

The UK Climate Change Risk Assessment 2012
Evidence Report Annex A and Annex B

The UK Climate Change Risk Assessment 2012
Evidence Report Annex A and Annex B

Presented to Parliament pursuant to Section 56
of the Climate Change Act 2008

© Crown copyright 2012

You may use and re-use the information featured in this document/publication (not including logos) free of charge in any format or medium, under the terms of the Open Government Licence <http://www.nationalarchives.gov.uk/doc/open-government-licence/open-government-licence.htm>

Any email enquiries regarding the use and re-use of this information resource should be sent to: psi@nationalarchives.gsi.gov.uk. Alternatively write to The Information Policy Team, The National Archives, Kew, Richmond, Surrey, TW9 4DU.

Printed on paper containing 75% recycled fibre content minimum.
PB PB13699A

This report is available online at:
<http://www.defra.gov.uk/environment/climate/government/>

**UK
2012** | **Climate
Change
Risk
Assessment**

(Defra Project Code GA0204)

**The UK Climate Change Risk
Assessment 2012
Evidence Report**

Project deliverable number D.4.2.1
Release 7
January 2012

**Annex A: Scenarios of climate
variability and change**

The Met Office

Contractors: HR Wallingford
AMEC Environment & Infrastructure UK Ltd
(formerly Entec UK Ltd)
The Met Office
Collingwood Environmental Planning
Alexander Ballard Ltd
Paul Watkiss Associates
Metroeconomica



Llywodraeth Cymru
Welsh Government



Department of
the Environment
www.doeni.gov.uk



The Scottish
Government



defra
Department for Environment
Food and Rural Affairs

Statement of use

See full statement of use in the main Evidence Report.

Keywords:

Climate change, risk, UKCP09, climate models, climate projections

Research contractor:

HR Wallingford

Howbery Park, Wallingford, Oxon, OX10 8BA

Tel: +44 (0)1491 835381

(For contractor quality control purposes this report is also numbered EX6693)

Defra project officer:

Soheila Amin-Hanjani

Defra contact details:

Adapting to Climate Change Programme,
Department for Environment, Food and Rural Affairs (Defra)

Area 3A

Nobel House

17 Smith Square

London

SW1P 3JR

Tel: 020 7238 3000

www.defra.gov.uk/adaptation

Document History:

Date	Release	Prepared	Notes
10/11/11	R1.0	The Met Office	Draft to accompany R4 of the Evidence Report
14/12/11	R2.0	The Met Office	Updated to accompany R5 of the Evidence Report
13/01/12	R3.0	The Met Office	Updated to accompany R6 of the Evidence Report
24/01/12	R4.0	The Met Office	Updated to accompany R7 of the Evidence Report

Summary

A comprehensive set of projections of climate variability and change over the UK across the 21st Century over the UK have been provided in UKCP09, covering changes in annual, seasonal and monthly mean meteorological quantities and also some extremes.

The projections cover a range of future changes that may arise from both natural climate variability and long-term human-induced climate change.

Three emissions scenarios were examined, covering the range of scenarios previously examined by the Intergovernmental Panel on Climate Change (IPCC). For each emissions scenario, a range of possible changes in UK climate were projected.

Although UKCP09 provided estimated probabilities to demonstrate the levels of confidence in different climate changes, these probabilities were not used to describe the outputs in the CCRA because the further translation into risks introduces additional uncertainties that rendered the probabilities meaningless.

Instead, projected climate changes in the middle and near the upper and lower ends of the UKCP09 projections were used in CCRA to provide a range of scenarios of plausible change. Changes in 30-year average conditions were considered.

On average and over the long term, UK mean temperatures are expected to warm. The precise magnitude of warming will likely vary somewhat with location and is uncertain. The CCRA scenarios examined a range of magnitudes of warming.

Long-term UK precipitation responses to global warming are more uncertain than temperature, and this is reflected in the scenarios used in CCRA. The CCRA scenarios all included wetter winters, with a range of precipitation increases being considered. Summer precipitation changes ranged from large decreases to small increases, reflecting the projections of UKCP09.

In the short term, natural variability in climate remains more important than the more gradual effect of increased greenhouse gas concentrations. Fluctuations in both temperature and precipitation over the next few years may therefore be temporarily in the opposite direction to the trends that emerge in the longer term. For precipitation, this fluctuation may also occur in the 30-years averages.

The “wet” end of the range of summer precipitation changes considered in CCRA therefore extends more to wetter conditions in the next few decades than at the end of the century.

The CCRA methodology did not consider individual extreme years or seasons, as the climate projections are based on 30-year averages. It should therefore be borne in mind that very wet summers or very cold winters, for example, can still be expected to occur from time to time.

Future advances in climate modelling may alter the projections, so decisions based on the current projections should be made as resilient as possible to possible changes outside the current range.

Contents

1	Introduction	1
2	Sources of uncertainty in projections of future UK climate	2
3	Projecting climate variability and climate change	5
3.1	Projecting UK climate change: UKCP09 and its application in the CCRA	10
3.2	Key results from the UKCP09 climate projections	15
3.3	Further developments in UK climate projections since UKCP09	24
3.4	Limitations of the UKCP09 projections: known shortcoming in climate models, and ongoing developments	25
4	References	28

Tables

Table 3.1	CCRA emissions scenarios and the code names used for these in IPCC AR4	6
Table 3.2	Interpretation and naming convention for probability levels for temperature change	11
Table 3.3	Interpretation and naming convention for precipitation change scenarios, and relation to UKCP09 probability levels	11
Table 3.4	30-year time periods assessed in CCRA and their short names	14

Figures

Figure 2.1	Projected climate change in Europe from multiple models	3
Figure 2.2	Relative importance of different sources of uncertainty for climate projections over the 21 st Century, with CCRA time periods highlighted	4
Figure 3.1	Scenarios of atmospheric CO ₂ concentrations (parts per million) arising from five of the IPCC SRES emissions scenarios, with those used for the CCRA scenarios identified	7
Figure 3.2	UK-scale comparison of the "Aggressive Mitigation" scenario with CCRA scenarios (minimising the influence of differences between climate models)	9
Figure 3.3	Scenarios of changes in summer mean precipitation from the 2020s to 2080s for South-East England under the High emissions scenario, reflecting uncertainties in both natural variability and long-term response to global warming for a single 25km gridbox in central London, reflecting uncertainties in both natural variability and long-term response to global warming. Reproduced from Murphy <i>et al.</i> (2009)	12
Figure 3.4	Projected changes in global mean temperature (°C) relative to the 1961-1990 baseline, for all three UKCP09 emissions scenarios and the three UKCP09 future time periods (blue=low, purple=medium, red=high)	15
Figure 3.5	Changes in winter and summer mean temperature, averaged over administrative regions, by the 2050s under the Medium emissions scenario. Lines show the range between the p10 and p90 scenarios for each administrative region	17
Figure 3.6	Changes in annual, winter and summer mean precipitation, averaged over administrative regions, by the 2050s under the Medium emissions scenario. Lines show the range between p10 (dry) and p90 (wet) scenarios for each administrative region	18
Figure 3.7	Projected changes in annual, winter and summer precipitation (%) by the 2080s for the p10(dry), p50 and p90(wet) scenarios with Medium emissions	19
Figure 3.8	UKCP09 probabilistic projections of mean daily maximum temperature change in South East England by 2010-2039 relative to 1961-1990, for three emission scenarios. Probabilities are not used in CCRA but the distributions are shown here to illustrate the extent to which the ranges of possible change overlap for different emissions scenarios	20
Figure 3.9	UKCP09 probabilistic projections of mean daily maximum temperature change in South East England by 2070-2099 relative to 1961-1990, for three emission scenarios. Probabilities are not used in CCRA but the distributions are shown here to illustrate the extent to which the ranges of possible change overlap for different emissions scenarios	21
Figure 3.10	Range of projected changes in annual and seasonal mean precipitation	22
Figure 3.11	Range of projected changes in seasonal extreme precipitation	23
Figure 3.12	Projected changes in return period of the 1976 drought in the UK, estimated using a soil moisture metric	24

1 Introduction

Predictions of future climate change are subject to high uncertainty, so it is important that decision-makers can consider a range of possible future changes. The CCRA aims to consider a range of possible future changes in climate arising from both anthropogenic causes and natural variability. The main source of information for this is the UK Climate Projections 2009 (UKCP09), which represent the current state-of-the-art assessment of future climate changes in the UK over the 21st Century. UKCP09 used a sophisticated methodology to combine information from a number of different sources in order to provide estimated probabilities of changes in key climate variables, in order to allow decision-makers to begin to consider which climate changes may be more or less likely. The estimated probabilities do not include uncertainties in processes which aren't captured by any current climate models, and in this sense they are partial representations of the uncertainty. Since the release of UKCP09 climate modelling has continued to advance and generate new insights into the processes that may affect UK climate.

The CCRA used aspects of the UKCP09 projections as scenarios for future climate changes, and combined these with simple relationships between weather/climate and impacts in order to estimate future risks. Although the UKCP09 projections represent estimated probabilities of change based on current knowledge and modelling, the scenarios used in this first CCRA are not interpreted probabilistically because the uncertainties arising from the translation to impacts are very large. The use of probabilities is also not required in this assessment, as the analysis looks to provide a range of plausible risks only.

This Annex discusses the different sources of uncertainty in climate projections, explains the key aspects of the UKCP09 methodology and how the projections are used as scenarios for CCRA, and also discusses other climate science issues that should be borne in mind when making decisions on the basis of the CCRA.

2 Sources of uncertainty in projections of future UK climate

There are a number of sources of uncertainty which affect the accuracy with which future climatic conditions can be estimated. The different sources of uncertainty vary in their relative importance depending on whether the focus is on near-term or long-term changes.

Natural variability

Weather and climate vary naturally. At the scale of the UK and more locally this variability can be very large. On the timescale of years to decades, average temperature and precipitation can fluctuate by large amounts. Hence the climate risks of the next 2-3 decades will be very strongly dependent on the characteristics of natural variability. While the general character of climate variability can be quantified in a statistical sense, specific forecasts remain difficult due to the complexity of the processes involved and the need for precise input data. To explore the possible ranges of natural variability, large numbers of climate model simulations are used so that a range of possibilities can be represented.

Regional responses to changes in greenhouse gas concentrations

Although the global response to increased greenhouse gas concentrations is an increase in average temperature, there are considerable differences in the response at smaller scales such as that of the UK. This is particularly the case for precipitation, which can increase in some places and decrease in others, depending on changes in atmospheric circulation as well as changes in the water cycle. Additional human influences on climate, such as aerosol particles and land cover change, exert further effects in addition to those of greenhouse gas concentration increases. These can have strong regional influences which need to be considered along with the regional responses to increased greenhouse gas concentrations.

Different climate models project different future changes for the UK (Figure 2.1), and while there is relatively strong agreement on annual mean temperature changes and on a general increase in winter precipitation, there is rather less agreement on summer precipitation changes. A majority of the models assessed in the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report projected an overall decrease in summer precipitation over most of the UK, but some models projected an increase (Figure 2.1) (Christensen *et al.*, 2007).

Because of long response timescales in the climate system, the climate of the UK could take several decades to fully respond to a particular change in greenhouse gas concentrations or other drivers of change.

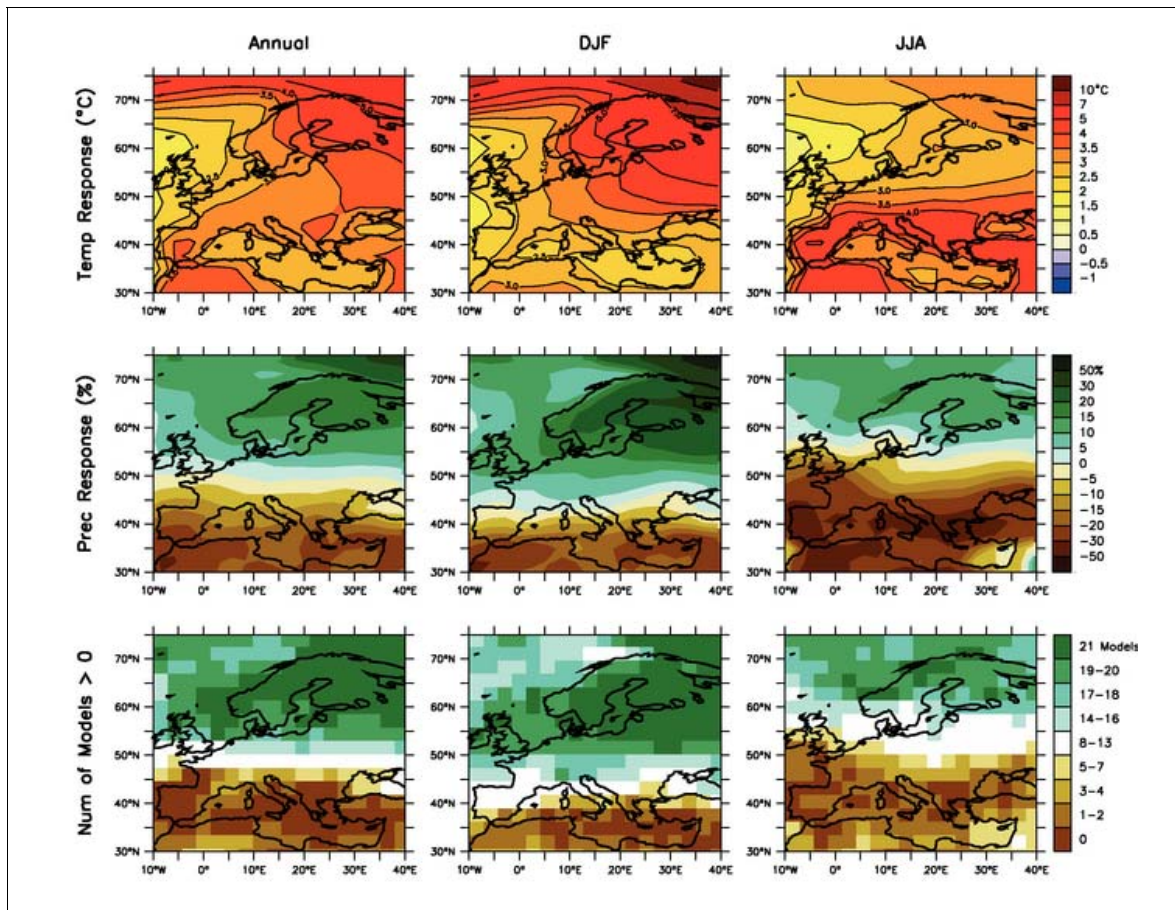


Figure 2.1 Projected climate change in Europe from multiple models

Top row: mean of 23 model projections of changes in annual mean, winter (DJF) and summer (JJA) temperature, by 2080–2099 relative to 1980–1999. Middle row: mean of projected changes in precipitation. Bottom row: level of agreement between model, expressed as the number of models projecting an increase in precipitation. Projections used 23 global models from the 3rd Coupled Model Intercomparison Project (CMIP3), driven by greenhouse gas and aerosol concentrations from the A1B scenario. Reproduced from Christensen *et al.* (2007), copyright IPCC (2007).

Magnitude of changes in greenhouse gas concentrations

The extent of the change in future greenhouse gas concentrations will also affect UK climate. Future greenhouse gas concentrations will depend on both the rate of emissions from human activities and also the extent to which natural sources and sinks may change.

Future emissions will depend on socio-economic factors such as the size and behaviour of the global human population, the quantity and sources of energy it chooses to use (and indeed is able to use), and the extent to which it alters ecosystems by use of the land. Scenarios of future emissions have been generated by the IPCC, based on different sets of assumptions of how the various socio-economic factors may change.

In addition to human emissions of carbon dioxide, there are natural processes which also emit carbon dioxide from the atmosphere and others which remove it. The balance between these natural sources and sinks is currently towards a net uptake of carbon dioxide from the atmosphere in both land ecosystems and the oceans, and consequently, atmospheric carbon dioxide concentrations are currently only rising at about 50% of the rate of human emissions. The strength of all these processes may be affected by climate change itself, so this may affect the rate of net removal of

carbon dioxide from the atmosphere and hence alter the relationship between human emissions and changes in carbon dioxide concentrations.

However, given the long response timescales mentioned above, the effect of different future trajectories of greenhouse gas concentrations may take several decades to become evident. For the range of emissions scenarios considered by the IPCC and CCRA, the difference in future emissions does not become a significant contributor to the overall uncertainty in UK temperature change until the second half of the 20th Century. For precipitation, the relative contribution of emissions uncertainty is even smaller; the uncertainties in natural variability and regional climate response are so large that the systematic influence of the different emissions scenarios becomes relatively unimportant.

Implications for near-term and long-term climate change risk assessment

The main uncertainty in UK climate for the next few years to decades arises from natural variability, since the year-to-year fluctuations are larger than the relatively gradual trend in long-term average conditions due to the build-up of greenhouse gases. The details of these fluctuations are mostly unpredictable at present, but a range of possibilities can be examined. Nevertheless, given that global greenhouse gas emissions will continue to some extent for the foreseeable future, this can be confidently expected to introduce systematic changes in UK climate of some kind on the medium to long term. Exactly what these systematic changes will be remains a difficult question, although a range of estimates can be made. By the middle of the century, the uncertainty in the UK climate response to ongoing greenhouse gas build ups becomes more important in comparison with the uncertainty due to natural variability. The exact quantity of greenhouse gas emissions is important in the longer term, but this does not become a significant contribution to uncertainty until near the end of the 21st Century due to long timescales of respond. For precipitation, the difference between the usual IPCC emissions scenarios remains relatively unimportant in comparison with uncertainties in the regional climate response and natural variability (Figure 2.2).

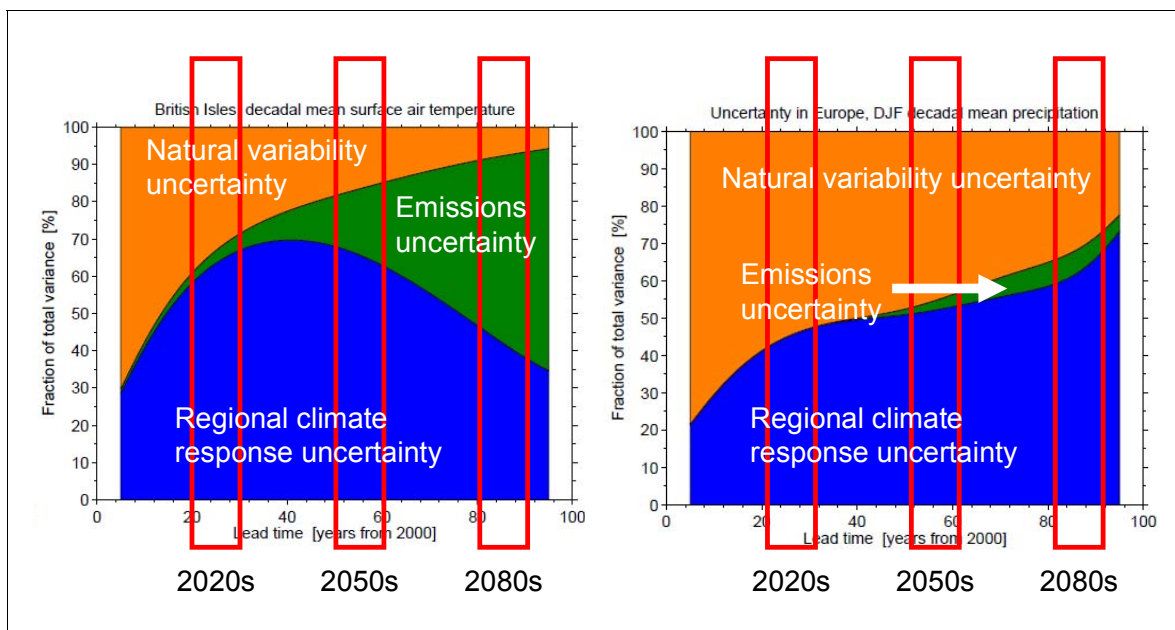


Figure 2.2 Relative importance of different sources of uncertainty for climate projections over the 21st Century, with CCRA time periods highlighted

Based on figures from Hawkins and Sutton (2009) and Hawkins and Sutton (2011).

3 Projecting climate variability and climate change

Climate models

General circulation models of climate (GCMs) bring together a vast array of understanding of the Earth's atmosphere, oceans, and life, and represent the physical, chemical, and biological processes in the form of mathematical equations solved by a computer programme. For example, the models simulate the global patterns of wind, the flows, and changes of water, energy and chemical compounds between atmosphere, land, and ocean, and the biological processes that affect these. They simulate the cycling of water through precipitation on the land and ocean, the flow of rivers to the ocean, evaporation back to the atmosphere from land and ocean, the condensation of water vapour back to liquid water ready for precipitation again, and the freezing and melting of ice at various points in the water cycle. The models simulate the energy that the planet receives from the sun, the proportions that are reflected back to space by clouds or that reach the surface, and the proportions of the latter that are absorbed by the surface or reflected. They also simulate the emission of energy from the Earth's surface and the proportion that is absorbed in the atmosphere through the "greenhouse effect" – and again, clouds are also important here as they also reduce the loss of energy to space. These processes are affected by the chemical composition of the atmosphere, particularly the concentrations of greenhouse gases such as water vapour, carbon dioxide, and methane, and again this chemical composition is simulated by the models. The equations are solved at several thousand points over the surface of the Earth, and at a number of levels in the atmosphere and ocean.

The same models are used to forecast the weather on a daily basis. For climate projections, the results are examined over the longer term, and while the day-by-day or even year-by-year simulations cannot be interpreted as representative of changes by exact dates, the general long-term character of the simulated weather conditions provide a representation of climate change consistent with the understanding of climate processes as represented in the model.

One of the important features of climate models is that weather systems, atmospheric and ocean circulations and natural variability of the climate system emerge as automatic consequence of representing the atmosphere, oceans and biosphere in this way. It is commonly asked whether a particular climate processes (such as El Nino or the gulf stream) is "factored in to the models". However, such processes are not inputs to the models, they emerge naturally as part of the behaviour of the system. Small differences in the starting conditions of a climate model simulation can lead to very large differences in the details of climate variability, due to the chaotic nature of the climate system.

In the long term, the models also simulate changes in climate in response to changes in key quantities such as the concentration of greenhouse gases. Different models, or even different versions of the same model, produce different responses to such forcings, particularly at regional scales. This reflects the uncertainty in regional responses to global climate change.

Uncertainties in climate projections can be explored by using large numbers of GCMs differing either/both in the starting conditions of their simulations or/and the details of the equations or numbers used in the equations.

Climate models need to simulate the climate of the entire globe, as there are no boundaries to climate zones; the climate system is global in character. However, in order to provide finer detail at selected regions, further versions of the models (Regional Climate Models, RCMs) can be run with equations solved over a finer mesh of gridpoints; the conditions around the boundaries of the region are provided from outputs of global climate models.

Emissions scenarios

In the long-term, a key influence on future climate change will be the quantity of greenhouse gas emissions. These will depend on global population numbers, their lifestyle, and the way this is supported by the production of energy and the use of the land. In turn, these are affected to a large extent by policy.

Rather than make predictions of future emissions, the CCRA follows standard practice in examining the risks that arise from changes in climate projected for a number of plausible scenarios of emissions. This allows decision makers to consider the implications of each scenario and inform decisions on reducing emissions and/or dealing with their consequences.

In recent research, climate models have generally used a set of global emissions scenarios from the IPCC as presented in the Special Report on Emissions Scenarios (SRES; Nakićenović *et al.*, 2000). These scenarios were grounded in plausible story lines of the human socioeconomic future, with differences in economy, technology, and population. A large number of such scenarios were developed, and the CCRA uses three of these which span most of the range of the SRES scenarios (Figure 3.1). The SRES scenarios were identified with code names, but CCRA simply refers to the three scenarios as “High”, “Medium” and “Low”, following the convention used in the UK Climate Projections (Table 3.1).

Table 3.1 CCRA emissions scenarios and the code names used for these in IPCC AR4

IPCC Scenario name	UKCP09/CCRA Scenario name
A1FI	High
A1B	Medium
B1	Low

The “High” scenario (A1FI) describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, with convergence among regions and decreasing global differences in per capita income. New technologies are introduced rapidly, but with a continued intensive use of fossil fuels (“FI” stands for “Fossil Intensive”). The “Low” scenario (B1) describes the same pattern of population change as A1FI but with much greater emphasis on clean and resource-efficient technologies, with global solutions to economic, social, and environmental sustainability and improved equity. The “Medium” scenario (A1B) is similar to A1FI in its underlying assumptions, except that energy production is more balanced between fossil fuel and other sources.

Are higher/lower emissions scenarios possible?

Yes. Although the B1 scenario considers the case of a large fraction of energy being derived from non-fossil fuel sources, there is no explicit inclusion of emissions reductions policies in this scenario. More recently, in order to understand the extent to which emissions reductions policies could avoid climate change, further scenarios have been developed and applied in climate models. These “aggressive mitigation”

scenarios have not been examined in the CCRA and therefore the lower rates of warming of the Low scenario were used as an imperfect proxy for a mitigation scenario; the implications of this are discussed below. At the other end of the scale, it is possible that emissions could grow faster than those suggested by the high scenario.

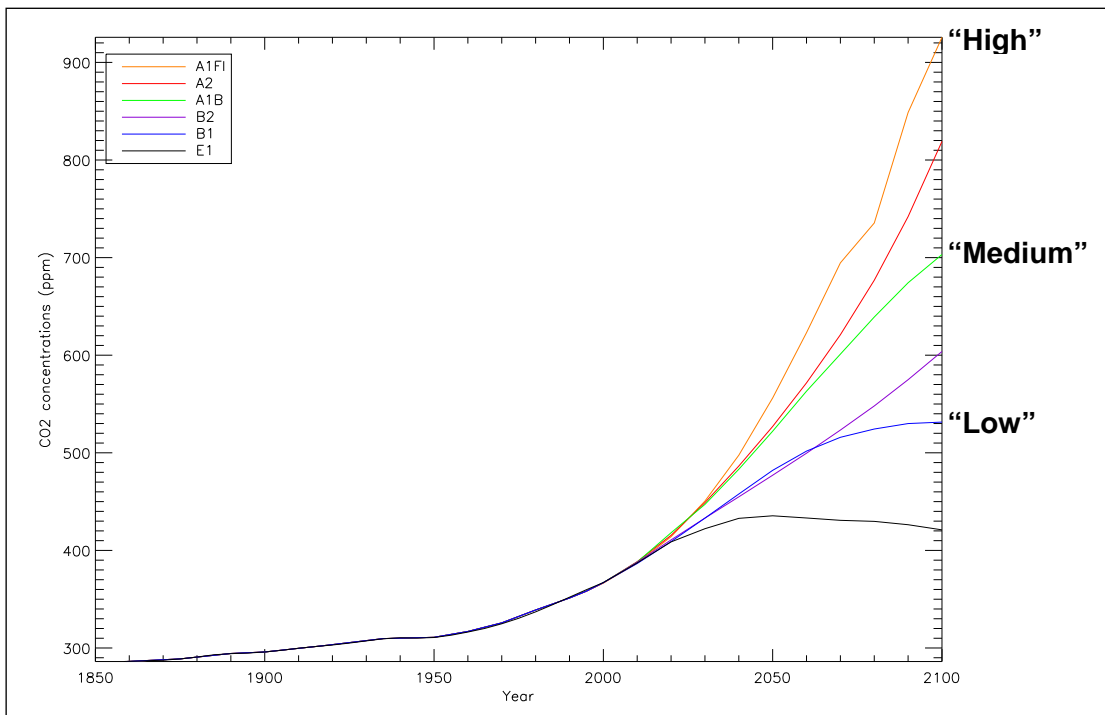


Figure 3.1 Scenarios of atmospheric CO₂ concentrations (parts per million) arising from five of the IPCC SRES emissions scenarios, with those used for the CCRA scenarios identified

Also plotted for reference is the “Aggressive Mitigation” scenario (E1) which assumes an early peak of global emissions followed by a rapid reduction – this scenario was not used in CCRA as it had not been part of UKCP09.

Can it be seen whether emissions are following any particular scenario?

The scenarios are intended to represent long-term evolution of the driving forces of emissions as opposed to capturing short-term variations in the global economy. From 2000 to 2007, fossil fuel CO₂ emissions grew by 3.6% per year, driven largely by world gross domestic product (GDP, but growth in emissions slowed to 2% in 2008 in association with the global financial crisis (Le Quéré *et al.*, 2009). Global emissions fell by approximately 1 per cent in 2009; emissions from Organization for Economic Cooperation and Development (OECD) countries and Russia fell by 7 per cent due to the economic situation, but this was almost balanced by an increase in emissions from China and India (Olivier *et al.*, 2010). Global emissions rose again in 2010.

Emissions over the last decade appear to have been near the upper end of the early part of the range of scenarios used by IPCC. However, it may still be too early to reliably assess whether any particular emissions scenario is more plausible than any other (Leggett and Logan, 2008). In particular, it should be noted that the “high” emissions scenario used in CCRA actually features slightly lower emissions than the “medium” scenario until the 2020s, due to details of the models used in the different scenarios (Betts *et al.*, 2010).

Uncertainties in translating emissions scenarios into atmospheric CO₂ concentrations

A given emissions scenario does not translate into a single CO₂ concentration pathway as there are uncertainties in the strength of carbon sinks in the ocean and on land which, are important in determining the fraction of CO₂ emissions which remain in the atmosphere. The UKCP09 methodology accounted for the implications of uncertainties in carbon cycle feedbacks for the uncertainty in climate change by scaling the global mean temperature and regional climate patterns based on previous modelling studies with coupled climate-carbon cycle models. This simple methodology allowed for the wider range of climate responses to a given emissions scenario to be considered, but since it used relationships directly between emissions and climate change, it did not include explicit quantification of a range of CO₂ concentrations for each emissions scenario. When such concentrations were required as direct input to risk metrics, for example for crop yields or ocean acidification, a single scenario of CO₂ concentrations were used for each emissions scenario.

“Locked-in” climate change: the need for adaptation even if strong mitigation takes place

Results from global climate models suggest that all three CCRA emissions scenarios result in global warming that are indistinguishable at the 2020s, but become more different at the 2050s and then more distinct at the 2080s (Meehl *et al.*, 2007). Similar results are seen for the UK in the UKCP09 projections (Figure 3.2), and indeed, even the “Aggressive Mitigation” scenario does not diverge significantly from the CCRA scenarios until near the middle of the 21st Century.

At the 2020s all scenarios are indistinguishable. Both the Low and Aggressive Mitigation scenarios have produced essentially the same level of UK warming as the High scenario. For this reason, the CCRA has only considered the Medium emissions scenario for the 2020s; the Low and High scenarios would be expected to give risks which are indistinguishable from those indicated by the Medium scenario.

By the 2050s, the High and Medium scenarios are still indistinguishable from each other, but these are slightly warmer than the Low and Aggressive Mitigation scenarios. The latter two are still, however, largely indistinguishable from each other. Hence the Low emissions scenario could reasonably be regarded as a guide to the minimum level of climate change expected in the UK even if rapid and deep cuts in global emissions are achieved within the next few years.

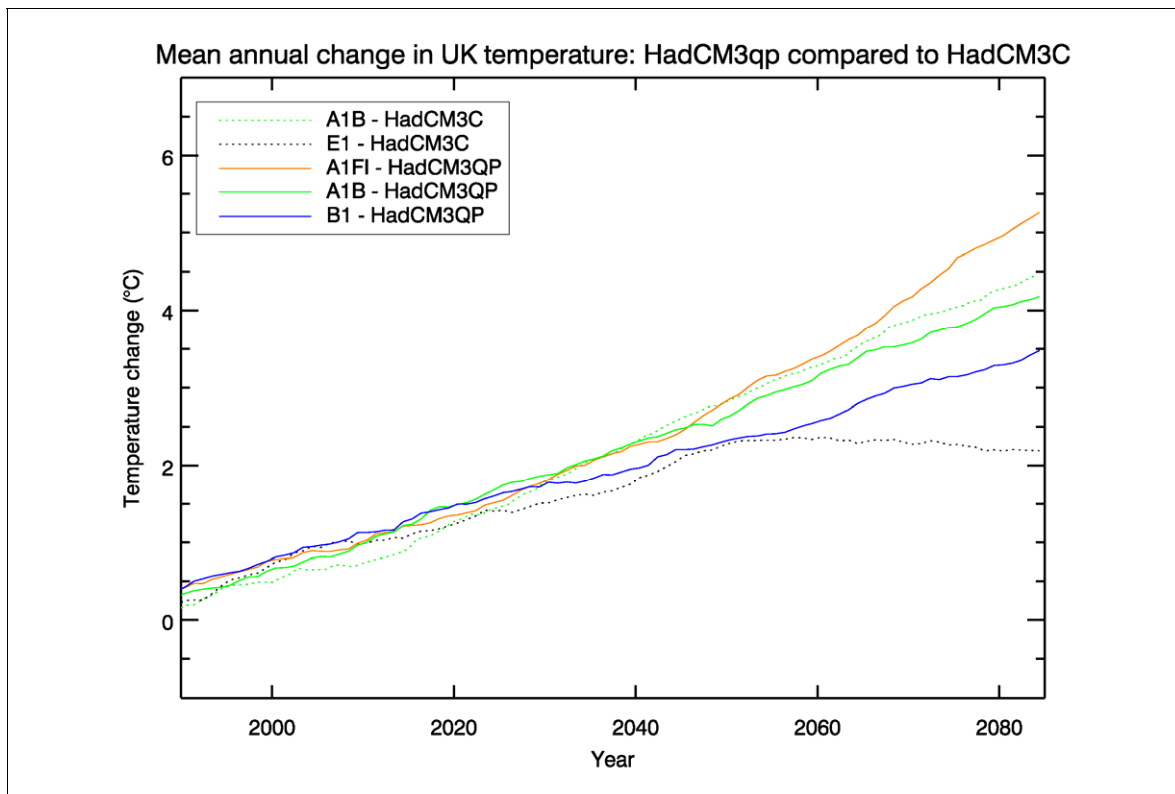


Figure 3.2 UK-scale comparison of the “Aggressive Mitigation” scenario with CCRA scenarios (minimising the influence of differences between climate models)

Note: Solid lines show the projected change in UK annual mean temperature (°C) simulated by a variant of the global climate model used within the UKCP09 methodology, for the High (A1FI: orange), Medium (A1B: green) and Low (B1: blue) emissions scenarios. Dotted lines show projections for “Aggressive Mitigation” (E1: dotted black) and a second realisation of the Medium scenario (dotted green); this was necessary because the E1 scenario was examined with a different variant of the climate model, so comparison of the two Medium projections allows the influence of the change in model variant to be seen.

By the 2080s, the scenarios have diverged significantly, demonstrating that different pathways of global emissions would have an impact on UK temperatures in the second half of the 21st Century. GCM results indicate that the Aggressive Mitigation scenario is at least 1°C cooler than the Low scenario at this time, but is still at a similar level of annual mean temperature as the Low scenario in the 2050s. Therefore, in the CCRA, the physical climate impacts arising from the Low scenario in the 2050s might, as a first approximation, be regarded as a minimum level of physical impact under the Aggressive Mitigation scenario at the 2080s. However, not all aspects of the climate would necessarily be similar in the 2080s as the 2050s even if annual mean temperature was similar; in particular, sea level may continue to rise. Moreover, vulnerability may be different due to further changes in socio-economic conditions, so the economic consequences could be different in the 2080s to the 2050s even if the physical climate impacts were similar.

3.1 Projecting UK climate change: UKCP09 and its application in the CCRA

UKCP09 probabilistic projections and their interpretation as scenarios for CCRA

UKCP09 provided projections of climate change over the 21st Century for the Low, Medium and High emissions scenarios. A key feature of UKCP09 was that uncertainties in the response of the climate to a given scenario were estimated where possible, and the projections of change for a given time period in the future considered these uncertainties along with those which arose from natural climate variability. The projections were “probabilistic” in that they were a systematic, traceable methodology for estimating the relative probability of different levels of change. The aim of this was to strike a practical balance between providing single scenarios with no indication of likelihood and a vast range of scenarios with even the most extreme being thought of as being as likely as less extreme scenarios. Results were expressed in terms of the probability of changes in key climate variables being smaller the result in question, so the 10th percentile of temperature change indicated that there was estimated to be a 10% probability that the warming would be smaller than that value (and consequently a 90% probability of warming being greater than that value). For changes that could be of either sign, such as precipitation, the 10th percentile occurred towards the drier end of the range of possible changes irrespective of whether the overall change was an increase or decrease in precipitation. Conversely, the 90th percentile occurred towards the wetter end of the range. Further details can be found in the UKCP09 technical documentation (Murphy *et al.*, 2009). The estimated probabilities themselves were uncertain, and the relative probabilities of different outcomes may change as a result of ongoing developments in understanding of climate processes and the formulation of models.

However, the CCRA did not require assessment of the likelihood of different risks, it just required a range of plausible scenarios to be examined in order for the comparison of risks to be begun. Moreover, the application of UKCP09 to individual risk metrics introduced further large uncertainties since the response functions used to translate climate changes to risks were necessarily simplistic and only very generally applicable. The CCRA therefore just used selected aspects of UKCP09 as scenarios of plausible change, and did not assign any numerical probabilities to different outcomes. The CCRA used the low emissions (or medium for the 2020s) 10% and high emissions (or medium for the 2020s) 90% probability projections from UKCP09 as “lower” and “upper” scenarios of change. These are interpreted as scenarios that cover the range of possibilities that are sufficiently likely to warrant examination in the risk assessment.

This is relatively easy to interpret for changes in temperature, since the changes are mostly in a single direction, warming (in UKCP09 there were some low-probability projections of cooling in some variables such as maximum temperature due to natural variability, but these were mostly outside the 10%-90% range so are rarely an issue in CCRA). However, for precipitation, greater care is needed with interpretation because the changes can be in either direction, either an increase or decrease. The p10 and p90 projections can therefore not be considered as “smallest” or “largest” change in terms of the magnitude of change, instead, they should be interpreted as the “smallest wetting / largest drying” and “largest wetting / smallest drying” respectively. For convenience in CCRA, p10 for precipitation is referred to as “dry” and p90 as “wet”.

P10 and p90 are *not* intended to represent the upper and lower limits of possible change, but are merely a guide to the more plausible range of outcomes. The CCRA also used 50% probability projections from UKCP09 as scenarios of intermediate level of change, for applications when a single representative scenario may be useful. It is

very important to recognise that this is *not* intended to represent the “most likely” scenario. No indication of a “most likely” scenario is given.

Table 3.2 Interpretation and naming convention for probability levels for temperature change

UKCP09 probability level	Interpretation	CCRA probability level
10%	p10	A relatively low scenario of warming
50%	p50	Intermediate scenario of warming
90%	p90	A relatively high scenario of warming

Table 3.3 Interpretation and naming convention for precipitation change scenarios, and relation to UKCP09 probability levels

UKCP09 probability level	CCRA scenario name	CCRA interpretation
10% This is towards the “drier” end of the distribution of changes projected by UKCP09	p10 (dry)	A relatively dry scenario (more drying, or less wetting, compared to other scenarios)
50%	p50	An intermediate scenario
90% This is towards the “wetter” end of the distribution of changes projected by UKCP09	p90 (wet)	A relatively wet scenario (more wetting, or less drying, compared to other scenarios)

Consequences of natural variability in the probabilistic projections

A notable feature of the uncertainty representations in UKCP09 is that the range between 2 given percentiles (for example, p10 and p90) increases rapidly between the 1961-1990 baseline and the first forecast period of 2010-2039, but then increases less rapidly from then on. Related to this, some outer percentiles can exhibit significant non-linearities; for example, in Figure 3.3 showing results for a single 25km gridbox, p90 at 2010-2039 indicates an increase in precipitation of approximately 19% in 2010-2039 relative to the baseline, but in 2070-2099 p90 indicates only approximately a 4% increase. This pattern is typical for summer precipitation changes across the UK in the UKCP09 projections, with the central estimate being close to zero in the 2020s but the p10, p50 and p90 percentiles all trending towards a smaller wetting / larger drying later in the century.

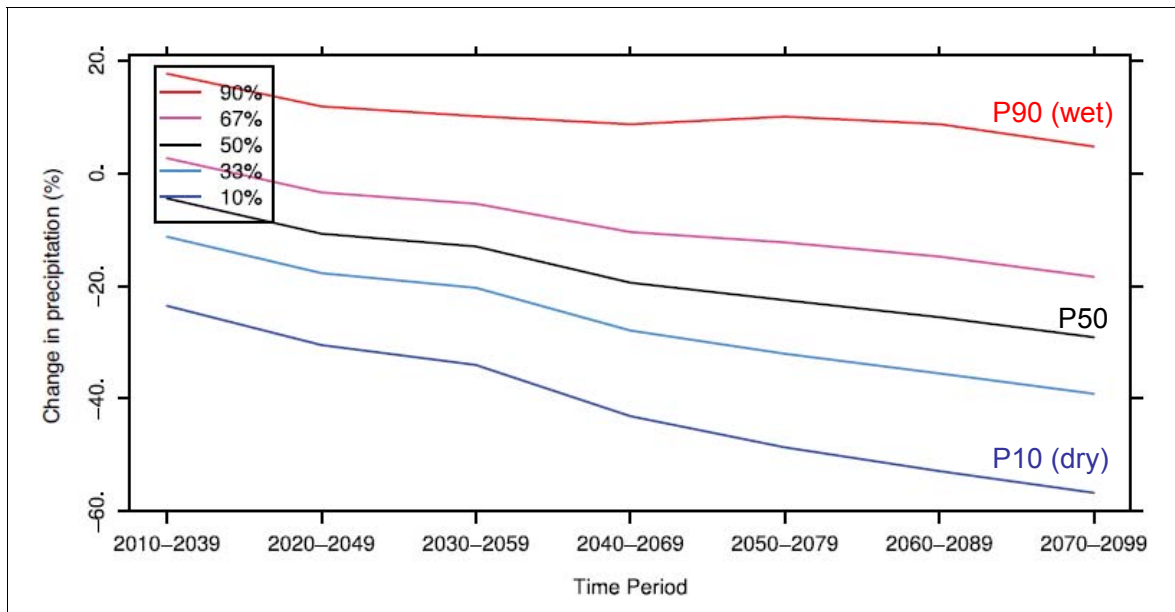


Figure 3.3 Scenarios of changes in summer mean precipitation from the 2020s to 2080s for South-East England under the High emissions scenario, reflecting uncertainties in both natural variability and long-term response to global warming for a single 25km gridbox in central London, reflecting uncertainties in both natural variability and long-term response to global warming. Reproduced from Murphy *et al.* (2009)

The apparent non-linearity of some scenarios (e.g. p90 for precipitation in Figure 3.3) arises because natural variability causes changes in either direction that are equally likely, even if the long-term response to global warming is in one direction or another. Consequently, in the near-term the scenarios cover both positive and negative changes of similar magnitudes or zero change, but the balance then shifts systematically as a consequence of the underlying trend in long-term climate.

As a result of this, some of the biophysical impacts and consequences assessed the CCRA reports show a degree of non-linearity in the future scenarios, with the some risks emerging as relatively large in the 2020s but not greatly increasing for the rest of the century. In some cases it may be possible for some risks to actually increase by the 2020s and decrease thereafter in the p90 (wet) scenario, although the importance of other factors may override the non-linearity of the p90 precipitation scenarios.

The implications of this are that decision-makers need to account for large uncertainties in climate projections even in the relatively near term, and also that they need to account for near-term changes that may arise from natural variability that are very different (possibly opposite) to those expected in the long-term trend due to anthropogenic climate change.

It should be remembered that the scenarios at each time period are not necessarily linked to each other; the p10, p50 and p90 scenarios are independent at each time period and are not pathways across the century. Any one particular realisation of future climate may lead to changes that are near, for example, p50 in 2010-2039 but closer to p90 in 2030-2069, depending on natural variability.

The projections used for long-term assessments represent the overall trend of global mean temperatures, but not the precise year-to-year variations for specific dates. While the models do include year-to-year variations that are realistic in a statistical sense, they simulate relatively warmer and cooler years with about the right frequency; they are not expected to be realistic for individual years. This aspect of uncertainty is

included in the probabilistic projections. Forecasting shorter-term changes for informing adaptation, including year-to-year variations, is an active area of research and the current status of this emerging field of climate science is discussed in Section 3.4 below.

In UKCP09, and hence in CCRA, no judgements are made on the relative probability of different emissions scenarios. As discussed in section 1, it is too early to establish whether actual emissions are following any particular emissions scenario. Although the CCRA “Low” scenario considers emissions and concentrations that are higher than the “Aggressive Mitigation” scenario, this does not imply that the UK Government considers the CCRA scenarios to be any more (or less) likely than scenarios that include specific policy interventions at the global scale.

Scenarios of CO₂ concentrations for direct impacts on ecosystems

Although the UKCP09 methodology accounted for the implications of uncertainties in carbon cycle feedbacks for the uncertainty in global mean temperature rise (and hence in UK climate change), it did not permit a quantification of the uncertainty in the CO₂ rise itself. The Sector assessments which examined risks sensitive to atmospheric CO₂ concentrations directly (ocean acidification, crop and forestry yield) assumed a CO₂ concentration pathway used for the High, Medium and Low emissions scenarios in IPCC AR4, which were generated by a model which is somewhat low in the range of uncertainty in climate-carbon cycle feedbacks (Betts *et al.*, 2010). For any given time period in the future, therefore, the CO₂ concentration may be either higher or lower than that assumed in the CCRA assessments, but current evidence suggests that it is more likely to be higher. This would mean that fertilization of vegetation growth (including crops and trees) would be greater than assumed in CCRA, but ocean acidification would also be stronger.

There is also evidence that the direct effects of CO₂ on vegetation can modify the impacts of climate change on hydrology, by increasing the efficiency of water use by plants. That is, under higher CO₂ concentrations, the evidence suggests that plants generally extract less water from the soil, leaving more moisture behind in the soil and allowing more to drain into streams and river. However, the strength of this effect is again poorly known. The drought metrics in CCRA did not consider effects of CO₂ on soil moisture, runoff and drought through plant responses. Therefore there is a possibility that agricultural and hydrological drought may have been systematically overestimated to some extent, although the extent of this overestimate is not known, and could be either large or negligible. This is an ongoing area of research in the UK and internationally, for example as part of the NERC Changing Water Cycle programme and greater evidence may have emerged for the next CCRA in 2017.

Baseline, future time periods and spatial scale of information

Previous climate projections for the UK (UKCIP02) were relative to a baseline of the 1961-1990 climatological average. When establishing the UKCP09 experimental design, consultation with users by UKCIP showed an overwhelming preference for retaining this baseline for the new projections in UKCP09. The climate projections used in the CCRA are all relative to the UKCP09 1961-1990 baseline.

However, the requirement of the CCRA is to assess changes in climate risk relative to a present-day baseline. Since climate change has already been occurring for the last few decades, this means that the 1961-1990 baseline may not be representative of the “present-day”, with the latter being defined in CCRA as the few years around 2010.

The CCRA baseline for the ‘present-day’ is defined as a reasonable estimate of present day conditions based on at least one decade of climate data. In many cases the data for the risks of interest may have only be monitored over the last two decades.

The length of record needed to provide a reasonable estimate depends on the variable being considered. For example, any estimate of extremes requires a long length of record, at least from the 1960s to present, whereas estimates of annual average temperature can be made (within reasonable errors) with a decade of data.

As the CCRA study did not include trend detection or climate change attribution studies no attempt was made as quantifying ‘present day’ climate values to natural variability and climate change. Instead the sector analysts provide details of the analysis completed and record where differences in ‘present day’ versus 1961-1990 climate may affect estimation of current and future risks.

Since predictions cannot be made for individual years because of natural climate variability, UKCP09 provides projected changes averaged over 30-year time periods. As well as the annual mean changes, many variables are also provided as the 30-year mean for each season or each calendar month. Some information on extremes is also included, such as the hottest day of summer or wettest day of winter; again these are means of these quantities over the 30-year time period.

UKCP09 provided projections for seven overlapping time periods from 2010-2039 to 2070-2099. CCRA focuses on the three time periods which do not overlap (Table 3.4), and for convenience these are referred to as the central decade of the 30-year period. However it is important to note that this is just a convenient shorthand, and the projections are not specifically for those individual decades. In practice, natural variability may cause the climate in those decades to be different from the 30-year mean.

Table 3.4 30-year time periods assessed in CCRA and their short names

30-year period	Name of period for CCRA
2010-2039	2020s
2040-2069	2050s
2070-2099	2080s

Geographical scale of information

Over land, UKCP09 provides probabilistic projections geographically in 3 forms:

1. At a resolution of 25km
2. Averaged over administrative regions
3. Averaged over river basins.

Over sea, projections are available in 2 forms:

1. At a resolution of 25km
2. Average over defined marine regions.

A key aspect of the UKCP09 projections is that the projections are not fully coherent across different locations. This means that the scenarios of change only apply to individual gridboxes, or individual administrative regions / river catchments, independently of others. This means that the changes at, for example, p90 in London would not necessarily occur concurrently with the changes at p90 in Edinburgh. Since the release of UKCP09 and its application to CCRA, further projections have been provided which address this issue.

3.2 Key results from the UKCP09 climate projections

Global climate projections

UKCP09 involved a complex methodology using a number of different models, including both global and regional climate models. As part of this methodology, projections of global mean temperature change were generated. Although these largely are not directly relevant to the UK, the level of global warming is a widely-used indicator of climate change and hence may provide a useful reference point for the risks assessed in CCRA for the UK. Figure 3.4 shows the range of projections of global mean temperature rise, calculated as the 10th and 90th percentiles using the UKCP09 methodology. The changes are presented relative to the UKCP09 baseline of 1961-1990. However, the extent of anthropogenic global warming is often discussed in terms of changes relative to pre-industrial. The 1961-1990 global mean temperature was approximately 0.3°C warmer than 1850-1900, which is the earliest time for which global temperature is estimated from observations. Hence, warming relative to pre-industrial can be estimated by adding 0.3°C to the change projected relative to 1961-1990.

The UKCP09 global climate projections suggest that the global mean temperature in 2040-2069 has a high probability of exceeding 2°C relative to pre-industrial for all three CCRA scenarios “Low”, “Medium” and “High”. It appears to be highly unlikely to reach 4°C relative to pre-industrial at this time, again for all scenarios. However, by the 2080s, there is estimated to be almost a 90% chance of global warming exceeding 4°C in the “High” scenario, although there is judged to be less than a 10% chance of reaching this level in the “Low” scenario.

This may provide useful context for the CCRA risk assessments. The risks quantified for 2040-2069 provide an approximate indication of the implications of a 2°C-3°C world in the UK, while those for the High scenario in the 2080s illustrate a 4°C+ world in the UK.

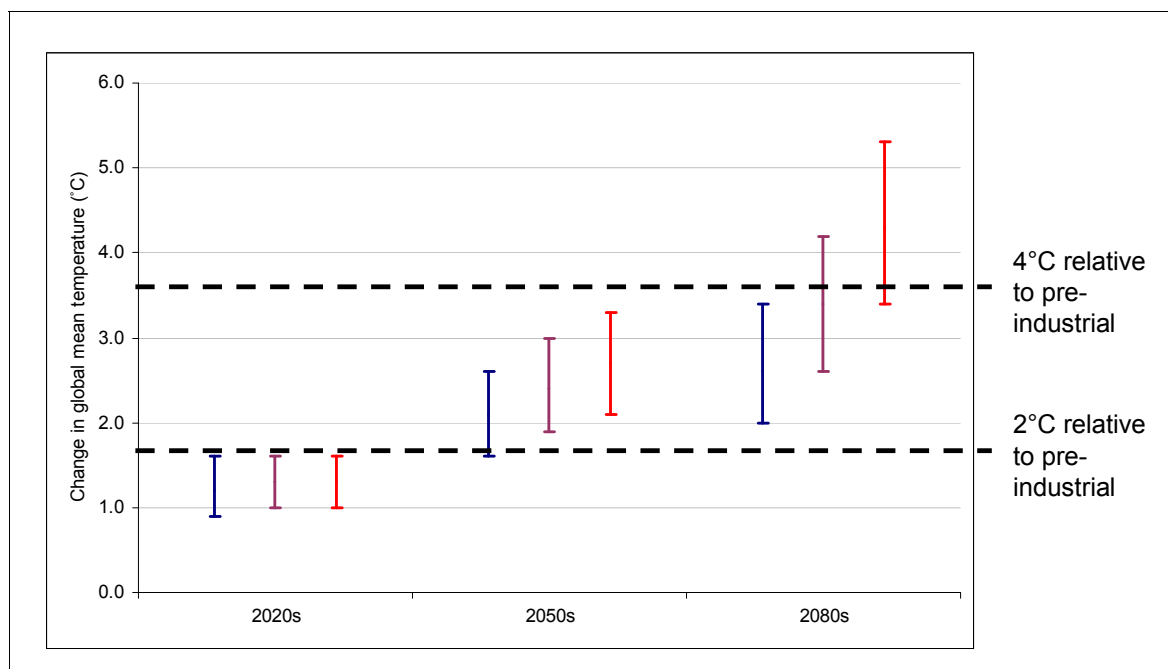


Figure 3.4 Projected changes in global mean temperature (°C) relative to the 1961-1990 baseline, for all three UKCP09 emissions scenarios and the three UKCP09 future time periods (blue=low, purple=medium, red=high)

Scenarios of changes in UK seasonal climates

Since the UKCIP02 projections it has become conventional wisdom that the expectation is for the future climate of the UK to feature hotter, drier summers and milder, wetter winters. This arose from the climate model projections in UKCIP02, which only used one variant of one climate model, so only provided one illustrative climate scenario for each emissions scenario. The UKCIP02 report clearly highlighted the uncertainties in a general sense, but in the absence of any quantification the perceived message became focussed on the single projection.

UKCP09 moves beyond this and provides a range of outcomes for a given emissions scenario. There is therefore now information on a wider range of possible climate changes. UKCP09 still projects warming at all time periods and all locations in the UK, relative to the 1961-1990 baseline, for all CCRA scenarios (p10, p50 and p90) (Figure 3.5). For the medium scenario in the 2050s, warming ranges from approximately 1°C to 3°C in winter, and from 1°C to 4°C. However, the uncertainty in the projected precipitation changes is large, and indeed for summer precipitation the sign of the changes (either a decrease or increase in precipitation) varies between the p10 and p90 projections. For the Medium scenario in the 2050s, for example, the projected changes in summer precipitation averaged over administrative regions typically range from decreases of 20%-40% (p10 dry) to increases of approximately 1%-7% (p90 wet) (Figure 3.6). Winter precipitation shows a more consistent signal of increase, from approximately 5% (p10 dry) to 30% (p90 wet). This is the case for all administrative regions across the UK, but generally the uncertainty in percentage precipitation changes is larger in southern parts of the UK, and p90 shows larger percentage increases in the south (Figure 3.6, Figure 3.7). However this may be largely a consequence of the higher baseline precipitation in the north; any given change in absolute precipitation will appear as a larger percentage change if the baseline value is smaller.

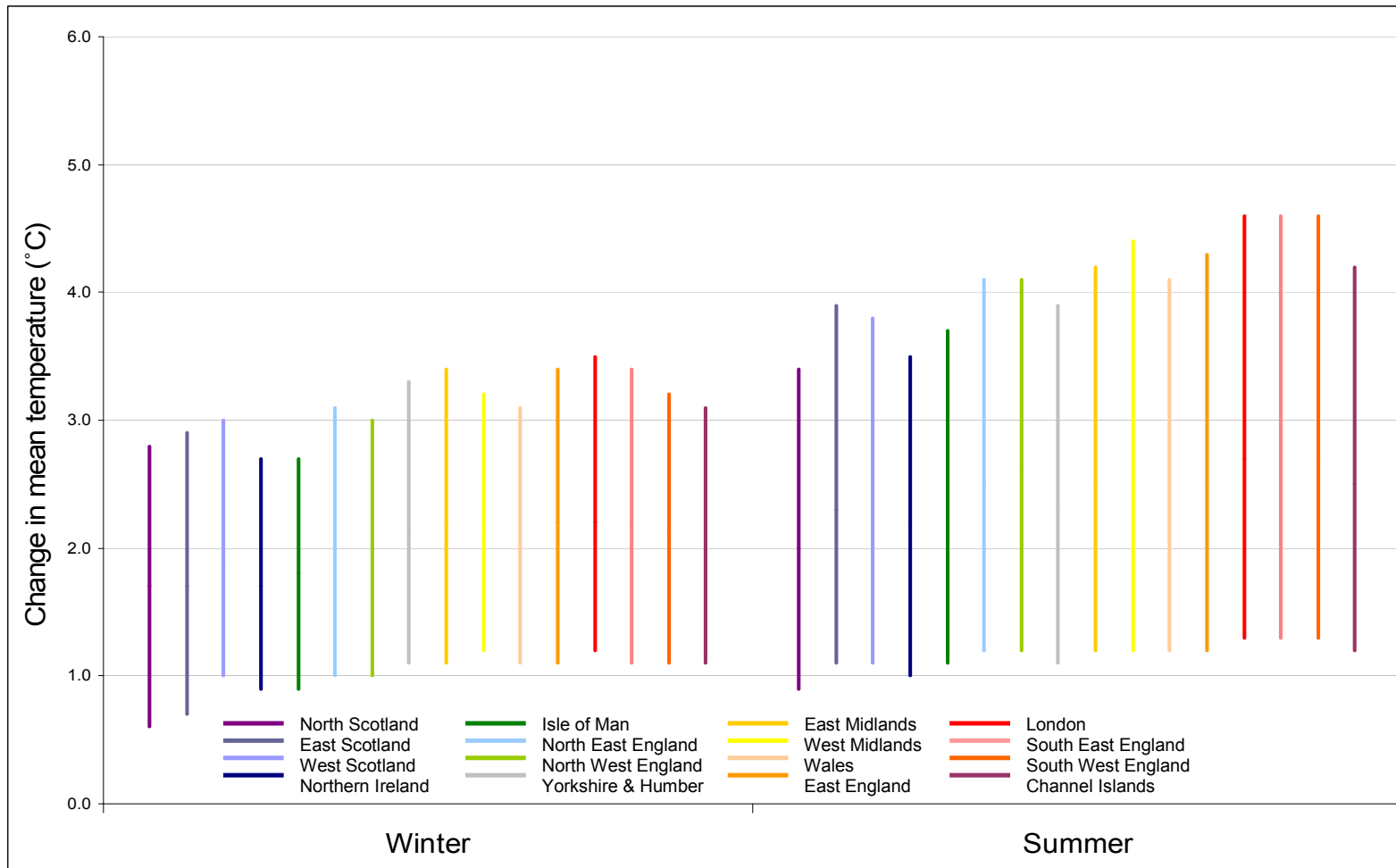


Figure 3.5 Changes in winter and summer mean temperature, averaged over administrative regions, by the 2050s under the Medium emissions scenario. Lines show the range between the p10 and p90 scenarios for each administrative region

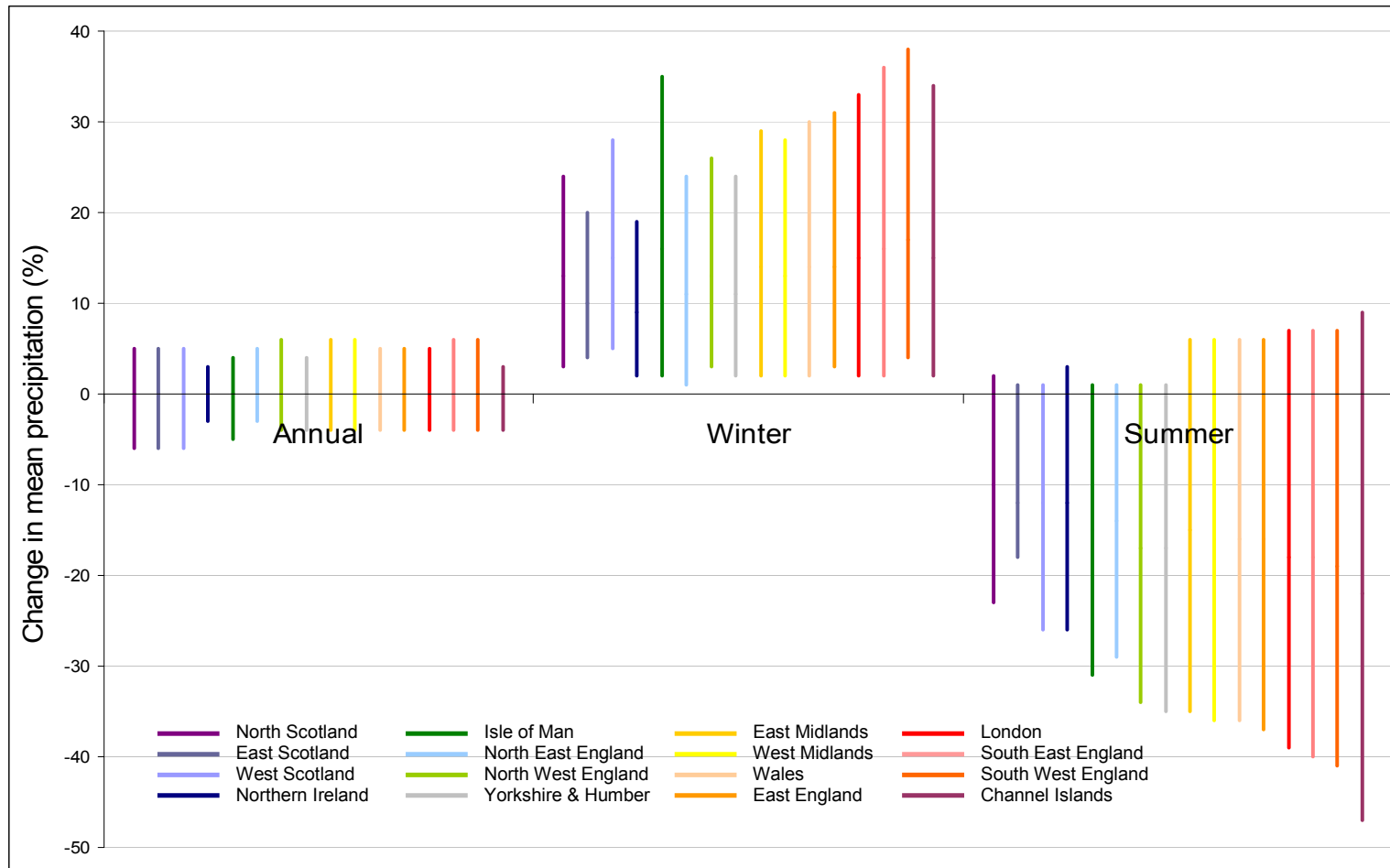


Figure 3.6 Changes in annual, winter and summer mean precipitation, averaged over administrative regions, by the 2050s under the Medium emissions scenario. Lines show the range between p10 (dry) and p90 (wet) scenarios for each administrative region

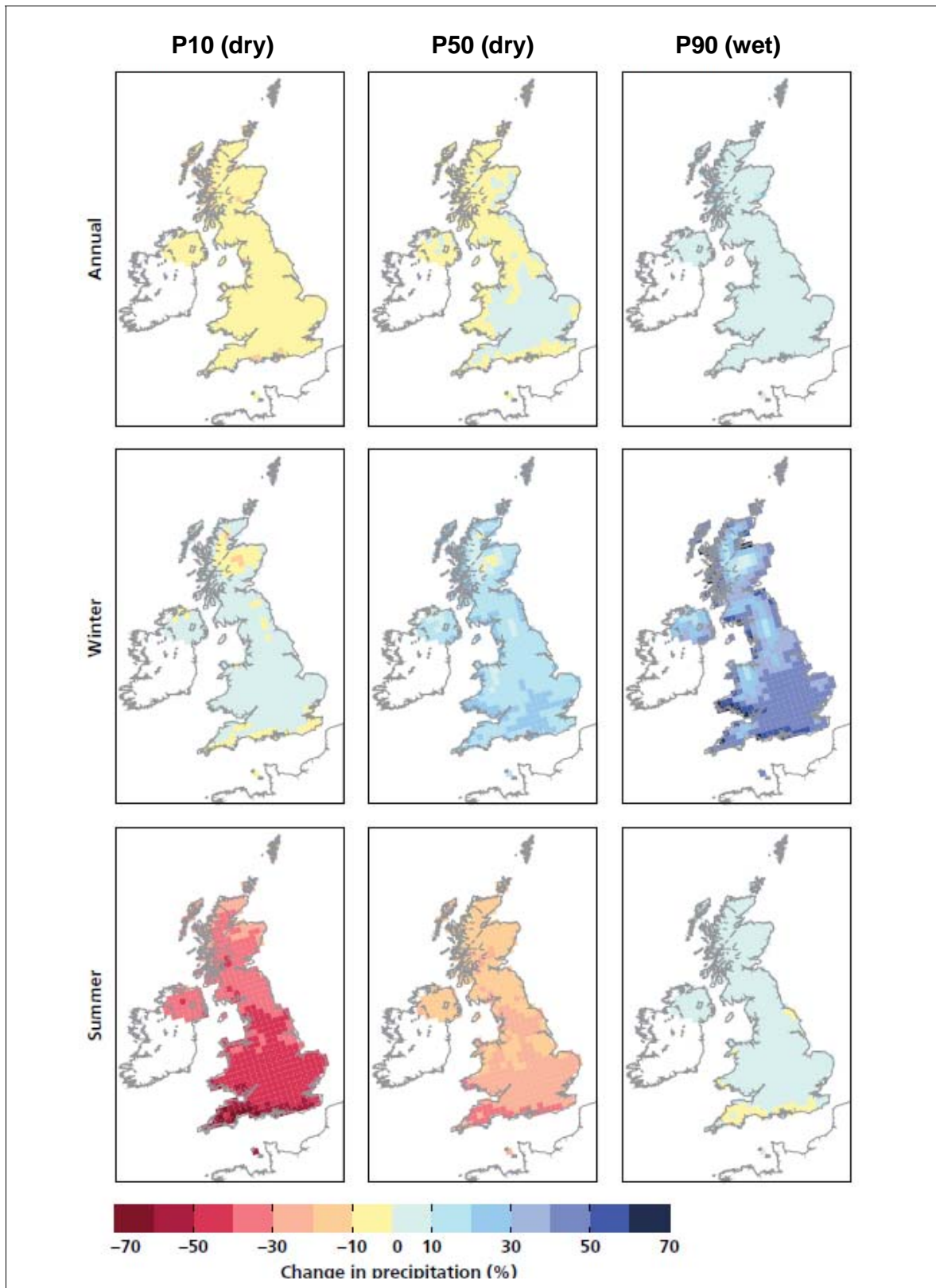


Figure 3.7 Projected changes in annual, winter and summer precipitation (%) by the 2080s for the p10(dry), p50 and p90(wet) scenarios with Medium emissions

Comparing uncertainties in climate response with uncertainties in emissions scenario

The three CCRA emissions scenarios result in indistinguishable climate projections at the 2020s (Figure 3.8), and projections which are still somewhat similar to each other in the 2050s. By the 2080s, however, the climate projections for the different scenarios are becoming different (Figure 3.9). Nevertheless, uncertainties in the climate response are still relatively large, especially at the gridbox scale. When considering gridbox-scale quantities such as the smallest or largest change in any gridbox across the UK, the difference between p10 and p90 can be large, and even in the 2080s this difference can be larger than the difference between two emissions scenarios for a given probability level (Figure 3.10).

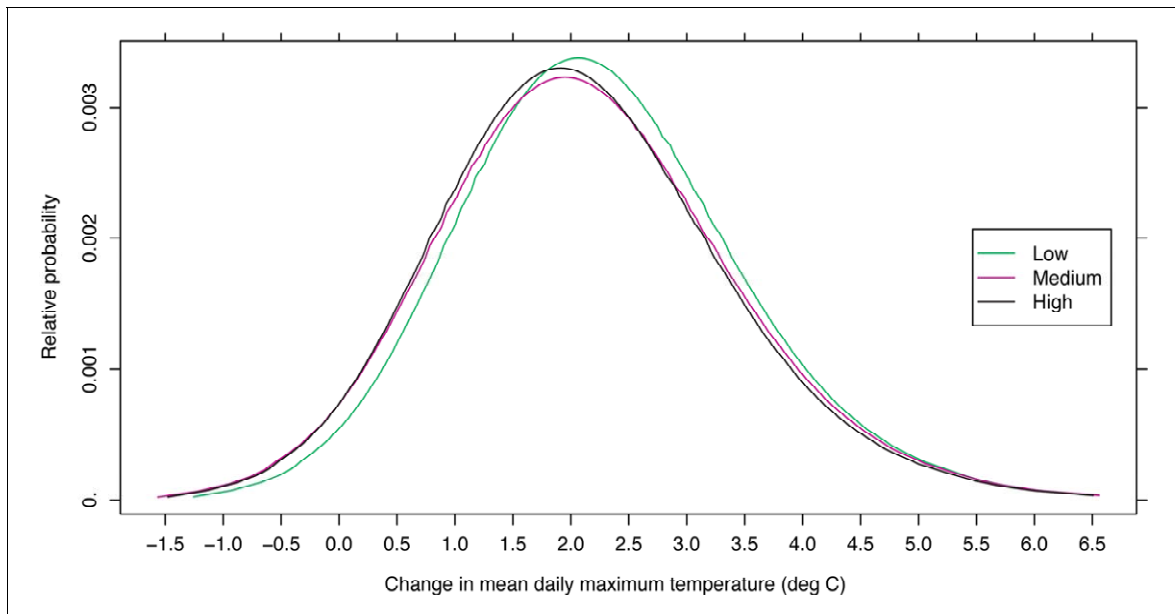


Figure 3.8 UKCP09 probabilistic projections of mean daily maximum temperature change in South East England by 2010-2039 relative to 1961-1990, for three emission scenarios. Probabilities are not used in CCRA but the distributions are shown here to illustrate the extent to which the ranges of possible change overlap for different emissions scenarios

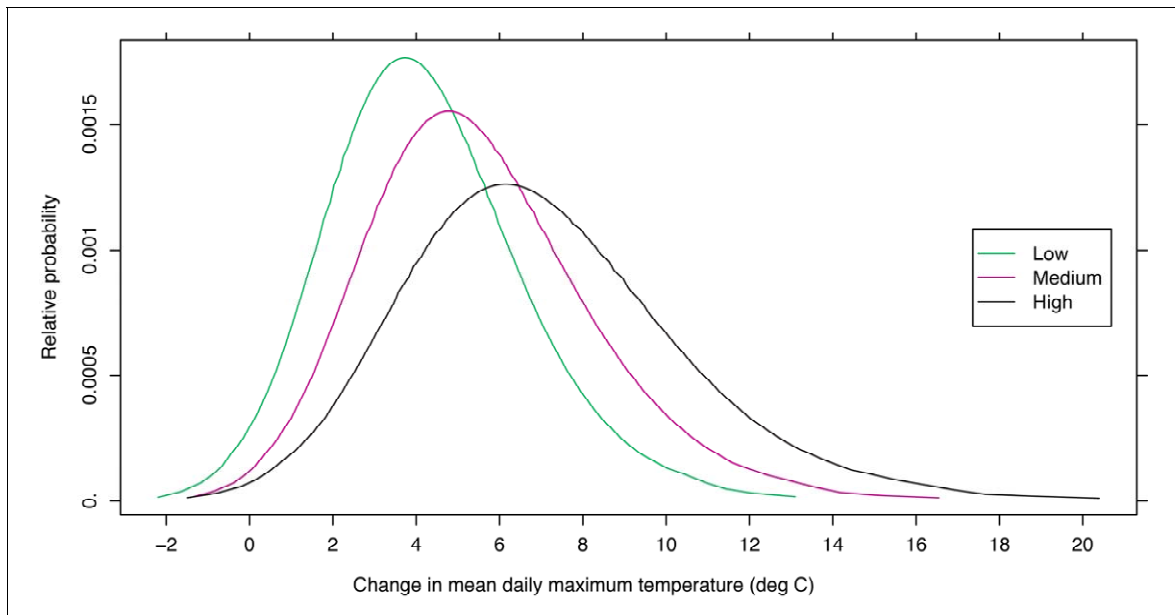


Figure 3.9 UKCP09 probabilistic projections of mean daily maximum temperature change in South East England by 2070-2099 relative to 1961-1990, for three emission scenarios. Probabilities are not used in CCRA but the distributions are shown here to illustrate the extent to which the ranges of possible change overlap for different emissions scenarios

For example, for the Low scenario, the lowest change in summer mean daily precipitation in the UK ranges from 1% to -55%, which overlaps quite considerably with the range of -10 to -74 for the High scenario. Hence adaptation planning may not necessarily depend significantly on which emissions scenario is assumed to be followed. The key issue is being flexible enough to deal with the large uncertainties in the climate response. In particular, even if the low emissions scenario is followed, large changes in precipitation in some parts of the UK remain possible.

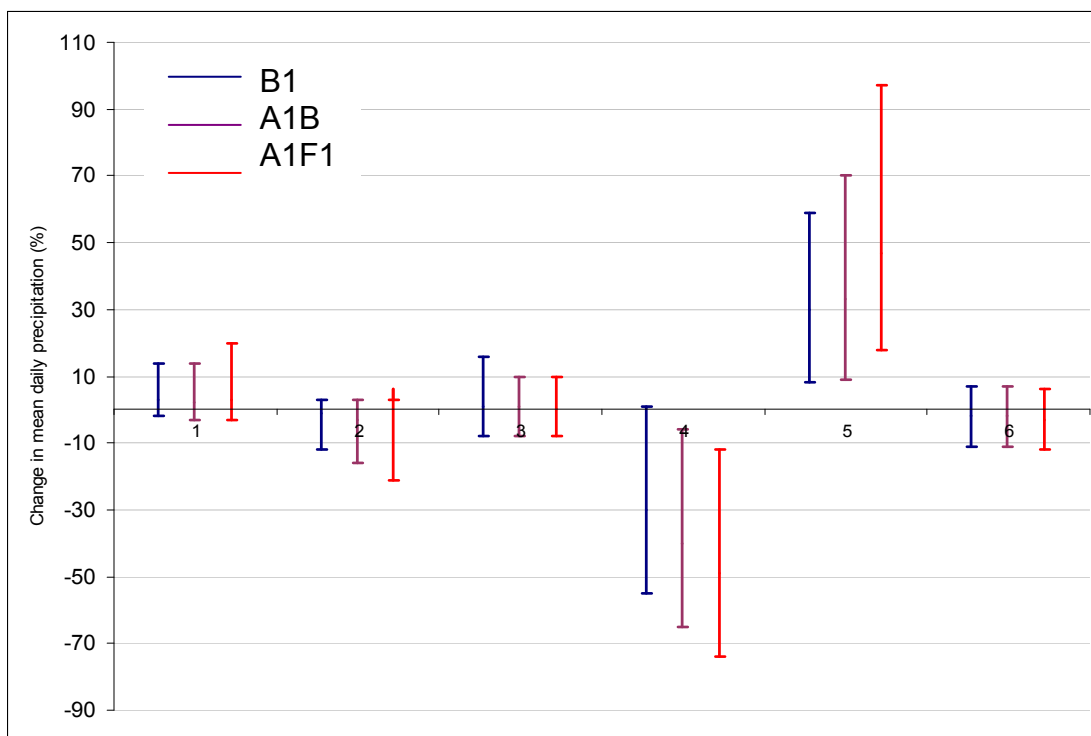


Figure 3.10 Range of projected changes in annual and seasonal mean precipitation

- 1: Annual mean daily precipitation (highest change in UK)
 - 2: Annual mean daily precipitation (lowest change in UK)
 - 3: Summer mean daily precipitation (highest change in UK)
 - 4: Summer mean daily precipitation (lowest change in UK)
 - 5: Winter mean daily precipitation (highest change in UK)
 - 6: Winter mean daily precipitation (lowest change in UK)
- Lower and upper ends of bars show p10 and p90 respectively.

Nevertheless, it is still clear that the likelihood of larger changes increases with higher emissions scenarios. A lower emissions scenario decreases the likelihood of large extremes.

Extremes

UKCP09 provides probabilistic projections of some aspects of weather extremes, specifically the temperature of the hottest and coldest day and night of each season, and the precipitation rate for the wettest day of each season. It should be noted that these are still defined as 30-year averages; so the results for hottest day are the 30-year average hottest day, for example. Hottest days in individual years could be significantly higher than this.

Regarding the hottest day of summer, the p10 level shows a decrease in temperature relative to the baseline in all emissions scenarios for the 2020s, 2050s and 2080s, but p90 shows an increase in temperature of 4°C for the 2020s for all scenarios and increases of 12°C across the most of the UK for the 2080s for the High scenario.

Projected changes in the wettest days of the seasons are complex, and vary significantly across the UK as well as across probability levels. Regarding the wettest days of summer and winter, the largest increases in any 25km gridbox in the UK range from approximately 50% to approximately 75% at the p90, but remain around 0 – 10% for p10 (Figure 3.11). At the p90 level, the smallest changes in the UK are approximately 10-12 %, but at p10 the smallest changes in wettest day of the summer

are -30% to -50% (either least positive or most negative) changes across the UK. As is found with seasonal mean temperature, the range of uncertainty between p10 (dry) and p90 (wet) is very large compared to the difference between emissions scenarios.

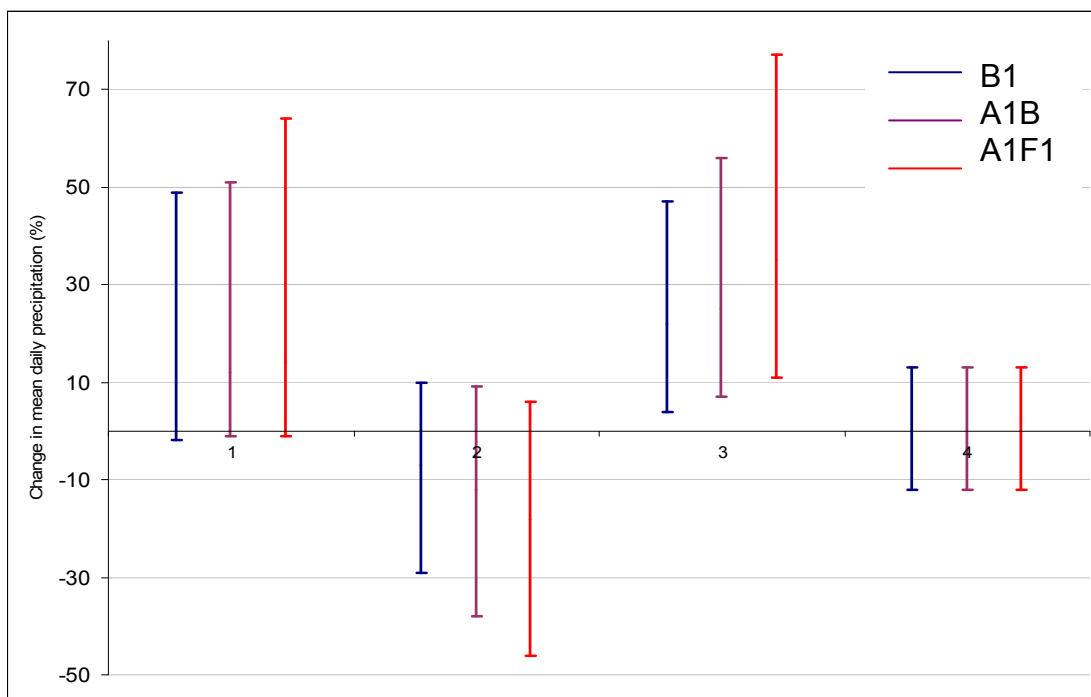


Figure 3.11 Range of projected changes in seasonal extreme precipitation

- 1: Precipitation on wettest day of summer (highest change in UK)
 - 2: Precipitation on wettest day of summer (lowest change in UK)
 - 3: Precipitation on wettest day of winter (highest change in UK)
 - 4: Precipitation on wettest day of winter (lowest change in UK)
- Lower and upper ends of bars show p10 and p90 respectively.

Other extremes, namely drought, fog, and lightning, were assessed using the regional climate model ensemble which was a component of the UKCP09 projections. This explored uncertainty by using 11 variants of the model with different parameter settings, but did not provide probabilistic projections. This information was only available for the medium emissions scenario. Similarly, a preliminary assessment of storms was carried out in the global climate model ensemble which was a further component of UKCP09. Changes in monthly mean wind were presented in the full probabilistic projections, but this did not include extreme winds.

Changes in storms and monthly mean windspeeds are projected to be small in the models used within UKCP09, with the sign of the projected windspeed varying from positive to negative. There was little change in frequency of storms projected over the UK in winter, and although the North Atlantic storm track showed a southward shift, the impact of this occurred away from the UK. There was also little change in the intensity of UK storms in the main model used in UKC09.

Projected changes in drought vary between different variants of the regional climate model, and also depend significantly on the metric used to define drought. Drought can be defined in various ways. Most obviously it can be defined in terms of reduced precipitation (meteorological drought), which is readily quantified from standard meteorological records, but drought can also be defined in terms of reduced soil moisture which is arguably more relevant to agricultural impacts (agricultural drought). Soil moisture is also influenced by evaporation and transpiration, which are affected by other atmospheric variables including temperature, humidity, and windspeed.

Transpiration by plants is also affected by the atmospheric CO₂ concentration; under higher CO₂, plants tend to use less water for transpiration so extract less moisture from the soil. All these factors were included in the RCM projections.

The projected drought changes vary from small decreases to large increases. For example, the level of soil moisture drought seen in 1976 was estimated to have a return period of greater than 50 years at the present day in Southern England, and by the end of the 21st Century the projected return period of this ranged from a value similar to the present day to once in 10 years (Figure 3.12). The differences in soil moisture drought change in the RCM ensemble arise from differences in a range of climatic variables, including precipitation, temperature and the response of plants to atmospheric CO₂ concentrations.

Reductions in fog are projected for most places and seasons, with the main exception being southern Britain in winter.

Lightning is projected to increase for all seasons across the whole of the UK.

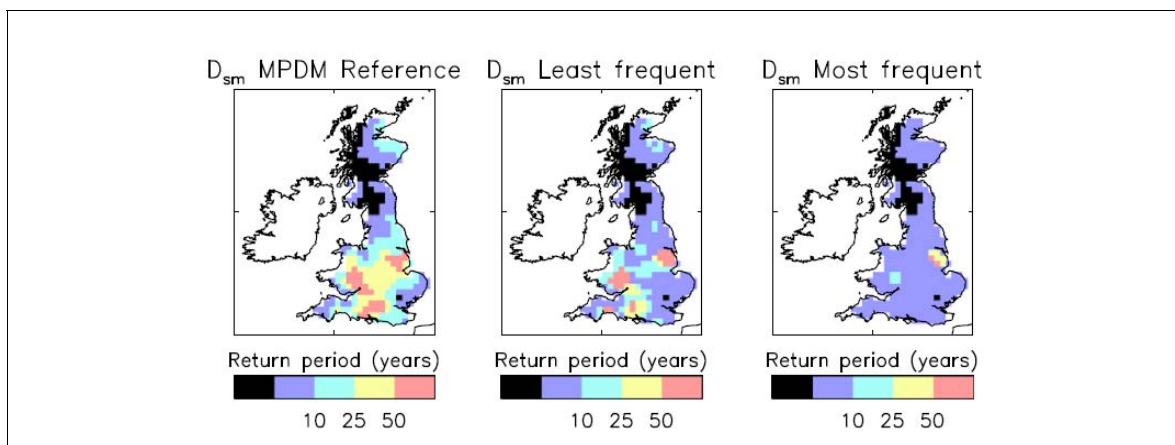


Figure 3.12 Projected changes in return period of the 1976 drought in the UK, estimated using a soil moisture metric

The left hand panel shows the return period (years) of for August 1976. Regions in black are not extreme in August 1976. The second and third columns show the least and most frequent estimates of drought occurrence by the end of the 21st Century.

3.3 Further developments in UK climate projections since UKCP09

Wind, fog and lightning

The Regional Climate Model used as part of generating the UKCP09 projections was also used to generate projections of additional weather variables, namely wind, snow, fog and lightning. 11 simulations were examined, which each used different values for key quantities within the model formulation in order to explore uncertainty.

The range of projected changes in summer wind speed for the 2050s covers both positive and negative changes but is generally slightly skewed towards negative changes. This is indicated by small reductions at most UK locations in the 50% probability level, between 0 ms⁻¹ and -0.2 ms⁻¹. A windspeed of 0.2 ms⁻¹ is about 0.4 knots which is small compared with the typical magnitude of summer mean wind speed of about 7–10 knots over much of England and Northern Ireland, and 7–14 knots over much of Scotland and Wales.

In winter for the 2050s, the ranges of projected changes in wind speed are approximately symmetric about near-zero change. The largest uncertainty ranges are over Scotland, where the 10–90% probability range is typically -0.5 ms^{-1} to 0.5 ms^{-1} . This range equates to -1 to 1 knots, however these changes in 30-year mean winter wind speeds are small compared with the typical winter averages for present day climate, which are 10–14 knots over the Lowlands and 18–24 knots over the Highlands.

Reductions in fog are projected for most places and seasons, with the main exception being southern Britain in winter.

In winter, when fog days are observed to be most numerous, the general picture shows that reductions of 50% or more are projected in many areas of northern Britain and north Wales, with increases (in the range 0–30%) over southern and midland areas of England.

In summer, large reductions are projected in most parts of England, but of course these are reductions from what are already generally small frequencies. In parts of northern Scotland and Northern Ireland changes tend to be smaller or, in the case of a few grid squares in Scotland, positive.

Projections of changes to number of lightning days were generated using a threshold of Convectively Available Potential Energy (CAPE) to estimate the occurrence of lightning, and apply this to projections of CAPE from the 11-member RCM ensemble, over the period 2069–2099 (the 2080s) under the Medium emissions scenario. Changes in the number of lightning days, averaged over all the ensemble members, relative to the baseline period of 1961–1990, can be summarised as follows.

Increases in the number of lightning days are projected for all four seasons across the whole of the UK.

In summer, projected increases are largest (i.e. in excess of 2 days per season) over parts of Scotland and Northern Ireland. When expressed as percentage changes relative to historical values, there is a distinct north–south gradient of change, such that increases are projected to be smallest in parts of south east England, where they can be less than 30%.

In winter, small increases are also found, with somewhat larger increases (more than 1 day per season) across coastal regions in southern England, and some western coastal regions. These translate into large percentage changes in places; however the percentage changes are not statistically robust, due to the small values found in the baseline climate. Indeed, in many locations in winter, it is not possible to calculate a percentage change for future climate, as some ensemble members simulate zero occurrences in their simulations of 1961–1990.

3.4 Limitations of the UKCP09 projections: known shortcoming in climate models, and ongoing developments

Climate predictions for the next few years: forecasting natural climate variability

Climate prediction in the near term (years to a few decades) is made more difficult by the fact that natural variations are still relatively important on this timescale, whereas on multidecadal timescales we expect the increased greenhouse warming to lead to long-term changes that are greater than the natural year-to-year variability. This poses a huge challenge when attempting to forecast on these timescales in order to inform

adaptation. This area of climate science is only just beginning to demonstrate predictive skill, but nevertheless some skill is there. The key lies in good measurements of the current state of the climate (especially ocean temperatures), including the direction of any trends in the system, in order to set off the forecast in the right direction. Forecasts of global temperatures on decadal timescales have been shown to be credible, with techniques developed by Smith *et al.* (2007) in the Met Office Hadley Centre having been used to reproduce decadal temperature changes over the 1980s–1990s and 1990s–2000s using only the information that would have been available to forecasters at the start of those periods.

A key aspect of this affecting the UK is Arctic sea ice and its influence on UK climate, particularly summer precipitation. Since 2007, Arctic summer sea ice has been anomalously low; several studies suggest that this correlates to colder conditions in winter and wet conditions in summer in the UK. In UKCP09, sea ice changes were simulated from the pre-industrial initial conditions, and recent trends in sea ice were not factored into the forecasts. Hence the influence of observed sea ice and its subsequent evolution on UK climate were not taken into account.

Decadal forecasting is still in its early stages, and significant challenges remain, especially for forecasting of local rather than global changes. However, rapid progress is being made, and such forecasts are likely to be invaluable to adaptation planners in the coming years.

Including the stratosphere in climate models: “high-top” models

There is a large body of evidence in the literature suggesting that increasing the upper limit of the model atmosphere to include the stratosphere can alter both climate variability and climate change at the surface e.g. Ineson & Scaife (2010). Scaife *et al.* (2005) have shown that the observed warming of European winters from 1962-1990s depended on stratospheric winds.

The new set of climate models in the CMIP5 activity being undertaken for the IPCC 5th Assessment Report includes a number of high-top models for the first time. It is expected that systematic differences in northern European projections will be seen between these new models and the established “low-lid” models.

Atmospheric blocking

It has been noted that regional climate projections for UK may be unreliable because the seasonal climate in the UK depends heavily on blocking events (high pressure systems which cause storm tracks to be diverted) and these are poorly represented in GCMs. Blocking events can create heatwaves and protracted cold spells in the UK.

All models used in IPCC AR4 were subject to systematic errors in Atlantic blocking, so it was not possible to eliminate this problem by including other models in the UKCP09 methodology.

Model developments are making good progress on simulating blocking in the Atlantic. The new Met Office Hadley Centre model Hadgem3H has much improved representation of Atlantic blocking due to improvements in Gulf Stream path (Scaife *et al.*, 2011).

Solar variability

Although solar effects have been shown to be a minimal contributor to the historical global mean temperature rise, there is statistical evidence that solar variability has an impact on regional climates, especially in the North Atlantic in winter. Low solar activity correlated with colder conditions in winter and has been anomalously low in recent

years (Lockwood, 2010) and there is also expected to be a fall in solar activity in coming decades. This influence is currently not included in climate projections.

Implications of ongoing climate model developments for UK climate projections

A number of processes not included in UKCP09 have the potential to significantly influence the outcome of the projections. Revised projections with updated models may therefore be different from UKCP09, or at least may be near the extremities of the large ranges of uncertainty. Decision-makers should interpret UKCP09, and hence CCRA, as preliminary indications of the potential range of climate changes in the UK and subsequent risks. Long-term planning should remain flexible to revised advice as climate science continues to develop. A key message for the CCRA as a whole is that decision making needs to demonstrate resilience to wide range of possible future and not use projections to 'predict and provide' adaptation requirements.

4 References

- Betts, R.A., M. Collins, D. Hemming, C.D. Jones, J. Lowe, M. Sanderson (2010) When could global warming reach 4°C? *Phil. Trans. R. Soc. A* (2011) **369**, 67–84, doi:10.1098/rsta.2010.0292.
- Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Predictions. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H. L. Miller, Eds., Cambridge University Press, Cambridge, UK, 847-940.
- Hawkins, E. and Sutton, R. (2009) The potential to narrow uncertainty in regional climate predictions. *Bull. Amer. Meteor. Soc.*, **90**, 1095-1107.
- Hawkins, E. and Sutton, R. (2011) The potential to narrow uncertainty in projections of regional precipitation change, *Climate Dynamics*, **37**, 407-418.
- Ineson, S. and Scaife, A. (2009) The role of the stratosphere in the European climate response to El Niño. *Nature Geoscience*, **2**, 32-36.
- Leggett, J. A. & Logan, J. 2008 Are carbon dioxide emissions rising more rapidly than expected? CRS report RS22970, Congressional Research Service, Washington, DC, USA (17 October 2008 version).
- Lockwood, M., Harrison, R.G., Owens, M.J., Barnard, L., Woolings, T., and Steinhilber, F. (2011) The solar influence on the probability of relatively cold UK winters in the future. *Environ. Res. Lett.* **6** 034004.
- Le Quéré, C., M. Raupach, J.G. Canadell, G. Marland, L. Bopp, P. Ciais, T.J. Conway, S.C. Doney, R.A. Feely, P. Foster, P. Friedlingstein, K. Gurney, R.A., Houghton, J.I. House, C. Huntingford, P.E. Levy, M.R. Lomas, J. Majkut, N. Metzl, J.P. Ometto, G.P. Peters, I.C. Prentice, J.T. Randerson, S.W. Running, J.L. Sarmiento, U. Schuster, S. Sitch, T. Takahashi, N. Viovy, G. van der Werf and F.I. Woodward. (2009) Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, **2**, doi:10.1038/NGEO689.
- Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Murphy, J.M. Sexton, D., Jenkins, G., Boorman, P., Booth, B., Brown, K., Clark, R., Collins, M., Harris, G. and, Kendon, E. (2009). UKCP09 Climate change projections. ISBN 978-1-906360-02-3.
- Nakićenović N., Alcamo J., Davis G., de Vries B., Fenhann J., Gaffin S., Gregory K., Grübler A., Jung T. Y., Kram T., La Rovere E. L., Michaelis L., Mori S., Morita T., Pepper W., Pitcher H., Price L., Riahi K., Roehrl A., Rogner H.-H., Sankovski A., Schlesinger M., Shukla P., Smith S., Swart R., van Rooijen S., Nadejda V., Dadi, Z., 2000. IPCC Special report on emissions scenarios. Cambridge University Press, Cambridge, United Kingdom, and New York, NY.

Olivier, J. G. J. & Peters, J. A. H. W. 2010 No growth in total global CO₂ emissions in 2009. Report no. 500212001, Netherlands Environmental Assessment Agency, The Netherlands. See www.pbl.nl/en.

Scaife, A. (2005) A stratospheric influence on the winter NAO and North Atlantic surface climate. *Geophysical Research Letters*, **32**, L18715, doi:10.1029/2005GL023226.

**UK
2012** | **Climate
Change
Risk
Assessment**

(Defra Project Code GA0204)

**The UK Climate Change Risk
Assessment 2012
Evidence Report**

Project deliverable number D.4.2.1
Release 7
January 2012

**Annex B: Social Vulnerability to
Climate Change Impacts**

Dr. Clare Twigger-Ross¹ and Paula Orr¹

Contractors: HR Wallingford
AMEC Environment & Infrastructure UK Ltd
(formerly Entec UK Ltd)
The Met Office
¹Collingwood Environmental Planning
Alexander Ballard Ltd
Paul Watkiss Associates
Metroeconomica



Llywodraeth Cymru
Welsh Government



Statement of use

See full statement of use in the main Evidence Report.

Keywords:

Climate change, risk, social vulnerability

Research contractor:

HR Wallingford

Howbery Park, Wallingford, Oxon, OX10 8BA

Tel: +44 (0)1491 835381

(For contractor quality control purposes this report is also numbered EX6694)

Defra project officer:

Soheila Amin-Hanjani

Defra contact details:

Adapting to Climate Change Programme,
Department for Environment, Food and Rural Affairs (Defra)

Area 3A

Nobel House

17 Smith Square

London

SW1P 3JR

Tel: 020 7238 3000

www.defra.gov.uk/adaptation

Document History:

Date	Release	Prepared	Notes
09/08/11	R1.0	CEP	Issued alongside R3 of the Evidence Report
08/11/11	R2.0	CEP/HRW	Minor corrections. Issued alongside R4 of the Evidence Report
14/12/11	R3.0	CEP	Minor amendments based on feedback. Issued alongside R5 of the Evidence Report.
13/01/12	R4.0	CEP	Minor format changes. Issued alongside R6 of the Evidence Report.
24/01/12	R5.0	HR Wallingford	Minor format changes. Issued alongside R7 of the Evidence Report.

Contents

1	Introduction	1
2	Defining Social Vulnerability	2
2.1	Use of Evidence	5
3	Heat	7
3.1	Introduction	7
3.2	Approaches to social vulnerability and heat	7
3.3	Social vulnerability categories: Location and place	8
3.4	Poor health (physical or mental)	9
3.5	Fewer financial resources and little access to systems and support services (e.g. health care)	11
3.6	Living and working in poor quality homes or workplaces	12
3.7	Limited access to public and private transport	12
3.8	Limited or lack of awareness of risk	12
3.9	Lack of social networks	13
3.10	Other relevant social vulnerability issues	14
4	Drought	16
4.1	Approaches to social vulnerability and drought	16
4.2	Social vulnerability categories: Location and place	16
4.3	Poor health (physical or mental)	18
4.4	Fewer financial resources	18
4.5	Living and working in poor quality homes or workplaces	21
4.6	Limited access to public and private transport	21
4.7	Limited or lack of awareness of risk	21
4.8	Lack of social networks	21
5	Floods	23
5.1	Approaches to social vulnerability and floods	23
5.2	Social vulnerability categories: Location and place	25
5.3	Poor health (physical or mental)	26
5.4	Fewer financial resources and little access to systems and support services (e.g. health care)	27
5.5	Living and working in poor quality homes or workplaces	29
5.6	Limited access to public and private transport	29
5.7	Limited or lack of awareness of risk	29
5.8	Lack of social networks	30
5.9	Other relevant social vulnerability issues	31
6	Summary of Expert Views	34

6.1	Defining social vulnerability	34
6.2	Evidence	35
7	Synthesis	36
8	References	39
Appendix		45
	Appendix 1 Social Vulnerability Checklist	45
Tables		
Table 2.1	Social vulnerability categories and characteristics	5
Table 3.1	Risk factors associated with heat stress in old age	10
Table 4.1	Variations across Government Office regions	17
Table 7.1	Social vulnerability categories and characteristics	36
Table 7.2	Other social vulnerability factors	37
Figures		
Figure 2.1	Approaches to social vulnerability	3

1 Introduction

This short review of evidence on social vulnerability and climate change impacts takes forward the assessments of social vulnerability carried out as part of the work for the Climate Change Risk Assessment (CCRA) sector reports.

Section 2 presents a review of definitions of social vulnerability in order to establish the scope of this work and clarifying the focus on social vulnerability rather than social impacts¹. We have included a short note about the evidence that we have drawn on at the end of Section 2.

Sections 3, 4 and 5 examine in more detail the question of vulnerability to the major types of climate change impacts: heat, drought and flooding. To complement this analysis, the team interviewed a small number of experts and Section 6 provides a summary of their views.

Finally Section 7 provides a synthesis and conclusions emerging from this review.

¹ The approach taken here is focused on social vulnerability rather than on wider social impacts, but that focus invariably raises issues about social impacts. For example: in relation to flooding, a vulnerability focus looks primarily at those groups or individuals that are more likely than others to experience negative consequences during a flood incident or in the subsequent recovery process or are likely to be more severely impacted. A focus on social impacts on the other hand seeks to document and understand the extent and nature of damages to individuals and society.

2 Defining Social Vulnerability

The CCRA defines climate vulnerability as: *“the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. It depends not only on a system’s sensitivity but also on its adaptive capacity. Hence arctic alpine flora or the elderly may be more vulnerable to climate change than other components of our flora or population.”* (Defra, 2010)

This definition includes both sensitivity of a system and its adaptive capacity. Within the broader definition, social vulnerability may be described as the sensitivity and adaptive capacity of social systems. Our definition of social vulnerability then, *“explicitly focuses on those demographic and socioeconomic factors that increase or attenuate the impacts of hazard events on local populations (Tierney et al. 2001; Heinz Center 2002), in other words who is at risk and the degree to which they can be harmed.”* (Cutter et al., 2009, p. 2-3). Brookes et al. (2005) point out that: *“there are certain factors that are likely to influence vulnerability to a wide variety of hazards in different geographical and socio-political contexts. These are developmental factors including poverty, health status, economic inequality and elements of governance.”* (p. 153). While Brookes et al. are here focusing on developing countries, the point they make is relevant to climate change vulnerability generally: there are a number of characteristics that are recognised to make individuals, groups or communities vulnerable to a range of hazards, including the impacts of climate change.

Similarly in the UK, for some people exposure to climate impacts (working in direct sunlight and high temperatures in the summer, in agricultural occupations, for example) may be exacerbated by a lack of knowledge and information about the nature of the risk and limited adaptive capacity (inability to move out of exposed locations even on a temporary basis as they rely on working outdoors for their income) (UK Trade Union Congress, 2009).

In the UK the Index of Multiple Deprivation (IMD)² has been developed as a tool to measure the combined influence of a number of factors contributing to deprivation, including income, housing, health and education. The IMD can provide a useful starting point for a broad-brush mapping of social vulnerability and has been used in this way in recent studies (Walker et al., 2006). However, this approach to identifying vulnerable people or groups has been criticised for taking a static view of vulnerability which focuses on sensitivity and / or exposure and fails to take account of the way that those affected perceive and respond. Benzie et al. (2011) refer to this as a ‘top-down’ assessment of vulnerability, contrasting it with a ‘bottom-up’ assessment. Both approaches have their uses: for example, a top-down approach could use climate change models to identify locations which are likely to be particularly affected by heatwaves in the future. This information could then be looked at in relation to demographic trends resulting in changes in the population age structure and an increase in sensitivity to heat impacts (ibid.).

This sort of social vulnerability mapping is described within Tier 3 of Stage 3 of the risk assessment process within the CCRA method statement:

“Social vulnerability mapping approaches are well established in some sectors. Indices will be mapped on a national and regional basis for several

² The Indices of Multiple Deprivation are a set of indices developed originally in 2000 when a comprehensive survey of deprivation was undertaken by the Department of the Environment and the Regions (DETR), for each ward within England. They were updated in 2004 and again in 2007 by the Social Disadvantage Research Centre at the University of Oxford. The 2007 IMD is made up of 7 Domain Indices comprising a. Income (22.5%); b. Employment (22.5%); c. Health and Disability (13.5%); d. Education, Skills and Training (13.5%); e. Barriers to Housing and Services (9.3%); f. Living Environment (9.3%); and g. Crime (9.3%). 2007 IMD data uses 2001 Census data and 2003 – 2005 government data.

sectors, including flood risk management and health (related to heat wave vulnerability) and trial mapping in other sectors, where social vulnerability is not used, e.g. the water sector". (p. 37 -38)

Of course deprivation and vulnerability are not synonymous: deprived communities are not necessarily vulnerable to all hazards and vulnerable people are not always deprived. While there may be considerable agreement that these kinds of factor are likely to influence vulnerability, it is important to note that there is still limited understanding of the way that this happens and the relationship between vulnerability characteristics. Understanding these processes requires a 'bottom-up' approach which starts from a location and examines the practices and relationships in place which contribute to exacerbate or attenuate climate impacts (Brown and Walker, 2008). An examination of the ways in which vulnerability is created by everyday life has led some researchers to the conclusion that aspects of vulnerability to climate change are socially constructed (Brown and Walker, 2011, Expert interview).

The figure below (from Benzie *et al.* 2011, *op cit*) shows the way that top-down and bottom-up assessments of social vulnerability to climate change complement one another:

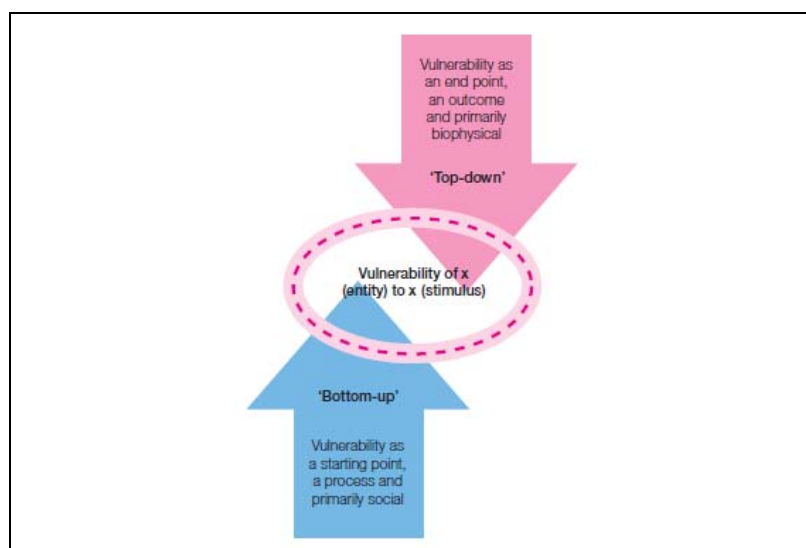


Figure 2.1 Approaches to social vulnerability

The tendency for policy-makers to focus on top-down, evidence-driven assessments of social vulnerability, combined with the difficulty of measuring some of the factors involved, may contribute to make social vulnerability less visible:

“Socially created vulnerabilities are largely ignored, mainly due to the difficulty in quantifying them which also explains why social losses are normally absent in after-disaster cost/loss estimation reports. Instead social vulnerability is most often described using the individual characteristics of people (age; race; health; income; type of dwelling unit; employment). Social vulnerability is partially the product of social inequalities – those social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond. However, it also includes place inequalities – those characteristics of communities and the built environment, such as the level of urbanisation, growth rates and economic vitality that contribute to the social vulnerability of places”. (p. 242) (Cutter, Boruff and Shirley, 2003)

It may not just be individuals or communities experiencing social inequalities whose vulnerability is rendered invisible by a top-down approach:

“In some localities people become vulnerable because of their lifestyle or other factors, e.g. commuters moving into areas where there are low levels of social capital; tourists and transient populations are badly cared for by emergency responders – they are ‘invisible’.” (Benzie, M, 2011, Expert interview)

Another expert warns against the:

“... danger of pathologising some groups – labelling people as vulnerable – the real world is more nuanced – in different situations different people are going to be impacted.” (Houston, D, 2011. Expert interview)

It has also been pointed out that where efforts are made to gather data about social vulnerability, a common failure to interact with the people affected means that vulnerability can become understood as a static condition rather than a complex set of characteristics and relationships which can be maintained and reproduced or altered:

“A number of relevant approaches and indicator initiatives have therefore been identified that have been, and can be, used to measure vulnerability in its different dimensions within Europe and for different natural hazards. However, it can be argued that while indicator analysis is useful, it is best used as input for interacting with populations themselves, or their surrogates, to obtain their input about potential vulnerability reduction measures. People’s vulnerability thus needs to be seen in light of their capacities and abilities to influence and define their own fortunes”. (Tapsell et al., 2010 p. 61)

Lindley *et al.* (2011) provide a timely review of conceptual approaches to social vulnerability and integration into debates around climate justice. In drawing on work by Sen (2009) they provide a framework that encompasses the wider set of well-being impacts from climate change, and in doing so describes a wider set of social vulnerability characteristics.

For the purposes of the CCRA, social vulnerability is recognised as a relevant factor in assessing the social consequences of climate change impacts. Evidence from CAG Consultants (2009) suggests that the people who are likely to be most vulnerable to social impacts of climate change are those:

- a. Living in places at risk
- b. Who are socially deprived
- c. Who are disempowered because of lack of awareness, adaptive capacity, support services and exclusion from decision-making.

Within each of these categories are a number of social vulnerability characteristics which are summarised in Table 2.1.

Table 2.1 Social vulnerability categories and characteristics

Social vulnerability category	Social vulnerability characteristics
People living in places at risk	Location and place
People who are socially deprived	Poor mental and physical health
	Fewer financial resources
	Living and working in poor quality homes or workplaces
	Limited access to public and private transport
People who are disempowered because of lack of awareness, adaptive capacity, support services and exclusion from decision-making	Limited or lack of awareness of risks
	Lack of social networks
	Little access to systems and support services (e.g. health care)

This classification combines both sensitivity and adaptive capacity and was used to develop the CCRA’s social vulnerability checklist (see Appendix 1 of this annex), and also used to frame this review of evidence. However, we would suggest that our focus has been on examining individuals’ adaptive capacity within the evidence on social vulnerability to heat, drought and flooding, rather than a more general examination of adaptation to climate change.

2.1 Use of Evidence

It is vital at this point to raise a key issue about the type of evidence that has been drawn upon in this review and what it enables us to say about social vulnerability to climate change. Firstly, largely, the studies reported here are of actual events (e.g. heatwaves, floods, droughts) which have provided an opportunity to investigate the question of who is most at risk and whether there are generalisations that can be drawn out about the potential vulnerability characteristics of those people that has made them more at risk in that event. So, for example, work on the health impacts of flooding in Banbury and Kidlington, was carried out post-event with those who had been flooded and provided a useful account of those impacts. In our review then, we are focussed on presenting evidence that shows relationships between specific events, outcomes and people with vulnerability characteristics. It is important to remember that this gives us evidence of who might be vulnerable in specific events, and those events are predicted to increase with climate change therefore putting more of those people at risk.

This approach also reflects the limitations in the evidence of climate change impacts that is currently available which has been referred to as ‘*very fragmented... you would need resources to build a patchwork quilt of evidence.*’ (Lucas, K, Expert interview, 2011)

The other trend in research is to link current hazard maps with maps of current social characteristics in order to examine distribution and composition of people at risk and we have drawn on that research as well (e.g. Walker *et al.*, 2006; Oven *et al.*, 2012). Research using climate change projections and linking that with projections of population numbers and composition have not been carried out for the UK until recently with key projects being commissioned through the Joseph Rowntree Foundation

“Climate Change and social justice” programme. We have used the evidence from four of those projects all of which were published in 2011:

- Benzie., M., Harvey, A., Burningham, K., Hodgson, N., and Siddiqi, Ayesha Vulnerability to heatwaves and drought: Case studies of adaptation to climate change in south-west England.
- Houston, D., Werrity, A., Bassett, D., Geddes, A., and Hoolachan, A., The Invisible Hazard: Pluvial Flooding in Urban Areas.
- Lindley, S.J., O'Neill, J., Kandeh, J., Lawson, N., Christian, R., O'Neill, M:Justice, Vulnerability and Climate Change: An Integrated Framework.
- Zsamboky, M., Fernandez-Bilbao, A., Smith, D., Knight, J. and Allan, J. Impacts of climate change on disadvantaged UK coastal communities.

Given this, the research evidence we have largely does not focus on estimates of those numbers of people at risk, rather it provides information about potential factors that increase risk from a specific climate change impact, and should be read with that in mind.

3 Heat

3.1 Introduction

Whilst the review of the sector reports provides some insight into social vulnerability issues, this is complemented by a further review of current social vulnerability evidence looking at heat, drought and flooding within the UK. This provides a wider view of social vulnerability issues and climate change impacts. Each section starts with a general introduction on approaches to social vulnerability for that impact followed by an examination of the different categories of potential social vulnerability identified by CAG (2009) in relation to each of the impact categories. This section focuses on heat.

3.2 Approaches to social vulnerability and heat

The current approach to impacts on people from heat focuses largely at the individual level on heat-related morbidity and mortality. Benzie *et al.* (2011) suggest this is likely to come from a top-down approach to assessing vulnerability, one that sees vulnerability as an outcome, and primarily as biophysical. Brown and Walker (2008) comment that to date the understanding of vulnerability during heatwaves is based largely on epidemiological analysis of past mortality data. They suggest an alternative approach, based on their work in care homes that looks more at the practices surrounding the management of heat.

Benzie *et al.* (2011) raise this issue in relation to the Department of Health's outline of who might be at risk, in the Heat Plan:

“the DoH outline of who may be at risk from extreme heat takes a conventional physiological (or health-centric) perspective of vulnerability. It fails to highlight the relationships or links between any of the determinants given or of the causal factors that might lead to the conditions described. It looks at age, existing medical conditions, and lifestyle as factors leading to vulnerability.... These health criteria do indeed affect vulnerability at the individual level but there could be a far wider set of criteria that stakeholders need to be aware of when implementing actions of the Heat wave Plan. Crucially, it is important to understand whether and how there is a spatial element to the distribution of vulnerability to heat, and to look more closely at how vulnerability overlaps with other forms of social disadvantage”. (Benzie *et al.*, p.55)

Taking this Department of Health (DoH) approach to social vulnerability focuses effort on understanding characteristics at the individual level which is useful but it is also important to understand community, institutional and particularly the spatial levels of social vulnerability as will be discussed later in this section.

A further issue that needs consideration is the framing of the “problem” of heat and the influence on behaviour of that framing. It has been noted that:

“Images of heatwaves do not have the same destructive properties as a tsunami, flood or terrorist event. This makes it difficult to garner popular and political will for prevention and planning for response” (Macgregor, 2007).

Within the UK as well as heat being associated with leisure and affluence, social and discourse analysis of historic material (Brown, 2011) shows that “being cold” is

constructed as a medical issue within care homes, such that many practices focus on maintaining and increasing residents' warmth in order for them to keep well. Framed as a "health" problem, being cold is to be avoided and many practices are associated with that avoidance and prevention. In contrast, "heat" has not been problematised in the same way or to the same degree. Whilst the cold is a well established problem amongst both the staff and residents, heat is viewed almost as an inconvenience and an issue of comfort rather than a real threat to health within care homes. For example, care homes, as with all working environments in the UK, are required to be maintained above a minimum temperature and inspectors verify that this is done; there is no equivalent maximum temperature. Benzie *et al.* (2011) point out how heatwaves are not seen as posing a significant threat in the South West of England from their descriptions on the Community Risk Registers.

Lindley *et al.* (2011) have developed a socio-spatial index for vulnerability to heatwave impacts and flooding. They used existing indicators (e.g. census data) to measure sensitivity, enhanced exposure (e.g. type of building), adaptive capacity (ability to prepare, ability to respond and ability to recovery) to develop an index which they then used to map the UK in terms of socio-spatial vulnerability to heat and flooding. The indices were then looked at alongside exposure (where possible, e.g. flood risk maps) to assess the level of heat and flood disadvantage. This approach has been carried out to some extent within flooding (see Section 6) is welcome as it provides UK wide data on social vulnerability to heat and flood risk.

3.3 Social vulnerability categories: Location and place

This relates to the first aspect of social vulnerability – whether or not there are differential impacts across locations in the UK.

Cities need some special attention as during heatwaves due to the Urban Heat Island effect, people in cities are usually much warmer than people in rural areas. Macgregor (2007) highlights that living in cities may be a health risk factor for those most at risk from heat. Further, Donaldson *et al.* (2002) give a breakdown of heat-related mortality by age, sex and attributed cause in England and Wales during the 1995 and 1976 heatwaves. These data indicate that the impact of heatwaves was greater in an urban area (Greater London) than in the population as whole. Lindley *et al.* (2011) in looking at socio-spatial heat vulnerability (this is a measure of indicators relating to sensitivity, enhanced exposure and adaptation but does **not** include potential exposure to excess heat), have found that many of the most socially vulnerable locations in terms of heat are in urban areas.

Oven *et al.* (2012) in their examination of the probability of heatwave events looking at a baseline (2006) and climate change scenario (2030) periods show that the areas that are expected to exceed the greatest increase in heatwaves (which exceed the 95th percentile of the prevailing temperature range in the locality which include: East of England, North West and Yorkshire and Humber, and these areas are "*most likely to have to adjust their resilience strategies to cope with climate change by 2030s*" (Oven *et al.*, 2011, p 20)

Knowlton *et al.* (2009) in their study of the Californian 2006 heatwave explain regional differences in terms of a range of factors, both behavioural, and physical:

"The large RR [rate ratios for heat related excess hospitalisations] for the Central Coast region, where there are typically moderate summer temperatures, suggests that residents are less acclimatized, have less access to climate-controlled environments, or may not consider themselves

vulnerable to heat waves and therefore do not take measures to prevent heat stress". (Knowlton et al. 2009 p. 65)

In terms of particular types of place to live, Kovats *et al.* (2006) in their study of mortality by place of death³ report:

"After accounting for the usual pattern of mortality by place of death, a larger than expected proportion of the excess⁴ deaths in the elderly occurred in hospitals and nursing homes.

In the non-elderly population, there was a large excess of mortality observed in nursing and residential homes, although the absolute numbers of deaths were small." (Kovats et al., 2006, p. 8)

This study is focussed on examining where people died in heatwaves, and not surprisingly perhaps found that the excess deaths were in places where people are generally in poorer health although that is not discussed within the paper. The authors are not suggesting that there is a causal relationship between living in a certain place and heat-related mortality, rather they are describing the distribution of excess deaths by place. This analysis would be useful for local authorities in terms of focussing delivery of heatwave advice and guidance.

3.4 Poor health (physical or mental)

This relates to the second aspect of social vulnerability - whether or not there are differential impacts across people with poor health, physical or mental.

Within the CCRA there is most focus on this aspect, and it is covered by a number of the health metrics as noted above.

The CCRA Health Sector Phase 1 report listed the following in relation to who were considered by the health sector experts to be more vulnerable generally to climate change risks. We have listed those relating to heat only:

- a. Elderly people (over 75), especially those who are socially isolated or living on their own, are at higher risk during extreme weather events.
- b. People with compromised health (chronic cardiovascular, respiratory illness, diabetics, etc.) may be at higher risk during heatwaves due to heatstress and dehydration, and increased exposure to ozone pollution.
- c. Pregnant women may be more vulnerable to heat stress (Kovats, 2004).
- d. Hospital inpatients and care home residents will be at risk if indoor temperatures are not appropriately controlled.
- e. Elderly affected by side-effects of certain medications (e.g. impaired thermoregulation, suppressed thirst) may be at higher risk during heatwaves.
- f. People with mobility or cognitive constraints (including those having Alzheimer's disease) would be at higher risk during extreme weather events, such as floods and heatwaves, as they may be unable to adapt quickly and follow guidelines.

³ This research categorised place of death into the following five types of places: own home, hospices, nursing homes, residential home, and other places

⁴ Excess deaths is the difference between expected deaths and observed deaths.

- g. People consuming too much alcohol or taking illicit drugs may also be unable to adapt quickly and follow guidelines during extreme weather events (from Vardoulakis, 2010 p. 13).
- h. People working outdoors, including construction workers and drivers.
- i. Sports persons and amateur athletes exercising outdoors.

Further, the health sector report (Hames and Vardoulakis, 2012) states that people with pre-existing respiratory problems will be more vulnerable during heat together with the elderly. The evidence that vulnerability to heat increases with age is a key health issue because it is linked to intrinsic changes in the regulatory system or to the presence of drugs that interfere in the normal homeostasis (Vasselto *et al.*, 1995). There are other environmental and situational factors linked to age which we discuss later but unlike other risks e.g. flooding where old age is a proxy for relevant hazard related health problems e.g. reduced mobility, the body is intrinsically more sensitive to heat with age.

Donaldson *et al.* (2002 p. 73) provide a useful list of risk factors associated with heat stress in old age (see Table 3.1 below). This in turn comes from Vasselto *et al.* (1995) who carried out a retrospective study on marginal hyperthermia in elderly patients living in an institution in Malta.

Table 3.1 Risk factors associated with heat stress in old age

Risk factor	Comments
Extreme old age	Over 80
Dependency	Being bedridden is a greater risk factor than being semi-dependent which in turn is a greater risk than being mobile
Drugs	Especially phenothiazines, antidepressants, alcohol, diuretics
Cardiovascular	Congestive heart failure, ischaemic heart disease
Neurological	Cerebrovascular disease, autonomic impairment, head injury, cerebral tumour or abscess
Mental condition	Dementia, confusional states
Endocrine	Diabetes mellitus, hyperthyroidism, hyperpituitarism
Skin disorders	Disorders that impair sweating
Infections	Respiratory, intestinal and septicaemia

Knowlton *et al.* 2009 found that there was a significant increase numbers in Emergency Departments during the heatwave in California in 2006; with children age 0 - 4 and those over 65 years especially at risk. Johnson *et al.*, 2004 also found that the worst affected by the 2003 heatwave in England were those who were over 75 both in terms of excess deaths and excess hospital admissions.

Kaiser *et al.* (2001) in a small study looking at the 1999 heatwave in Cincinnati where there were 18 heat related deaths, found a significant number of those had mental illness and that there was a suggestion of an interaction effect between age and mental illness (Kaiser *et al.* 2001). The evidence raises more questions than it answers but does suggest more work on the people with mental illness and their vulnerability to heat should be undertaken.

Age is linked to non-melanoma skin cancers in the over 60s (Hames and Vardoulakis, 2012).

Hames and Vardoulakis (2012) also indicate that people with pre-existing respiratory illnesses are more likely to be affected by Summer Air Pollution.

Ovens *et al.* (2012) in mapping the baseline (2006) and 2030 climate change scenario of heatwaves and floods, and separately, the population projections for older people in England, conclude that:

“The maps shown here suggest that areas experiencing the most rapidly changing hazards may often also be coping with high proportions of older people, especially in the oldest age groups who are most vulnerable, for example, in the South East, East of England, Yorkshire and Humber and the North West” (Oven et al., 2012, p 22).

These types of trends will be very important to examine and to translate into development of resilience plans.

3.5 Fewer financial resources and little access to systems and support services (e.g. health care)

These two factors are taken together as they are interrelated. In the CCRA Health Sector Phase 1 report it suggests that: Impoverished and homeless individuals are at higher risk due to potentially higher exposure to high temperatures during heatwaves (Vardoulakis, 2010) although this is based on expert judgement rather than empirical research evidence.

As an underlying factor, MacGregor *et al.* (2007) point out socio-economic deprivation explains most of the geographical variation in life expectancy in the UK (Woods *et al.*, 2005) and so it might be expected that differences in responses to heatwaves may reflect variations in deprivation. That is, areas of deprivation already have people with lower life expectancies and so in heatwaves it might be expected that there would be greater number of deaths than in less deprived areas. A study across 11 European countries showed that high excess mortality from all causes, among the elderly population of lower socio-economic status (as measured by education and housing tenure) constitutes an important health problem for Europe (Huisman *et al.*, 2004). In absolute terms more elderly people die who have lower educational status than those with higher educational status, than would be expected. In terms of housing tenure, the relative difference in mortality between homeowners and renters declines in the over 80s, however, differences in absolute mortality levels peaked in the 70 – 79 age range with more people dying who lived in rented accommodation than those living in their own homes. People living in care were not included in the analysis.

Further, as Macgregor *et al.* (2007) report, Middlekoop *et al.* (2001) found that mortality risk in data from under 65s in The Hague, generally increased with an increase in deprivation score of a residential area. They found that the key diseases contributing to mortality differences between the high and low deprivation quartiles were ischaemic heart disease and other diseases of the circulatory system. The findings are interesting as these diseases increase sensitivity to heat, suggesting that sensitivity to heat may be partly conditioned by the degree of deprivation.

Donaldson *et al.* (2002) report that preliminary analysis for the 1995 heatwave in Greater London, England and Wales (McMichael *et al.*, 1998) suggested that heat related excess mortality was proportionally higher in deprived areas.

⁵ Woods *et al.* (2005) used the income index from the indices of multiple deprivation in their analyses.

In their work for the JRF programme on Climate Change and Social Justice, Benzie *et al.* (2011) make a key point about how the factors that make people vulnerable to heat stress overlap with certain communities of disadvantage e.g.

- i. *“Low income jobs are more likely to involve outside labour or long hours spent in confined spaces such as driving cabins (TUC, 2009) which increases exposure to heat.*
- ii. *Low income groups may be more likely to suffer from poor health in general, which could increase sensitivity to heat.*
- iii. *Low income householders are also more likely to live in social housing and have lowered capacity to adapt their homes either for tenure or affordability reasons, which reduces their capacity to adapt to high temperatures” (Benzie *et al.*, 2011, p. 59).*

These points from Benzie *et al.* (2011) would be important to investigate further as there are few studies that address these issues.

Interestingly, in terms of skin cancer due to UV sunlight, those in more affluent areas have higher rates of skin cancer than those in more deprived areas of the UK, although that difference has reduced over the past decade. (Cancer Research, 2011).

3.6 Living and working in poor quality homes or workplaces

Macgregor *et al.* (2007) comment on the role of housing characteristics and their influence on vulnerability to heat. They suggest that design standards, location of buildings in specific areas of cities, and architectural styles all shape exposure to heat, but they conclude that *“Although housing characteristics appear to play a role in determining sensitivity in the US (Smoyer, 1998) as yet no evidence has emerged of its role during heat waves in the UK (Kovats *et al.*, 2006)”*.

The TUC (2009) highlight the exposure of some frontline workers. For example, indoor staff who work in poorly ventilated environment or restricted vehicles are at higher risk. In the 2003 heatwave, tube train drivers in the London Underground suffered temperatures up to 41.5°C (Metroeconomica, 2006).

Young (2009) in their review of key epidemiological papers on occupational solar exposure and skin cancer show that there are links between occupational exposure and a range of skin cancers.

3.7 Limited access to public and private transport

Semenza *et al.* (1996) report that the risk of death during the Chicago heatwave in 1995 was reduced by, among other things, having access to transportation. They do not discuss in detail how this may have helped but it is likely that it was linked to being able to leave the overheated areas and go somewhere cooler.

3.8 Limited or lack of awareness of risk

Lack of awareness will also become an issue due to (for example) potential increased levels of UV exposure and associated preventative measures (Vardoulakis, 2010).

Abrahamson *et al.* (2008) in their qualitative study of older people's perceptions of heat, not carried out in a heatwave, found that many older people and those with a chronic condition did not consider themselves as risk despite their age or medical condition. Their finding that older people do not readily identify with the label "old" is crucially important to recognise if campaigns for adaptation are intended to target people of a specific age. They cite the literature that has considered risk perception and its impact on capacity and action which supports their findings.

The issue of perception of risk in relation to heat is highlighted by Benzie *et al.* (2011) as a factor that is vital yet outside of the health and identity perspectives embodied in the Heatwave Plan and its Equalities Assessment.

3.9 Lack of social networks

There is some evidence around social networks and social capital and its role in terms of the risk of heat related mortality. Specifically, in the analysis of the 1995 heatwave in Chicago, carried out by Semenza *et al.*, (1996) 339 relative neighbours or friends of those who died and 339 controls matched to the case subjects in terms of neighbourhood and age were interviewed. They found that having social contacts such as group activities or friends in the area was a protective factor in relation to heat-related deaths. Further, living alone was associated with increased risk.

On the other hand, interviews by Wolf *et al.* (2008) with older people and their social contacts suggest that narratives of independence and common sense, together with a lack of perception of being at risk from heat could challenge adaptation strategies for managing excessive heat., thereby suggesting that those social contacts may be more of a hindrance than a help in a heat emergency.

Klinenberg (2002a, 2002b) in his work on the Chicago 1995 heatwave, describes the more nuanced picture that emerges when this is further investigated. From the individual analysis it would be expected that more women than men would have died in the heatwave given the larger numbers of elderly women living alone. However, this was not the case and Klinenberg (2002b) suggests that this was partly because women keep up social networks in older age whereas men are less likely to. He also highlights differences between ethnic groups, showing that proportionately more African-Americans died than white elderly people (a ratio of 3:2), yet proportionately fewer members of the Latino population died than might be expected. This in part was attributed to the strong family ties evident in the Latino area of town, but Klinenberg (2002b) points out that there was a spatial element: "*Chicago's Latinos tend to live in neighborhoods with high population density, busy commercial life in the streets, and vibrant public spaces. Most of the African American neighborhoods with high heat wave death rates had been abandoned—by employers, stores, and residents—in recent decades. The social ecology of abandonment, dispersion, and decay makes systems of social support exceedingly difficult to sustain*" (Klinenberg, 2002b).

What this suggests is that social networks and social isolation are important factors with respect to risks from heatwaves, but that they need to be examined in relation to the socio-spatial context. Specifically, in relation to the UK, understanding if, and where those characteristics may come together will be important to supporting resilience of communities to heatwaves.

3.10 Other relevant social vulnerability issues

3.10.1 Children

The Health Sector Phase 1 report (Vardoulakis, 2010) highlights possible vulnerabilities to children:

“c. Young children (especially when playing outdoors) may be affected by heat stress, and higher ozone and pollen levels. This could exacerbate the prevalence and severity of allergic and respiratory disorders, including childhood asthma.

l. Babies and very young children would be unable to follow guidelines during extreme weather events. Children left unattended in private cars during hot weather.”

3.10.2 Gender

There is some evidence that women are more susceptible to heat related illnesses than men in heatwaves. Vassello *et al.*, (1995) in their retrospective case-note review of 872 patients in a large institution during a hot summer identified characteristics in the elderly that increase the risk of marginal hyperthermia. A key finding was that women were more likely to be affected than men (25.6% vs. 16.9%) which confirmed findings of Macy *et al.* (1993). D'Ippoliti *et al.* (2010) concur in their analysis of heatwave related mortality across nine European cities:

*“We found that the impact on daily mortality increases with age. Moreover, gender was among the factors that increases individual vulnerability to heat waves; we observed a higher susceptibility of females even after stratifying by age groups. Other authors observed similar results..... and this finding may be attributable to social conditions⁶ of elderly women living alone and to physiological differences, such as a reduced sweating capacity that affects the ability to respond to heat stress..... It may also be due to residual confounding of age, as within the older age groups there will be a greater number of women than men.” D'Ippoliti *et al.* *Environmental Health* 2010, 9:37p. 6*

This evidence suggests that gender is an issue that needs further consideration in relation to susceptibility to heat related illnesses, as there is a complex interplay of social and physiological factors at play.

3.10.3 Community and institutional issues

In terms of the community level this is where the interaction between different factors is often brought out. Macgregor *et al.* (2007) draw on the classic study of the Chicago heatwave of 1995 carried out by Klinenberg (2002a) showing how the health impact of the heatwave was magnified by a number of failures of communication, physical and social infrastructure:

- a. Communications failures such as the failure to issue an emergency heat warning until the last day of the heatwave;

⁶ It should be noted that in this study social conditions refers to standard of living rather than to social networks or social isolation.

- b. Failure of physical infrastructure, e.g. the loss of the electricity supply to 49,000 homes; and
- c. Social infrastructure, including the collapse of community life in some districts, high crime rates.

Care does need to be taken when looking at studies focussed in specific places but there are general points about potential effects of failures in communication, physical and social infrastructure.

Further, Magregor *et al.* (2007) point out how having to manage a heatwave can disrupt other routine emergency planning in an locality leading to increased vulnerability of a community or district. Understanding the levels of institutional vulnerability/resilience to events is crucial in understanding how individual's vulnerability may be managed.

Brown and Walker (2008) in their pilot study of heat related practices within nursing and residential homes examined how the routines and practices of everyday life may have implications for how vulnerabilities are constructed and managed. This work provides valuable insight into how the institutional and social practices within certain places can be barriers or facilitators to the reduction of vulnerability. For example in the care home, the practice in terms of heat regulation was around opening/closing windows and doors rather than regulating the heat sources (radiators) which were controlled centrally. In a heatwave it may be that those practices would not be enough to manage the heat within the care home effectively. In addition, within the care home, choice over clothing for residents was carried out by staff, taking from residents the ability to decide what to wear and its regulation depending on the temperature.

Whilst the focus on mortality and morbidity in heatwaves is vital to understanding the extent of the problem, work is also needed on understanding why and how people become vulnerable in certain places so that adaptation responses can be appropriately targeted.

3.10.4 Social impacts of extreme heat

In reading the literature around extreme heat, it is clear that there are a number of social impacts that should also be noted as part of the CCRA. Specifically, these are: crime and social unrest, (CAG, 2009; Macgregor, 2007). Anderson (2001) reviews a range of research carried out in the US (field studies and laboratory studies) and concludes that in "*many settings hot temperatures causes increases in aggression*". p. 37. Cohn and Rotton (2000) conclude after thoroughly examining reported property crime (burglary, larceny-theft and robbery) in Minneapolis (1987-1988) that the police in that city received more calls about those crimes during warm periods than in cool or cold periods. However, evidence for a relationship between riots (e.g. Oldham, UK, 2001) and increased temperatures is considered rather more speculative (Macgregor *et al.*, 2007).

4 Drought

4.1 Approaches to social vulnerability and drought

Drought has wide ranging impacts on people, including:

- i. Pressure on public water supply, potentially leading to increased prices for water and/or restrictions on the provision or use of water;
- ii. Impacts on crops and food production;
- iii. Damage to gardens, recreational areas such as sports pitches and areas of natural beauty;
- iv. Health risks associated with increased concentration of pollution in waterways and sewers;
- v. Fires; and
- vi. Drying of soils causing subsidence which in turn causes structural damage to properties and infrastructure.

Drought often coincides with heatwaves which in themselves increase demand for water for personal use (both for drinking and for cooling down in pools, showers and baths), for agriculture and for maintaining private and public spaces used for recreation.

The analysis of climate change risks to the water sector indicates that the evidence that future changes in drought magnitude and frequency will impact on water resources is contested:

“The impact of future changes in drought magnitude and frequency on water resources) is an area where different views exist and more research is required. For example, some recent papers have suggested an increase in rainfall droughts (Vidal and Wade, 2009) but others, including recent Met Office Hadley Centre research have concluded that it is not yet possible to robustly predict changes in UK meteorological droughts arising from increased greenhouse gases (Burke et al., 2010).” (Rance et al., 2012)

The same report indicates that by the 2020s, the majority of the UK population could be affected by rising costs of maintaining water supplies and sewerage services, although the costs will be set by the water regulators in England and Wales, Scotland and Northern Ireland respectively. By the 2050s, water users may be affected by more frequent restrictions, unless a wider range of measures are taken to close the supply-demand balance (Rance et al., 2012).

4.2 Social vulnerability categories: Location and place

This relates to the first aspect of social vulnerability – whether or not there are differential impacts across locations.

4.2.1 Water poverty

The primary pressures on water supply are currently in the south and east where available supplies are most limited, demand is highest and there is also forecast growth in population (Rance *et al.*, 2012). In many of these regions, water prices are already higher than the national average. The following table shows how the percentage of people in water poverty (column 3) varies across England and Wales, strongly influenced by differences in water prices. South West England has the highest average weekly water prices and also the highest percentage of the population in water poverty in England (19.9%).

Table 4.1 Variations across Government Office regions

Region	Average £ per week on water	% spending more than 3% water	Composition of those spending more than 3% on water	Composition of the sample
North East	5.04	12.7	4.3	4.9
North West/ Mersey	6.08	17.9	15.5	12.6
Yorkshire/ Humber	5.47	13.2	8.7	9.6
East Midlands	5.63	14.9	8.4	8.2
West Midlands	5.45	15.0	10.2	9.9
East of England	6.32	12.9	9.2	10.4
London	5.14	10.8	10.3	14.0
South East	5.94	11.9	12.4	15.2
South West	6.86	19.9	13.3	9.7
Wales	6.52	20.2	4.3	4.9
Total	5.85	14.6	100	100

(Snell and Bradshaw, 2009)

Water prices bear no relation to income levels, with prices in some cases being highest in parts of the country with low incomes (e.g. the South West and Wales) and lower in London where incomes are highest (Fitch and Price, 2002).

The differences in water prices across the country generally reflect regional differences in water costs. This is not a situation that is likely to change. Inter-company transfers of water to deal with affordability were not considered acceptable by the people to who made submissions to the Walker Review (Walker, 2009 p. 17).

The whole of the UK is projected to be affected by water supply-demand deficits by the 2020s. Looking to the 2050s, the largest deficits are projected to occur in the Thames river basin district, with high deficits also expected in the Humber and North West river basin districts.

4.2.2 Private Water Supplies

The vast majority of the UK population is supplied with water from a Water Utility, but about 1% of the population is supplied from a private supply. There are about 140,000 private supplies in the UK. Most private supplies are situated in the more remote, rural

parts of the country. The source of the supply may be a well, borehole, spring, stream, river, lake or pond. The supply may serve just one property or several properties through a network of pipes (Drinking Water Inspectorate, 2011).

Water from a single private water supply may be used for one or more residences or premises, including businesses, holiday homes, caravan parks or hotels. Because they do not have the benefit of continuous monitoring and professional surveillance, private supplies are much more vulnerable than those from a Water Utility. Statistics show that instance of disease caused by a private water supply is increased 5 fold, so proper treatment and monitoring of the supply is essential (UK Water Treatment Association⁷, consulted 09 March 2011).

Users of private supplies should also be aware that the characteristics of their water supply may also change if levels get low. And there may be more suspended solids (higher colour in the supply) which can reduce the effectiveness of existing treatment such as UV disinfection.

4.2.3 Subsidence

Certain parts of the country are particularly vulnerable to subsidence. This review has not identified any research into the types of household that are most vulnerable to subsidence. This is an issue that merits further research.

4.3 Poor health (physical or mental)

This relates to the second aspect of social vulnerability - whether or not there are differential impacts across people with poor health, physical or mental.

Drought impacts reduce flows in rivers and watercourses leading to impacts on water quality. It is to be expected that people using rivers and watercourses for recreational activities such as fishing or boating may therefore be particularly vulnerable to health impacts; however, this review has not been able to explore the evidence for this kind of impact.

Similarly, further work is needed to draw out the potential consequences of drought-related degradation or even loss of recreational resources (sports pitches, gardens) for mental and emotional wellbeing.

4.4 Fewer financial resources

This section covers impacts on people with fewer financial resources. The main focus is on the affordability of water.

4.4.1 Water affordability and water poverty

The concept of water poverty has been developed to identify households that are unable to pay for 'essential' water use. A measure of water poverty (similar to that of fuel poverty) is used to describe the situation of households where the cost of water

⁷ <http://www.ukwta.org/privateWaterSupplies.php>

represents over 3% of the household income. By this definition, there may be up to 4 million households in the UK that are water poor (Fitch and Price, 2002).

Benzie *et al.* (2011) studied vulnerability associated with water charging, which is used as a means of restricting the supply of water to households:

“This research was interested in how customers experience planned responses to drought, namely water charging. In practice, therefore, the issue of vulnerability is largely about affordability. We characterise this kind of vulnerability as ‘one-dimensional’: a person is somewhere on a line between ‘can easily afford’ and ‘cannot afford’ Vulnerability to water charging is therefore largely about income and poverty at household level”.
p 10

Water charging is not the only measure that can be used to restrict the water supply, however other measures, such as turning off the water supply to homes for periods of the day, sometimes combined with the use of standpipes in the street, are considered draconian and unacceptable today, even though they were used as recently as the 1970s (Medd *et al.*, 2008). These practices affect certain groups more than others: for example, those who need regular drinks or washing. People who are less mobile because of health conditions or because they are caring for the less mobile (e.g. young children, the sick or elderly) are likely to find it difficult to reach standpipes or carry water back to their homes.

Water charging is the preferred measure used to restrict consumption today. Benzie *et al.* (2011) identifies four main ways in which differential water charging based on usage could cause harm and create inequalities:

- a. Affordability: households may be unable to afford their bills because of low income or other reasons⁸.
- b. High use: households may have legitimate reasons for using large amounts of water but still be penalised (for example, where a member of the household has a medical condition that makes frequent washing or washing of clothes and bedding necessary; or if the residents cannot afford water efficient appliances).
- c. Absolute availability: some regions may have insufficient water while others are better resourced because of supply and distribution arrangements.
- d. Approaches to water charging: water poverty may result from interventions by water companies or authorities. Restricting supply to non-paying household is not a measure used at present but is one that has been considered (e.g. in the Walker Review, 2009).

Two studies have looked in detail at the differential impacts of water charging (Fitch and Price, 2002 and Snell and Bradshaw, 2009). Their findings are broadly similar and indicate that over time certain household circumstances (workless households, single pensioners and the bottom income quintile) have tended to be associated with higher rates of water poverty.

Snell and Bradshaw (2009) used data from the Family Resources Survey 2006-7 to analyse the socio-economic characteristics of those at risk of water poverty in England and Wales. They found that 14.6% of the population were in water poverty, i.e. they spent more than 3% of their net income on water. Spending on water does not vary

⁸ The concept of water poverty has been developed to describe the situation of households where the cost of water represents over 3% of the household income. By this definition, there may be up to 4 million households in the UK that are water poor (Fitch and Price, 2002). The concept of water poverty is important because it highlights that some households are unable to pay for 'essential' water use.

much in relation to income: while higher income households spend more, the difference is small. The average domestic water charge in the UK varies from £5.20 per week for the lowest income group to £6.90 for the highest income group. As a result, water spending as a proportion of net income varies more from 8.3% in the lowest group to 0.5% in the highest income group (Snell and Bradshaw, *op cit*).

The same study identifies some specific vulnerabilities amongst those in water poverty:

- Of all households in water poverty, 30.7% are single pensioners.
- 54.4% of households in water poverty are single occupancy households; 23.4% of single occupancy households are water poor.
- 54.9% of those in the lowest income quintile are in water poverty; of all those in water poverty, 71.3% are in the lowest income quintile.

Without public intervention, more frequent droughts and scarcity of water would almost certainly result in increases in the price that consumers pay for water. It has been suggested that people with fewer financial resources would be forced to cut back on essential water use. There is little research on this subject, but what research there is paints a more nuanced picture.

The Consumer Council for Water (CC Water) commissioned a study in 2009 into 'Living with Water Poverty'. This research was based on interviews with a small sample of 42 people in England and Wales who were either living in water poverty (water bill $\geq 3\%$ of disposable income) or were borderline (water bill represents 2.5-3.0% of income). All respondents were on below average disposable incomes (typically under £18k p.a.) and met one or more definitions of vulnerability (ill health, disabilities, age, etc).

Only those interviewees with water meters (less than half) were in a position to try to control the size of their bill and those who attempted to do this generally found it stressful and thought it had little impact. Many of the measures these interviewees said they had taken were the water efficiency measures that are recommended in public campaigns. One interviewee with chronic incontinence reported having to wash soiled clothes and bedclothes less frequently and several families said that they managed without always flushing the toilet.

However, people felt that these behaviours did not make a noticeable difference to their water bills and as a result actually raised their stress and anxiety levels. Having to cope with water debt, like other forms of debt, has adverse effects on mental health:

“A range of negative emotions are experienced by respondents as a result of struggling to meet outgoings or being in arrears, regardless of how well they are coping. These include powerlessness, feeling worn down, hopelessness, anger and guilt and are particularly acute for those who manage their finances chaotically and are constantly fire-fighting”. (Creative Research, 2009)

It is often assumed that older people are an especially vulnerable group who need extra support. The CC Water report suggests that younger people (singles and couples without children and especially lone parents) are less experienced at managing bills and are most likely to end up in debt.

4.5 Living and working in poor quality homes or workplaces

More research is needed into the types of housing that face greater difficulties in coping with periods of drought. This review found references to two types of housing that may be associated with particular problems related to drought:

- High-rise flats are potentially vulnerable to restricted water supplies in drought conditions (Standley *et al.*, 2009).
- Risk of subsidence may make homes and properties in certain areas uninsurable; which in turn could have an impact on house values.

4.6 Limited access to public and private transport

There is no evidence of an association between access to transport and drought impacts.

4.7 Limited or lack of awareness of risk

Reducing water consumption is the most obvious way of coping with water scarcity. Market research for the Consumer Council for Water conducted in 2009 found that 60% of respondents reported seeing campaigns to use water wisely during the previous year and 70% said they had taken specific action to reduce their water consumption. However, for poor households taking measures to become more water efficient can become a source of stress and is felt by many not to lead to any significant reduction:

“I’ve now become quite paranoid about it, because we can’t see it. You know we need water to drink, okay maybe we should only have one cup of tea. I quite often put stuff in a flask which is stupid, if the kettle is boiled I’ll put water in a flask... but it’s having no effect.” (Creative Research, 2009)

4.8 Lack of social networks

While it might be expected that the impact of drought will be exacerbated by a lack of social networks and social support, there is little documented evidence of this relationship. Research by the Consumer Council for Water (2010) provides examples of the way that family support can be vital in helping people in water poverty to cope with debt. Some limited information is provided below about ways in which lack of networks of support makes some rural communities more vulnerable to drought impacts such as fires.

4.8.1 Fires

A report by the Department of Communities and Local Government (DCLG, 2006) suggested that higher summer temperatures could lead to more secondary fires: the report estimated that if summer temperatures rose by 1°C, there could be an increase of 17 – 28% in secondary fires, while an increase in summer temperatures of 2°C could see secondary fires go up by 38 – 56%. While secondary fires occur in both cities and

the countryside (affecting outdoor areas such as grassland and stubble, derelict buildings and outdoor structures, waste containers and derelict cars) the response system in rural areas is much less robust. In rural areas the Fire and Rescue Service relies heavily on firefighters working on the retained duty system, which means that they are called out to respond to specific incidents and will often need to be released by their employers to do so. An increase in the number of fires will put this social support system under additional strain.

4.8.2 Private water supplies

Many households that rely on private water supplies are in isolated areas or are vulnerable in other ways. If they are not part of social networks or do not have neighbours living relatively close by who are on a different water supply and can provide water, they may need to buy an emergency bottled supply. They may also need social networks to reach the nearest village or town where they can buy bottled water.

5 Floods

5.1 Approaches to social vulnerability and floods

Social vulnerability has been examined through two main approaches in the UK: quantitative, indicator approaches e.g. Social Flood Vulnerability Index (Tapsell *et al.*, 2002; Lindley *et al.* (2011); Risks to Life (HR Wallingford, 2005) and more qualitative approaches e.g. Burningham *et al.*, 2005; Tapsell *et al.*, 2008; Whittle *et al.*, 2010).

Quantitative vulnerability indices such as the Social Vulnerability Index (SoVI) have been developed in flood risk management (e.g. Social Flood Vulnerability Index, Tapsell *et al.*, 2002) and more widely in environmental hazard literature e.g. Cutter *et al.*, 2003. Typically this consists of statistically grouping social vulnerability variables. The SFVI is a national dataset covering the whole of England and Wales. The attributes used within this index to define vulnerability to all sources of flooding are: elderly (>75 years); lone parents; long-term sick; financial deprivation (i.e. unemployed, non-car ownership, non-home owning and household over-crowding). The SFVI is an additive index that combines these seven indicators in a process of statistical transformation, through which the social and financial factors are attributed equal weight. Tapsell *et al.* (2005a) provide a very useful and comprehensive overview of approaches to social indicators for flood risk which draws out some key issues that need to be borne in mind when considering the social indicator approach. Specifically, whilst women are found to be more vulnerable to flooding, this is not equally distributed and interacts with social class and ethnicity, for example. Using a categorical approach to social vulnerability does risk stereotypical and generalised responses. This is linked with the general “top down” approach to vulnerability discussed in Section 2. This approach is still useful; however the assumptions and limitations to taking such an approach need to be considered. This is developed further in Tunstall *et al.* (2007) who comment “*But in order to make clear that we will not be interested in atomised individuals but rather in people who in mutual social relationships create intersubjective sense, trust, knowledge and interpretation, there is a further concept that deserves our attention: social capital*” p. 3.

Lindley *et al.* (2011) provide a very useful progression of the work on indices. As noted in Section 4 they have developed a comprehensive index covering five dimensions sensitivity (biophysical characteristics), physical neighbourhood characteristics (enhanced exposure), preparation (taking precautions), response (avoiding losses) and recovery. A key part of the work has been to conceptualise the factors within each dimension regardless of whether there is currently data for those factors which is very useful. Beyond the conceptual work they have found data to use within each dimension, for example, sensitivity includes age, health, and special care. What is also important about this work is that it uses climate change projections to examine possible future vulnerabilities. The second approach to vulnerability in flooding has been work which examines the experience of being flooded, generally through qualitative research, e.g. Burningham *et al.* (2008); Tapsell *et al.* (1999; 2003; 2008); Watson *et al.* (2009); McCarthy (2004). Tapsell *et al.* (1999) carried out a seminal piece of research examining the health effects of floods in 1998 in Banbury and Kidlington, which they then followed up four years later (Tapsell *et al.*, 2003; 2008). What this work brings is the bottom up experience of vulnerability before, during and after flooding and shows the interactions between the hazard, vulnerability and resilience in context. Further, it is a rare example of research that followed up respondents some time after the flood. The work by Whittle *et al.* (2010) similarly provides this approach to vulnerability. Their longitudinal piece of research examined the experience of flooding

in Hull in 2007, through diaries and provides a unique insight into the work of recovery from flooding, and the role of vulnerability. Walker *et al.* (2011) continued this qualitative exploration in their work with a focus on children who had been flooded in Hull.

The first approach to social vulnerability can be thought of as top-down and is complemented by the qualitative experiential bottom-up work.

What also emerges from the work on social vulnerability to flooding is the issue of vulnerability to “what”: what are the key social and health impacts that are related to flooding. Research has examined both health and social impacts seeking to describe and in places quantify the impacts on people’s lives of flooding, e.g. Hajat *et al.* (2005); RPA/FHRC (2004); Werrity *et al.* (2007); Walker *et al.* (2006). Below is a summary of the range of impacts that have been considered in research:

- Economic impacts, including damages to the property and its contents.
- Non-economic losses, including the loss of personal or sentimental items. The most important losses for victims are often personal possessions such as photographs.
- Impacts on physical health and psychological health.
- Impacts associated with evacuation and temporary accommodation.
- Household disruption, which may include: the stress and inconvenience of living away from the home if evacuation is necessary, cleaning and repairing, and dealing with builders and insurers.
- Community and neighbourhood changes, e.g. changes in population due to evacuation which may be short or long term.

The CCRA Health Sector Phase 1 report (Vardoulakis, 2010) lists the following health impacts from flooding:

“Flooding (river and coastal flooding, flash floods), heavy snow and rainfall (including windstorms) are related to the following illnesses and risks:

a. Direct loss of life and injuries (drowning, electrocution, carbon monoxide poisoning and hypothermia) during floods and windstorms.

*b. Exacerbation of chronic ill-health conditions (Head *et al.*, 2010).*

*c. Psychological stress and anxiety associated with flooding, and related loss of life, injury, property damage, displacement, fear and bereavement. Post-traumatic stress disorder. Anxiety over possible future floods (Hajat *et al.*, 2005)”.*

These are reflected in three of the health risk metrics: extreme event (flooding and storms) mortality; effects of floods and storms on mental health; and extreme event (flooding and storms) injuries. The discussion around the evidence of both these impacts within the health sector report is very useful and does not need repeating here. Clearly, there is evidence for the impacts of flooding on both physical and mental health.

Further, it is noted that not only are there direct impacts from the flood itself (e.g. physical injury; destruction of property), there are also impacts from dealing with the flood (e.g. stress from dealing with builders;), as well as longer term impacts associated with the “recovery” phase (e.g. losing a sense of home; anxiety associated with rain). Within both the social vulnerability approaches described above research has examined not only what factors are associated with increased negative social

impacts of flooding but also social factors associated with the uptake of warnings (e.g. Burningham *et al.*, 2005) and taking action (see Fernandez-Bilbao and Twigger-Ross, 2008 for overview) and recovery (e.g. Whittle *et al.* 2010). This is because it is known that taking specific actions, being aware of flood risk and receiving flood warnings all reduce negative social and health impacts of flooding. Where appropriate these distinctions will be drawn out in the discussion below.

5.2 Social vulnerability categories: Location and place

In terms of places that are more vulnerable to flooding, caravan parks are often located in floodplain environments that have lower land costs and high aesthetic and recreational value (McEwen *et al.*, 2002). There are several examples of loss of life in campsites: in 1996 an intense storm occurred over the Arás catchment near Biescas in the central Pyrenees. Eighty-seven people were killed as a result of the subsequent flood of a campsite (White *et al.*, 1997). Tunstall *et al.* (2007) in their reanalysis of several large datasets of flooded and at risk populations in the UK found that those respondents living in vulnerable properties⁹ scored significantly higher on measures of general health, subjective severity and subjective stress.¹⁰

In a key study looking at relationships between flooding and deprivation, Walker *et al.* (2006) found a link between deprivation (as measured by the Indices of Multiple Deprivation) and tidal flood risk, people living in deprived areas were 62% more likely than others to be at high risk of coastal flooding. This work is important as it begins to highlight areas that are doubly vulnerable to the impacts of flooding, because of both hazard and people characteristics. Regional analysis showed that whilst the finding was pretty consistent across all the English areas, the coastal flood risk population in the most deprived deciles was concentrated in regional areas: London, and Yorkshire and Humberside.

Work for the JRF Climate Change and Social Justice research programme on Impacts of Climate Change on disadvantage UK coastal communities (Zsomboky *et al.*, 2011) shows how place, and social vulnerability come together in a number of coastal areas. The research identified five areas where the combined impacts of climate change and coastal change are likely to be particularly severe (Yorkshire and Lincolnshire; East Anglia; Thames Estuary; South Wales; Northwest Scotland). Within those areas four case studies were chosen which in turn highlighted a range of social vulnerabilities that can be found in those areas, specifically disadvantage, older age and remoteness. The case study areas were Great Yarmouth, East England; Skegness, East England; Llanelli, South Wales; Balivanich, Benbecula Island in the Outer Hebrides, Scotland.

Finally, urban areas have high density populations, which has an impact on the number of people that need to be warned. There is also the issue of more basement flats, the presence of non-English speakers and the nature of urban flooding which can have different sources and it is difficult to predict (e.g. floods in Carlisle 2005 and Hull, 2007). Urban areas are often characterised as low probability/ high consequence in terms of flood risk, that is, low probability of flooding but potentially catastrophic consequences because of the density of the population. Awareness of flood risk in urban areas is also usually low and there are communities who do not know they are at risk of flooding (Twigger-Ross, 2005). Houston *et al.* (2011) in their JRF funded work on pluvial

⁹ Defined as ground floor, basement, no upper floors to seek refuge from flood waters includes bungalows, ground floor and basement apartments and mobile homes

¹⁰ In the re-analysis four outcome measures were examined: General Health Questionnaire 12 – current score General Health Questionnaire 12 – worst time score; Overall severity of effects of the flood on the household; The effects of the stress of the flood event itself on the life of your household.

flooding in urban areas provide detailed work on current and projected numbers of people at risk from pluvial flooding in urban areas, giving a regional breakdown:

“The three regions with the largest urban populations are London, the Southeast and the Northwest. Together, these regions account for over two-fifths of the UK’s urban population and nearly 750,000 people at potential pluvial flood risk. Adding the West Midlands accounts for the majority of the UK’s urban population and takes the total number of people at potential risk to pluvial flooding to almost 1 million” p 23

Further, using climate change projections¹¹ and populations projects they suggest that:

“Nationally across the UK by the middle of the twenty-first century demographic change and climate change in combination have the potential to put an additional 1.2 million people at risk from pluvial flooding [in urban areas].” p 30

5.3 Poor health (physical or mental)

As noted above the key health impacts from flooding are death or injury due to the event, and together with mental health effects of both the event and dealing with its aftermath. Not surprisingly, prior poor physical health has consistently been shown to be linked with increased negative health impact of flooding, specifically long term illness or disability. Pre-existing health problems is one of the four variables included in the SFVI: *“post-flood morbidity (and mortality) is significantly higher when the flood victims suffer from pre-existing health problems”* (Tapsell *et al.*, 2005, p. 13).

Tunstall *et al.* (2007) in their re-analysis of UK datasets, found that people who were ill or disabled at the time of flooding were greater affected by the flooding but also took longer to recover suggesting they had less resilience than others. This was measured using the General Health Questionnaire¹².

Thrush *et al.* (2005) cite Environment Agency post-event surveys that show that almost a fifth of households surveyed contained at least one long-term ill or disabled member, and that many of those households would find it *‘difficult or impossible’* to act on a flood warning (p. 12).

Within the flooding literature there has been quite a bit of work carried out that links being “elderly” with a greater risk of negative social impacts of flooding (especially health impacts) both during and after a flood. However, there is no agreement in the literature as to what constitutes being ‘elderly’, and there is contradictory anecdotal evidence about how the “elderly” respond in floods. As Thrush *et al.* (2005) point out *“Chronological age does not in itself engender vulnerability but interacts with many other factors: for example, pre-existing health and fitness; mobility; income; and family support”* p. 7.

However, age has been considered as a proxy for the likelihood of higher instances of prior ill health which in turn are associated with negative health effects of flooding. Tapsell *et al.* (2005) considered ‘elderly’ as being over 75. They drew on epidemiological research that shows after this age there is a sharp increase in the incidence and severity of arthritis (and other conditions) which is sensitive to the damp, cold environmental conditions that follow a flood event. The Social Flood Vulnerability Index uses “over 75” as one of its measures of vulnerability to health impacts from flooding.

¹¹ This project used the Weather Generator interface in UKCP09.

¹² In terms of prior illness and disability, these were correlated with increased GHQ12 scores both current and worst time scores.

RPA/FHRC (2004) in their work on health effects of flooding found an interesting relationship between age and self-reported psychological and physical health measures (Post Traumatic Stress Scale and General Health Questionnaire) which showed that people in their early 50s suffered more than those who were younger or older. Tunstall *et al.* (2007) who include the data from the RPA/FHRC study (as well as from two other Flood Hazard Research Centre projects) in their re-analysis of data, conclude “*counterintuitively, the very old, those aged 75 and over, were less affected than the middle aged and the relationship between age and vulnerability variables was not a linear one*” p. 128.

The evidence suggests prior poor health is a key vulnerability characteristic in relation to exacerbating the physical and psychological impacts of flooding. Age does not appear to be linked in a linear fashion with increased vulnerability to flood impacts, and indeed those in their early 50s showed higher levels of stress than those older or younger in the research by Tunstall *et al.* (2007). Further, in some of their multivariate analysis, somewhat counter-intuitively being over 65 and living alone were predictors of lower vulnerability, but they suggest this could be because the variable covering prior health and illness may have covered much of the vulnerability associated with old age. Whilst the findings relating age and vulnerability to health impacts of flooding on their own may seem contradictory, it is the links with other variables (e.g. low income, poor health) that increase older people’s vulnerability to flooding impacts (Walker and Burningham, 2011), therefore making age, potentially a useful starting point for an examination of a range of vulnerabilities.

Houston *et al.* (2011) in their work on pluvial flooding in urban areas provide two relevant conclusions in their interim report about the relationship between poor health and projections of daily rainfall:

“Social deprivation and poor health are slightly over-represented in urban areas with the most intense daily rainfall.

Climate change will amplify the concentration of people with poor health in the urban areas with highest intensity rainfall.” p. 4

5.4 Fewer financial resources and little access to systems and support services (e.g. health care)

Within this section, SV3 and SV8 are considered as they both focus on access to resources in a wider sense. Wealth and financial resources have been found to have a significant ‘*buffering effect*’ against the severity of a flood event (Green *et al.*, 1994; Ketteridge and Fordham, 1997).

Financial deprivation is one of the four variables included in the Flood Hazard Research Centre’s Social Vulnerability Index (Tapsell *et al.*, 2002) as those who are financially deprived are also less likely to have contents insurance and would have more difficulty to replace furniture and other possessions and it would also take them longer. ABI (2007) research¹³ found that:

“35 per cent of people in very low-income households (less than £10,000 a year) have no insurance of any kind, compared to only five per cent of households with an average income (£15,000-£30,000).

¹³ 1,047 face to face interviews were conducted with people in three low – average household income per year groups: very low = under £10,000; low = between £10,000 - £15,000 and average = between £15,000 - £30,000

Under half of low income households hold home contents insurance compared to over 80 per cent of those with average incomes, and only a quarter hold life insurance, compared to half of those on average incomes.

Of those with a low income and no insurance, a third borrow funds to replace stolen or damaged household items, increasing their indebtedness.” (ABI, 2007, p. 3).

Werrity *et al.* (2007) in their work looking at the social impacts of flooding in Scotland found that “the stress of the flood itself and future worry about flooding were other intangible impacts, far more severely felt by low income households¹⁴” p. 79.

Tunstall *et al.* (2007) found that low-income households were less likely to receive a warning. Higher income households are often more aware of, and are better able to afford, a wider range of technologies, such as access to the internet (Tapsell *et al.*, 2005b). Tapsell *et al.* (2005a) cite financial reserves of affected households and communities as one of the factors that relates to people’s ability to overcome the consequences of flood impacts. Fielding *et al.* (2007) in their secondary analysis of Environment Agency At-Risk surveys¹⁵ found that those who were employed took more actions in a flood than those who were not employed.

As well as the direct impact of having fewer financial resources to aid recovery from flooding people on low incomes are more likely to live in houses that are more at risk from floods and storms e.g. caravans, mobile homes, and more easily damaged by water from those floods (Pitt, 2008; Walker and Burningham, 2011).

Whilst recognising that this approach is essentially top-down categorisation of those who might be vulnerable and therefore there is a need to be cautious about generalising, Walker and Burningham (2011) suggest:

“In combination these different interactions between flooding and socio-economic or deprivation status build up a picture that suggests that deprived or poorer households are likely to experience the impacts of flooding more severely than others. They are typically less prepared, less able to access financial resources to aid recovery and more susceptible to a range of health impacts than those that are better off. (Walker and Burningham, 2011 p. 9.

Zsamboky *et al.* (2011) focus on disadvantaged coastal communities, where disadvantage was translated as high levels of economic deprivation¹⁶, higher than average numbers of older people or geographical remoteness. Coastal communities face a series of socio-economic challenges including high levels of seasonal unemployment, and are another case where both climate and social vulnerability come together.

Houston *et al.* (2011) have a key finding with respect to their analysis of three urban areas (Belfast, Glasgow and Luton), comparing the socio-demographic composition of populations living in flood risk areas with those living in non-flood risk areas. They show that of all the fourteen socio-demographic groups¹⁷ they examined, twelve were over-

¹⁴ Low income households refers to people with incomes of under £20,000. Tangible impacts were: Financial loss; Loss of house value; Disruption to electricity supply; Damage to car or van and Used holiday entitlement. Intangible impacts were split into immediate and lasting. Immediate = Discomfort/inconvenience; Stress of flood itself; Having to leave home; Dealing with insurers; Living in temporary accommodation; Dealing with builders and Being stranded in/out of home and lasting = Time and effort to return to normal; Worry about future flooding; Irreplaceable/sentimental items; Strains between family Loss of community spirit; Deterioration to mental health; Deterioration to physical health; Loss or distress to pets.

¹⁵ The secondary analysis was of the 2001 At Risk Survey conducted by the British Market Research Bureau (BMRB) for the Environment Agency. These annual surveys sample respondents who have been designated as ‘at risk’ of flooding by the Environment Agency, although they may not have experienced a flood event during their time of residence in their homes.

¹⁶ In three of the case studies they used unemployment as the main criteria for economic deprivation.

¹⁷ The study used the 2001 census data.

represented in flood risk areas, all of which could be termed “vulnerable” which were: elderly (75+), ethnic minority, limiting long term illness, poor health, unemployed, lower socio-economic group, households with no car, renters (social and private), over crowding, single pensioner households and lone parent households. Although the differences are small the patterns were the same for all three urban areas which is striking, showing that people living in the areas of those three cities at risk of pluvial flooding are more likely to have characteristics that may make them more vulnerable to the impacts and recovery from flooding than those people living in areas not at pluvial flood risk.

5.5 Living and working in poor quality homes or workplaces

Basement properties, car parks, low rise commercial and industrial properties, bungalows, mobile homes, busy roads, parks, single storey schools, campsites, are considered ‘high risk’ buildings in the ‘Risk to Life work’ (HR Wallingford *et al.*, 2005).

The type of property can affect what people do in floods. For example: single storey homes or small homes, e.g. caravans, bungalows, etc. often do not provide dry storage or space to move possessions to (Thrush *et al.*, 2005); these type of properties do not have an ‘upstairs’ where pets or people can be moved to.

5.6 Limited access to public and private transport

No direct evidence was available.

5.7 Limited or lack of awareness of risk

Within flood risk research awareness of risk can be divided into three areas:

- Awareness of living in an area at risk of flooding and potential impacts;
- Receipt of flood warnings; and
- Knowing what actions to take in a flood.

These three things have been linked to more actions taken during or before a flood (Environment Agency, 2006), which in turn reduces the negative impacts of flooding.

The impact of flood risk awareness is consistently signalled by recent research (see Thrush *et al.*, 2005; Tapsell *et al.*, 2005b; McCarthy *et al.*, 2006; Tunstall *et al.*, 2007) as a key factor that influences the willingness to adopt flood warning technologies and other forms of preventative measures and also response to warnings, and floods. People with greater flood risk awareness are more likely to sign up for flood warnings and also to respond to flood warnings. Pre-flood hazard awareness and preparedness have been found to be important determinants in willingness and ability to understand flood warnings and respond effectively (McEwen *et al.*, 2002).

Research on the benefits of flood warnings (Parker, Tapsell and McCarthy, 2007) suggest that improving warning lead time reduces stress and mental effects of flooding. (RPA/FHRC, 2004) found some evidence that a longer warning lead time had a mitigating effect on the mental health of flood victims at the time of flood and in the longer term. Through multiple regression analyses, a wide range of variables were

examined as possible explanatory factors for the mental health and stress effects experienced as a result of flooding. Warning lead time emerged as one of ten factors that had an influence on mental health at the time of flooding (measured by the GHQ-12 scale). It was also one of ten factors influencing the current stress levels of flood victims measured by the Post Traumatic Stress Disorder Intensity score with a longer warning lead time associated with reduced mental health and stress problems.

However, receiving a warning will not necessarily lead to action if people lack information and advice on what actions to take (Thrush *et al.*, 2005). Literature reviewed by Fielding *et al.* (2007) shows that despite evidence of a link between flood knowledge and response, information on what to do on receipt of a flood warning is sparse, especially when it is most needed during the event. People's behaviour can be mistaken as irrational or panicky when it is merely lack of knowledge on what to do; not knowing what to do can also lead to increased stress during the flood. Fielding *et al.* (2007, p16) conclude that "*A lack of relevant knowledge therefore not only constrains appropriate response, it also exacerbates the long-term adverse effects of flooding with personal, social and economic consequences*".

Perceptions of risk and vulnerability have a clear effect on response, e.g. a belief that one's home is at risk or a feeling of vulnerability increases the likelihood of appropriate response; whilst fear of looting has been found to reduce the probability of response (Fernandez-Bilbao and Twigger-Ross 2009).

5.8 Lack of social networks

Evidence, both anecdotal and research suggests a complex relationship between impacts of flooding and social networks/social capital, with evidence to suggest the development of networks during flooding, what has been termed the "therapeutic community" (Flint and Luloff, 2005) as well as evidence suggesting that different types of social capital (bonded, bridging and linking), and the lack of, can impact on the way people cope during and after flooding. Deeming (2008) in his work in three coastal communities concluded that "*merely having social capital in a community does not mean that it is readily instantiated into any form of hazard resilience*" p.295. Tunstall *et al.* (2007) emphasise the role of social networks and drawing on sociological research in that area, unpack the relationships between the type and nature of ties between people in social networks, which in turn provides useful insights into the circumstances under which those ties are likely to increase or reduce vulnerability to flooding impacts. The strength of the weak ties hypothesis suggests that heterogenous social networks (with weaker bonds between people) in a range of places, have more diverse information than dense networks of people with similar social characteristics. In a flood having weak but broad ranging networks may help someone to find information quickly and to respond appropriately. On the other hand, strong ties in physically dense networks may be useful in terms of exchanging information quickly, having emotional and physical capital but could be a barrier to hearing the range of information. Whilst much of the evidence does not look in such detail at different types of networks they are important to be aware of.

Walker *et al.* (2006) state that: "*research in developing countries concludes that poorer communities and those with lower levels of social capital are hit harder by flooding than their more affluent and better-integrated counterparts*" (p.29). Tunstall *et al.* (2007) also found that some disadvantaged groups were less likely to obtain help during a flood: "*It may be that older people, the disabled and those living alone are less linked into local support networks than others around them and therefore may get overlooked when it comes to neighbourly help..... In both surveys, households with children under ten years of age were more likely to be helped by neighbours and friends than other households..... However, it is possible that these families received help from*

neighbours and friends not because of their need but because of their greater connections to local social networks as compared with other needy groups". (p. 65)

Tapsell (2009) in her discussion of German research (Steinführer and Kuhlicke, 2007) concluded that in that case,

"Networks of strong ties potentially provide important resources to draw upon in response to a flood event, however, these resources may be weakened if they too experience the flooding.

People who did not receive any useful information prior to flooding have significantly smaller social networks than people who were informed by any source.

People with exclusively local networks were endangered by relying on a similar stock of information and knowledge.

Informal networks were the most important resources for coping with the flood. There is no evidence that social networks generally played a major role in activating support, however, specific networks like membership of local associations reported influencing increased levels of support" p. 110.

5.9 Other relevant social vulnerability issues

Within the flood risk research there are a number of other factors that have been associated with increased vulnerability to social and health impact of flooding. Some of these areas, e.g. ethnicity have had little research carried out but what research has been carried out raises important issues.

5.9.1 Gender

Research suggests that women are often more severely affected than men by floods. Walker and Burningham (2011), provide a useful overview of evidence in this area highlighting that women tend to experience particular physical and psychological flood-related health problems themselves (RPA/FHRC, 2004; Tapsell *et al.*, 2003; Tunstall *et al.*, 2007) as well as tending to carry the physical and emotional burden of caring for sick household members (Thrush *et al.*, 2005; Tapsell *et al.*, 1999). Responsibility tends to fall on them to cope with the stress of the flood and with their children's anxieties and distress (Ketteridge and Fordham, 1998). Women are more involved in the work of recovery, obtaining relief and 'rebuilding' the home, yet have to deal with male dominated emergency services, authorities and institutions that are not always sympathetic to their needs (Enarson, 2000; Fordham and Ketteridge, 1998; Tapsell and Tunstall, 2001; Tapsell *et al.*, 1999, 2002).

*"As well as suffering the emotional impact of flood events themselves, women carry the primary responsibility in caring for other family members whose health or psychological well-being may have been damaged. For many women, care-giving arrangements (child-care, day centres for older relatives) may have been disrupted by relocation, making their lives all the more difficult" (Thrush *et al.*, 2005, p. 9).*

5.9.2 Ethnicity

Tapsell *et al.* (2003) suggest that ethnic minority groups may take longer to recover from disasters and have a chance of disproportionate risk of psychological distress. Non-English speaking Asian women participants in focus groups in Banbury were less likely to know who to contact to obtain information about flooding (Tapsell *et al.*, 1999). In the 2003 follow up study in Banbury and Kidlington, Tapsell *et al.* (2003, p. 62) found that:

“In 1998 and 1999 it was observed that ethnic minority communities, particularly non English-speakers are likely to be more isolated following flooding. Most of the Asian women also stated that they did not know where to go to seek help or advice. For the Asian community in 2002 it was still largely a matter of helping themselves and each other. However, one Asian family were from a different area in Pakistan from the rest of the community and they had felt particularly isolated as no help had been offered by the other Asians in the community, and they had no other relatives in the UK”.

5.9.3 Social class

Social class¹⁸ has been found to be a predictor of increasing flood awareness as measured by awareness of home being in an area that may be at risk of flooding, with those in social classes A and B showing greater awareness of their flood risk than those in social classes D and E (Burningham, Fielding and Thrush, 2008). Interestingly, in a logistic regression analysis, where the relative significance of multiple variables relationship to flood awareness can be tested, Burningham, Fielding and Thrush (2008) conclude that *“social class has the most influence on predicting awareness of flood risk, followed by flood experience and then length of time in residence”*. P. 224. Tunstall *et al.* (2007) found whilst there were no significant differences in General Health Questionnaire¹⁹ GHQ12 scores post-flood, in terms of social class, there were, significant differences in how severe and how stressful people rated the flood event, with those in social grades A, B or C1 rating these effects lower than those in C2 or D, E grades. However, within their multivariate analysis, where a range of variables were considered, this relationship was no longer significant. Burningham, Fielding and Thrush (2008) suggest that lower levels of awareness among those in lower social classes might be explained by lower levels of education, and/or a lack of participation in awareness raising activities, or inappropriate provision of information but that more research is need to understand this in more detail. Indeed, other explanations may be plausible and are worthy of further investigation. It could be that owner occupiers, which is correlated with class, are more likely to find out their property is at flood risk through surveys and property searches in the process of buying a house; and that lower social classes face higher risk of unemployment, poverty and poor health meaning awareness of flood risk may be given less priority (Houston, personal communication, 2011).

Walker *et al.*, (2006) found that those in lower socio-economic groups had lower flood risk awareness.

¹⁸ Social class is measured using classifications A, B, C1 C2, D and E (see Tunstall *et al.*, 2007 p20 -21 for a detail explanation)

¹⁹ The General Health Questionnaire is a screening device for identifying minor psychiatric disorder and the GHQ-12 is a short version that is quick and reliable, used often in research studies.

5.9.4 Housing tenure

Werrity *et al.* (2007) found that council house tenants had lower self reported tangible²⁰ impacts from flooding than owner occupiers but much higher lasting intangible impacts.

5.9.5 Experience of flooding

Prior experience of flooding has been linked to an increased likelihood of receiving a flood warning and undertaking protective actions (e.g. Fielding *et al.*, 2007; Tunstall, *et al.*, 2006).

However, Green *et al.* (1994) found that previous experience of flooding does not necessarily buffer the consequences of an event. Moreover, frequent flooding may increase anxiety about future events (Werrity *et al.*, 2007). Qualitative research findings in England indicate that prior experience can also hinder response and preparedness in some circumstances: e.g. some people may not expect a worse event than the one they have previously experienced, some flood victims just want to 'move on' and forget about their experiences, for them undertaking any preparation measure increases anxiety and worry about future flooding, others particularly if they suffered considerable damage before may feel that their actions will not be useful (McCarthy, 2004; Whittle *et al.*, 2010).

²⁰ Tangible impacts were: Financial loss; Loss of house value; Disruption to electricity supply; Damage to car or van and Used holiday entitlement. Intangible impacts were split into immediate and lasting. Immediate = Discomfort/inconvenience; Stress of flood itself; Having to leave home; Dealing with insurers; Living in temporary accommodation; Dealing with builders and Being stranded in/out of home. Lasting = Time and effort to return to normal; Worry about future flooding; Irreplaceable/sentimental items; Strains between family; Loss of community spirit; Deterioration to mental health; Deterioration to physical health; Loss or distress to pets.

6 Summary of Expert Views

As part of this evidence review we contacted 10 social scientists who work in the areas of social vulnerability relating as far as possible to the different sectors in the CCRA. In addition, we included researchers working on the JRF Climate Change and Social Justice programme and one of the authors of the CAG report. From these experts we received useful information and further references and we followed up seven with short telephone conversations covering their own research together with a range of key issues. Those we contacted are listed below, with the names in bold indicating who we followed up with a telephone conversation. The draft version of this report was also sent to these experts for their comments which were then incorporated into this final version.

- **Professor Gordon Walker**: University of Lancaster – environmental justice, flooding, heatwaves and climate change
- **Dr. Sam Brown**: University of Lancaster – heatwaves, care homes
- **Dr. Helen Chalmers**: CAG consultants – social impacts of climate change
- **Magnus Benzies**: AEA Technology – social justice, heatwaves and drought (JRF project)
- **Dr. Donald Houston**: University of St Andrews – pluvial urban flooding and social issues (JRF project)
- **Dr. Kate Burningham**: University of Surrey – environmental justice; social vulnerability and flooding (JRF project)
- **Dr. Karen Lucas**: University of Oxford – environmental justice; climate change and transport
- **Dr Sarah Lindley**: University of Manchester (JRF project)
- **Josh Stott**: Joseph Rowntree Foundation Climate Change and Social Justice programme manager
- Dr Anna Lawrence: Forest Research
- Dr Justin Martin: Commission for Rural Communities.

This section provides a summary of some key issues from the conversations. The information was derived from notes taken of the conversations.

6.1 Defining social vulnerability

Some key issues around defining social vulnerability emerged from the conversations.

Specifically the contextual nature of vulnerability was highlighted. In terms of heat, vulnerability to high temperatures will change within a town where the Urban Heat Island (UHI) effect is experienced: vulnerability will vary within the town and within individual buildings. This needs considering, and links to a further point raised about vulnerability to “what” and for “whom”. The different levels at which vulnerability can be experienced was expressed e.g. flooding affects individual households and there are general impacts but insurers are also vulnerable to flooding plus the state especially if infrastructure is hit. It was suggested that clarity is needed in terms of understanding whose vulnerability is being considered so that it can be addressed effectively. If the

aim is to reduce the vulnerability of the state to flooding then it is likely to be looked at in terms of costs, which leads to defending larger properties. However, if the aim is to reduce individual vulnerability then the focus is likely to health and well-being which will shift the focus on to supporting vulnerable (in terms of health and well-being) individuals and communities.

A further perspective expressed considers the social construction of social vulnerability. Whilst not denying the biophysical aspects of e.g. heat related impact on older people, the social practices around the management of hazards play a key role in defining vulnerability, and adaptation planning needs to be cognisant of this.

6.2 Evidence

A further issue discussed by the participants was the quality of evidence in the areas that they work in and more generally in climate change and social vulnerability. Generally, the evidence across the areas is considered quite patchy. Flooding is an area that is quite well developed but there was considered to still be a lack of quantitative data. The literature in the area of heat is just emerging and whilst there is epidemiological evidence in terms of heat, that does not necessarily explain why people are vulnerable. In terms of transport, again the evidence was considered to be thin and fragmented. The Index of Multiple Deprivation which is often used was considered as a good enough proxy, and in highly deprived areas there are likely to be concentrations of vulnerability, but it is income driven and people are considered to be vulnerable in other ways.

We asked the researchers what sort of evidence they thought would be most useful for policy makers and what were the facilitators and barriers to using information on social vulnerability in the context of climate change.

In terms of useful evidence it was suggested that case studies/stories were good for getting attention but need to be based on solid evidence, literature reviews were considered to sometimes “get buried”, maps were thought to be good for conveying information and for introducing a story but are based on a top-down account. Case studies were felt to be very important for conveying the complexity of situations and for conveying contextual issues.

Barriers to using social vulnerability information included: data limitations – the fact that there is limited data and evidence; the tendency to take a “science first” approach, top-down starting with climate drivers, but that does not provide information on who is going to be affected. The lack of social science knowledge in some areas e.g. flooding was raised, leading to a potential risk of labelling people as vulnerable by using indices, etc. without an understanding of the nuances of vulnerability and impacts.

7 Synthesis

The evidence base on social vulnerability and climate change for the UK is patchy overall and this is recognised as a problem by experts working in the field. It was experienced as such in the process of this review. Therefore, care has to be taken that generalisations are not being made on the basis of individual studies, whilst still recognising that the studies that exist do provide valuable and important findings for this area, that need to be further investigated. Clearly there is a need for more research in this area. Even in the relatively mature area of the social aspects of flooding, the complexity of social vulnerability needs further unpacking.

Further, a key evidence issue is that the vast majority of these studies have not been carried out with the context of climate change. Studies focus largely on understanding social vulnerability from analyses of past events which are projected to increase under climate change (e.g. 2007 UK Summer Floods, 2003 European heatwaves) and/or correlating current hazard maps with current social vulnerability factors (e.g. Walker *et al.*, 2006). As a result they do not use projections of social data or scenarios to consider likely future social vulnerabilities. Only more recently is work, largely through the JRF Programme “Climate change and social justice”, examining climate projections and population composition and distribution (e.g. Houston *et al.*, 2011; Lindley *et al.*, 2011).

Given the caveat above, a number of tentative conclusions can be drawn in relation to social vulnerability and climate change.

Firstly, using the CAG (2009) framework (Table 7.1) and extending it to cover droughts, it is concluded that these categories cover the broad range of factors that exacerbate negative social impacts of flooding, heatwaves, and drought, all of which are projected to increase due to climate change.

Table 7.1 Social vulnerability categories and characteristics

Social vulnerability category	Social vulnerability characteristics
People living in places at risk	Location and place
People who are socially deprived	Poor mental and physical health
	Fewer financial resources
	Living and working in poor quality homes or workplaces
People who are disempowered because of lack of awareness, adaptive capacity, support services and exclusion from decision-making	Limited access to public and private transport
	Limited or lack of awareness of risks
	Lack of social networks
	Little access to systems and support services (e.g. health care)

There is also some evidence of a number of other factors which exacerbate negative aspects of floods and heat, specifically, that did not fit into these categories. These are presented in Table 7.2:

Table 7.2 Other social vulnerability factors

Floods	
Gender	Social Class
Research suggests that women are often more severely affected than men by floods. Walker and Burningham (2011), provide a useful overview of evidence in this area highlighting that women tend to experience particular physical and psychological flood-related health problems themselves as well as tending to carry the physical and emotional burden of caring for sick household members.	Social class ²¹ has been found to be a predictor of awareness of your home being in an area that may be at risk of flooding, with those in social classes A and B showed greater awareness of their flood risk than those in social classes D and (Burningham, Fielding and Thrush, 2008). This could be explained by lower levels of education or participation.
Heatwaves	
Gender	Age
There is some evidence that women are more susceptible to heat related illnesses than men in heatwaves possibly to do with physiological differences (Vassello <i>et al.</i> , 1995).	Evidence that vulnerability to heat increases with age and is linked to intrinsic changes in the regulatory system or to the presence of drugs that interfere in the normal homeostasis (Vassello <i>et al.</i> 1995). Unlike other risks e.g. flooding where old age is largely a proxy for relevant hazard related health problems (e.g. reduced mobility) the body is intrinsically more sensitive to heat with age.

It should be stressed that whilst the focus here is on characteristics of individuals, recent work shows the important effects of community, institutional and organisational structures and practices on social vulnerability to floods and heat (e.g. Brown and Walker, 2008; Steinfuhrer, 2009). This is an area that is under-researched.

From this analysis, it is clear that social vulnerability to climate change impacts can be seen as being of two main kinds (after Walker and Burningham, 2011):

1. Those social vulnerabilities that reflect and reproduce the existing pattern of inequalities in society, or systemic inequalities. So the people who are most vulnerable to climate change impacts in many cases will be those people who are most vulnerable to other negative impacts, i.e. people who are already affected by poverty, poor health, disabilities. As Walker and Burningham (2011) note, this leads to a consideration of fundamental issues of inequality and social justice. For those policy makers concerned with poverty, poor health and disability, the impacts of climate change need to be understood so that those vulnerabilities are not further exacerbated.
2. Those social vulnerabilities that are directly linked to climate change impacts. Examples of this vulnerability to flooding that is associated with

²¹ Social class is measured using classifications A, B, C1 C2, D and E (see Tunstall *et al.*, 2007 p20 -21 for a detailed explanation)

location: people will be vulnerable to flooding if they are in flood risk area, whether or not they have other vulnerabilities. Similarly, people living in urban areas will be vulnerable to Urban Heat Island effects.

In many cases the two kinds of vulnerability can be found in the same people or social groups. Take heat and elderly people: elderly people are vulnerable to heat impacts for physiological reasons. Elderly people are also more likely to be vulnerable for social systemic reasons: more elderly people are poor, for example and this condition of poverty makes it more difficult for them to take actions to reduce their vulnerability to heat, for example by buying air conditioning or other equipment to reduce heat impacts.

Secondly, some people will have contexts, circumstances and practices that mean they are at risk from a number of climate change impacts, and it is those clusters of characteristics where there needs to be focus. For example, an old person, on a low income, living in a basement, in a city, with arthritis and no social networks is going to be vulnerable to heat, flooding and the effects of drought. Rather than delivering statistical data that map and quantify these aspects in ever increasing levels of detail, we suggest having an understanding of the range of potential vulnerabilities and then working out in practice what that might mean for an area would be useful to developing adaptation and resilience. This comes out clearly in the case studies of Zsomboky *et al.* (2011) on vulnerability and coastal change.

Thirdly, the ‘top down – bottom up’ framework for understanding climate change vulnerabilities is a particularly useful one because it takes account of the dynamic nature of this vulnerability. Top down approaches can be very useful in mapping vulnerabilities against known climate impacts; bottom up analysis will be needed to make sense of how those relationships play out in particular locations or among specific groups of people. In practice this could mean having social vulnerability maps for flood, heat and drought at a national and regional level to help with strategic planning. At the local level these would be “ground truthed” with local authority staff, third sector groups, and local communities to ensure that interventions were appropriate. “Ground truthing” is likely to take the form of discussions and collection of local data (e.g. local knowledge on social networks). Benzie *et al.* (2011) provide a useful analysis of how those different approaches might be used in practice in relation to heatwave planning. Lindley *et al.* (2011) have done some ground truthing with their mapping approach and have found it beneficial at the local level. The top-down approach is useful as a starting point and for national and regional levels but the bottom up approach is needed in order to develop locally relevant interventions.

Fourthly, as well as measuring and mapping these relationships, understanding how and why people with specific characteristics, contexts and practices become more vulnerable to climate change impacts is vital if climate change adaptation is to be effective and equitable. Without having that understanding adaptation will only focus on symptoms and not underlying causes of social vulnerability.

Finally, the question remains as to whether or not the science led CCRA and subsequent decision making, is able to adequately incorporate social vulnerability issues such that procedural as well as distributional justice is ensured. Is it able to take account for the inherently political and social nature of the outcomes of the assessment? This is something that should be monitored as the adaptation process is developed and considered for the next CCRA cycle.

8 References

- Association of British Insurers (2007) *Access for All: Extending the Reach of Insurance Protection*. London: ABI.
- Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., Adger, N.W., and Raine, R. (2008) *Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich*.
- Bayliss, D. (2009) Low income motoring in Great Britain. RAC Foundation Report No 09/116.
- Benzie, M., Harvey, A., Burningham, K., Hodgson, N., and Siddiqi, Ayesha (in press) *Vulnerability to heatwaves and drought: Case studies of adaptation to climate change in south-west England*. York: Joseph Rowntree Foundation.
- Brookes, N., Adger W.N. and Kelly M. P. (2005) The determinants of vulnerability and adaptive capacity. *Global Environmental Change* 15 (2005) pp 151 – 163.
- Brown, S. (2011) *In the Heat of Power: Understanding Vulnerability to Heatwaves in Care Homes for Older People*. Lancaster University: Unpublished PhD Thesis.
- Brown, S. and Walker, G. (2008) *Understanding heat wave vulnerability in nursing and residential homes*. *Building Research and Information*, 36:4, pp 363-372.
- Burningham K., Fielding, J., Thrush, D., and Gray, K. (2005) *Flood Warning for vulnerable groups*. Science Report SC990007 Bristol: Environment Agency.
- Burningham K., Fielding, J., and Thrush, D. (2008) 'It'll never happen to me': understanding public awareness of local flood risk. *Disasters: vol 32, issue 2* pp 216 - 238.
- CAG Consultants (2009) *Differential Social Impacts of Climate Change in the UK* SNIFFER report UKCC22.
- Cancer Research (2011) *Skin Cancer UK Incidence Statistics*. <http://info.cancerresearchuk.org/cancerstats/types/skin/incidence/#depriv> (accessed 12 May 2011).
- Creative Research (2010) *Cross Subsidies and Social Tariffs. The consumer perspective*. Consumer Council for Water, London.
- Creative Research (2009) *Living with Water Poverty: A Report of Research Findings*. Consumer Council for Water, London. <http://www.ccwater.org.uk/server.php?show=nav.444> (accessed 08 March 2011).
- Cutter, S., Boruff, B., and Shirley, W.L., (2003) Social Vulnerability to environmental hazards. *Social Science Quarterly*, 84(2), pp 242-61.
- Cutter S., *et al.* (2009) *Social Vulnerability to Climate Variability Hazards: A Review of the Literature*. for Oxfam America.
- Deeming, H. (2008) *Increasing resilience to storm surge flooding: risks, social networks and local champions* PhD Thesis Division of Geography Lancaster University, UK.
- Defra (2010) *Method for undertaking the CCRA Part II - Detailed Method for Stage 3: Assess Risk*, UK 2012 Climate Change Risk Assessment, Defra, London.

Department of Communities and Local Government (2006) Effects of Climate Change on Fire and Rescue Services in the UK. Fire Research technical Report 1/2006.

Donaldson, G., Kovats, R.S., Keatinge, W.R. and McMichael, A.J. (2001) *Heat- and cold-related mortality and morbidity and climate change*. In: Maynard, RL (ed.), Health effects of climate change in the UK. Department of Health, London, 70-80.

D'Ippoliti, D, Michelozzi, P., Marino, C., de'Donato, F., Menne B., Katsouyanni, K., Kirchmayer, U., Analitis, A., Medina-Ramón, M., Paldy, A., Atkinson, R., Kovats, S., Bisanti, L., Schneider, A., Lefranc, A., Iñiguez, C. and Perucc, C.A (2010) The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environmental Health*, 9:37 pp 1-9.

Drinking Water Inspectorate website (<http://www.dwi.gov.uk/stakeholders/private-water-supplies/index.htm>) (accessed 17th March 2011).

Enarson, E. (2000) Gender and Natural Disasters, Working Paper 1, InFocus Programme on Crisis Response and Reconstruction. Geneva: Recovery and Reconstruction Department, ILO.

Environment Agency (2006) Response to flooding 2005: Response to the flood event of January 2005 in the North West.

Fernandez-Bilbao, A., and Twigger-Ross, C. (eds) (2009) *Improving Response, Recovery and Resilience: Improving Social and Institutional Responses to Flooding Work Package 2*. SC060019 Bristol: Environment Agency.

Fielding, J, Burningham, K, Thrush, D and Catt, R (2007) Public responses to flood warnings. Environment Agency Science Report SC020116.

Fitch M and Price H (2002) *Water Poverty in England and Wales*. Chartered Institute of Environmental Health.

Flint, C. G. and Luloff, A. E. (2005) Natural Resource-Based Communities, Risk, and Disaster: An Intersection of Theories. *Society and Natural Resources* [Online] 18 Available at: DOI: 10.1080/08941920590924747 pp. 399–412 [Accessed 12/11/2009].

Fordham, M. and Ketteridge, A.M. (1998) Men Must Work and Women Must Weep: Examining Gender Stereotypes in Disasters, pp. 81–94 in E. Enarson and B. Morrow (eds) *The Gendered Terrain of Disaster: Through Women's Eyes*. Westport, CT: Praeger.

Green, C., Van Der Veen, A., Wiestra, E. and Penning-Rowsell, E. (1994) Vulnerability refined: analysing full flood impacts. In Penning-Rowsell, E. and Fordham, M. (eds) *Floods across Europe*. Enfield, Middlesex University Press.

Hajat S., Ebi, K.L., Kovats, S., Menn, B., Edwards, S., and Haineset, A. (2005) The human health consequences of flooding in Europe and the implications for public health: a review of the evidence. *Extreme Weather Events and Public Health Responses*. Part 4, 185-196.

Hajat, S., Kovats, S. and Lachowycz, K. (2007) Heat-related and cold-related deaths in England and Wales: who is at risk? *Occupational and Environmental Medicine*, 64, pp 93-100.

Hames, D. and Vardoulakis, S. (2011) CCRA Risk Assessment for the Health Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Houston, D., Werrity, A., Bassett, D., Geddes, A., and Hoolachan, A., (2011) *The Invisible Hazard: Pluvial Flooding in Urban Areas* Draft Final Report to the Joseph Rowntree Foundation (JRF).

HR Wallingford, RPA and FHRC (2005) *Flood Risks to People Methodology*. Technical Report FD2321/TR1 Defra / Environment Agency Flood and Coastal Defence R&D Programme.

Huisman, M., Kunst, A.E., Bopp, M., Borgan, J.K., Borrell, C., Cost, G., Deboosere, P., Gadeyne, S., Glickman, M., Marinacci, C., Minder, C., Regidor, E., Valkonen, T. and Mackenbach, J.P. (2005) Educational inequalities in cause-specific mortality in middle-aged and older men and women in eight Western European populations. *Lancet*, 365, 493-500.

Johnson, H., Kovats, S., McGregor, G.R., Stedman, J.R., Gibbs, M., Walton, H., Cook, L. and Black, E. (2005) The impact of the 2003 heat wave on mortality and hospital admissions in England. *Health Statistics Quarterly*, 25, 6-11.

Kaiser, R., Rubin, C.H., Henderson, A.K., Wolfe, M.I., Kieszak, S., Parrott, C.L. and Adcock, M. (2001) Heat-related death and mental illness during the 1999 Cincinnati heat wave. *American Forensic Medicine and Pathology*, 2, 303-7.

Ketteridge, A.M. and Fordham, M. (1997) Flood warning and the local community context. In: Handmer, J (ed.) *Flood warnings: issues and practice in total system design*. Hazard Research Centre. London: Middlesex University.

Kovats, R.S., Hajat, S. and Wilkinson, P. (2004) Contrasting patterns of mortality and hospital admissions during heat waves in London, UK. *Occupational Environmental Medicine*, 61, 893-898.

Kovats, R.S., Johnson, H. and Griffiths, C. (2006) Mortality in Southern England during the 2003 heat wave by place of death. *Health Statistics Quarterly*, 29, 6-8.

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H.G, Smith, D., Solomon, G., Trent, R. and English, R. (2009) The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits *Environmental Health Perspectives*, vol 117, number 1, January 2009.

Klinenberg, E. (2002a) *Heat Wave: A social autopsy of disaster in Chicago*. Chicago: University of Chicago Press.

Klinenberg, E. (2002b) *University of Chicago Interview about his book "Heat wave"*. Online at <http://www.press.uchicago.edu/Misc/Chicago/443213in.html>

Lindley, S.J., O'Neill, J., Kandeh, J., Lawson, N., Christian, R., O'Neill, M. (forthcoming) *Justice, Vulnerability and Climate Change: An Integrated Framework*. Draft final report to Joseph Rowntree Foundation.

Macey, S.M., Schneider, D.F. (1993) Deaths from excessive heat and excessive cold among the elderly. *Gerontologist* 1993; 33: 497-500.

MacGregor, G.R., Pelling, M., Wolf, T. and Gosling, S. (2007) *The Social Impacts of Heat Waves Environment Agency Science Report SC20061/SR6*, Bristol: Environment Agency.

McCarthy, S., Parker, D. and Penning-Rowsell, E. (2006) Preconsultation social survey: Community based flood risk reduction options, Reach 4: Walton Bridge to Teddington. Enfield: Flood Hazard Research Centre, Middlesex University.

McCarthy, S. (2004) Definition and experience of flooding: residents' and officials' perspectives. PhD thesis, Department of Sociology, University of Surrey.

McEwen, L., Hall, T., Hunt, J., Dempsey, M. and Harrison, M. (2002) Flood warning, warning response and planning control issues associated with caravan parks: the April 1998 floods on the lower Avon floodplain, Midlands region, UK. *Applied Geography*, 22, 271-305.

- McMichael, A.J., Megens, T., Wilkinson, P. and Rooney, C. (1998) *Material deprivation: a risk factor for heat related mortality?* Unpublished report. London: London School of Hygiene and Tropical Medicine.
- Medd, W. and Chappells, H. (2008) *Drought and Demand: Consumers, Water companies and Regulators.* Lancaster University.
- Middelkoop, B.J., Struben, H.W., Burger, I. and Vroom-Jongerden, J.M. (2001) Urban cause-specific socio-economic mortality differences. Which causes of death contribute most? *International Journal of Epidemiology*, 30, 240-247.
- Oven, K.J., Curtis, S.E., Reaney, S., Riva, M., Stewart, M.G., Ohlemuller, R., Dunn, C.E., Nodwell, S., Dominelli, L and Holden, R (2012) Climate change and health and social care: Defining future hazard, vulnerability and risk for infrastructure systems supporting older people's health care in England. *Applied Geography*, 33, 16-24 doi: 10.1016/j.apgeog.2011.05.012.
- Parker, D., Tapsell, S. and McCarthy, S. (2007) Enhancing the human benefits of flood warnings. *Natural Hazards* 43 pp 397-414.
- Quinn, M., et al. (2001) *Cancer Trends in England & Wales 1950-1999.* Vol. SMPS No. 66. 2001: TSO.
- Rance, J., Wade, S.D., Hurford, A.P., Bottius, E. and Reynard, N.S. (2012) *CCRA Risk Assessment for the Water Sector.* UK 2012 Climate Change Risk Assessment, Defra, London.
- RPA/FHRC (2004) *The Appraisal of Human-Related Intangible Impacts of Flooding.* Report to Defra/Environment Agency. R&D Technical Report FD2005/TR, Defra, London.
- Semenza, J.C., Rubin, C.H., Falter, K.H., Selanikio, J.D., Flanders, W.D., Howe, H.L., Wilhelm, J.L. (1996) Heat-related deaths during the July 1995 heat wave in Chicago. *New England Journal of Medicine*, 335, 84-90. Statistical Information Team, Cancer Research UK, 2009.
- Snell, C. and Bradshaw, J. (2009) *Water Affordability in England and Wales.* Consumer Council for Water.
- Standley, S., Miller, K., Okamura, S., Wynn, D., Greenhalgh, S., and Horrocks, L. (2009) *Wild Weather Warning: a London climate impacts profile.* Greater London Authority, London, UK.
- Steinführer, A. (2009) *Vulnerability, resilience and social constructions of flood risks in exposed communities: A Cross-Country Comparison of Case Studies in Germany, Italy and the UK.* Available on www.floodsite.net.
- Steinführer, A. and Kuklicke, C. (2007) *Social vulnerability and the 2002 flood. Country Report Germany (Mulde river).* Report T11-07-08 of FLOODsite Integrated Project, Leipzig: UFZ Helmholtz Centre for Environmental Research.
- Tapsell, S. (2009) *FLOODsite case study.* In Fernandez-Bilbao, A. and Twigger-Ross, C. (eds) *Improving Response, Recovery and Resilience: Improving Social and Institutional Responses to Flooding Work Package 2 SC060019* Bristol: Environment Agency.
- Tapsell, S., Penning-Rowsell, E., Tunstall, S. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. *Philosophical Transactions of the Royal Society*, 360, 1511-1525.
- Tapsell, S., Tunstall, S., Green., C. and Fernandez-Bilbao, A. (2005a) *Task 11 Social Indicator Set.* Floodsite. Available on www.floodsite.net.

- Tapsell, S., Burton, R., Oakes, S. and Parker, D. (2005b) *The Social Performance of Flood Warning Communications Technologies*. Technical Report. The Environment Agency, Bristol, UK.
- Tapsell, S., Tunstall, S., Penning-Rowsell, E.C. and Handmer, J.W. (1999) The health effects of the 1998 Easter flooding in Banbury and Kidlington. Report to the Environment Agency, Thames Region Flood Hazard Research Centre, Middlesex University.
- Tapsell, S. and Tunstall, S. (2008) "I wish I had never heard of Banbury". *Health and Place*, 14 p 133-154.
- Tapsell, S., McCarthy, S., Faulkner, H. and Alexander, M. (2010) Social vulnerability and Natural Hazards. CapHaz-Net WP4 Report. Flood Hazard Research Centre – FHRC Middlesex University, London (available at http://caphaz-net.org/outcomes-results/CapHaz-Net_WP4_Social-Vulnerability.pdf)
- Thrush, D., Burningham, K. and Fielding, J. (2005) Flood Warning for Vulnerable Groups: A qualitative study. Report for the Environment Agency. Science Report SC990007/SR3.
- Tunstall, S. (2007) Vulnerability and flooding: a re-analysis of FHRC data: Country Report England and Wales. Available on www.floodsite.net.
- Twigger-Ross, C.L. (2005) The Impact of Flooding on Urban and Rural Communities. (R&D Technical Report SC040033/SR1) Environment Agency Bristol.
- Twigger-Ross, C. (2010) *Review of the social vulnerability checklists for the CCRA*. Internal Report.
- TUC (2009) *Changing Work in a Changing Climate* London: Trade Union Congress.
- Vardoulakis, S. (2010) *CCRA Health Sector Report Phase 1*.
- Vassallo, M., Gera, N.K. and Allen, S. (1995) Factors associated with high risk of marginal hyperthermia in elderly patients living in an institution. *Postgraduate Medical Journal* 1995; 71: 213-216.
- Walker, A. (2009) The Independent Review of Charging for Household Water and Sewerage Services. Final Report.
- Walker, G. and Burningham, K. (2011) Flood Risk, vulnerability and environmental justice: Evidence and evaluation of inequality in a UK context. *Critical Social Policy* published online 16th February, 2011
<http://csp.sagepub.com/content/early/2011/02/16/0261018310396149>.
- Walker, G., Burningham, K., Fielding, J., Smith, G., Thrush, D. and Fay, H. (2006) Addressing environmental inequalities: flood risk. Science Report. The Environment Agency, Bristol, UK.
- Walker, M., Whittle R., Medd, W., Burningham, K., Moran-Ellis, J. and Tapsell, S. (2010) Children and young people 'After the rain has gone' – learning lessons for flood recovery and resilience. Final project report for 'Children, Flood and Urban Resilience: Understanding children and young people's experience and agency in the flood recovery process', Lancaster University, Lancaster UK www.lec.lancs.ac.uk/cswm/hcfp.
- Watson, N., Walker, G., Medd, W., Kashefi, E., Tapsell, S., Twigger-Ross, C. and Fernandez-Bilbao, A. (2009) Understanding Response and Resilience in Post-Flood Communities: Lessons from the Carlisle Pilot Study. In Fernandez-Bilbao, A. and Twigger-Ross, C. (eds) *Improving Response, Recovery and Resilience: Improving Social and Institutional Responses to Flooding Work Package 2*. SC060019 Bristol: Environment Agency.

Whittle, R., Medd, W., Deeming, H., Kashefi, E., Mort, M., Twigger-Ross, C., Walker, G. and Watson, N. (2010) After the Rain – learning the lessons from flood recovery in Hull. Final project report for 'Flood, Vulnerability and Urban Resilience: a real-time study of local recovery following the floods of June 2007 in Hull', Lancaster University, Lancaster UK.

Woods, L.M., Rachet, B., Riga, M., Stone, N., Shah, A. and Coleman, M.P. (2005) Geographical variation in life expectancy at birth in England and Wales is largely explained by deprivation. *Journal of Epidemiology and Community Health*, 59, 115-120.

Young, C. (2009) Solar ultraviolet radiation and skin cancer. *Occupational Medicine*, Vol 59, Issue 2 pp. 82-88.

Zsamboky, M., Fernandez-Bilbao, A., Smith, D., Knight, J. and Allan, J. (2011) Impacts of climate change on disadvantaged UK coastal communities.

UK Water Treatment Association (2011)

<http://www.ukwta.org/privateWaterSupplies.php>, consulted 09 March 2011.

Appendix

Appendix 1 Social Vulnerability Checklist

This is an example of the social vulnerability checklist used within the CCRA. This one is focussed on the Water sector, specifically considering potential reduction in water supply.

Category of social vulnerability factor	Questions to ask	Comment	Evidence	Extent
Place	Which locations are affected by reduced supply of water? Is it spread evenly across regions or not?			
Social deprivation	How will people with poor health (physical or mental) be affected by reduced supply of water?			
	How will people with fewer financial resources be affected by reduced supply of water?			
	How will people living or working in poor quality homes or workplaces be affected by reduced supply of water?			
	How will people who have limited access to public and private transport likely be affected by reduced supply of water?			
Disempowered	How will people with lack of awareness of the risks associated with security of supply of water be affected by reduced supply of water?			
	How will people without social networks be affected by reduced supply of water?			
	How will people with little access to systems and support services (e.g. health care) be affected by reduced supplies of water?			
Other social vulnerability factors associated with this impact				

Notes:

In filling in the checklist, information can be drawn from the sector papers, current research and the outputs of the Tier 2 risk assessment work. In the evidence column, it

will be important to note a) if there is evidence and b) what sort it is i.e. expert, published research, modelled etc, and the same measures that are applied to the impact evidence (e.g. pedigree) would be useful to apply here.

The extent column is where information on how many people might be affected could be indicated; these data will be available from the Tier 2 assessment based on baseline socio-economic data, the use of Government projections (for the near term) and scenarios (for the longer term).

The final row will capture any specific social vulnerabilities for that impact that are not included in the checklist.

The information from this assessment is designed to feed into the prioritisation of impacts.