas, then such decisions need to be transparent and made well in advance to allow markets to adjust gradually and rationally.

More controversially, we would argue that sustainable flood management requires that insurance premiums should begin to reflect actual risk, albeit in a gradual and planned way. This is essential if we are to incentivize homeowners to undertake mitigating actions. It would also encourage better land-use planning and zoning because high insurance premiums in areas with high flood risk will dampen housing demand in these areas, and discourage new development and uneconomic re-development. Such proposals are controversial because of the implications (in terms of increased premiums and falling house prices) for those worst affected. Continued subsidization of insurance, however, is simply not sustainable in the long run. At some point, house prices and insurance will inevitably adjust. Far better that this occurs in a systematic and gradual way that gives households time to plan and adjust, than through a period of prolonged ill-informed inertia followed by economic collapse. Concerns about vulnerable households and inequitable impacts on the poor should be addressed in ways that minimize the distortion to market signals. Governments should, for example, plan and build social housing in low flood-risk areas in anticipation of providing an escape for low-income households trapped in high-flood risk areas.

Finally, the market-sorting effect of price adjustment has important implications for social justice and public policy. Other things being equal, an expanding geography of significant flood risk will cause prices to fall in those areas, and prices in remaining low-risk areas to rise. Low income households will find it increasingly expensive to reside in neighbourhoods with low flood risks. They will, as a result, be sorted by the market into higher-risk areas. Clearly, there are social justice issues here, particularly if low income households have contributed less to global warming than high income households due to their lower levels of consumption (and hence their smaller carbon footprint). We suggest policies to temper this process and argue that appropriately constructed housing economic models of price adjustment could have an important role to play in achieving a socially optimal response to climate change. Note that models developed in the EWESEM project only hint at these sorting effects—fully worked sorting models need to be developed that take into account not only the direct of effect of flood risk on house prices but also the indirect effect via the impact on neighbourhood social mix—that households have preference for particular combinations of social mix adds another important layer of complexity yet to be explored in the context of an unstable climate.

Acknowledgements

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5

Chapter Five. The identification and assessment of coping measures for extreme weather events — Adapting UK dwellings to reduce overheating during heat waves

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Overview

The work builds on previous research to generate systematic, quantitative and holistic guidance for retrofitting UK dwellings to reduce overheating risk during heat waves, whilst at the same time minimising winter heating energy and considering the cost of retrofit. An interactive retrofit advice toolkit has been developed, and made publically available (http://www.extreme-weather-impacts.net/twiki/bin/view/Main/PublicTools).

External shutters are the single most effective adaptation for most of the house types considered, typically resulting in a 50% reduction in overheating exposure. The exception is the Victorian terraced houses with solid walls, where high albedo walls or external insulation is often more effective. External insulation consistently outperforms internal insulation, though the latter could be effective as an element of combined adaptations.

Of the dwelling types studied (Figure 1), 1960s top floor flats and 2006 detached houses (Tier 2) experience more than twice as much overheating as Tier 1 dwellings (end and mid-terraced houses, ground floor flats and semi-detached houses). Tier 2 dwellings are “harder to treat” and their overheating exposure could not be eliminated using the passive measures tested, as one could with Tier 1 dwellings. It is possible to substantially reduce overheating and winter heating energy use of Tier 1 dwellings at moderate cost. The costs for retrofitting Tier 2 dwellings could be many times higher.

Adaptation should be considered together with mitigation, both in design practice and in regulations. If existing houses (e.g. terraced) are retrofitted for energy efficiency, without considering summer use, overheating could increase dramatically. Subsequent corrective measures could be costly and energy efficiency may suffer as a result.

Overheating exposure can be significantly greater for residents who have to stay at home during the daytime, e.g. elderly or infirm and they should not, where possible, be housed in the most vulnerable dwellings (Tier 2).

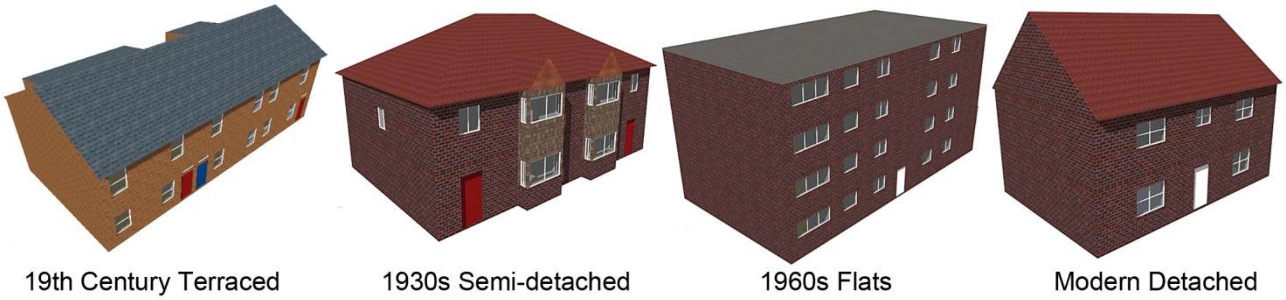

Figure 1. Dwelling types assessed in the research

Background

The emphasis on UK dwelling refurbishment to date has concentrated on reducing energy use and CO_2 emissions during the heating season. However, there has been increasing evidence pointing to the need for a more holistic approach. Climate change projections show an increase in both the frequency and severity of extreme weather events. These include heat waves, such as the one in August 2003, which resulted in the deaths of more than 35,000 people around Europe, over 2,000 of which were in the UK. Future retrofit planning therefore needs to take account of not only winter thermal performance and associated carbon emissions, but also the need to reduce summer overheating to provide a safe and comfortable environment in a changing climate. To achieve these goals detailed quantitative advice is required. The research presented here builds on previous published work by quantifying the effect of a range of single and combined adaptations during heat wave periods.

Methodology

Dynamic thermal simulation computer modelling (EnergyPlus) was used to assess and rank the effectiveness of selected single and combined passive adaptations (see Appendix A1) or interventions (for example, use of external shutters and changes to ventilation strategies) in reducing overheating during a heat wave period for a range of dwelling types, building orientations and occupancy profiles. Three options were considered for providing simulation weather data: future weather data, developed using a morphing methodology as used in CIBSE TM36; European weather data, to approximate the predicted future UK climate; and real UK heat wave periods from 1976, 1995 and 2003. A parameter tree was constructed to select combinations of adaptations, producing a total of 47,104 simulations for each weather file. The effectiveness of each adaptation was assessed in relation to the base case dwelling to which it was applied. Detailed descriptions of the methodology can be found in the academic papers listed in the 'Publications' section.

Overheating exposure of various building types

There are two 'Tiers' of building types in terms of overheating exposure. Tier 1 includes the 1930s semi-detached house, the 1960s ground floor flat, and the Victorian (19th century) end and mid-terraced houses. Tier 1 buildings typically experience less than half the overheating exposure of Tier

2 buildings (see Figure 2), which include the 1960s top floor flat and the modern detached house, constructed to 2006 Building Regulations. It is not surprising for the top floor flat to be in Tier 1 but it is not satisfactory for the modern new build to be in the same category.

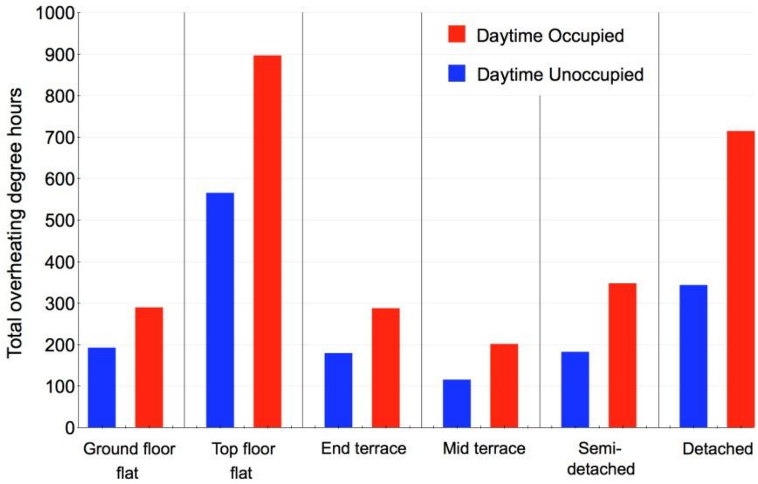

Figure 2. Overheating exposure of the targeted house types

Note: 'Degree hours' is a commonly-used building design measure indicating the number of hours at which the temperature exceeds a stated threshold temperature multiplied by the degrees that the threshold is exceeded.

Ranking of single adaptation measures

Based on the modelling, external shutters (Figure 3) are the single most effective adaptation for all house types considered, except the Victorian terraced houses, resulting typically in a 50% reduction of overheating exposure. External shutters should be integrated in future window designs and installed systematically at the time of window replacement. For Victorian terraced houses, where solid walls facilitate inward transmission of solar heat, high albedo, light-coloured walls could be marginally more effective, as shown Figure 4 (compare the blue bars for external shutters and light walls).

Figure 3. Examples of external shutters used in the Mediterranean region

Behavioural adaptations

The CREW results demonstrate the value of behavioural (zero cost) adaptations. For example window rules, whereby the building users refrain from opening windows when the outside temperature is higher than the indoor temperature, could result in a 30% reduction in overheating exposure for dwellings occupied during the daytime, as shown by the red bars in Figure 4 (compare the base case and window rules bars). Other behaviour related adaptations include closing internal blinds or curtains and using night ventilation. An illustration of their impact on overheating reduction can also be seen in Figure 4. These adaptations also feature significantly in the combined adaptations discussed below and form an integral part of many lower cost solutions. Their effectiveness necessarily depends on correct operation, which may require education.

Insulation

External insulation consistently outperforms internal insulation in all of the considered dwelling types, occupancies and building orientations for total overheating exposure (adding together the time spent in the living room and bedroom). Furthermore, internal insulation could lead to worse overheating, in some cases, than if no adaptation is implemented, as shown in Figure 4 (compare the red bars for base case and internal wall insulation). However, it should be said that internal wall insulation still has a role to play if combined correctly with other adaptations by using the retrofit advice toolkit (see below).

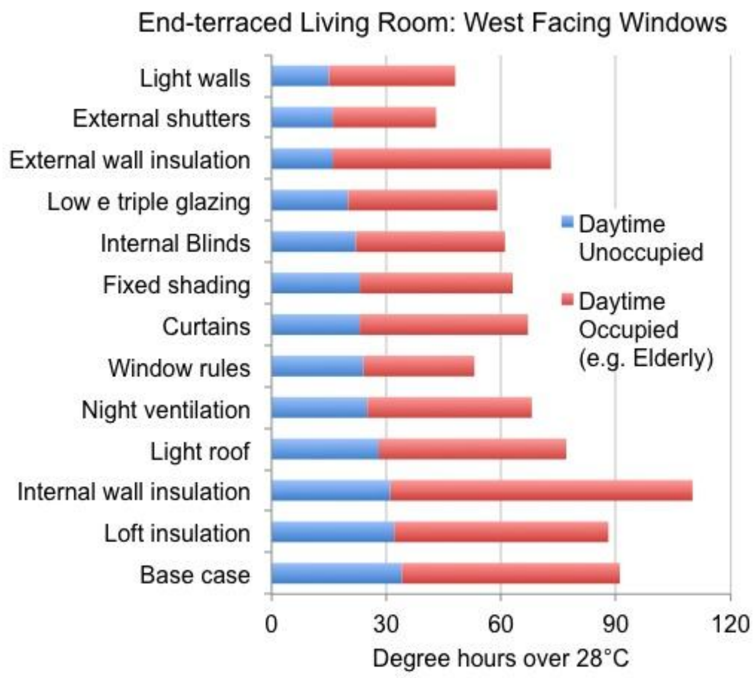

Figure 4. Sample graph showing effectiveness of single adaptations for the end-terraced house

Effect of occupancy

Figure 2 shows that across all building types studied, daytime occupied dwellings (e.g. those used by elderly people) experience much higher overheating exposure than those occupied only in the evenings (e.g. family occupancy). The overheating exposure associated with daytime occupancy could be over twice as much as the daytime unoccupied dwellings (e.g. compare the blue and red base case bars in Figure 4). This makes the elderly and infirm more vulnerable. The ranking of effectiveness of the single adaptation measures changes too with occupancy, as shown in Figure 4.

Combined adaptation measures

As illustrated in Figure 4, no single adaptation measure could eliminate the overheating exposure and combinations of measures are usually needed to maximise overheating exposure reduction. The assessment of compatible combined adaptations (Figure 5) involved approximately 100,000 computer simulations. The process was automated through a parametric control interface (jEPlus), using a cluster of parallel processors at the IESD. The data analysis was greatly facilitated by the creation of a series of interactive and information rich scatter plots (Figures 6, 7 and 8), which also form part of the retrofit advice web toolkit. Interventions were assessed against the 'base case' of no intervention.

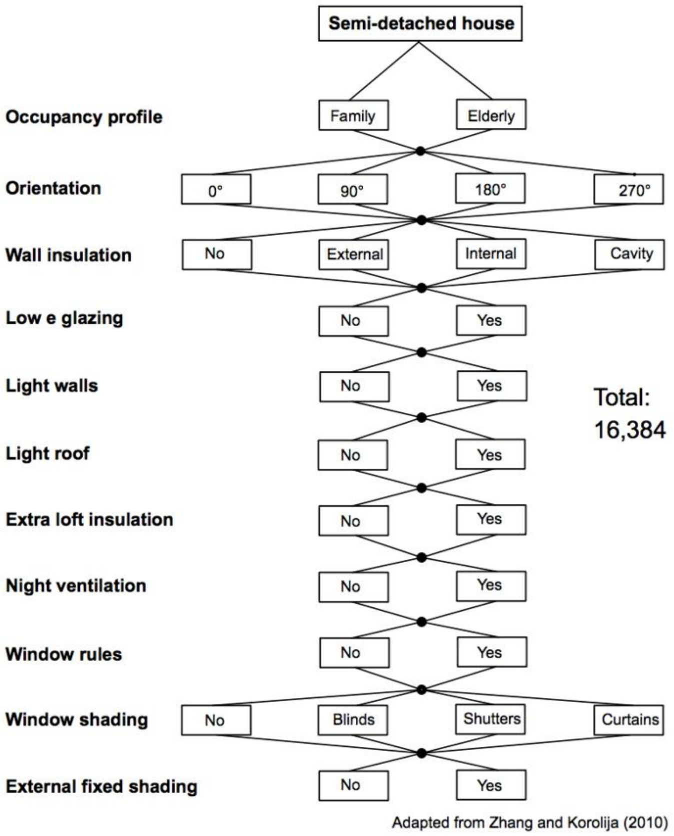

Figure 5. Selection of compatible combined adaptations

Note: for each intervention, the figure shows the relevant options assessed by the model as the full series of permutations was addressed.

Tier 1 dwelling types (semi-detached, terraced and ground floor flats)

It was found that overheating can be eliminated using the selected passive adaptations, although low-cost adaptations often lead to greater winter energy use, as indicated by the yellow and red points in Figure 6. On the other hand, many adaptations could reduce winter energy use by over 40%, as indicated by the green points. The retrofit advice web toolkit should be used to determine the performance and cost of any particular combination of adaptations.

Samples of cost/performance: For the semi-detached house, combined adaptations costing £3k result in an 85% reduction of overheating and up to 20% reduction of winter heating energy use. Better performance is achievable through more expensive interventions, for example combined adaptations costing £10k result in a 95% reduction of overheating and over 40% reduction of winter heating energy use. Costs/performances are broadly similar for other Tier 1 building types.

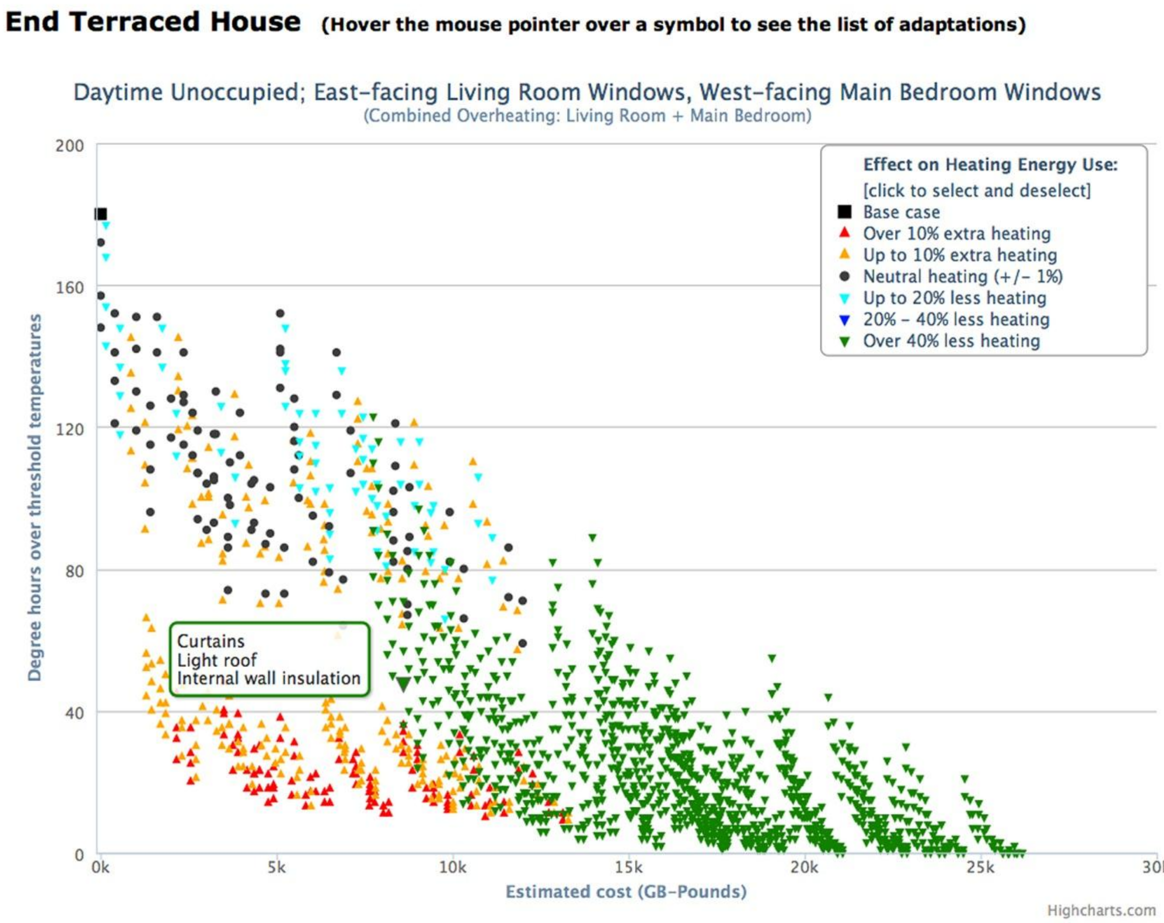

Figure 6. Sample scatter plot of combined adaptations for an end-terraced house

Note: each point represents a particular combination of adaptations, with the vertical axis indicating the overheating reduction, horizontal axis cost, and the colour of the points the winter heating implications of the adaptations.

Tier 2 dwelling types (top floor flat and 2006 detached house)

The performance of adaptations applied to Tier 2 buildings is dramatically different from those for Tier 1. *Generally, Tier 2 buildings are "harder to treat".* As illustrated in Figure 7, overheating exposure could not be eliminated using any of the combined adaptations. The modern detached house is already well insulated and it is much harder to find adaptations that would lead to a reduction in winter heating energy use. Most adaptations would result in greater energy use in winter, as indicated by the contrast between the numbers of yellow (triangular) and blue (circular) data points shown in Figure 7.

Furthermore, the *costs of adaptations are much higher* than those for Tier 1. For example, the highlighted adaptation in Figure 7 costs £23k with an overheating minimisation performance achieved with adaptations costing £3k in the semi-detached house.

It is worth noting that for Tier 2 the cost of adaptation increases significantly for daytime occupancy, which effectively *penalises the elderly*, who are already more vulnerable as explained in the section 'Effect of Occupancy'. For example, for similar levels of overheating and winter energy use reduction, it would cost £13k to retrofit a daytime unoccupied (family occupancy) top floor flat, but £17k if the dwelling is daytime occupied (elderly occupancy). There is a similar cost increase for the elderly in the 2006 detached house, in contrast to Tier 1 dwelling types where this cost difference is insignificant.

Discussion of the physical reasons for overheating in top floor flats and modern houses and the associated difficulty in their reduction can be found in our academic papers. Basically, top floor flats overheat due to excessive gains through the roof and modern houses overheat because heat is trapped in the house, as do highly insulated retrofits. High levels of insulation should be retained for energy efficiency, though the appropriate form of insulation should be adopted, together with solar control and other measures. Also important is the integration of mitigation and adaptation in retrofit design (see below).

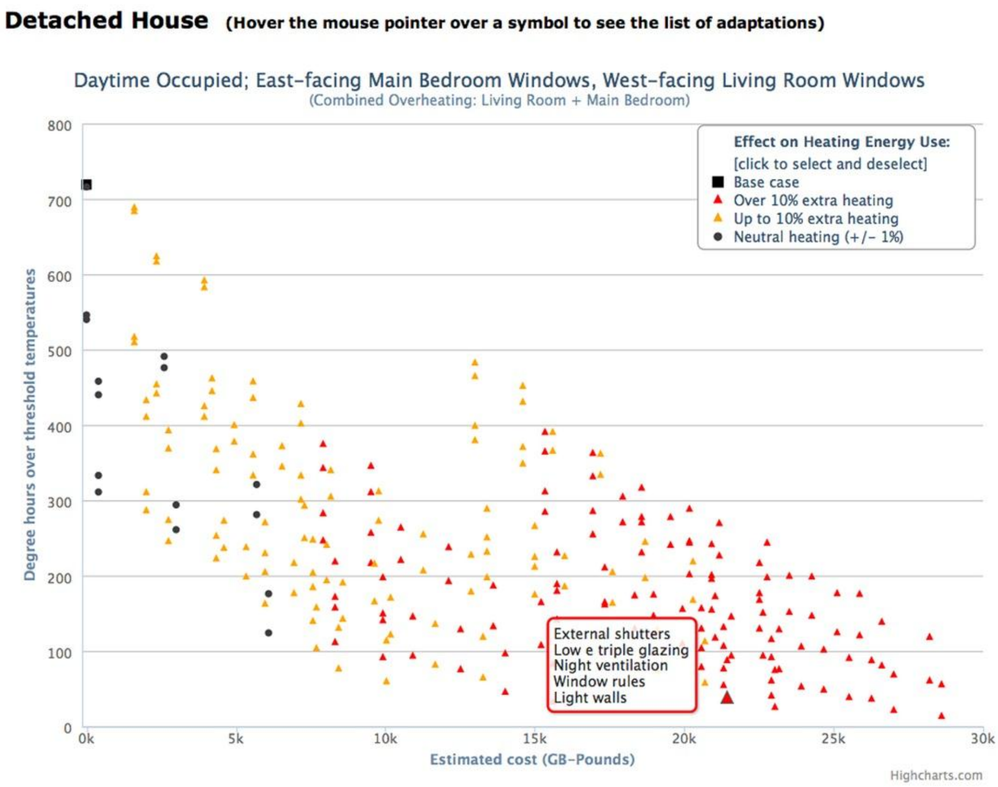

Figure 7. Sample scatter plot of combined adaptations for the 2006 detached house

The retrofit advice web toolkit

An interactive retrofit advice toolkit for designers, decision makers and householders has been developed, and made publically available (http://www.extreme-weather-impacts.net/twiki/bin/view/Main/PublicTools), to allow rapid and informed selection of the optimal adaptations for their dwellings (Figure 8).

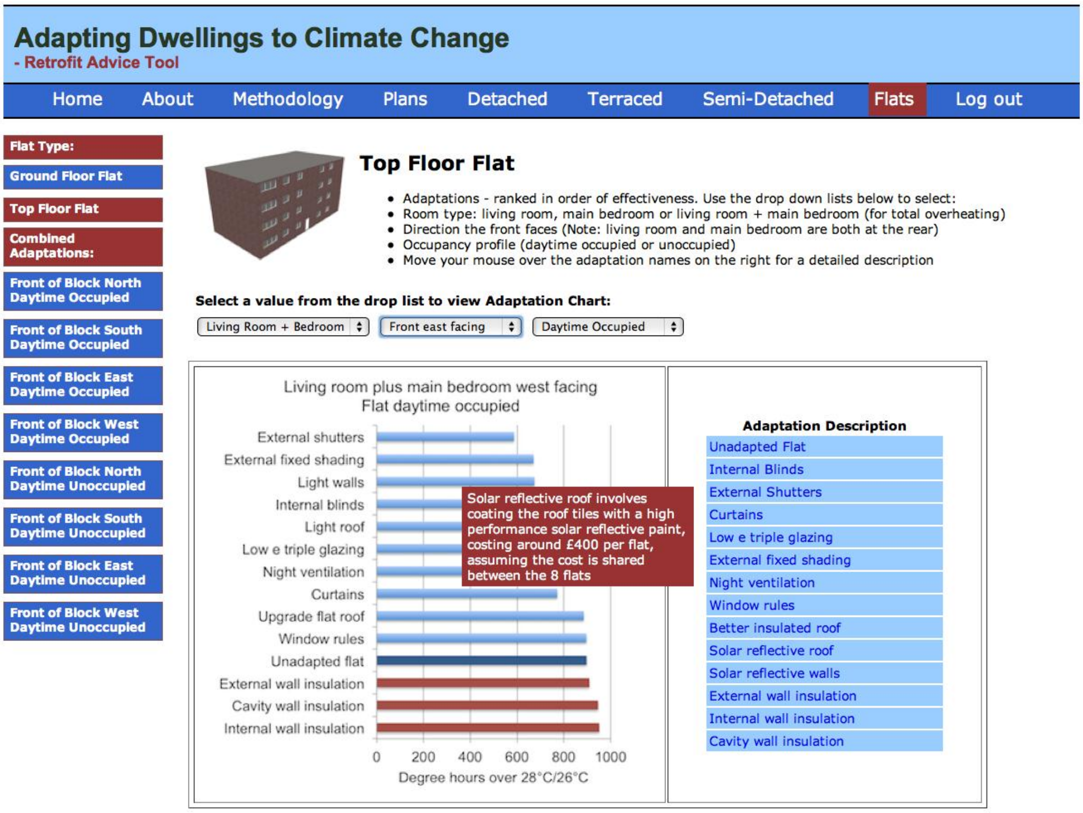

Figure 8. Screenshot of the web toolkit for rapid access to retrofit guidance

The advice toolkit informs users of both summer overheating reduction and winter heating energy use of adaptations, as well as their cost. The integrated consideration of all three aspects is important. For example, many of the best performing adaptations in terms of summer overheating with low costs could lead to more heating energy use in winter. On the other hand, with the exception of the modern detached house, many of the cooling adaptations could lead to a substantial (>40%) reduction of winter heating energy demand.

An important part of the web toolkit are the scatter plots, as illustrated in Figure 9, which can be used to obtain the best combined adaptations. Users should choose points in the area indicated by the grey band, which includes the best performing adaptations at various costs. Each point is a set of combined adaptations, the detail of which is revealed when the mouse is hovered over the point. One should choose the lowest points for the available budget and blue or green points should be chosen rather than yellow or red points, because the latter would lead to greater winter heating energy use.

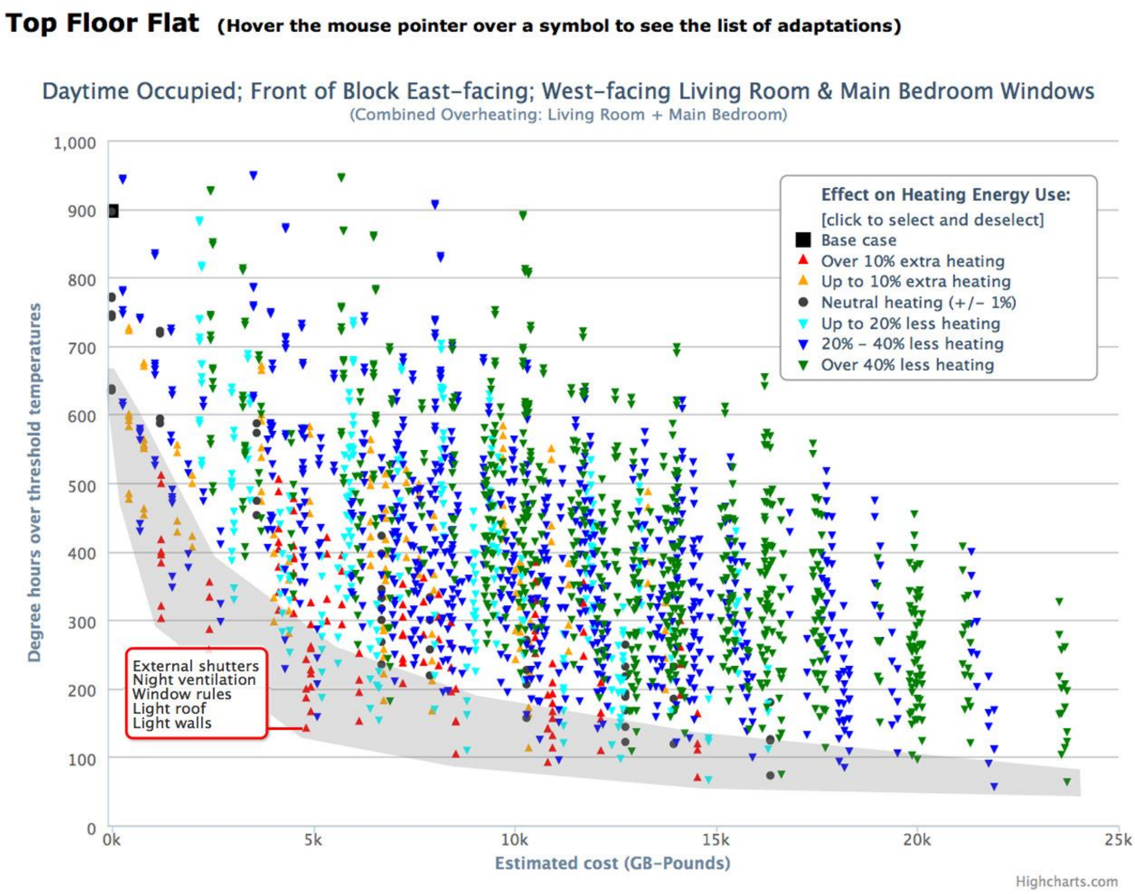

Figure 9. A sample scatter plot showing a range of combined adaptations.

Note: each point is a set of adaptations, which is revealed when the mouse hovers over the point.

Households on the top and ground floors of the same block of flats would require different solutions. The advice tool will allow selection of compatible solutions with the least total cost for a target performance.

The toolkit also provides designers, consultants and researchers with an interactive facility to gain insights into the relationships between overheating exposure, adaptation performance, cost, construction type, occupancy and orientation.

Importance of integrating adaptation with mitigation

The excessive overheating exposure of the 2006 detached house (and much anecdotal evidence of overheating in modern new builds of various types) prompts the question that if older houses are retrofitted to dramatically reduce carbon emissions, e.g. by having comparable standards of thermal insulation and air tightness as the 2006 detached house, would they overheat as much as the latter. Our simulations indicate that this is indeed the case. *It follows that unless adaptation is integrated with mitigation in retrofit of existing dwellings, one could end up with a building stock that overheats and becomes harder and more expensive to treat*. Worse, if occupants of overheating dwellings opt for energy intensive air conditioning as a quick (and often cheaper, by first cost) fix, the mitigation objective would be compromised too.

Secondly, as indicated above, the cost of adaptation is typically £3-10k for Tier 1, and much higher for Tier 2, building types. If £10k is taken as the indicative per house cost, nationally the overall cost would be c.a. £250bn or just over £6bn p.a. until 2050. This is a significant amount and much cost savings could be achieved by integrating retrofit for adaptation with that for mitigation. The integrated approach to retrofit helps to prevent costly sub-optimal designs when only one of the two aspects is considered, for example in the choice of insulation type.

Acknowledgements

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6

Chapter Six. A What-If Scenario Portal (WISP) — the development of a web-based portal for supporting community resilience to extreme weather events

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Overview

The Community Resilience to Extreme Weather (CREW) project has developed a set of tools for improving the resilience of local communities in SE London to the impacts of extreme weather events. An integrated part of CREW is the 'What-If' Scenario Portal (WISP). WISP represents a series of interlinked toolkits used for mapping the projections of future weather-related hazards developed in Programme Package 4 (PP4) and presenting coping measures via the Internet. WISP provides user-centred tools to address a series of stakeholder scenarios by presenting textual reporting combined with interactive maps, tables and charts. Users are presented with up-to-date information that requires only a web browser to access. The WISP tools also incorporate the facility to capture community contributions and comments, providing the opportunity for engagement with users. WISP aims to integrate the CREW outputs of: community engagement; socio-economic impact modelling; and the probabilistic mapping of hazards. This section outlines the WISP tools, the methods employed in their development and the learning points derived from stakeholder engagement.

Introduction

In order for communities to plan for extreme events they need realistic estimates of the spatial and temporal distribution of weather related hazards and the likely impact. Baseline climate simulations and future projections from the UK Climate Projections (UKCP09) were used as inputs into hazard models to derive probabilistic projections of flooding, heat wave, subsidence drought and wind for the 2020s and 2050s as described by Programme Package Four (PP4) These were in turn used as the input to socio-economic modelling of community resilience, as described in Programme Package 3 (PP3).

Communities are only able to adapt their collective behaviour or plan for extreme weather events if they have access to information on how they can mitigate their impact. Technical information and assessment of building retrofit coping measures, ranging from flood-proof infrastructure and fan-evaporation cooling for individual comfort, form an integral part of CREW and this informed the research into drivers and barriers of community resilience.

An integrated part of CREW is the 'What-If' Scenario Portal (WISP): the toolkit for mapping scenarios of future weather-related hazards and presenting coping measures via the Internet. The WISP tools are designed to share the output of the research themes within CREW and deliver tailored tools designed to meet user requirements in preparing for a more resilient community.

Capturing Stakeholder Views

An important element in the design of the WISP toolkits within CREW was the capture of the range of representative user requirements from the three groups of stakeholders addressed in the project, namely householders, local decision makers and SMEs. To do this, there was close collaboration with CREW Programme Package Two (PP2). Key to this was the outcome of a project stakeholder-representation conference whereby groups of the PP2 team within the CREW consortium acted 'in role', informed by their dealings with the end-users and stakeholder groups that they were actively involved with and interviewing. The WISP team were then provided the opportunity to interview these groups 'in role', proving an effective and efficient means to elicit key information required. In this way tables of user requirements could be drawn up, comprising typical questions that each stakeholder group might pose, together with other feedback and commentary. Digests of these 'user-conversations' are reported in Tables 1 to 3.

Table 1. Householder Questions

• Show me where my house is on the map.
• Is my house likely to flood or suffer from any of the other perils modelled?
• Will there be any changes in the hazards affecting my house between now and say 2020?
• What practical, effective measures could I take to mitigate impacts of these hazards?
• I am considering moving house. I am considering a few possible locations - can I compare them using your system?
• Can I use the map to check or search for Postcodes in different brackets of combined risk?
• As a householder, can you show me the local schools, hospitals, religious institutions and high streets in my location, as well as other points of interest?
• How will transport nodes in my community be affected by climate change?
• Is your system easy to use? Should I be an IT expert?
• Is your system clearly written and intuitive?
• How could I change my behaviour to mitigate and adapt to these effects?
• I've already made some changes to my house, how will these changes affect things?
• How often do I need to visit your website to receive updates? How often will it change?
• How accurate and trustworthy is the information you tell me?
• If I made changes based on this information and nothing happens who is responsible?
• How will I find out more about the site? Is it on TV?
• Can I look at the impacts of climate change on transport infrastructure?
• What would be the effect of an extreme weather event in my area?
• Where would we get help from to actually use these tools?
• What can we expect from the local authorities, and from the emergency services?
• Typically, how long does it take to get things back to normal after an extreme event like a flood?
• How do insurers deal with this information?
• Will the WISP tool be able to advise me on what actions to take if I discover I am at risk? Or at least who to go to, or contact, based on my location?
• I am trying to sell my house. Will the WISP tool be accountable if my house price is lowered, or if other potential buyers check WISP to see that I am living in a risk area?

- Will there be a version of the WISP tool available to people with disabilities? For example with colour blindness or those requiring larger on-screen text display?
- Householders already ignore the EA flood maps, looking maybe once for novelty. How will WISP ensure that people don't ignore it?
- How will the WISP tool incorporate local knowledge of hazards.
- Will the WISP tool be able to provide specific adaptation advice for my house type and occupancy?

Table 2. Small and Medium-Sized Enterprise Questions

- As a Registered Social Landlord (RSL), give me a summary of how the portfolio of my properties is affected by the hazard models in WISP.
  - What measures to mitigate effects of these hazards might be most cost-effective for my portfolio?
  - What would the impact be on my tenants?

- As an SME, what would be the implications of a given hazard scenario be on my business operations?
  - How might it affect my suppliers or employees also?
  - How resilient is my business?
- How is my supply chain (transport infrastructure) affected?
- What are the likely implications for the demands on my business?
- What is the interface with business continuity planning?

- As an insurer, how can our actuaries correctly rate risk within a given set of locations (e.g. a book of business)?

General questions

- How simple is this tool to use?
- How reliable is this information?
- Can you tell me what's going to happen next year?
- How often will your site and the information change?
- How often will I need to check your site?
- How will I find out about this website? Will it be advertised on TV?
- Will I only get one warning or will I receive messages about weather risks still?
- What are the economic costs and benefits of the physical coping measures?
- Show us some possible means of reducing our own (specific) risks?
- Give us an indication of the extent to which the implementation will reduce our risk.
- How simple is the WISP toolkit to use? We do not have the technical capability (or time) to interpret complex scientific data.
- Provide some guidelines as to how we can use this WISP toolkit, and on which of the many aspects of it will be of benefit to us.
- Show how the hazard scenarios will affect my business - what are the possible effects on my business?
- How accurate is the information presented? Can we rely on the figures?
- We are limited in financial resources - we need strong reasons to invest in possible measures.
- What is the maximum resolution we can resolve to in your WISP models?

Table 3. Local Decision Maker Questions

• Where do the citizens live who might be affected by a given hazard/scenario combination? • How does this relate to other vulnerability maps already produced for London? • How close are all the affected citizens to public transport networks? The same for hospitals, schools etc. • Where else in the local area are citizens who might be affected in the same manner as were the ones for 'this one'? (e.g. a given event) • What might the effect of a given hazard/scenario be on local employment rates, on house prices or business establishments be? • In which areas should I direct the most effort to ensure the greatest protection of business continuity, or the residential population? • In terms of planning contingencies, which road and rail links, and power and communication networks might be affected by a given hazard? • Will the information be static until the next UKCIP scenarios arrive? • How will you keep the site fresh and relevant? • Will this information be part of the existing EA / SEPA portals? • What's the accuracy or reliability of the predictions? • Will the predictions and outputs on the site be certified by any authority? • How will I find the website? • How will this WISP tool improve our community engagement? • Which one of my policy colleagues should use this, and at what level is it intended for use? • 2050 is the earliest we want in terms of future predictions. The CREW project could be misinterpreted should there be no clear discernible impacts evident by 2020. • Use a lower resolution flood risk dataset, but with more time slices if this means the same degree of effort - e.g. focus on patterns of temporal change not spatial resolution. • What is the quantitative evidence to support and justify and decisions we take? • How does this support NI188? • How is this novel from other tools already available? • What are its limitations? • How 'robust' are the scenarios? Could we end up spending money unnecessarily? • Where are we better doing community-level measures and where are we better doing building level actions?

These points formed a useful basis for the design brief for the development of the WISP toolkits. It was not possible to address each and every point raised in the scope of the research but the points formed a useful body of representative commentary.

WISP design approach

WISP is designed as a prototype GIS-based composite web portal designed to deliver the project outputs of CREW. Delivering information to the end user over the Internet reduces the barriers to access imposed by specialist software and enables the data and models to be stored remotely. The stakeholders require only an Internet connection and a browser to access the information but do not require specialist training in the CREW methods nor their own storage capacity for the data. Separation of the user interface from the data also permits the presentation of contemporary information via efficient up-date of datasets at a single source.

WISP requires a Spatial Data Infrastructure (SDI) comprised of a range of technologies, data structures and skills upon which the mapping and reporting functionality is built. Outputs from

CREW research include raster maps, spatial vector datasets, reports, models and tables in a diverse range of formats requiring a flexible approach to the SDI. To reduce the normalization and processing of these potentially large datasets the SDI was designed to store the CREW data on a central server in a variety of databases with access through stateless web services. Software layers provided by server technologies such as GeoServer and ArcGIS® Server are able to manage a variety of data formats and respond to defined queries to deliver data in a format suited for dissemination over the Internet. Where possible, the use of internationally accepted standards for web standards also allows for the use of existing software tools in development of the user interface as well as the ability to incorporate existing services into WISP. Figure 1 shows a diagram of the SDI for WISP with CREW outputs accessed through service layers that return maps and data in response to requests from the WISP tools on the client. The SDI makes data available to the WISP developers to incorporate into their prototypes while still providing flexibility as new data becomes available or requirements change because of stakeholder feedback. WISP functionality was developed in consultation with the stakeholders and defined by 'What if?' scenarios. These are questions, as noted above, posed by householders, SMEs and decision makers for which information can be drawn from the database and presented in a structured way that incorporates textual reports, maps, tables and charts. The development was conceived as a series of levels built over a core set of mapping and reporting functions, with each successive level having increased functionality. Therefore, Level 1 extended core functions by allowing the selection of an area of interest, up to Level 4 where a range of predefined options are presented in a single report containing the appropriate advice on applicable coping strategies.

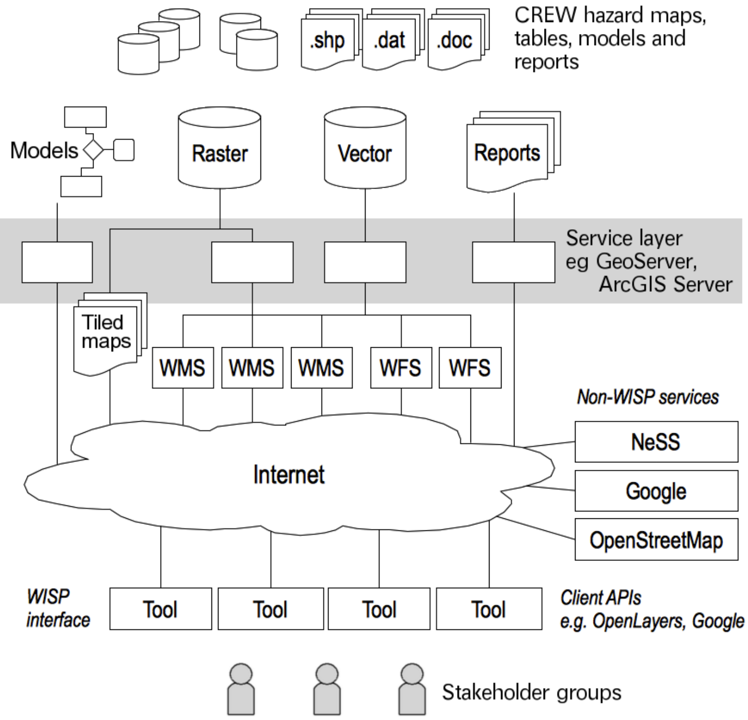


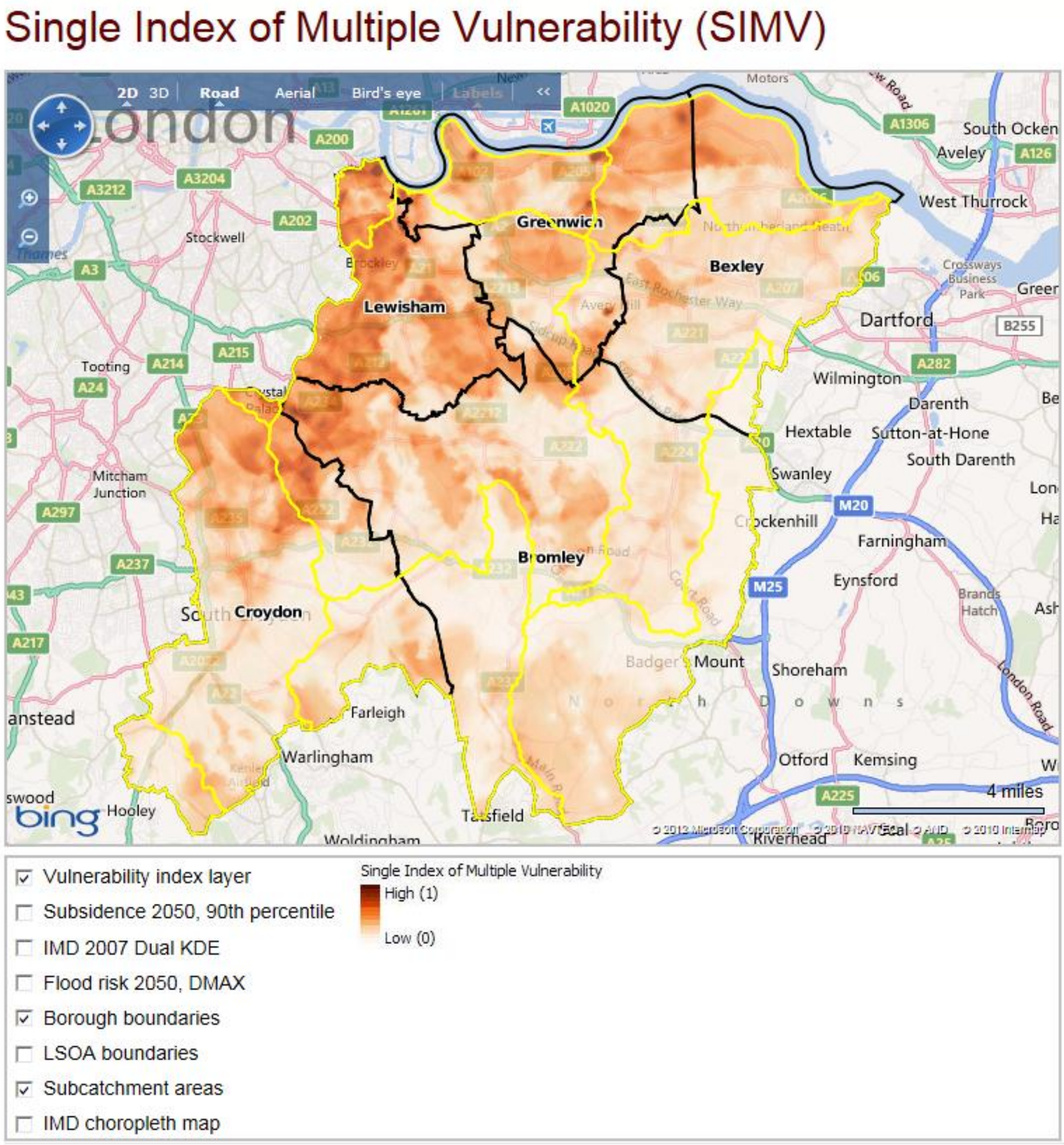
Figure 1: Diagram of the SDI for WISP highlighting the service layer, which forms the interface between the stakeholder tools and the outputs from the CREW research themes.

Tools for Decision makers and SMEs

A range of ten showcase toolkits were developed and are presented below, each aimed to service one or more anticipated user requirements and intended stakeholder groupings, Figs 2-13.

Integrated Risk Tools

Tool 1. Single Index of Multiple Vulnerability (SIMV) - This tool allows a decision maker to identify hotspot areas of vulnerability in a web-mapping interface.



This work comprised the Cranfield University MSc thesis of C.Emberson

Commentary: This tool allows a decision maker to identify hotspot areas of vulnerability from a continuous mapping layer. The individual component layers can also be viewed individually to identify the hazards that contribute to an identified hotspot.

The SIMV tool allowed for the combination and overlay of a range of factors output by the hazard modelling, together with the geodemographic indicator of the Index of Multiple Deprivation (IMD) (Noble et al., 2008). Expressed at Lower-level Super Output Area (LSOA), IMD is considered a useful metric because whilst the literature generally regards financial constraints as a key factor when considering a person's inability to adapt to the effects of climate change clearly other factors also come into play and other forms of deprivation such as employment, health, education and living environment can also be equally as relevant depending on the nature of the hazard.

The toolkit utilised a dual kernel density (KDE) methodology to combine the IMD with Ordnance Survey Address Layer 2 (AL2) data. This was then combined with future climate-modelled data from CREW by way of a weighted index overlay in the study area of five contiguous boroughs in South East London, to produce a 'Single Index of Multiple Vulnerability' (SIMV).

The KDE process was found to successfully add granularity to the IMD data, and the SIMV was also found a useful metric, particularly for the identification of hotspots that straddle borough boundaries.

Figure 2: Single Index of Multiple Vulnerability (SIMV)

Tool 2. Integrated EWE Decision Support Tool - This integrated tool allows a decision maker to draw up maps of each hazard scenario, assign weightings as required and interrogate and view the result in a web-mapping interface.

This work comprised the Cranfield University MSc thesis of M.vanHoek, (van Hoek, 2011)

Commentary: The Integrated EWE Decision Support Tool allows a combination of data to be presented concurrently for the various risk assessment model outputs available. Wind, Flooding, Subsidence and Heat wave data are selectable and a weighting can be applied to explore the combinatorial effects on locations. The result can be presented along with output photography from 'Google Street View'. The tool can present a further means to combine and overlay the various hazard datasets output by the SWERVE modelling component of CREW. Developed using the 'ESRI FlashViewer API', the tool integrated and collated the model outputs and research findings of the wider research effort, providing stakeholders with a powerful means to determine information to support decision making processes within the South East London Resilience Zone (SELRZ).

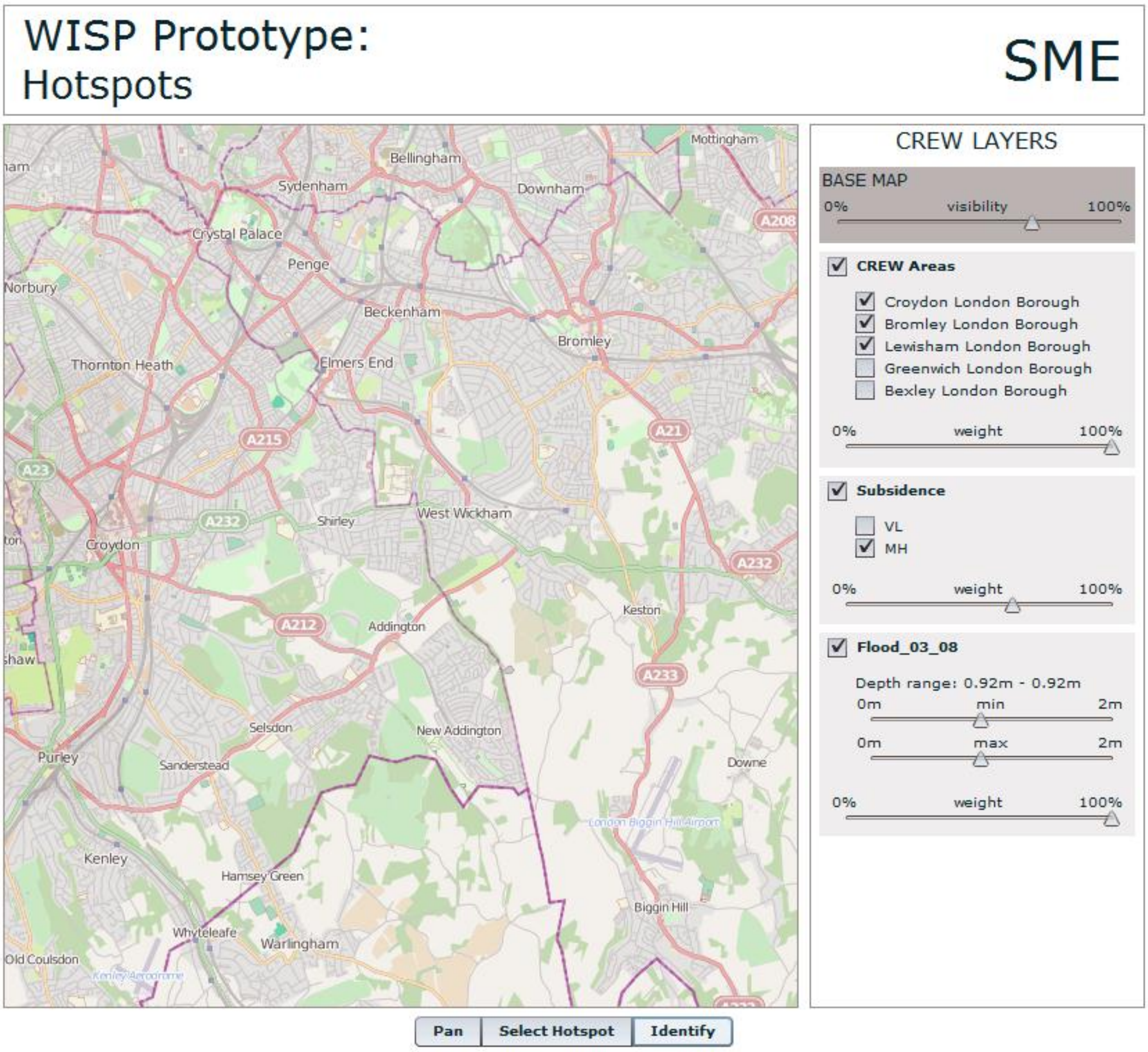
The design philosophy for the tool was informed by the representative user points and by identifying best-practices extracted from wider web-based GIS applications with similar scope. The design philosophy includes carefully selected, sympathetic colour schemes, the ability to provide additional supporting information and process, manage and analyse spatial-temporal data. The tool made full use of web geoprocessing services, which were found to offer a powerful facility, delivering extended functionality to the application.

The use of geoprocessing services in combination with web services was adopted to present and interrogate risk assessment model outputs for each of the selected hazards. This makes it possible to run an automated geoprocessing model on the web. In combination with rich Internet applications is it possible to deliver a ready to use a tool in a user-friendly interface. The power of this system is not only the ability of accessibility to multiple layers, but also the ability to create new virtual data products. This enables users to undertake analyses based on their own preferences, where the resulting map is a unique product.

The web-based mapping application presented here provides users with a powerful yet simple- to-use and ultimately extensible analysis package. The research evaluated differing technical approaches to the requirements, settling on Adobe Flex technology in combination with the ArcGIS as a powerful development medium for such decision support tools.

Figure 3: Integrated Extreme Weather Event Modelling tool

Tool 3. Integrated EWE Decision Support Tool - This integrated tool allows a decision maker to draw up maps of each hazard scenario, assign weightings as required and interrogate and view the result in a web-mapping interface.

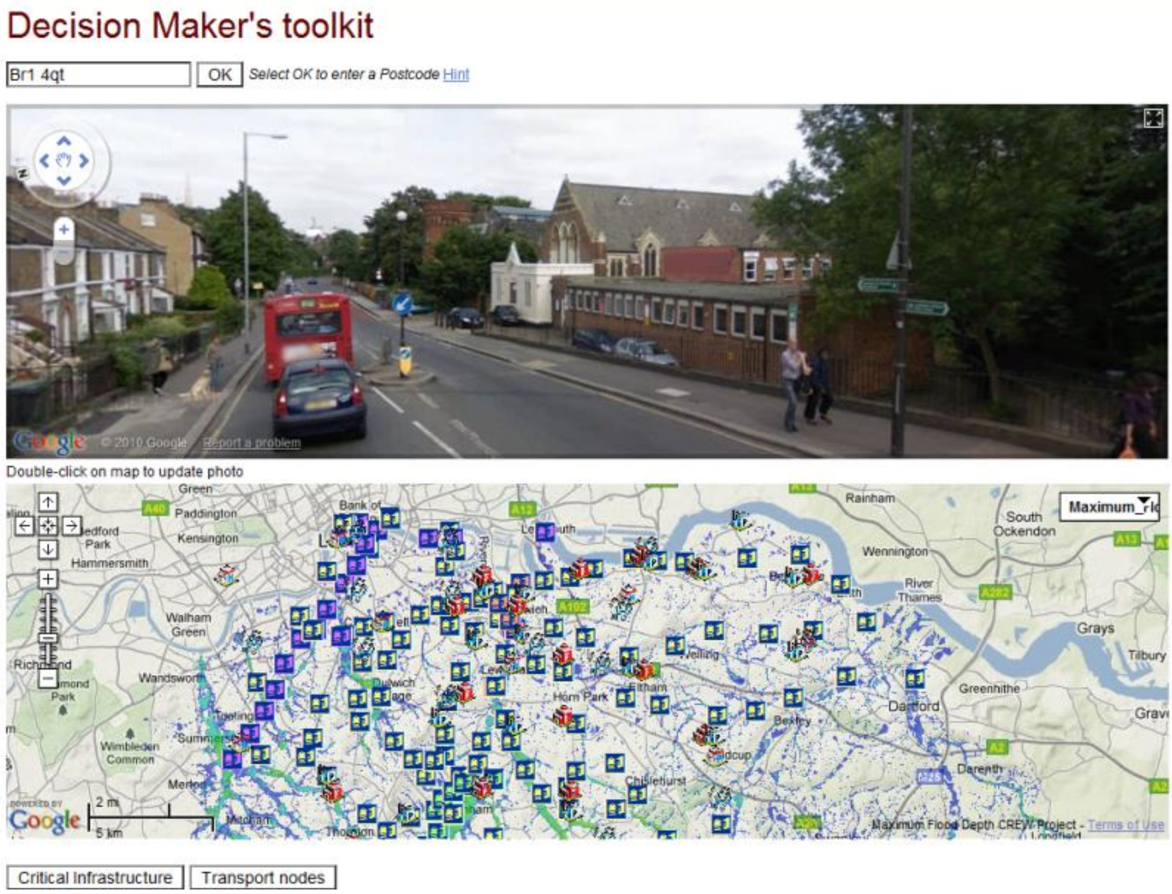


Commentary: The SME Hotspots toolkit, developed in the Adobe Flex technology, provided a prototype mapping presentation designed to allow overlay of multiple hazards. Instead of employing a statistical, combinatorial approach, as other tools presented here do, this tool adopted use of colours to alert visually the user to 'hotspots' that could appear. Each hazard was assigned a graded colour 'ramp' in shades of red. The user is able to shift the bounds of the ramp using slider scales to assign user weightings, apportioning greater or lesser importance to each factor as required. As each hazard was thereby overlain areas appearing with the deepest red shading represented the highlest points of intersecting 'vulnerability'. These areas could then be inspected, or identified, for the contributory factors. This approach was adopted to seek to circumvent the issues of combining ordinal hazard scales which were constructed with divergent modelling techniques – effectively placing the 'preference' for weighting in the hands of the user. The tool can portray a set of thematic risks together and the consequent intersection to be saved and queried. Once the conditions of this intersection are known, all other areas of the map corresponding to these defined conditions may also be identified. Ultimately, whilst this proved an effective visual tool for identifying hotspot areas, this approach could not deliver any robust statistical basis for these combinations.

Figure 4: SME Hotspots tool

Flood management Tools

Tool 4. Decision makers mapping tool - providing a community decision maker with the tools to inspect rapidly a neighbourhood or community.



Commentary: The Decision Maker's toolkit is designed to allow a decision-maker to rapidly appraise a neighbourhood or community. This tool also allows the superimposition of the hazard model results (e.g. flood extent). Maps may also be overlain with the critical infrastructure and transport nodes for the study area.allows the overlay of the complex flooding scenario data on Google street views across the SELRZ area of interest. Also selectable were layers of critical infrastructure and key transport nodes. A powerful addition to the tool was the integration of the Google 'Street View' photography with the modelled outputs – allowing users to traverse a particular community in synchronisation with the modelled risk display. Flood scenarios were selectable for a range of modelled outcomes.

Figure 5: Decision makers' mapping tool

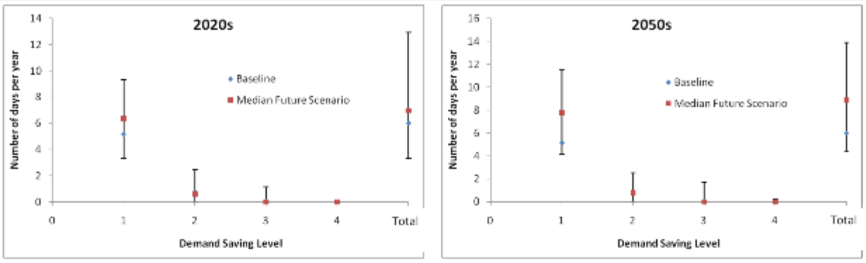
Water Resource management Tools

Tool 5. Future Water Resources Modelling for London – allows the identification of the critical demand saving thresholds in the London Water Resource Zone under a range of future probabilistic climate change scenarios and changes in water demand.

Future projections are based on one hundred, 100-year long future UKCP09 scenarios for the 2020s and 2050s. The 100 scenarios for eac time period are randomly sampled from UKCP09 future and are presented to show the likely increase in the number of occurrences of the following demand saving measures:

- **Level 1**: Media campaigns, additional water efficiency activities, enhanced activity and restrictions to reduce risk to water supply;
- **Level 2**: Enhanced media campaign, customer choice/voluntary constraint, sprinkler ban;
- **Level 3**: Hosepipe ban, non-essential use ban, drought order;
- **Level 4**: Severe water rationing e.g. rota cuts, stand pipes.

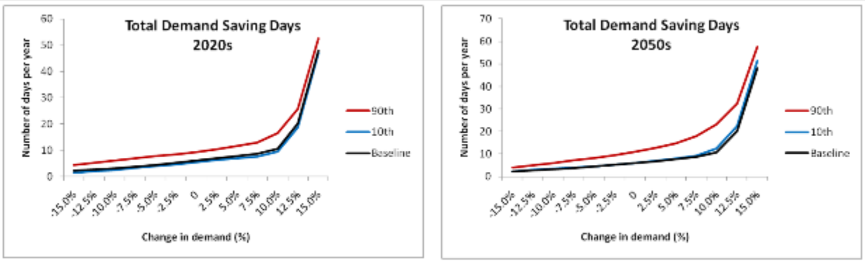
Eleven baseline period runs (1961-1990) were also generated and the median run is used as the indicative control period comparison.



Click on the graphs ...

Range of future projections of demand saving days for the 2020s and 2050s (based on 100 runs). The blue data points indicate the results for the control runs (1961-1990). The red data points indicate the medium future scenario value. The black bars indicate the range of results from the 100 runs.

Based on these initial results, a sensitivity analysis looking at changes in water demand was conducted. At present the London Demand component of the model is set as 2115 ML/day; a range of increases and decreases (+/- 2.5%, +/- 5%, +/- 7.5%, +/-10%, +/-12.5%, +/-15% were applied to this demand level for the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th ranked (in terms of total demand saving days fc all 100 runs) future climate runs for the 2020s and 2050s.



Click on the graphs ...

London demand sensitivity plots based on the 10th and 90th ranked climate runs for the 2020s and 2050s (based on total demand saving days).

Commentary: The Future Water Resources Modelling toolkit for London allows identification of the critical demand saving thresholds in the London Water Resource Zone under a range of future probabilistic climate change scenarios and changes in water demand. Information is presented as a report for stakeholders. This allows local decision makers a useful overview of the impacts of water shortages across the region and for each of the modelled temporal periods. Scenario variations for different levels of water demand are combined with a range of potential future climates.

Figure 6: Future Water Resources Modelling tool

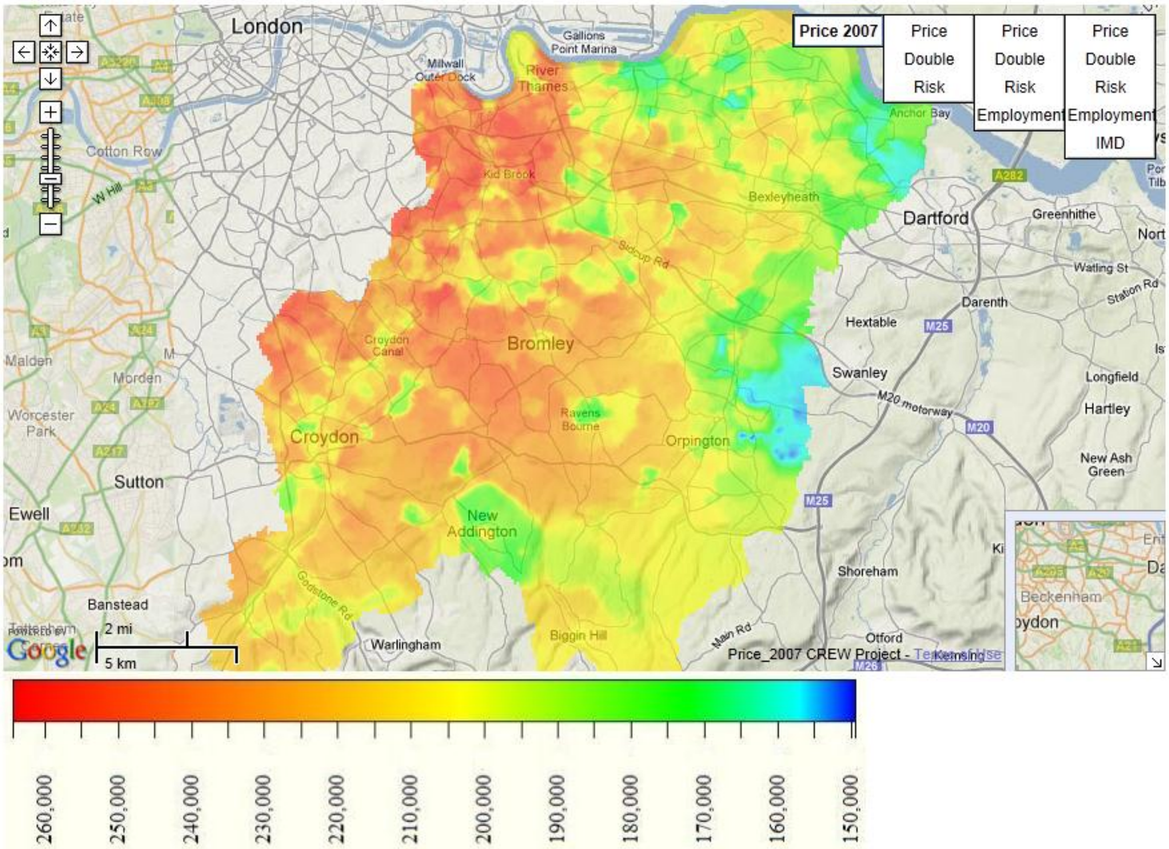
Property Value Tools

Tool 6. House Price Impacts mapping tool — allows a community decision maker the tools to inspect the possible impacts of extreme flood events on house prices.

House Price Impacts mapping tool

This web mapping application demonstrates how house prices are affected by extreme weather events. The legend shows house prices in pounds sterling.

zoom level: 11
centre: (51.40777268236964, 0.03570556640625)



Map controls

Additional layers
LA Boundaries: ☐

Zoom to initial extent

Instructions

The maps below show the output of the EweSem model concerning impact of flood events on house prices, augmented by the other impact factors of employment and the index of multiple depravation (IMD). The map unit is house price in GBP Sterling. Select the appropriate map layer using the button interface on the map.

Commentary: The House Price Impats modelling tool allows a community decision maker to inspect the possible impacts of extreme flood events on house prices. House prices are mapped within the SELRZ for doubled flood risk, with and without employment and effects of social deprivation. The tool allows local decision makers to access mapped sub-regional representations of the outputs of the EWESEM socio-ecomonic models, described in Programme Package 3 (PP3). The mapping integrates a range of calibrated scenario outcomes which can be juxtaposed against local mapping.

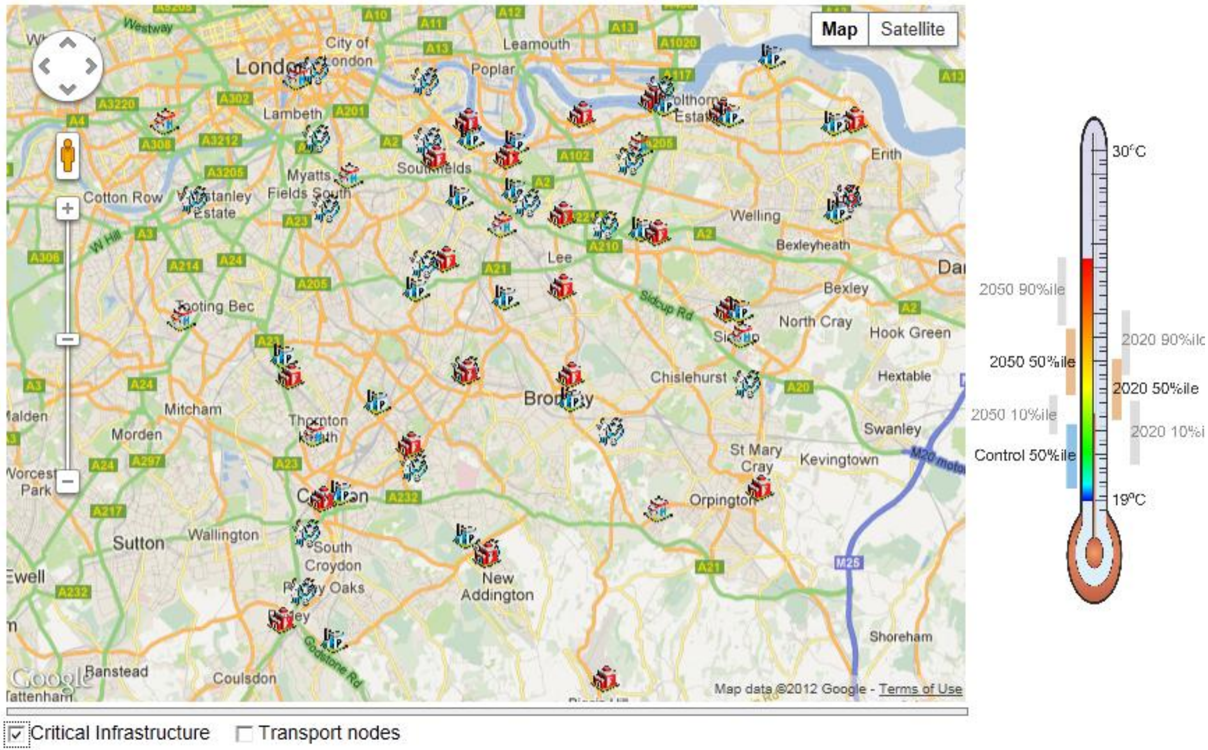
Figure 7: House Price Impacts Modelling tool

Heat wave Tools

Tool 7. Heat wave Impacts Modelling for London — allows the identification of the critical temperature thresholds for heat waves in the London study area under a range of future scenarios

Average Summed Maximum Temperature

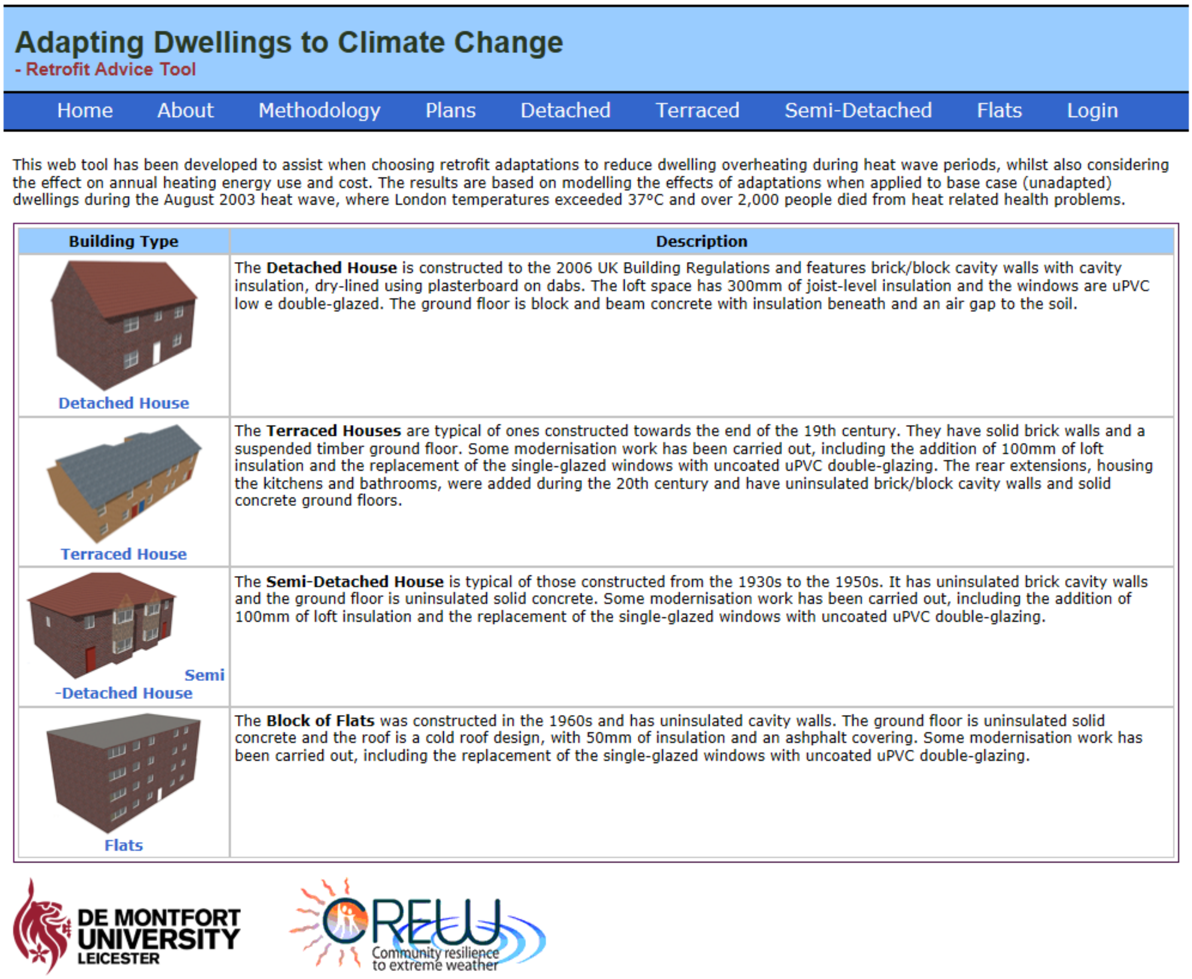
This map presents the mean summer maximum temperature (Tmax), based on the standard climatological definition of June-August, in degrees Celsius and relates to the presentation of Average Summed Maximum temperature for the 2020s (10th, 50th and 90th percentiles) the 2050s (10th, 50th and 90th percentiles) and the control baseline period, 50th percentile, for the study area. The thermometer graphic shows the data range of the model outputs for each of these percentile datasets, in perspective against each other. This is necessary because as the spatial pattern of data variation does not change hugely between the datasets the maps appear rather similar. Thus it is the data range variation that changes, rather than the spatial variation. Initially, an alternate set of maps had also been prepared having a consistent colour range from 19 to 30 degrees. That is a variation of 11 degrees; most of the seperate datasets vary only by 2 or 3 degrees. As a result the single legend was deemed confusing as each map broadly was represented by only a narrow range of colour from the wider legend. In summary, it is considered most useful to have a seperate legend as used here for each of the maps, ranging the colours across the specific data range, and in association to present the 'thermometer' graphic to show the shift occuring between datasets. You can 'right click' and copy the thermometer to paste it as a large graphic into a seperate document.



Commentary: The Heat wave Impacts Modelling tool allows identification of the critical temperature thresholds for heat waves in the SELRZ. Heat wave mapping layers have user-controlled transparencies for comparison with the baseline dataset. Modelled temperature ranges are displayed on the same graphic for comparison. It allows presentation of the mapped interplay between structured demographic projections across the study area, and predicted heat wave (accumulated heat) calculations. This allows both areas of risk and vulnerability or Urban Heat Islands (UHI) to be easily identified. Critical infrastructure can also be mapped alongside the heat wave data.

Figure 8: Heat wave Impacts Modelling tool

Tool 8. Building Retrofit Toolkit. Developed by Dr S.Porrit at DeMontfort University. A web tool to assist when choosing retrofit adaptations to reduce dwelling overheating during heat wave periods, whilst also considering the effect on annual heating energy use and cost. The results are based on modelling the effects of adaptations when applied to base case (unadapted) dwellings during the August 2003 heat wave, where London temperatures exceeded 37°C and over 2,000 people died from heat related health problems. For further information, see Porritt (2012).



Adapting Dwellings to Climate Change
- Retrofit Advice Tool

Home | About | Methodology | Plans | Detached | Terraced | Semi-Detached | Flats | Login

This web tool has been developed to assist when choosing retrofit adaptations to reduce dwelling overheating during heat wave periods, whilst also considering the effect on annual heating energy use and cost. The results are based on modelling the effects of adaptations when applied to base case (unadapted) dwellings during the August 2003 heat wave, where London temperatures exceeded 37°C and over 2,000 people died from heat related health problems.

Building Type	Description
Detached House	The **Detached House** is constructed to the 2006 UK Building Regulations and features brick/block cavity walls with cavity insulation, dry-lined using plasterboard on dabs. The loft space has 300mm of joist-level insulation and the windows are uPVC low e double-glazed. The ground floor is block and beam concrete with insulation beneath and an air gap to the soil.
Terraced House	The **Terraced Houses** are typical of ones constructed towards the end of the 19th century. They have solid brick walls and a suspended timber ground floor. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing. The rear extensions, housing the kitchens and bathrooms, were added during the 20th century and have uninsulated brick/block cavity walls and solid concrete ground floors.
Semi -Detached House	The **Semi-Detached House** is typical of those constructed from the 1930s to the 1950s. It has uninsulated brick cavity walls and the ground floor is uninsulated solid concrete. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing.
Flats	The **Block of Flats** was constructed in the 1960s and has uninsulated cavity walls. The ground floor is uninsulated solid concrete and the roof is a cold roof design, with 50mm of insulation and an ashphalt covering. Some modernisation work has been carried out, including the replacement of the single-glazed windows with uncoated uPVC double-glazing.

DE MONTFORT UNIVERSITY LEICESTER
CREW Community resilience to extreme weather

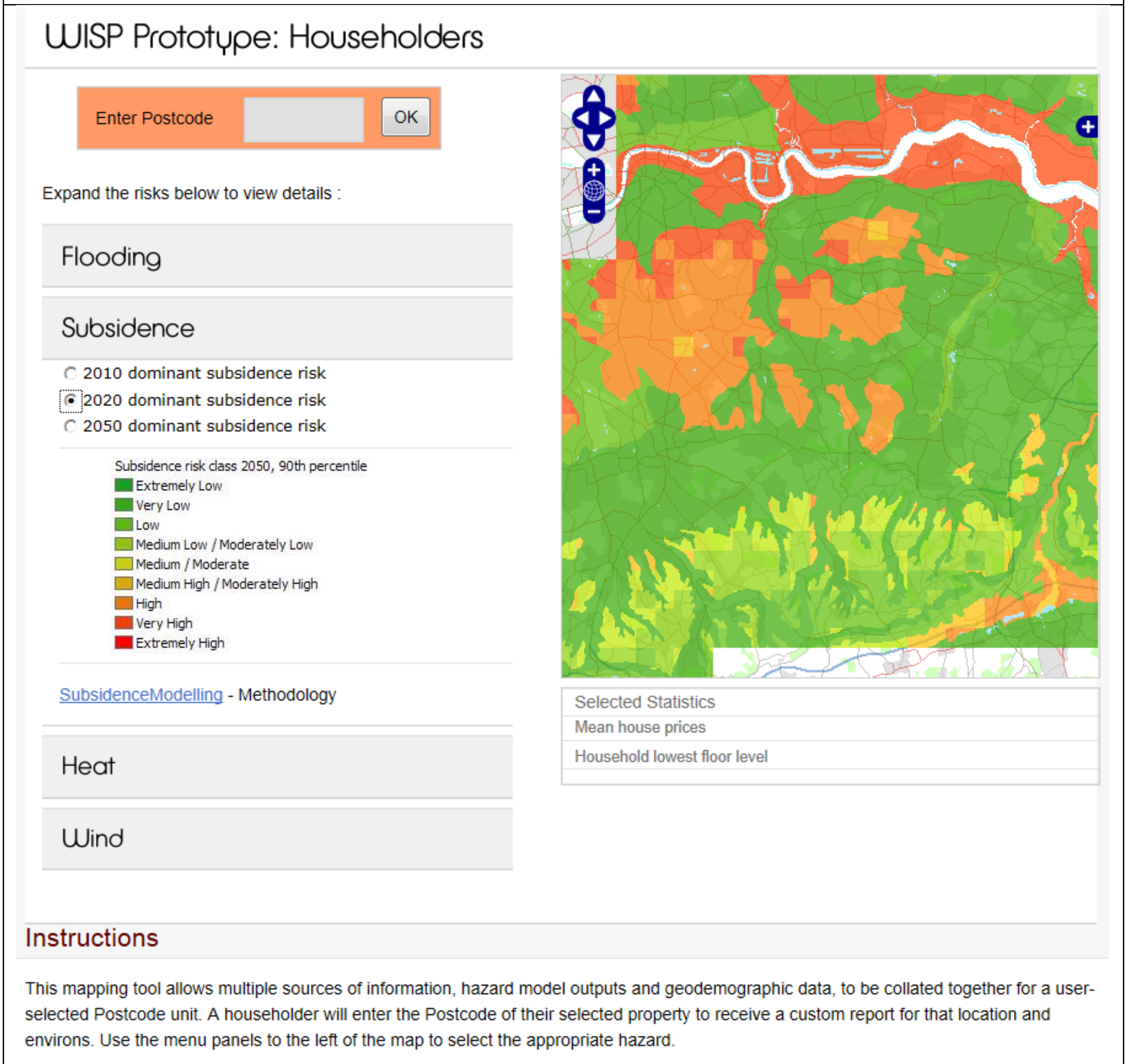
Commentary: The Building Retrofit Toolkit is used to assist when choosing retrofit adaptations to reduce dwelling overheating during heat wave periods, whilst also considering the effect on annual heating energy use and cost.This tool is described in full in the section "Programme Package One: Identification and assessment of coping measures for extreme weather events. Adapting UK dwellings to reduce overheating during heat waves". It presents a powerful tool for investigating the various retrofit measures available to householders and housing associations for a range of building types. A key output of this research is to provide the means for selecting coping measures based on a matrix of technologies ranked by their performance and potential for community uptake.

Figure 9: Building Retrofit Toolkit

Tools for Homeowners

Integrated Risk Tools

Tool 9. Householder prototype — shows 'my property' location and the results of modelling for that area.

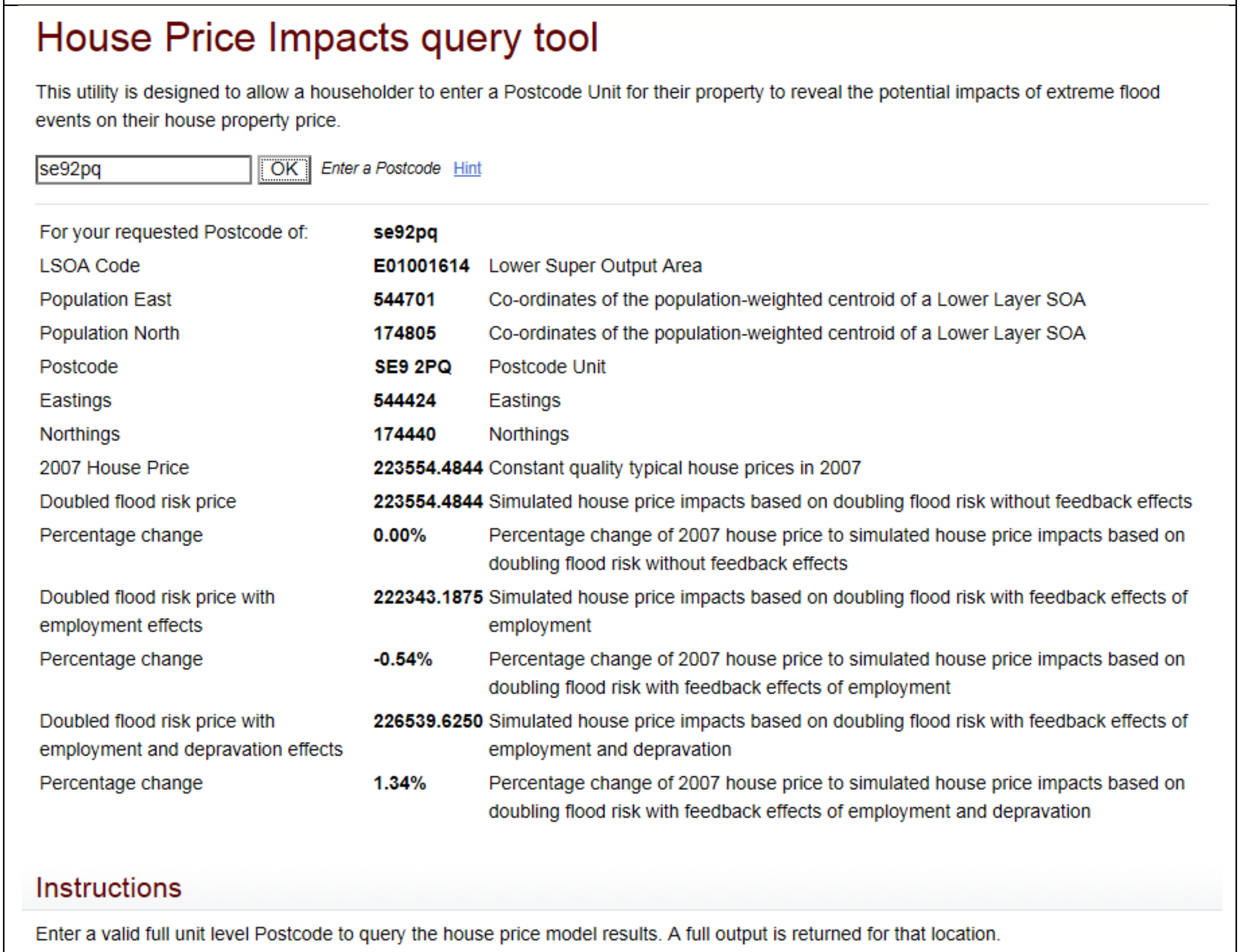


Commentary: The Householder tool seeks to present a composite set of hazard vulnerability ratings for a given user Postcode. Further cross-referenced geodemographic data is collected and represented from the Office of National Statistics' 'NESS' service for the area in question. The mapping tool allows multiple sources of information, hazard model outputs and geodemographic data, to be collated together for the user-selected Postcode Unit. A house-holder enters the Postcode of their selected property to receive a custom report for that location and environs. Demographic information is drawn from the Office of National Statistics (ONS) Neighbourhood statistics service (NeSS).

Figure 10: Householder Toolkit

Property Value Tools

Tool 10. House Price Impacts query tool — allows a householder to inspect the possible impacts of extreme flood events on their house price.



House Price Impacts query tool

This utility is designed to allow a householder to enter a Postcode Unit for their property to reveal the potential impacts of extreme flood events on their house property price.

se92pq [OK] *Enter a Postcode* Hint

For your requested Postcode of:	**se92pq**	
LSOA Code	**E01001614**	Lower Super Output Area
Population East	**544701**	Co-ordinates of the population-weighted centroid of a Lower Layer SOA
Population North	**174805**	Co-ordinates of the population-weighted centroid of a Lower Layer SOA
Postcode	**SE9 2PQ**	Postcode Unit
Eastings	**544424**	Eastings
Northings	**174440**	Northings
2007 House Price	**223554.4844**	Constant quality typical house prices in 2007
Doubled flood risk price	**223554.4844**	Simulated house price impacts based on doubling flood risk without feedback effects
Percentage change	**0.00%**	Percentage change of 2007 house price to simulated house price impacts based on doubling flood risk without feedback effects
Doubled flood risk price with employment effects	**222343.1875**	Simulated house price impacts based on doubling flood risk with feedback effects of employment
Percentage change	**-0.54%**	Percentage change of 2007 house price to simulated house price impacts based on doubling flood risk with feedback effects of employment
Doubled flood risk price with employment and depravation effects	**226539.6250**	Simulated house price impacts based on doubling flood risk with feedback effects of employment and depravation
Percentage change	**1.34%**	Percentage change of 2007 house price to simulated house price impacts based on doubling flood risk with feedback effects of employment and depravation

Instructions

Enter a valid full unit level Postcode to query the house price model results. A full output is returned for that location.

Commentary: The House Price Impacts query tool provides householders a tabular presentation of the outcome of the EWESEM model, described in Programme Package 3 (PP3), for the location of their property (a Postcode Unit representing on average some 15 or so properties). Model output includes the various house price scenarios modelled and represents the potential impacts of a flood event. The utility is designed to allow a householder to enter a Postcode Unit for their property to reveal the potential impacts of extreme flood events on their house property price. Results are output as a table including percentage change with doubled flood risk and with and without associated employment and deprivation effects.

Figure 11: House Price Impacts Querying Toolkit

Lessons learned

Overall, the WISP development and the iterative revision of the stakeholder 'What if?' scenario tools identified a number of issues surrounding the integration of datasets produced by the individual research themes. The following is a summary of the lessons learned and areas identified for further development in the evolution of WISP.

Presentation of spatial data

Future climate-related projections contain a significant and inherent degree of uncertainty. Presenting information to stakeholders requires a balanced approach that conveys the variation in the projected risk without overloading the user with large amounts of complex data to interpret. The pluvial flooding results proved a good example of a complex dataset to present to a user. Within WISP, flood data for both severity and frequency of events was combined using a matrix. Colours were assigned to the classes based on the total number and the average severity of events within a Postcode Unit for three modelled datasets from the 2020s and 2050s. The modelled datasets represent the central - or most likely - projection and a high and low extreme. The data can then be interrogated by clicking on any individual unit. Users can interpret both the frequency and severity of the flood events at a broad Postcode scale and then 'drill down' further into the data for finer resolution information. This hierarchical approach removes the burden of interpretation from the user while still allowing access to detailed information.

Also of concern was the misinterpretation of information based on scale. Gridded output from the hazard modelling at a resolution of 1 km can have sharp discontinuities at the street level and infer a greater spatial accuracy in the delineation of hazards than is actually modelled. However, it is important to show the spatial distribution of the data at a scale such that the user can identify where events might be expected to happen. Summarising continuous data within discrete parcels is one approach to control the scale of the data. Thus the model output is aggregated within areas that have meaning to the stakeholder groups, e.g. Postcode Units. This has the advantage that information is also then cross-comparable with other information sources collected against national geographies such as Postcode Unit or Super Output Areas (SOA) items in the census for example. A disadvantage of presenting the data in this way is that parcels defined for one purpose may not reflect the physical divisions in the modelled data. Pluvial flooding was presented this way in WISP as the modellers were able to aggregate event statistics within Postcode Units and the scale of the modelled data was at a higher resolution than the reporting level.

The 'Integrated EWE Decision Support Tool' risk mapping application (van Hoek, 2011), (Fig.12 and 13), shows a virtual data product created based on the user-specified weightings and selections. To the right (Fig. 12) it can be seen how these weightings may be changed, as well as the period of projection, likelihood of scenarios and the risk category for wind speed. Furthermore, a 'widget' is shown in the bottom left panel (Fig. 12), providing the user with additional supporting information through an elevation profile chart along a user-specified line. Further widgets enable the integration of legends, elevation charts and Google 'Street View' photography to aid visual navigation around the study area in areas highlighted by the model outputs.

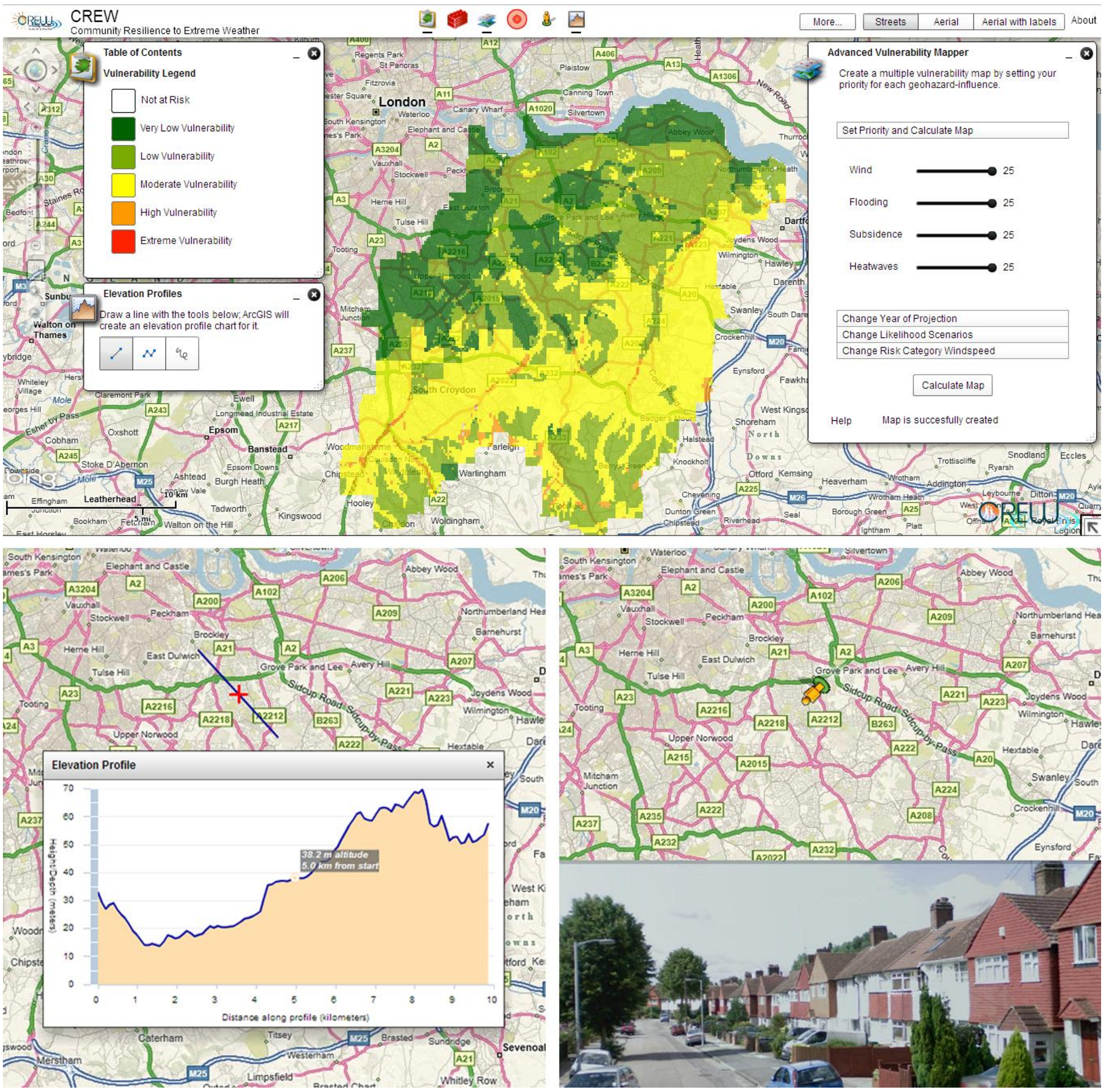


Figure 12: Prototype CREW Hazard Vulnerability Mapper

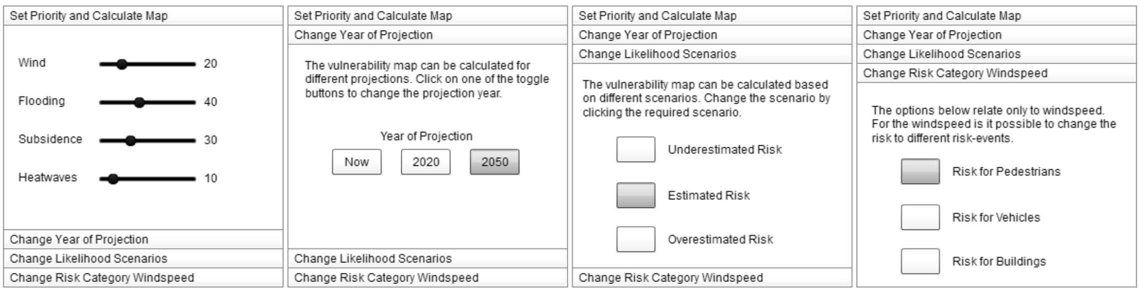


Figure 13: Overview of the accordion navigation tool for the input parameters of the geoprocessing work flow.

Hazard specific thresholds

Deciding on the threshold of weather-related hazards that will impact on the community is an important consideration when presenting risk information to stakeholders. In CREW the hazard datasets are predictive and contain a measure of both severity and frequency/probability. This leads to difficulty in conveying the nature of the risk: whether it is unlikely to occur but extreme in nature or less severe but with a much higher frequency. CREW modellers devised a hazard numbering system to help in interpreting the severity of their outputs. However, the thresholds determined for each numbered band for one hazard do not always map easily to those of the other hazards.

Combining multiple risks

A single index of vulnerability was attractive for SMEs and decision makers to remove the interpretation of multiple hazard datasets from the user. Even with a uniform scale of hazard severity across the physical datasets, combining them is not a straight-forward process. The output of each of the physical models is derived from a different approach dependent on the nature of the hazard itself. For example pluvial flooding is modelled using many permutations of rainfall data at the catchment scale, which produces multiple flooding events for any set of inputs from the Weather Generator. Each of these events is represented by a flood depth map or risk map classified according to a hazard number. For any future prediction the dataset will contain a frequency of flood events, each with their own mapped output at the sub-catchment scale. Congruent with this, the variability of the modelled subsidence is represented by three mapped risk surfaces - ranging from extremely low to extremely high risk - for each of the 2020 and 2050 predictions.

The approach taken by Emberson (2010) was to integrate an Index of Multiple Deprivation (IMD) (described in Noble *et al.*, 2008) with address information and weighted hazard overlays to identify hotspots where stakeholders could target resources. The IMD was used to represent the ability of a group of individuals to adapt based on their financial restraints and access to services. The advantage to a decision maker of a mapped index of risk is that a single map layer can be used to identify hotspots where further investigation can be targeted. Weighting of the input variables provides increased control to the user who can alter the influence of the individual components of the combined risk according to their requirements. However, representing information in this way also presents potential disadvantages. In areas exhibiting both a high and a low risk in different hazards, combining inputs may serve to cancel each risk out, with consequent areas of high risk for individual hazards being excluded from resulting hotspot mapping. Thus extending green shade proximal to dwellings to help alleviate heat may increase subsidence risk. Furthermore, the range of hazards considered in the CREW project are unlikely to be temporally concurrent. Given that hazard-related effects may exhibit at different time of the year, there may not be added benefit from adopting a combined approach to implementing coping strategies. Selection of weighting factors gives the hotspot tool flexibility but places the onus on the user to derive appropriate weighting criteria. The decision maker can use the tool to identify hotspots, adopting their own strategies to create their own information by selecting inappropriate weightings to hazards that may be spatially or temporally unrelated. The ability to subsequently ‘drill down’ into the data can help illuminate the causal factors for given ‘composite’ risks.

Network of risk

Risk is not limited to the areas directly affected by the weather-related hazard. Damage to critical infrastructure in one part of the community will have a knock-on effect to those who would consider themselves not at risk. Stakeholders highlighted that key workers for a given critical industry and their dependants represented a vulnerable group. Hazards could impact on the transport infrastructure between these worker’s homes, their children’s schools and their places of work so impacting on the delivery of the key services they provide. Identification of so called ‘pinch points’ requires that the community be considered as a network, both in terms of physical infrastructure and through human interactions, to take into account the displacement of impacts that could affect both the most vulnerable groups and those who are considered more resilient. WISP only goes as far as incorporating transport nodes and elements of critical infrastructure such as hospitals, fire stations and police stations in the mapping tool kits to demonstrate, in principal, these effects. Understanding that the integration of datasets can result in impacts spatially independent from the mapped hazard is an important consideration in implementing future WISP-like toolkits.

Stakeholder feedback

Consultation with stakeholder groups is an integral part of CREW. Feedback was collected through questionnaire surveys, workshops, assemblies and direct feedback from project members on a 'Wiki' website. WISP mapping of hazard serves as the main tool for raising the awareness with stakeholders. By hosting the WISP tools on a Wiki - a website that can be edited directly by a user - comments can be added to the relevant pages directly, stimulating discussion. The approach adopted was consistent with the 'Web 2.0' philosophies permeating the wider Internet, where 'crowd-sourcing' of community-interest information and collaborative interactions become more common-place. Further to this, stakeholder assembly workshops have already identified several points that can be fed back into the WISP tools.

The main comment across the three stakeholder groups relates to the accuracy of the hazard projections presented. Householders, SMEs and decision makers need strong reasons to change their behaviour and invest in coping measures. Decision makers also expressed the need to show the evidence for their planning decisions and needed more information on what thresholds mean in terms of planning. The stakeholder's feedback also highlighted the need for simplicity in the presentation of the data as users may not have the skills or the time to interpret the data themselves.

Feedback that was more specific to decision makers related to how this stakeholder group could integrate WISP tools with other sources of data such as demographics. They also pointed out that there are other tools available to them, namely flood mapping, that may not appear to be in agreement with the information presented via WISP and how would they know which to use.

Householder feedback contrasted with that of decision makers in the perception of what impacts an increased risk would have. An individual had a feeling of being disadvantaged by increased information: that the value of their property would be affected and insurers would use the information to increase premiums. Whereas decision makers wanted to identify the areas of risk in order to target their limited resources more efficiently.

Conclusion

WISP is the main tool for communicating the project outputs of CREW to the selected community stakeholder groups. Dissemination of information using stateless web services via the Internet requires no specialist software or knowledge that could be a barrier to data access. Users require an Internet connection and a browser to access a large repository of data and methods.

The engagement with stakeholders has defined toolkit functionality and highlighted issues in mapping future hazards and the potential spatial displacement of their impacts. This process feeds back to the WISP developers to create better tools to help build communities that are more resilient to the potential impacts of climate change.

Acknowledgements

WISP — Weather impact 'What-If' Scenario Portal (EP/F036817/1) was funded by the Engineering and Physical Sciences Research Council (EPSRC).

Andrew Rayner, formally of Cranfield University for his outstanding programming skills.

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Porritt, S. M. *Adapting UK Dwellings for Heat Waves* (2012). PhD Thesis, De Montfort University. Available from: http://hdl.handle.net/2086/6327.

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7

Chapter Seven. CREW Project Governance and Coordination

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Programme Package Six was developed to formulate the management, governance and guidance of the CREW project, research team activities, dissemination and outreach events. Key dissemination moments for the CREW project are presented in Appendix Two. Three General Assemblies (GA) were held, bringing together stakeholders and academics:

GA1	3rd April 2009	Greenwich University, London
GA2	2nd July, 2010	UCL, London
GA3	25th November, 2011	Royal Institute of Chartered Surveyors (RICS), London

To ensure the alignment of the project activities with the requirements of key stakeholders, a Project Advisory Group (PAG) was established comprising pre-eminent industry and public-sector representatives.

The project web portal www.extreme-weather-impacts.net remained an effective tool to communicate with project partners as well as interested public during and after the project.

CREW Advisory Board

The CREW project partners are extremely grateful for the consideration and guidance received from the CREW Project Advisory Board, who met during the conduct of the project to advise and guide the partners. The final advisory group composition comprised the following members:

Alex Nickson, Greater London Authority (*Chair*)
Jo Allchurch, Policy and Development Programmes, Local Government Group
Katie Carmichael, Health Protection Agency
Juliette Daniels, London Climate Change Partnership
Rob Hitchen, ERG-ACC, Defra
David Holtum, EPSRC
Jo Lovell, Defra, Adapting to Climate Change Programme
Trevor Maynard, Lloyd's of London
Roger Street and Anastasia Mylona, UKCIP
Tony Petim, Globe Connections Ltd
Josh Stott, Joseph Rowntree Foundation

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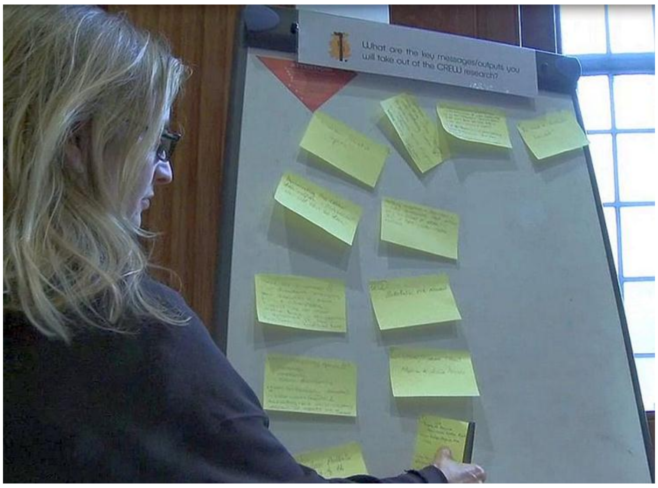
Chapter Eight. Stakeholder Report — Responses to CREW

The CREW project involved a large array of differing stakeholder groups and interested parties. One effective means by which to reach these persons and to elicit and capture their views was through the programme of 'General Assemblies', of which CREW held three.



The last and final General Assembly was held on 25 November, 2011 in the Royal Institute of Chartered Surveyors building near Parliament Square in London. At the event, delegates were invited to respond to a series of key themed questions. These responses were collated together with a multiple coding methodology employed in MS Excel for every statement received in order to reveal the common points arising. This section reports on the findings of this analysis, thereby representing a summary stakeholder viewpoint of the issues addressed in CREW.

Key messages from CREW

Participants left the Assembly with several key messages from CREW. The capacity for modelling the socio-economic impacts of flood risk surprised a few and the potential for such a decision-making aid was keenly appreciated. The value of the CREW risk definition tools was remarked upon with equal enthusiasm. The multiple perspectives of adaptation were seen through the multiple disciplines of CREW, which in of itself conveyed the necessity of such an approach. Socially and organisationally, the multiple scales, interconnectedness and layered nature of community resilience were recognised.

How to use the CREW messages in practice

In feeding back how they could envisage using the messages from CREW, attendees reported significant synergies with existing work streams, on mitigation and socio-economic justice issues. Many felt that they could feed through CREW findings to the relevant parts of their organisation and that this would help them inform their respective senior management and in building the case for adaptation generally.

CREW findings and tools helped officials in understanding the nature, spatiality and movement of the risk, by targeting work towards exposed and vulnerable areas and communities.

Further needs to make outputs more relevant to users and informing emerging user requirements

Delegates frequently remarked that access to data and tools would most readily make the CREW research more useful to their organisation. Several highlighted that CREW should interface with the Climate Change Risk Assessment, the National Adaptation Plan and the health sector generally. CREW researchers were involved with the CCRA production process.

Demonstrable impact of results was an emerging demand from stakeholders who were keen to see utility. Though at an early stage, the participatory method of engagement, especially with local decision-makers is tangible amongst concerned stakeholders in Lewisham and Croydon.

Nationally-applicable decision-making aids and community resilience tools were also mentioned. The Building Retrofit Toolkit from Programme Package 1 (PP1) as well as the Risk assessment framework and forthcoming post-LCLIP tool emerging from the Community Coping work in Programme Package 2 (PP2) speak to this requirement.

One of the limits to progress on adaptation brought up by this question was the limited, narrow interest shared amongst the stakeholders the CREW project sought to address. The CREW research highlighted that this limiting factor may be subverted by open dialogue, which emphasises reception as well as communication of risk, impact and options.

There were emerging questions about the potential to engage the public using a 'quality of life' argument, and the potential for the uninsured to be stigmatised. Attendees were also interested in the implications of community ecology and the non-idealised adaptive citizen. These demonstrate how adaptation and resilience are set to transform in the coming years as policy discourse and institutional arrangements unfold.

Opportunities and requirements for your sector for the use of CREW outputs

With the mitigation-led climate change activity now well established, significant potential was seen to incorporate CREW outputs within established and in-pipeline programmes, such as the 'Green Deal'.

Adaptation-proofing mitigation programmes were identified as a key first step in developing integrative approaches for addressing the climate change mitigation and adaptation strategies.

As envisaged, mapping of hazards was seen as particularly persuasive decision-making tool. Believable and easily understandable communication of the issues to non-experts was also mentioned.

Who to involve in effectively implementing results?

There was broad agreement that community-based organisations were crucial for success in community resilience. Built environment actors, from construction through to operation and maintenance were highlighted as was central government.

Further action for dissemination

As highlighted, in linking to existing spaces, a framework to access data and tools were marked as further action points. Channels explicitly mentioned included: the Green Deal, the building standards debate (PP1), retrofit programmes, the CLG-EA built environment study, local stakeholder forums, the TCPA think-tank, and the Training Climate Change Skills Fund.

It is worth noting finally that in addition to standalone data and institutional engagement, some delegates perceived a need for a 'human network', with a readily accessed online and physical presence allowing engagement with interested parties and present to senior management.

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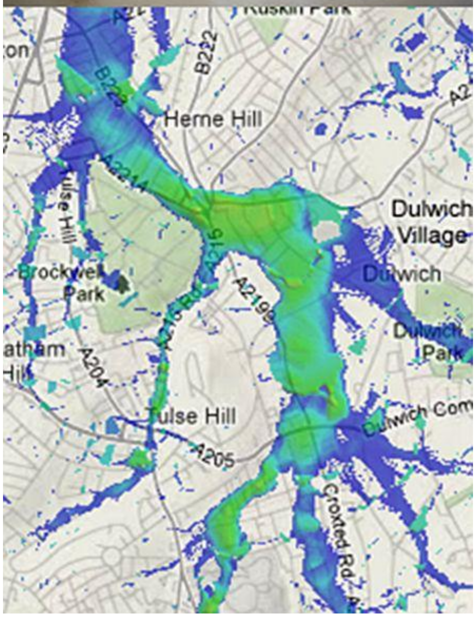
Chapter Nine. CREW Conclusions



Commenced in spring, 2008, and concluding in November 2011 with a well-attended and successful final General Assembly and conference[4], the CREW project has represented a significant body of EPSRC-sponsored research conducted by a consortium of some 45 researchers from 14 Universities considering the local impacts of climate change at the community level. The CREW research team drew together a wide spectrum of academic disciplines including geography, climatology, engineering, economics, statistics, sociology, and earth sciences.

CREW has recognised and addressed directly the profoundly inter-disciplinary impact of climate change. It is difficult to consider a single topic that is truly more inter-disciplinary. Simulating future weather scenarios has required the skills of physicists, mathematicians and climatologists, with the effects of those scenarios touching on just about every aspect of human enquiry. It was a contention of the CREW consortium that whilst there had been a great deal of research underway in relation to climate change, very little of it had been truly interdisciplinary. The establishment of the CREW consortium proved in itself a major developmental step towards providing future integrated solutions to complex issues.

The second innovation of the project overall has been the geographical focus of the work undertaken. Prior to CREW, quantitative work was pursued as to the impacts of climate change at the global, regional and national levels (the Stern report (2006) and the BESEECH project, for example), but few studies were focussed at the neighbourhood or community level. There has been previous qualitative and case-study research at the local level, but often with little integrated, quantitative modelling to simulate future weather and the impacts on local housing prices and other determinants of neighbourhood well-being. CREW has sought to undertake this.

Joining together climate projections from UKCP09 with socio-economic models of the effects on the local community seemed an ambitious task, and yet with this initial goal, CREW researchers were motivated by three powerful factors: psychology, resource scarcity and asymmetry of climate change impacts.

First, the psychology of household and institutional decision-making has often manifested such that seemingly no amount of 'gloomy statistics' and 'doomsday prophecies' will effect significant change in human behaviour unless the implications of those scenarios can be made real and tangible to the

[4] Videos made of the day are presented on the CREW web portal – www.extreme-weather-impacts.net.

non-expert stakeholder. Work by Zeckhauser (1995) and others on the economics of catastrophes has suggested that households, small companies and governments do tend to underestimate risks that appear distant or global, or which others seem to accept without concern. Critical questions, newly elicited from our stakeholders, included queries such as ‘What are the implications of climate change for me and my neighbourhood?’, ‘How will it affect the chances of me losing my job or my firm going bankrupt?’, ‘What might be the impact of flooding on the value of my house?’. These are the types of questions the CREW team have sought to address, being manifestly the kind of issues that people identify strongly with.

Second, whilst we may have unlimited capacity to dream up ever more elaborate methods for climate mitigation and adaptation, the reality is that we live in a world of scarce resources. Indeed, we have to face the fact in the wake of the economic downturn that there will be limited public funds to assist with resilience and regeneration. Britain is an island with the majority of its major cities located on the coast or on fluvial inlets. If the estimated flood risk implications of climate change proves correct (and 2050 in these terms is not so far away from the current day), many difficult decisions clearly lie ahead concerning the prudent and effective allocation of scarce public funds. Research that helps us identify the optimal allocation of such limited funds will therefore prove more important than ever. Quantifying the complex socio-economic impacts of future climate change scenarios at the local level may seem a difficult task but it is an essential one nonetheless. In the words of the great nineteenth century scientist Lord Kelvin, “… when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind” (Kelvin, 1883). To frame this more crudely in the context of current decision making processes, ‘what gets measured, gets addressed’. If we want to avoid potentially catastrophic oversights and major spatial inequalities emerging in our plans for coping with climate change, we need to quantify not only the incidence of extreme weather but also its consequences.

Third, anticipating the geographical effects of flooding and the other extreme weather events is complicated by potential asymmetries. The same event will devastate one area, but will exert only a superficial and temporary effect upon another. This is because the socio-economic impact of extreme weather events depends crucially on local social-cohesion and economic robustness. The UK already has one of the highest levels of economic spatial inequality in Western Europe. How climate change will therefore affect existing patterns of spatial inequality and its differential economic impacts could profoundly alter how we might (or should) prioritise the future use of public funds. Such complexities greatly increase both the risk of unanticipated impacts of climate change, and the likelihood of unintended consequences of policy intervention. Simulation tools that help policy makers think-through these unforeseen effects therefore have a potentially vital role in society’s attempts to address the challenges of global warming.

The CREW consortium has sought to deliver on the conflicting requirements of complex modelling and the need to engage with households, decision-makers and local businesses at the local level. The project aimed to channel the scientific outputs of weather simulation and socio-economic models into a set of web-based tools for mapping likely future extreme weather events and their socio-economic impacts. The composite output of this therefore embodies four years of research, from 2008 to the final general assembly in November 2011, spread across a series of inter-linked Programme Packages, as well as a coordination and management task:

- Community hazards (SWERVE) – computer simulation of local extreme weather events and consequent hazards for current and future climates.
- Community impacts (EWESEM) – a suite of statistical models that quantify and simulate the socio-economic impacts of current and future extreme weather events (particularly flooding) at a neighbourhood level.
- Community coping (capacity for resilience) – stakeholder-led research to understand better how community groups respond to extreme weather events.
- Community coping (people and buildings) – identification and assessment of existing coping measures, from simple personal options to hard engineering solutions.
- Community tools (WISP) – a web-based toolkit for mapping likely future extreme weather events and their neighbourhood impacts.

While CREW has been somewhat limited in geographical scope to the South East London Resilience Zone (SELRZ), comprising five local authorities to the south of the River Thames: Croydon, Bromley, Lewisham, Greenwich, and Bexley, it may also be seen that the integrated, inter-disciplinary research framework and interactive web-based tools that have emerged from the CREW consortium can provide an effective template for gauging and communicating the neighbourhood effects of climate change in other parts of the UK and abroad and also as a springboard for considering other urban and peri-urban impacts of the changing climate, such as urban biodiversity capacity.

In trying to understand and simulate the neighbourhood implications of future weather events, the CREW project and its members set out an onerous task. To quote Lord Kelvin once again (1871), "Science is bound, by the everlasting vow of honour, to face fearlessly every problem which can be fairly presented to it." Even where we are not inspired by Kelvin's spirit of scientific inquiry, the practical imperative to regenerate neighbourhoods in the face of the growing threat of climate change, necessitates and underpins this research.

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The research consortium would also wish to thank EPSRC for supporting this body of research, and the Adaptation and Resilience to a Changing Climate Coordination Network (ARCC CN).

Finding out more about CREW

The CREW project website contains a wealth of further information on the project, as well as access to the tools and materials from the Final General Assembly.

Visit the CREW website at www.extreme-weather-impacts.net

Videos are available online of the final CREW General Assembly

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Appendix One – Terminology and Definitions

To ensure compatibility in the usage and communication of key terms across the work packages, CREW employs the following 'working terminology', presented below and extending the Glossary of Abbreviations. It is recognized that many of the terms noted are used in different (and sometimes conflicting) ways across disciplines and approaches, but it is proved important for the purposes of the CREW project that a standard set of definitions be tailor-made to support a shared understanding of the *foci* of the project and be thus applied by all members. The definitions were therefore formulated to reflect the work of CREW programme, however they should also be regarded as 'living' definitions, which evolved as the research progressed, with new findings emerging.

Compilation of this list has been based on consultation of key existing glossaries, including the United Nations International Strategy for Disaster Reduction and Inter-governmental Panel on Climate Change (IPCC, 2001; 2007). For a useful discussion of terminology and its controversies/confusions see Levina and Tirpak (2006).

Core Terms

Term	Definition	Examples/explanation	Comments
Extreme weather event (EWE)	Meteorological conditions that are rare for a particular place and/or time.	e.g. severe storm, intense or prolonged precipitation, prolonged low levels of precipitation, intense or prolonged high temperatures, intense or prolonged low temperatures.	For meteorologists, the essence of extreme weather is that it is 'out of the ordinary': 'An event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile' (IPCC, 2001). But in lay terms, extreme weather also implies weather of sufficient severity to generate 'hazards'.
(EW) Hazard	A potentially damaging phenomenon associated with extreme weather that may cause the loss of life or injury, property damage,	e.g. flash flood, storm surge flood, gale-force winds, tornado, severe lightning, heat wave, cold wave, drought.	In this sense, it is the hazard (a phenomenon associated with extreme weather conditions) rather than the weather conditions themselves that can impact on people and society. The distinction is important to

Term	Definition	Examples/explanation	Comments
	social and economic disruption or environmental degradation.		make for hazards such as floods – which: i) are not weather events *per se*, and ii) which may result from multiple causes (e.g. combined river/tidal floods, weather/human alteration to land use)
Resilience (to EW)	The ability to prevent, withstand, recover from and learn from the impacts of EW hazards.	As a working term within CREW, this was seen to encompass the ability to avoid impacts, to tolerate disturbance without sustaining damage or harm, to bounce back from the effects of damage or harm, and to learn from and adapt in order to improve the inherent ability to cope with future EW events.	'Resilience' is a term currently subject to much debate over its usage: the definition provided here is a compromise solution that covers four key senses in which the term is used all of which have been applied in CREW. In social-environmental science the term is commonly used when referring to properties of 'social systems', including communities. However, it is also often used for discussing attributes of specific individuals, groups or organisations. A growing use of the term is to critique narrow interpretations of 'adaptation' and argue for a more holistic approach toward managing risks and building step-change transitions toward sustainability. This definition is of specific interest to CREW, but perhaps also it can be seen in a more academic than

Term	Definition	Examples/explanation	Comments
			practical sense in terms of project outputs.
Community resilience (to EW)	The ability of a community to prevent, withstand, recover from and learn from the impacts of EW hazards.	Specifically, the ability of a community: to continuously exist and function during an EWE; to bounce-back from the impacts of EW hazards; to build a capacity for learning and adaptation for similar kind of extreme weather in the future.	See related terms including Risk, Vulnerability, Coping capacity, and Adaptation.

Other Relevant Terms

Term	Definition	Examples/explanation	Comments
Adaptation	Initiatives and measures to reduce the vulnerability of humans and human systems to actual or expected climate change effects, including increases in the intensity or frequency of EWEs.	'Anticipatory' adaptation is adaptation that takes place before impacts of climate change are observed; 'reactive' adaptation takes place in response to observed impacts.	The term is used in two literal senses: 'adaptation' as a general process (of change); and 'an adaptation' as a specific outcome of that process e.g. cessation of building on floodplains.
Adaptive capacity	The ability of a system to implement effective adaptation measures.	It is shaped by available resources, institutions, skills and knowledge etc.	It refers specifically to ability to adapt, not to ability to manage risks (although adaptive capacity can and should enable better management of future risk).
Climate change	Climate change refers to a change	Climate change may be due to natural internal	Note that the IPCC does not define climate

Term	Definition	Examples/explanation	Comments
	in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.	processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2007).	change solely as the anthropogenic component.
Climate model	A numerical representation of the climate system….	...based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. (IPCC, 2007).	
Climate scenario	A plausible representation of the future climate….	...based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. (IPCC, 2007).	
Community	A group of people (including/or organisations) impacted by extreme weather.	They could be living or working: in a specific locality; suffering from extreme weather; having endured significant loss (financial or otherwise) as a result from such extreme	The so-called community could encompass one or more of these in the middle column. The meaning should be interpreted within the specific social, economic

Term	Definition	Examples/explanation	Comments
		weather; having a specific interest on the risk of the event in the locality, the event as it happens, and its recovery. Community could mean a geographical context (e.g. a village), a business (SMEs, or local farmers), a social (e.g. local interest groups), or other collective (e.g. a school/college).	and environmental context, as each might associate the term with different perspectives.
Coping capacity	The ability of people or organizations to limit adverse consequences of EW hazards, using available resources and capabilities.	Essentially this can be considered synonymous with the definition of resilience.	Coping capacity can, however, have different interpretations. The term ‘coping’ can imply a passive tolerance of impacts and/or reactive approaches to hazards, rather than anticipatory, preventive actions.
Coping mechanisms/strategies	Actions that increase ability to prevent, tolerate, avoid and/or recover from EWEs and their impacts.	e.g. flood defences, early warning systems, damage-resistant flooring, land use planning, insurance, education, social/community support.	As above, the term ‘coping’ can have passive connotations - rather than the active sense in which it is defined here.
Disaster	A serious disruption of the functioning of a community causing widespread human, material, economic or environmental losses which exceed the ability		Though disasters are often classified in terms of the hazards associated with them (e.g. hydro-meteorological, seismic, volcanic), very few disasters have such simple causality; it is commonly argued that the term ‘natural disaster’ is misleading -

Term	Definition	Examples/explanation	Comments
	of the affected community to cope using its own resources.		human decisions/actions and social conditions almost always contribute to the vulnerability that turns a hazard into a disaster.
Mitigation (of climate change)	Policies and action to reduce the sources of (or enhance the sinks for) greenhouse gases.	e.g. control of emissions from vehicles, fuel efficiency, alternative fuels, carbon markets, reforestation.	In terms of disaster risk management 'mitigation' has a different meaning: it refers to structural and non-structural measures undertaken to limit the adverse impact of hazards - because of the focus on climate change in the project the term was not adopted generally in the CREW project. However, the work of Programme Package 1 (PP1) did involve the identification of mitigating interventions in building design for addressing the effects of heat waves.
Passive Adaptations	Adaptations or interventions to dwellings that do not consume energy and therefore do not result in increased carbon emissions.	Shading devices, solar reflective coatings, modifications to ventilation strategies, additional insulation.	Note that in some cases (for example where noise or security is a problem) it may be necessary to install vents with low power or constant volume fans to achieve night ventilation.
Probability	Probability is the likelihood or chance that something is the case or a given	Probability may be expressed either quantitatively (a mathematical probability), or qualitatively (a	See related term Uncertainty.

Term	Definition	Examples/explanation	Comments
	event will happen.	statement such as ‘very likely’ or ‘likely), in order to assess the potential occurrence of a given event or set of circumstances.	
Probabilistic Projections	The production of large-ensembles of climate change projections enables the production of probability density functions to represent the range of projected change in a specific feature of the climate or event.	Specific probabilities may be assigned to individual events or climate change impacts by incorporating model uncertainties within a large model ensemble. Such an ensemble is provided by UKCP09.	
Risk	The probability of harmful consequences or expected losses resulting from interactions between extreme weather (EW) hazards and vulnerable conditions.	One may speak of risks to: life, health, property, livelihoods, economic systems, infrastructure, etc.	The term ‘risk’ is defined in many different ways by different disciplines. Sometimes it refers solely to the probability of occurrence of an EWE or a EW hazard. Because of the ‘community resilience’ focus of CREW, a more downstream, human-centred definition is considered preferable: risk as experienced by people/social systems. In this definition risk refers to the threats posed to humans by the impacts of extreme event hazards - it is therefore a

Term	Definition	Examples/explanation	Comments
			function of both the physical hazard and the vulnerability of people/societies exposed to it.
Risk management	The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the risk from the impacts of EWE hazards.	This comprises all forms of activities, including structural (engineered) and non-structural measures to prevent, prepare for, cope with or recover from adverse effects of hazards.	This was not addressed broadly within the CREW research. See the related term Mitigation.
Uncertainty	Uncertainty is the state of having limited knowledge where it is impossible to exactly describe either the existing condition or future outcome.	Uncertainty in projections of future climate may arise from incomplete knowledge of existing processes, or from different parameterisation of processes in different models. Not all forms of uncertainty are considered by CREW e.g. uncertainty in future emissions of greenhouse gases.	The IPCC uses specific terminology for both uncertainty (confidence) and probability (likelihood). For example, very high confidence is defined as "at least 9 out of 10 chance" of confidence being correct. Extremely likely is defined as ">95% probability of the occurrence/event".
Vulnerability	The characteristics and circumstances of humans and human systems that determine	Vulnerability can be shaped by various factors/processes: social, economic, cultural, political, technological,	The concept is sometimes divided into physical vulnerability (which refers to the chances of being

Term	Definition	Examples/explanation	Comments
	how susceptible they are to the impact of EW hazards.	environmental, that shape the likelihood of exposure to hazards and the likelihood of adverse consequences resulting from exposure.	exposed because of location of home or workplace) and social vulnerability (the chances of suffering impacts if exposed).

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Appendix Two – Outputs and Impacts from CREW

This Appendix lists the substantial body of research outputs and impacts ensuing from the CREW project.

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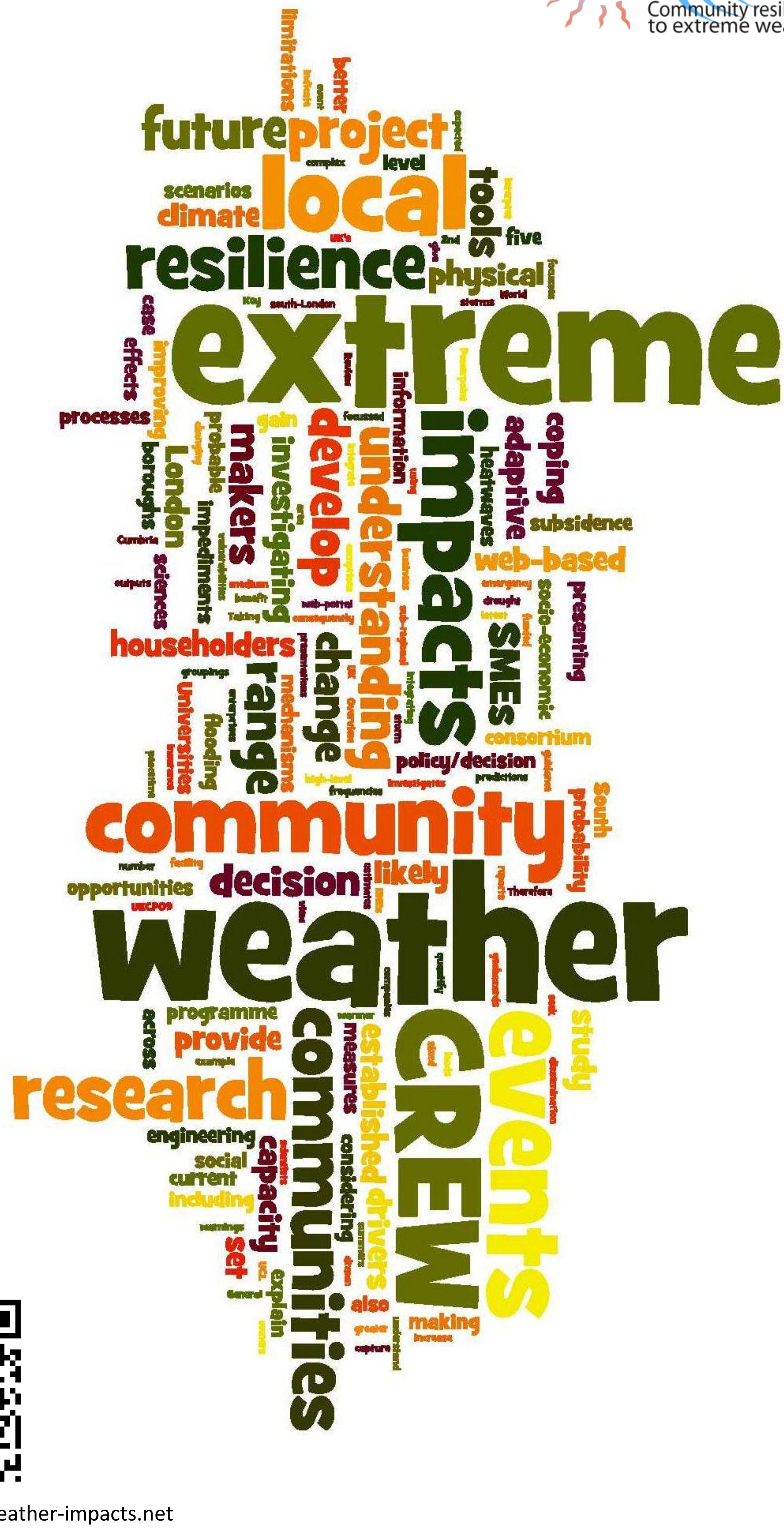

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