

(Defra Project Code GA0204)

Climate Change Risk Assessment for the Health Sector

January 2012

¹Hames, D. and ²Vardoulakis, S.

Contractors: ¹HR Wallingford
²Health Protection Agency
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



Department for Environment
Food and Rural Affairs

Statement of use

See full statement of use on Page v

Keywords:

Climate, risks, mortality, morbidity, ozone, flooding, mental health, sunlight, UV

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 EX 6364)

Defra project officer:

Dominic Rowland

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
08/11/10	1.0	HR Wallingford	First draft. This corresponds to version 1.4.
15/11/10	1.1	HR Wallingford	Sector summary added
31/01/11	2.0	HR Wallingford	Revised in response to peer review and Government Department review comments
28/03/11	3.0	HR Wallingford	Revised in response to 2 nd Government Department review comments
13/05/11	3.0A	HR Wallingford	High level concerns identified by Government Departments added (to be addressed in Release 4).
14/06/11	3.0A2	HR Wallingford	Minor Amendments
12/08/11	4.0	HR Wallingford, HPA	Restructuring of report to a standalone document
21/10/11	4.0A	HR Wallingford, HPA	Responded to OGD comments
05/12/11	5.0	HR Wallingford, HPA	Responded to further OGD comments
13/01/12	6.0	HR Wallingford, HPA	Minor edits
19/01/12	7.0	HR Wallingford	Minor edits
20/01/12	8.0	HR Wallingford	Minor edits

© 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.

This report is available online at:

<http://www.defra.gov.uk/environment/climate/government/>

Statement of Use

This report presents the research completed as part of the UK Climate Change Risk Assessment (CCRA) for a selected group of risks in the Health sector. Whilst some broader context is provided, it is not intended to be a definitive or comprehensive analysis of the sector.

Before reading this report it is important to understand the process of evidence gathering for the CCRA.

The CCRA methodology is novel in that it has compared over 100 risks (prioritised from an initial list of over 700) from a number of disparate sectors based on the magnitude of the consequences and confidence in the evidence base. A key strength of the analysis is the use of a consistent method and set of climate projections to look at current and future threats and opportunities.

The CCRA methodology has been developed through a number of stages involving expert peer review. The approach developed is a tractable, repeatable methodology that is not dependent on changes in long term plans between the 5 year cycles of the CCRA.

The results, **with the exception of population growth where this is relevant, do not include societal change in assessing future risks, either from non-climate related change, for example economic growth, or developments in new technologies; or future responses to climate risks such as future Government policies or private adaptation investment plans.**

Excluding these factors from the analysis provides a more robust 'baseline' against which the effects of different plans and policies can be more easily assessed. However, when utilising the outputs of the CCRA, it is essential to consider that Government and key organisations are already taking action in many areas to minimise climate change risks and these interventions need to be considered when assessing where further action may be best directed or needed.

Initially, eleven 'sectors' were chosen from which to **gather** evidence: Agriculture; Biodiversity & Ecosystem Services; Built Environment; Business, Industry & Services; Energy; Forestry; Floods & Coastal Erosion; Health; Marine & Fisheries; Transport; and Water.

A review was undertaken to identify the range of climate risks within each sector. The review was followed by a selection process that included sector workshops to identify **the most important** risks (threats or opportunities) within the sector. Approximately **10%** of the total number of risks across all sectors was selected for more detailed consideration and analysis.

The risk assessment used UKCP09 climate projections to assess future changes to sector risks. Impacts were normally analysed using single climate variables, for example temperature.

A final **Evidence Report** draws together information from the 11 sectors (as well as other evidence streams) to provide an overview of risk from climate change to the UK.

Neither this report nor the Evidence Report aims to provide an in depth, quantitative analysis of risk within any particular 'sector'. Where detailed analysis is presented using large national or regional datasets, the objective is solely to build a consistent picture of risk for the UK and allow for some comparison between disparate risks and regional/national differences.

This is a UK risk assessment with some national and regional comparisons. The results presented here should not be used by the reader for re-analysis or interpretation at a local or site-specific scale.

In addition, as most impacts were analysed using single climate variables, the analysis may be over-simplified in cases where the consequence of climate change is caused by more than one climate variable (for example, higher summer temperatures combined with reduced summer precipitation).

Sector Summary

Background

As a result of the Climate Change Act (2008) the UK is the first country in the world to have a legally binding, long-term framework to cut carbon emissions. The Climate Change Act also creates a framework for building the UK's ability to adapt to climate change. Part of the Act requires the Secretary of State to lay before Parliament assessments of the risks posed to the UK by climate change. This is being undertaken within the Adapting to Climate Change (ACC) cross government programme, based in Defra. The first assessment will be laid before Parliament in January 2012 and an updated assessment will be issued every five years. The purpose of the assessment is to inform a National Adaptation Programme for 2013.

Approach

The Climate Change Risk Assessment (CCRA) provides an assessment of the risk to the UK caused by climate change. In order to do this, the CCRA has gathered evidence across eleven sectors (Marine & Fisheries, Biodiversity & Ecosystem Services, Water, Floods and Coastal Erosion, Agriculture, Forestry, Built Environment, Transport, Energy, Health and Business, Industry and Services) and for several cross-cutting themes in order to gain a comprehensive overview of the potential risks of climate change. Preliminary assessments were presented in a series of sector papers and these formed the basis of the 'Tier 1' or initial qualitative risk assessment that identified more than 600 risks to the UK. The next stage of work, the 'Tier 2' assessment, involved further qualitative and quantitative analysis using a range of methods to gain a better understanding of risks both within and across sectors. This report outlines the assessment for the health sector.

It should be noted that the estimates given in this report are based on the assumption of the current regional demographics, with the absence of any physiological or planned adaptation to the risks identified in this report. A more realistic assumption of changed regional demographics, with some level of physiological acclimatisation and planned adaptation would result in changes to the estimates given in this report.

Key findings from this report

An analysis of past records indicates that our climate is changing, with mean temperatures and sea levels in particular having shown noticeable increases over the last 30 years.

Despite the severe cold weather at the end of 2010, globally it was the warmest year on record (equal with 1998 and 2005, WMO 2011), with nine of the ten hottest years on record having occurred between 2001 and 2010. This led to significant health related problems, with for example over 2000 excess deaths in England and Wales during the heatwave of August 2003.

Globally, sea levels have risen at a mean rate of 1.8mm per year since 1955, with a higher mean rate of 3mm per year since 1992. There has also been a noticeable increase in precipitation over northern Europe (an area which includes the UK) between 1900 and 2005, particularly since about 1979. These changes are likely to be the result of human activity. There have been more frequent spells of very wet weather and an increase in total precipitation, at least during the last 40 years.

UKCP09 projections indicate that many of these weather events, particularly heatwaves and floods, are anticipated to become even more frequent and intense in the UK over the 21st century causing more direct loss of life, physical and psychological illness, and substantial disruption to NHS services (including access to services).

Heat-related mortality due to warmer temperatures and mortality associated with ground-level ozone are projected to increase under current projections. Cases of respiratory illness associated with exposure to ground-level ozone (and potentially pollen) are also projected to increase. The incidence of melanoma skin cancer may also increase due to higher exposure to solar UV radiation. Certain medical specialities, such as respiratory medicine, mental health, and accidents and emergencies, are likely to be noticeably more burdened.

There is evidence also of health benefits associated with changing climatic conditions, mainly due to a projected reduction in cold-related deaths and hospitalisations, and a possible increase in outdoor activities involving physical exercise.

Climate change presents complex socioeconomic challenges which could act as risk magnifiers in the future, particularly for vulnerable populations. The UK public health sector will need to adapt and respond to these challenges.

Overall

Risks assessed

Over 40 direct and indirect risks were identified for the health sector in the scoping phase of the analysis (Tier 1). These risks were clustered under three overlapping themes: (a) Population health and wellbeing, (b) health care services, facilities and Infrastructure, and (c) environmental health.

The risks that were identified as the most significant for the health sector were taken forward to a more detailed 'Tier 2' analysis.

The risks taken forward were:

- Temperature mortality (heat)
- Temperature morbidity (heat)
- Temperature mortality (cold)
- Temperature morbidity (cold)
- Summer air pollution mortality/morbidity (ozone)
- Extreme weather event mortality (flooding and storms)
- Effects of floods/storms on mental health
- Sunlight/UV exposure
- Extreme weather event injuries (flooding and storms).

These risks were identified based on a simple multi-criteria assessment exercise, feedback from a CCRA health sector stakeholder workshop, feedback from a meeting at the Department of Health, and informal discussions with experts at the Health Protection Agency and the London School of Hygiene and Tropical Medicine.

The multi-criteria assessment exercise was carried out by scoring the magnitude of the impacts (in terms of economic, social and environmental consequences), the likelihood of the impacts occurring, and the urgency for decision making.

The scoring was primarily based on qualitative information and attempts to record orders of magnitude rather than offering precision at this stage of the study. The multi-criteria assessment exercise was repeated after comparing the risk scores for consistency with those from other sectors and taking into account comments received from stakeholders.

Metrics were proposed at the health sector workshop and discussed with a number of experts at the Health Protection Agency and the London School of Hygiene and Tropical Medicine. The pros and cons of different metrics for each risk were considered according to the following characteristics: (a) Easy to understand by decision-makers and non-experts, (b) easily and accurately calculated based on existing, routinely collected information, (c) measurable over a large proportion of the area in which the metric is likely to be used, and (d) sensitivity to the particular stressor (e.g. temperature).

It should be noted that the detailed (Tier 2) analysis for the CCRA focused on risks and metrics that could be characterised quantitatively or semi-quantitatively. However, limited quantitative evidence does not necessarily mean that certain other impacts, as summarised in the scoping study report (Vardoulakis, 2010), could not potentially pose a noticeably increased risk to public health in the future.

Emerging Challenges

The scoping phase (Tier 1) and the detailed analysis (Tier 2) of the climate change risk assessment identified certain emerging challenges (including risks and opportunities) for the UK health sector. The emerging challenges are presented below, with descriptions of the individual risks following.

One of the leading causes for concern, the magnitude of temperature-related mortality appears to be very sensitive to the chosen thresholds above or below which temperature may cause a number of excess deaths ("premature deaths") and hospitalisations in the population. Compared to previous estimates (Department of Health, 2002), the detailed analysis revealed a larger number of excess heat-related deaths and hospitalisations, and a smaller number of cold-related deaths and hospitalisations averted, due to increasing temperatures in the 21st century. It should be noted that the additional impact of heatwaves on mortality could result in even larger numbers of heat-related deaths in the summer estimated in this study, unless effective adaptation measures are taken targeting in particular the more susceptible (the elderly, the very young, and those with compromised health). Overall, based on this analysis and underlining assumptions, the impact of climate change on heat-related mortality and morbidity in the UK may be larger than previously estimated. NHS services could also be directly affected by heatwaves, if indoor temperatures (in hospital wards, care homes, IT rooms and medicine storage places) are not effectively controlled.

A key challenge lies in the estimation of future impacts of climate change on air quality. The methodology used to estimate the health impact of current ground-level ozone in the UK has yielded similar excess mortality and morbidity estimates to those reported in the scientific literature. However, the projection of future ground-level ozone concentrations and the independent effect of climate change on them are uncertain. The effect of changing climatic conditions on the prevalence of allergic respiratory diseases (including asthma) is likely to increase noticeably, although currently difficult to quantify.

The number of deaths and injuries directly caused by extreme weather event flooding and storms in the UK is relatively small, but there is emerging evidence of a substantial

impact on mental health. This may include long-term effects on mental health which are currently difficult to characterise. In addition, extreme weather (floods in particular) can cause disruption to NHS services (e.g. if hospitals, GP practices or community health centres are flooded) and to transport which would affect access to NHS services for patients and staff.

Impacts of climate change on food and agriculture, water quality, transport, power generation and the economy (national and global) are likely to pose an indirect risk to public health in the UK. These indirect risks are currently difficult to characterise.

Risk descriptions

Future risk possibilities narrative

Heat-related mortality currently accounts for around 1,100 premature deaths per year in the UK. Heat is also estimated to cause over 100,000 patient-days in hospital per year. However, substantially larger figures of premature deaths and excess hospitalisations have been estimated for exceptionally hot years such as 2003 and 2006. Increased temperatures associated with climate change are projected to cause an approximate 60% increase in heat-related premature mortality and morbidity by the 2020s, an approximate 200% increase by the 2050s and an approximate 400% increase by the 2080s compared to current levels based on the central estimate of the medium emissions scenario.

These estimates are based on the assumption of a constant population size and age distribution, in the absence of any physiological or planned adaptation of the population to heat. A more realistic assumption of a larger and older population would result in larger numbers of premature deaths and hospitalisations per year, while physiological acclimatisation and planned adaptation (e.g. wider use of passive cooling, heat alerts, etc.) would reduce these estimates.

The social, financial and environmental cost of heat-related mortality and morbidity is high due to the direct loss of life, the impact on the quality of life (particularly of the elderly), the financial cost of planned adaptation (e.g. retrofitting of buildings with cooling devices), and increased energy consumption associated with active cooling.

The increase in daily mortality and morbidity attributable to heat is likely to be compensated by a substantial reduction in cold-related deaths and hospitalisations due to generally milder temperatures. In this assessment, an estimate of around 26,000 to 57,000 premature deaths and 2,600,000 to 5,800,000 patient-days in hospital per year due to cold in the current climate have been made. These deaths and hospitalisations could be substantially reduced by the 2050s and approximately halved by the 2080s.

This assumes a constant population size and age distribution, and no changes in resilience to cold. However, people are likely to be less used to cold weather in the future and short periods of low temperatures similar in magnitude to the low extremes recently experienced may result in proportionally more deaths and hospitalisations during these periods. It should be noted that the numbers of cold-related deaths and hospitalisations per year calculated in this study are smaller than earlier estimates (around 80,000 cold-related deaths per year in the 1990s were reported for the UK by Donaldson *et al.*, 2002).

Social, financial and environmental benefits due to reductions in cold related mortality and morbidity are likely to accrue in the future due to avoided premature deaths and hospitalisations, improvements in the quality of life (particularly of the elderly), and savings in energy consumption due to the reduced need for domestic heating.

Flood events in the UK that lead to significant loss of life are few and far between, and are heavily driven by the type of flood event and/or warning and the local characteristics of the area. Flood related deaths as a result of a changing climate are

assumed to be proportional to the number of people at risk, which for the different scenarios and population projections are presented in the floods and coastal erosion sector report. Deaths due to coastal wave activity nearshore during storms are assumed to be exponentially related to increases in mean sea levels. Current estimates of deaths due to extreme event flooding and storms are given as 18 per year. This number could approximately double by the mid 2050s and triple by the mid 2080s due to climate change (for the medium emissions scenario of the current day demographics and adaptation levels).

Limited evidence exists that indicates how many people are at risk of injury as a result of extreme flooding, particularly in relation to coastal flooding. This is because injuries can be difficult to quantify, and often levels of injuries are not reported, or difficult to associate with a flood event. However, an approximate linear relationship between extreme weather event (flooding and storms) mortality and injuries has been suggested based on a literature review of available evidence, assuming 20 injuries for every 1 death. Therefore, physical injuries associated with flooding are expected to increase in the future proportionally with deaths.

The mental health impact of flooding varies due to a number of factors including the severity of the event, its nature (fluvial, flash, coastal etc), time of day, timeliness of warning, emergency preparedness and existing social and economic structures. Attempts to estimate effects on mental health are hampered by the varying definitions used in different studies. Similar to flood related deaths, the effect of floods on mental health as a result of climate change are assumed to be proportional to the number of people at risk due to fluvial or tidal flooding. This impact has been assessed as the number of people who go from a 12 item Global Health Questionnaire (GHQ-12) score of below 4, to 4 or above¹ as a result of a flood event, which is estimated to be between 30-40% of those flooded each year. The numbers of people affected in England and Wales per year according to this metric are projected to be between 4,000-7,000 by the 2050s and 5,000-8,000 by the 2080s based on the current day demographics. These projections would probably have been in the region of 10-15% larger if the required data for Scotland and Northern Ireland was available for this study.

It should be stressed that flooding events have a very substantial impact on the society (e.g. long-term mental health effects which are very difficult to characterise), the environment (e.g. uncontrolled overflow of sewage that can affect water quality) and the economy (e.g. damage to property and disrupted access to services), although they are unlikely to cause substantial numbers of directly attributable deaths or injuries.

At present, ground-level ozone is estimated to cause around 10,000 premature deaths and 33,000 respiratory hospital admissions per year in the UK. These estimates, based on a linear non-threshold exposure-response relationship, are in good agreement with ozone-related mortality rates reported by Stedman and Kent (2008) but larger in the case of hospitalisations, probably due to the regional baseline morbidity rates used in the present study. Future concentrations of ozone depend on a complex relationship between future emissions of nitrogen oxides and volatile organic compounds (the main ozone precursor gases), synoptic weather circulation, local weather conditions, and land use patterns.

In this study, the impact of climate change on ozone-related mortality/morbidity has been assessed for a business-as-usual scenario, i.e. in the absence of any significant changes in ozone precursor emissions (anthropogenic or biogenic) or land use. Based on these assumptions, it has been estimated that up to 2,900 additional premature deaths and 10,000 additional respiratory hospital admissions may occur in the UK relevant to the current estimates by the 2080s for the current day demographics. This risk appears to have major consequences for society, including a disproportionately

¹ Maximum GHQ-12 score is 12.

high health risk for people with pre-existing respiratory conditions such as asthma. In addition, higher ground-level ozone concentrations in the future can damage vegetation and crops, and deteriorate building materials. It should be noted, however, that current trends of rising background ozone concentrations across the northern hemisphere could be changed if more stringent emission control policies on ozone precursor gases are implemented at the international scale.

Changes in solar UV exposure, in particular UVB, associated with climate change have been linked to melanoma and non-melanoma skin cancer incidence and mortality. Although the relationship between future incidence of skin cancer and environmental conditions is an extremely complex issue driven mainly by changes in social behaviour rather than climate, there is limited evidence linking directly UVB radiation flux and melanoma risk. Current climate projections (UKCP09) indicate a slight increase in net surface UVB radiation flux by the end of the century for southern England (up to 10% by the 2080s for the high emissions scenario), reducing further north.

This could indicate a potentially significant impact on the UK society and economy due to increasing skin cancer incidence and mortality. However, there may be some public health benefits such as increased vitamin D levels and improved physical and mental health of people spending more time outdoors as a result of projected warmer weather.

Increased temperatures and changes in seasonal precipitation patterns is also likely to lead to more favourable conditions for the spread of certain water-borne, food-borne and vector-borne diseases in the future. Although a potentially significant risk for the UK, the public and environmental health infrastructure is likely to prevent substantial changes in the prevalence of these diseases in the UK. Therefore, a detailed analysis of these risks was not been carried out for this assessment.

Sensitivity

The health sector faces a number of challenges which are not directly associated with the climate but could be more difficult to tackle in a changing climatic environment. These include an ageing population and the increasing health care expenditure required for treating the elderly, inequity in the use of health care (including hospital services) and wider social inequalities, risk from infectious disease outbreaks and global trends in communicable diseases, risks related to new technologies and environmental hazards (such as nanotechnologies, radiation, and new chemical products), pressures caused by the obesity epidemic, alcohol, tobacco and illicit drug abuse, health staff shortages, and financial risks posed by global economic crises. Climate change could magnify some of these risks. For example the increasing frequency of floods and heatwaves will almost certainly disproportionately affect the elderly. Some health inequalities may also be exacerbated as a result of climate change due to disrupted access to services, poorer housing conditions and a reduced ability to adapt to climate change in lower socio-economic groups. Tackling social inequalities in health and tackling climate change must go together (Marmott Review, 2010).

It should be noted that heat and cold-related mortality and morbidity are much more sensitive to changes in climatic conditions compared to air pollution (ground-level ozone) which is more sensitive to changes in atmospheric emissions (of nitrogen oxides and volatile organic compounds) in the UK and abroad.

Current vulnerability

Climate change adaptation needs to be a material consideration in the design, building and maintenance of NHS infrastructure, as well as in allocation of resources, procurement and training. The UK Department of Health has produced a Climate Change Plan (2010-2012) which includes a Departmental Adaptation Plan and a

Carbon Reduction Delivery Plan providing an analysis of the priorities and needs in the health sector in the medium and longer term.

In this assessment, the current climate vulnerabilities, including estimates of the baseline risks in the sector, have been analysed and compared with future risks (results summarised in “Future risk possibilities narrative” sub-section). The risks in this sector are likely to increase gradually with time if unmitigated, and there is no clear evidence of onset timing. In some cases, where exposure-response thresholds apply (e.g. heat-related mortality), future impacts on public health may be significantly larger for greater or more rapid changes in climatic conditions. Although England and Wales have Heatwave Plans in place, similar to plans adopted in other European countries after the severe heatwave of August 2003, rapid changes in climatic conditions may result in the need for a change in policy. The devolved administrations have also developed climate change adaptation plans related to health, with broadly similar conclusions.

It is likely that certain risks are not going to be evenly distributed in the UK. Currently, urban areas (London in particular) and the East and South East of England appear to be more affected by heatwaves and heat-related mortality than the rest of the UK. Cold-related mortality and morbidity have more of an effect in the southerly regions of England. In a future climate (without taking adaptation into account), heat-related mortality and morbidity are likely to increase more in large urban areas partly as a result of the urban heat island effect.

Ground-level ozone concentrations and related health impacts are greater in the south east of England compared to the rest of the country. Rural and suburban areas usually experience higher concentrations of ozone than city centres. A future increase in ground-level ozone attributable to climate change is likely to be larger in urban areas, especially in the south east, although this trend is still uncertain and heavily dependent on global emissions of precursor gases.

Coastal and riverine areas will remain at a higher risk of flooding and related physical and mental health impacts, unless effective mitigation measures are put in place. It is difficult to assess which regions may or may not be at greater risk, but relatively low lying areas that are not currently considered to be at high risk of flooding, such as for regions around the Humber estuary, may be more at risk in the future as a result of tidal flooding.

Adaptive capacity/Awareness in sector

An assessment of adaptive capacity across sectors is being undertaken by Defra and will be reported later in 2012. A number of potential barriers and enablers to taking adaptation decisions and action in the health sector have been summarised in the scoping report (Vardoulakis, 2010).

Interdependencies

Key links to other CCRA risks/reports

The risks of climate change for the health sector are intrinsically linked to risks in other sectors, such as water, floods, built environment, agriculture, energy, etc. For example, any unmitigated climate-related impacts on food or water quality and availability will have knock-on effects on public health. Extreme weather events (such as floods and heatwaves) causing disruption in IT communications, power generation and distribution, or public transport are likely to affect NHS services, including access to hospitals, care homes and surgeries. Furthermore, adaptation/mitigation measures in the built environment, transport, energy, water, agriculture and other sectors will have implications for population health. For example, active travel and reduced car

dependency would help reduce obesity as well as greenhouse gas emissions. For the above reasons, stakeholders have expressed the view that health could also be presented and analysed as a cross-cutting issue within the CCRA.

For this report, three risks were assessed based on results from the floods and coastal erosion sector. Quantitative estimates of flood-related deaths and injuries were mainly derived using response functions for coastal and fluvial flooding. The quantification of the mental health effects of flooding (within England and Wales only) was based on the number of people at significant risk of flooding.

Other drivers

Socio-economic drivers of risk consequences of climate change in the health sector include the following:

- An ageing population is likely to be less resilient to changes in climate and associated weather events (such as heatwaves and floods). The ageing of the UK population, which is projected to continue during the 21st century, is going to put an additional burden on health and social care services.
- Several factors influence the likelihood of experiencing poor mental health following floods, especially pre-existing mental health conditions.
- A prolonged global economic crisis could pose budgetary constraints in the health and social care services, which would affect the availability of resources for mitigation/adaptation measures. Increased unemployment and lower living standards due to an economic crisis would affect population health (physical and mental).
- Availability of funding and resources would affect the resilience of the built environment, e.g. availability of cooling measures, including natural ventilation, passive cooling etc in the current and future building stock.
- Effective control of anthropogenic atmospheric emissions (mainly nitrogen oxides and volatile organic compounds) affecting ground-level ozone in the UK will depend on future transport, energy generation, industrial and commercial activity across the northern hemisphere and indeed globally.
- Behavioural patterns would be influenced by the availability of time and resources. A general rise in standard of living could result in more leisure time and increased outdoor activities, potentially involving increased exposure to ground-level ozone and sunlight / UVB radiation over the summer.
- International tourism, travelling and trade will almost certainly increase the risk of UK citizens being infected by vector-borne (e.g. malaria) and water-borne (e.g. diarrhoea) diseases during stays overseas. This trend is likely to increase in the future.
- UK citizens living overseas may repatriate due to climate related or other pressures. This would place an additional burden on the NHS.
- Climate change could exacerbate the migration trends away from areas affected by climate-related disasters and malnutrition (e.g. sub-Saharan Africa) towards Northern Europe and the UK, increasing demand for health care². This migration trend could increase in the future.

² The Foresight project “Global Environmental Migration” indicates that there is little evidence for climate change causing inter-border migration. See: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-environmental-migration>.

- Some aspect of globalisation, such as the international nurse and doctor migration, may put pressures on health care services in the UK and abroad.

About the analysis

Data quality and modelling issues

Temperature mortality and morbidity

The calculation of temperature-related mortality has been based on a well-established methodology that requires knowledge of regional temperature thresholds and exposure-response coefficients for heat and cold-related effects on health, as well as baseline population and mortality data. This information was available from several sources for heat-related effects, but limited information on thresholds and exposure-response coefficients was available for cold-related mortality.

The heat and cold-related morbidity outcomes are less well defined and thus more difficult to estimate at a high confidence level. Modelling the additional impact of heatwaves on mortality/morbidity would require an estimate of the frequency and duration of heatwaves in the future, which is currently uncertain. Furthermore, no attempt was made to account for improved tolerance of the population to heat (or reduced tolerance to cold) in the future.

Summer air pollution (ozone)

Estimates on ozone-related mortality and morbidity for the current climate are based on available ozone datasets and exposure-response coefficients, and are consistent with other published studies. However, they should be considered as conservative because of the assumption of non-threshold effects of ozone on human health. Projections of future ground-level ozone concentrations are highly uncertain as they depend on emission scenarios, atmospheric transport, chemical reactions and removal processes which are not fully understood. The modelling of these processes is very complex; it requires a large amount of data covering a range of input parameters and substantial computational resources.

In the current assessment, estimates of future ground-level ozone concentrations in the UK have been based on limited published evidence. A linear non-threshold approach has been used to calculate ozone-related mortality and respiratory morbidity, but other threshold models may be applicable. There was no attempt to quantify the health impact of potentially prolonged exposure to aeroallergens such as pollen, because of the lack of concrete evidence in terms of future exposure levels in the UK. The effect of climate change on winter air pollution (nitrogen dioxide and PM₁₀) has not been investigated, as this would require extensive modelling work and large input datasets.

Extreme weather events (mortality, injuries and mental health)

The quantitative estimates of future flood-related mortality, injuries and mental health effects are based on evidence from past flooding events in the UK. However, it should be noted that baseline estimates of the number of deaths and injuries directly associated with recent floods is small (particularly for coastal events), and highly clustered and extrapolation into the future is therefore uncertain. The calculation of the mental health effects of flooding is based on an empirical methodology that uses the global health questionnaire (GHQ-12) survey results in combination with estimates of people at risk of fluvial or tidal flooding to diagnose unspecified psychiatric distress. The small number of significant flood events as well as the highly clustered nature of flood related deaths and injuries means that it would be unreliable to break these estimates down regionally. This has therefore not been attempted.

Sunlight/ UV exposure

The relationship between excess melanoma skin cancer cases and deaths is based on very limited evidence indicating that an increase in the average annual UVB radiation flux is associated with an increase in melanoma risk. The current and future behavioural aspects related to UVB exposure are very complex and difficult to quantify. It should also be noted that sunlight exposure has several health benefits (mainly vitamin D levels, physical activity, and mental health) which have not been quantified in this study. Changes in the behaviour of individuals and the population in terms of leisure and lifestyle will probably be the main driver to changes in the health effect associated with exposure to sunlight.

What is certain and what is uncertain

Wherever possible, a quantitative analysis was carried out to estimate the health effects due to projected changes in climatic conditions in the UK over the 21st century. This included UKCP09 climate projections for the following variables: mean annual temperature, mean sea levels, seasonal average precipitation, and mean net surface shortwave and longwave radiation flux, as well as projected populations.

As outlined in the previous section, there were certain methodological challenges and/or information availability issues which did not allow a full quantification of certain impacts. Furthermore, some calculations were based on limited published evidence and related results should thus be interpreted with caution.

In general, there is higher confidence in the mortality estimates compared to the morbidity estimates because of the inherent uncertainty in the definition of morbidity outcomes. In this assessment, the heat and cold-related morbidity estimates, as well as the estimates of flood-related injuries, were calculated from the corresponding mortality estimates using empirically derived linear relationships.

In this assessment, the quantitative estimates of heat-related mortality are more certain than those of cold-related mortality, because of the relatively limited published evidence on thresholds and exposure-response coefficients for cold-related effects on health.

There is a medium degree of confidence in the ozone-related mortality and respiratory morbidity estimates for the current situation. These estimates would be substantially lower if a threshold was assumed for the effects of ozone on human health. Estimates of future ground-level ozone concentrations and related health impacts are very uncertain and highly dependent on emissions of precursor gases such as nitrogen oxides and volatile organic compounds.

Quantitative estimates of deaths and injuries directly attributable to future floods in the UK are inherently uncertain due to the currently very low frequency of reported cases. The estimates of psychological distress (based on the GHQ-12) associated with current and future floods are also uncertain as they are based on limited evidence (from only two studies which covered serious flood events and therefore can be considered pessimistic) and do not reflect long-term mental health effects.

Probably the most uncertain impacts in this assessment are those associated with sunlight / UVB exposure because they are based on very limited epidemiological evidence and do not take into account behavioural factors that may affect future exposure levels. In addition, the climate change impact on future UVB levels for the UK is uncertain and includes interactions with stratospheric ozone recovery. Although an initial quantitative risk assessment was carried out on the impacts attributable to future UVB levels, the level of uncertainty was considered too great to include future predictions of UVB related impacts in this report.

Overall, the strength of evidence varied widely for the different metrics used in this assessment. This mainly depended on the strength of evidence on future exposure levels and/or on the exposure-response relationship for each metric. The strongest evidence was available for the heat related mortality, both in terms of future exposure levels and exposure-response relationships. For cold related mortality, the evidence on exposure was strong, but there was limited and not consistent evidence on the exposure-response relationships (in particular, the temperature threshold below which mortality increases due to cold). The published evidence on exposure-response was weak for both heat and cold related morbidity (hospital patient-days). The evidence on ozone related mortality and morbidity was mixed; there was strong evidence available on the exposure-response relationship linking ozone to excess mortality and respiratory hospital admissions, but limited and uncertain evidence on future ozone levels in the UK regions. The strength of evidence on flooding and storms mortality and injuries as a result of climate change was weak, both in terms of future exposure estimates and exposure-response relationships. The level of evidence of the relationship between exposure to floods and mental health was limited, although not necessarily weak. Finally, the weakest overall evidence was related to the sunlight / UVB exposure metric, because of the uncertain projections of UVB exposure levels in the UK and the very limited quantitative evidence linking long-term UVB exposure of a relevant population to skin cancer. In addition, no quantitative evidence on the health benefits associated with increased exposure to sunlight could be identified.

It is recommended that a quantitative uncertainty analysis be carried out in future assessments of the risks of climate change on public health.

Key Term Glossary

Adaptation (IPCC, 2007a)

- **Autonomous adaptation** – Adaptation that does not constitute a conscious³ response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. This is also referred to as spontaneous adaptation.
- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptive Capacity - The ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (modified from the IPCC to support project focus on management of future risks) (Ballard, 2009). As such this does not include the adaptive capacity of biophysical systems.

Adaptation costs and benefits

- The costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs.
- The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures.

Consequence - The end result or effect on society, the economy or environment caused by some event or action (e.g. economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected etc).

General Health Questionnaire (GHQ) – The GHQ is a self-administered questionnaire used to detect unspecified psychiatric distress in the general population (Goldberg and Williams, 1998). There are four versions of the Questionnaire, of which the shortest, the GHQ-12, is commonly used in research studies. All GHQs have a 4 point scoring system that ranges from a “better/healthier than normal” option, through a “same as usual” and a “worse/more than usual” to a “much worse/more than usual” option.

Impact - An effect of climate change on the socio-bio-physical system (e.g. flooding, rails buckling etc).

Response function - Defines how climate impacts or consequences vary with key climate variables. These can be based on observations, sensitivity analysis, impacts modelling and/or expert elicitation.

Risk - Combines the likelihood an event will occur with the magnitude of its outcome.

Sensitivity- The degree to which a system is affected, either adversely or beneficially, by climate variability or change.

³ The inclusion of the word ‘conscious’ in this IPCC definition is a problem for the CCRA and we treat this as anticipated adaptation that is not part of a planned adaptation programme. It may include behavioural changes by people who are fully aware of climate change issues.

Uncertainty - A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known.

Vulnerability - Climate vulnerability defines 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.

Acknowledgements

There have been a number of individuals who have contributed to this work, and we would like to thank them all for their help. These include those who took part in the stakeholder workshop as well as in a follow-up meeting at the Department of Health. In particular we would like to thank the following individuals:

- Professor Ben Armstrong, Dr Shakoor Hajat, Dr Paul Wilkinson and others at the London School of Hygiene and Tropical Medicine who provided valuable help and advice on heat and cold mortality as well as ozone related functions. Ben Armstrong also provided the data sets for England and Wales that formed the basis of the heat and cold related mortality analysis. Shakoor Hajat also provided additional cold exposure response slopes for investigations of the sensitivity of cold related mortality.
- John Stedman and Andrew Kent at AEA Energy and Environment who provided the ozone maps that formed the basis of the analysis for the climatic effects of future ozone levels.
- Dr Richard Derwent for his comments on current and future ozone levels.
- Professor Robert Maynard, Professor Virginia Murray, Dr Clare Heaviside and Dr Giovanni Leonardi at the Centre for Radiation, Chemical and Environmental Hazards of the Health Protection Agency for fruitful discussion and recommendations on sections of the report.
- Dr Lisa Page at Kings College London for reviewing the section on mental health effects of flooding and storms.
- Dr Louise Newport, Chris Holme, Agatha Ferrao, Dr Ursula Wells and others in the Department of Health for discussion and advice on the selection and scoring of the risk metrics.
- Dr Ruth Asher Consultant Dermatopathologist at the John Radcliffe Hospital in Oxford for reviewing the medical aspects of sunlight / UV exposure.
- Dr Kevin Pollock at Health Protection Scotland for his assistance in assessing the impacts due to water borne diseases.
- Professor John Thornes for his help in the discussion on some of the Tier 1 impacts.

Contents

Statement of Use	v
Sector Summary	vii
Key Term Glossary	xix
Acknowledgements	xxi
Contents	xxiii
1 Introduction	1
1.1 Climate change and the Climate Change Act	1
1.2 Scope of the health sector	3
1.3 Background	5
1.4 Structure of this report	14
2 Methods	16
2.1 Introduction: CCRA Framework	16
2.2 Outline of the method used to assess impacts, consequences and risks	17
2.3 Identify and characterise the impacts	19
2.4 Assess vulnerability	19
2.5 Identify the main risks	19
2.6 Assess current and future risk	20
2.7 Report on risks	21
3 Impacts and Risk Metrics	22
3.1 Impact selection	23
3.2 Health risk metrics assessed in this report	24
3.3 Health risk metrics not assessed in this report	29
3.4 Cross sectoral impacts	38
3.5 Health risk metrics assessed in other reports	40
4 Sector Risk Analysis	46
4.1 Introduction	46
4.2 HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)	47
4.3 Temperature morbidity	59
4.4 HE3 – Extreme weather event (flooding and storms) mortality	65
4.5 HE4 – Summer air pollution (ozone)	77
4.6 HE9 – Sunlight/UV exposure	88
4.7 HE10 – Effect of floods/storms on mental health	95
4.8 HE7 – Extreme weather event (flooding and storms) injuries	103

5	Monetisation of Metrics	106
5.1	Summary	106
5.2	Introduction to health monetisation	108
5.3	Adaptation	109
5.4	Presentation of results, uplifts and discounting	110
5.5	HE1 – Temperature mortality (heat)	110
5.6	HE2 – Temperature morbidity (heat)	113
5.7	HE3 – Extreme weather event (flooding and storms) mortality	115
5.8	HE4a – Summer air pollution (ozone) - deaths	117
5.9	HE4b – Summer air pollution (ozone) - respiratory hospital admissions	119
5.10	HE5 – Temperature mortality (cold)	120
5.11	HE6 – Temperature morbidity (cold)	123
5.12	HE7 – Extreme weather event (flooding and storms) injuries	124
5.13	HE9 – Sunlight/UV exposure	126
5.14	HE10 – Effects of floods/storms on mental health	128
6	Adaptive Capacity	131
6.1	Overview	131
6.2	Assessing structural and organisational adaptive capacity	131
6.3	Adaptive Capacity in the Health Sector	133
7	Discussion	135
7.1	HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)	135
7.2	HE2 – Temperature morbidity (heat and cold)	136
7.3	HE3 – Extreme weather event (flooding and storms) mortality	136
7.4	HE4 – Summer air pollution (ozone)	138
7.5	HE9 – Sunlight / UV exposure	138
7.6	HE10 – Effect of floods / storms on mental health	138
7.7	HE7 – Extreme weather event (flooding and storms) injuries	139
7.8	Gaps in evidence	139
8	Conclusions	145
8.1	HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)	145
8.2	HE2 – Temperature morbidity (heat and cold)	146
8.3	HE3 – Extreme weather event (flooding and storms) mortality	146
8.4	HE4 – Summer air pollution (ozone)	146
8.5	HE9 – Sunlight/UV exposure	146
8.6	HE10 – Effect of floods /storms on mental health	146
8.7	HE7 – Extreme weather event (flooding and storms) injuries	147
	References	148
	Appendices	169

Appendix 1 Extent of consultation/review	171
Appendix 2 'Tier 1' List of Impacts	173
Appendix 3 Selection of Tier 2 consequences	179
Appendix 4 Systematic mapping	187
Appendix 5 Social Vulnerability Checklist	193
Appendix 6 Response functions	205
Appendix 7 Application of climate change projections	213
Appendix 8 Socio-economic influence	221

Tables

Table 3.1	Health sector tier 1 consolidated impacts	22
Table 3.2	Health sector: Climate change impacts and risk metrics	24
Table 3.3	Climate change impacts in other sectors that are linked to health	40
Table 4.1	Baseline premature deaths (heat) per year and premature deaths (cold) for each region (baseline period: 1993-2006)	57
Table 4.2	Additional premature deaths (heat) per year for the UK for the different emission scenarios (baseline period: 2003-2006) – heatwave scenario	57
Table 4.3	Risk factors for heat stress (DH, 2002)	60
Table 4.4	Baseline estimates of the health impacts of mapped ozone	81
Table 4.5	Baseline estimates of premature deaths and additional (or brought forward) respiratory hospital admissions due to ozone in 1995, 2003 and 2005	85
Table 5.1	Summary of results in £million per annum	107
Table 5.2	Valuation of life years lost (heat) per year for the UK for the different emission scenarios, current population, baseline period 1993-2006	112
Table 5.3	Valuation of life years lost (heat) per year for the English regions for the medium emission scenario, principal population, baseline period 1993-2006	112
Table 5.4	Valuation of life years lost (heat) per year for the UK for the different emission scenarios, low population, baseline period 1993-2006	112
Table 5.5	Valuation of life years lost (heat) per year for the UK for the different emission scenarios, principal population, baseline period 1993-2006	112
Table 5.6	Valuation of life years lost (heat) per year for the UK for the different emission scenarios, high population, baseline period 1993-2006	113
Table 5.7	Valuation of premature fatalities (heat) per year for the UK for the different emission scenarios, current population, baseline period 1993-2006	113
Table 5.8	Monetary value of annual additional patient days in UK per year due to increased temperatures (£m, annual, 2010 prices)	114
Table 5.9	Monetary value of annual additional patient days in UK per year due to increased temperatures (£m, annual, 2010 prices)	115
Table 5.10	Monetary value of annual additional flood related deaths per year due to extreme event flooding and storms, future climate change with current population (£m, 2010 prices)	116
Table 5.11	Monetary value of annual additional flood related deaths per year due to extreme event flooding and storms, future climate change, with future socio-economic change (population), population projections (£m, 2010 prices)	116
Table 5.12	Effect of future levels of ozone for the UK for the 2080s	118
Table 5.13	Effect of future levels of ozone for the UK for the 2080s	120
Table 5.14	Valuation of life years gained (cold) per year for the UK for the different emission scenarios, current population	121
Table 5.15	Baseline valuation of life years gained (cold) per year for the regions	122
Table 5.16	Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), low population	122
Table 5.17	Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), principal population	122
Table 5.18	Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), high population	123
Table 5.19	Monetary value of annual reduction of patient days per year due to Increased winter temperatures	124
Table 5.20	Monetary value of annual reduction of patient days per year due to increased winter temperatures	124
Table 5.21	Summary of non-fatal injury values per year by welfare component. (£, 2010)	125
Table 5.22	Monetary valuation of additional flood related injuries per year due to extreme event flooding and storms (current population)	125
Table 5.23	Additional flood related injuries per year due to extreme event flooding and storms with socio-economic change (population projections)	125
Table 5.24	Studies that estimate the WTP to avoid skin cancer	127
Table 5.25	Per case mean costs of treating depression (£, 2010)	129
Table 5.26	Additional people who go from a GHQ-12 score of below 4 to 4 or above as a result of extreme event flooding or storms, future climate change (current population), and with alternative population projections – England and Wales	130

Figures

Figure 1.1	Age structure of the UK population pyramid	7
Figure 1.2	UK population by age-group, mid 1981 to mid 2010 (SPA: State Pensionable Age)	7
Figure 1.3	NHS structure (May 2010)	8
Figure 1.4	Structure of the Scottish Health Service	9
Figure 1.5	Health care delivery chain of the DH working with the NHS	10
Figure 1.6	New roles for the new and existing organisations in the health sector	12
Figure 2.1	Stages of the CCRA (yellow) and other actions for Government (grey)	16
Figure 2.2	Steps of the CCRA method (that cover stage 3 of the CCRA framework: Assess risks)	18
Figure 4.1	Heat and cold related exposure response functions against daily deaths for London (1993-2006)	50
Figure 4.2	Maximum temperature against heat slope (%/°C) based on Armstrong (2010) 93 rd percentile and Hajat <i>et al.</i> , (2007) 95 th percentile	52
Figure 4.3	Additional premature deaths (heat) per year for the UK (baseline period: 1993-2006)	54
Figure 4.4a	Premature deaths avoided (cold) per year for the UK (baseline period: 1993-2006) – current day demographics and low population projection	55
Figure 4.4b	Premature deaths avoided (cold) per year for the UK (baseline period: 1993-2006) – principal and high population projections	56
Figure 4.5	Cold related mortality estimates against different thresholds for the central estimate (p_{50})	59
Figure 4.6	Annual additional patient days per year (p_{50}) due to increased high temperatures (thousands) – tentative estimates (baseline period: 1993-2006)	63
Figure 4.7	Annual patient days avoided per year (p_{50}) due to increased low temperatures (thousands) – tentative estimates (baseline period: 1993-2006)	64
Figure 4.8	Relationship between people exposed and fatalities	67
Figure 4.9	Location plan showing sea level measurements around the North West and North Wales coastline	69
Figure 4.10	Annual maxima recorded around the North Wales and North West coastline since 1854	70
Figure 4.11	Relative risk of mortality due to change in relative peak fluvial flows	72
Figure 4.12	Relative risk of mortality due to change in sea levels	72
Figure 4.13	Change in relative risk of fatalities due to overtopping of seawalls relative to changes in eustatic sea levels	74
Figure 4.14	Annual additional flood related deaths due to extreme event flooding and storms	76
Figure 4.15	Annual mean of the daily maximum of the running eight hour mean ozone concentration ($\mu\text{g}/\text{m}^3$)	80
Figure 4.16	Annual mean O_3 against annual mean daily maximum eight hour O_3 concentrations for 13 rural and 6 urban background monitoring stations over the period 1990-2009	83
Figure 4.17a	Effect of future levels of ozone for the 2080s on additional premature deaths and respiratory hospital admissions per year (current day demographics, regional estimates)	86
Figure 4.17b	Effect of future levels of ozone for the 2080s on additional premature deaths and respiratory hospital admissions per year (UK estimates)	87
Figure 4.18	Depth of penetration of different wavelengths of UV radiation into the human skin	89
Figure 4.19	Probability density of melanoma and non melanoma deaths against age for England and Wales	93
Figure 4.20	Annual number of additional flood victims who go from a GHQ-12 score of below 4 to 4 or above as a result of climate change (p_{50} estimates only) – England and Wales only	102
Figure 4.21	Annual additional flood related injuries due to extreme event flooding and storms	105

1 Introduction

1.1 Climate change and the Climate Change Act

It is widely accepted that the world's climate is being affected by the increasing anthropogenic emissions of greenhouse gases into the atmosphere. Even if efforts to mitigate these emissions are successful, the Earth is already committed to significant climatic change (IPCC, 2007b).

Over the past century, the Earth has warmed by approximately 0.7°C ⁴. Since the mid-1970s, global average temperature increased at an average of around 0.17°C per decade⁵. UK average temperature increased by 1°C since the mid-1970s (Jenkins *et al.*, 2009), however recent years have been below the long-term trend highlighting the significant year-to-year variability. Due to the time lag between emissions and temperature rise, past emissions are expected to contribute an estimated further 0.2°C increase per decade in global temperatures for the next 2-3 decades (IPCC, 2007b), irrespective of mitigation efforts during that time period.

The sorts of impacts expected later in the century are already being felt in some cases, for example:

- Global sea levels rose by 3.3 mm per year (± 0.4 mm) between 1993 and 2007; approximately 30% was due to ocean thermal expansion due to ocean warming and 55% due to melting of land ice. The rise in sea level is slightly faster since the early 1990s than previous decades (Cazenave and Llovel, 2010).
- Acidification of the oceans caused by increasing atmospheric carbon dioxide (CO_2) concentrations is likely to have a negative impact on the many marine organisms and there are already signs that this is occurring, e.g. reported loss of shell weight of Antarctic plankton, and a decrease in growth of Great Barrier coral reefs (ISCCC, 2009).
- Sea ice is already reducing in extent and coverage. Annual average Arctic sea ice extent has decreased by 3.7% per decade since 1978 (Comiso *et al.*, 2008).
- There is evidence that human activity has doubled the risk of a very hot summer occurring in Europe, akin to the 2003 heatwave (Stott *et al.*, 2004).

The main greenhouse gas responsible for recent climate change is CO_2 and CO_2 emissions from burning fossil fuels have increased by 41% between 1990 and 2008. The rate of increase in emissions has increased between 2000 and 2007 (3.4% per year) compared to the 1990s (1.0% per year) (Le Quéré *et al.*, 2009). At the end of 2009 the global atmospheric concentration of CO_2 was 387.2 ppm (Friedlingstein *et al.*, 2010); this high level has not been experienced on earth for at least 650,000 years (IPCC 2007b).

⁴ Global temperature trends 1911-2010 were: HadCRUT3 $0.8^{\circ}\text{C}/\text{century}$, NCDC $0.7^{\circ}\text{C}/\text{century}$, GISS $0.7^{\circ}\text{C}/\text{century}$. Similar values are obtained if we difference the decadal averages 2000-2009 and 1910-1919, or 2000-2009 and 1920-1929.

⁵ Global temperature trends 1975-2010 were: HadCRUT3 $0.16^{\circ}\text{C}/\text{decade}$, NCDC $0.17^{\circ}\text{C}/\text{decade}$, GISS $0.18^{\circ}\text{C}/\text{decade}$.

The UK government is committed to action to both mitigate and adapt to climate change⁶ and the Climate Change Act 2008⁷ makes the UK the first country in the world to have a legally binding long-term framework to cut carbon emissions, as well as setting a framework for building the nation's adaptive capacity.

The Act sets a clear and credible long term framework for the UK to reduce its greenhouse gas (GHG) emissions including:

- A legal requirement to reduce emissions by at least 80% below 1990 levels by 2050 and by at least 34% by 2020.
- Compliance with a system of five-year carbon budgets, set up to 15 years in advance, to deliver the emissions reductions required to achieve the 2020 and 2050 targets.

In addition it requires the Government to create a framework for building the UK's ability to adapt to climate change and requires Government to:

- Carry out a UK wide Climate Change Risk Assessment (CCRA) every five years.
- Put in place a National Adaptation Programme for England and reserved matters to address the most pressing climate change risks as soon as possible after every CCRA.

The purpose of this first CCRA is to provide underpinning evidence, assessing the key risks and opportunities to the UK from climate change, to identify priorities for action and to implement climate adaptation policies for current and future policy development as part of the statutory National Adaptation Programme which will begin from 2013. The CCRA will also inform devolved Administrations' policy on climate change mitigation and adaptation.

Climate Change Act: First 5 year Cycle

The Scope of the CCRA covers an assessment of the risks and opportunities to those things which have social, environmental and economic value in the UK, from the current climate and future climate change, in order to help the UK Government and Devolved Administrations identify priorities for action and implement necessary adaptation measures. The Government requires the CCRA to identify, assess, and where possible estimate economic costs of the key climate change risks and opportunities at UK and national (England, Wales, Scotland, Northern Ireland) level. The outputs from the CCRA will also be of value to other public and private sector organisations that have a stake in the sectors covered by the assessment.

The CCRA will be accompanied (in 2012) with a study on the Economics of Climate Resilience⁸ (ECR) that will identify options for addressing some of the priority risks identified by the CCRA, and will analyse their costs and benefits. This analysis will provide an overall indication of the scale of the challenge and potential benefits from acting; and, given the wide-ranging nature of possible interventions, will help to identify priority areas for action by Government on a consistent basis.

This will be followed by statutory adaptation programmes implemented by the UK Government and for Scotland, Wales and Northern Ireland through the DAs. These national adaptation programmes will set out:

- objectives in relation to adaptation

⁶ <http://www.defra.gov.uk/environment/climate/government/>

⁷ <http://www.legislation.gov.uk/ukpga/2008/27/contents>

⁸ <http://www.defra.gov.uk/environment/climate/government/>

- proposals and policies for meeting those objectives
- timescales
- an explanation about how those proposals and policies contribute to sustainable development.

The CCRA analysis has been split into eleven sectors to mirror the general sectoral split of climate impacts research namely; agriculture, biodiversity & ecosystem services, business/industry/services, built environment, energy, flooding and coastal erosion, forestry, health, marine & fisheries, transport and water.

1.2 Scope of the health sector

This health sector report is one of the 11 sector reports commissioned as part of the CCRA contract with HR Wallingford, and is a key step in the process of developing the evidence base required to deliver the UK CCRA to Parliament, as required by the Climate Change Act, by January 2012.

A wide range of impacts and consequences were identified for the health sector based on the CCRA Scoping Report (Vardoulakis, 2010), as well as from the CCRA Scoping Study (Watkiss *et al.*, 2009). Climate change is anticipated to cause a range of impacts on human health in the UK. These have been mainly related to higher mean temperatures as well as to the higher frequency and intensity of extreme weather events, such as floods and heatwaves.

A detailed report on the health effects of climate change in the UK was produced by the Health Protection Agency in partnership with the Department of Health (Department of Health, 2008). However, this assessment explicitly did not address adaptation options in the health sector or impacts on health care services. The CCRA scoping study summarised the findings of the Department of Health (2008) report, providing additional evidence and references where necessary. In addition, it reviewed climate related impacts on the National Health Service (NHS), and discussed adaptation issues and research gaps. It should be noted that the scoping of impacts focused on existing scientific evidence on health related impacts rather than plausible catastrophic events associated with climate change. The main findings of the scoping study for the health sector are summarised below.

Increased summer temperatures have caused excess heat-related mortality in the UK (Hajat *et al.*, 2007), despite the improved tolerance of the population to heat. Daily mortality significantly increased in the south of England during heatwaves, with over 2,000 excess deaths in England and Wales during the August 2003 heatwave (Johnson *et al.*, 2004 and Stedman 2004). Although annual cold-related deaths have substantially declined (by more than 33% from 1971 to 2003) due to generally milder winters, they still remain very high compared to heat-related mortality in the UK. Better insulated houses will protect people from cold indoors, but vulnerability outdoors may increase. Morbidity impacts associated with cold and heatwaves, including physical and mental health impacts, are rarely quantified.

As summer temperatures are projected to increase, people are likely to be inclined to spend more time in the sun, which will increase their ultra-violet (UV) radiation exposure and, although complicated to assess, may increase skin cancer incidence in the UK population (Diffey, 2004). UV radiation exposure will also be affected by the rate of recovery of the stratospheric ozone layer, which is expected to be altered by climate change (UNEP, 2010). On the other hand, increased sunlight exposure will enhance vitamin D levels and related health benefits (Holick, 2004).

Air pollution events (mainly increased ground-level ozone concentrations) and associated mortality and respiratory morbidity are likely to increase in frequency and intensity during summer time. This is estimated to cause an increase of 15-53% in attributable deaths and respiratory hospital admissions per year (depending on whether there is a threshold below which ozone does not harm human health, Department of Health, 2008). By contrast, winter air pollution episodes are expected to decline in frequency and intensity, resulting in a proportional decrease in associated mortality and morbidity.

Climate change may affect the prevalence and severity of allergic and respiratory illness through increases in the frequency, spatial distribution and concentrations of some airborne allergens (Schmier and Ebi, 2009). Higher temperatures may cause an earlier and possibly longer pollen season. More days with high pollen concentrations may result in more people with hay fever and pollen asthma (Sommer *et al.*, 2009).

Although climate change may be anticipated to have a negative impact on raw water quality through increased frequency of heavy rainfall events, with associated flooding and increased temperature, it is thought unlikely that public water supplies in the UK will be substantially affected⁹ (Hunter, 2003). However, private water and surface water supplies without filtration may be affected. There is certain evidence that both low rainfall and heavy rain have preceded drinking water-borne disease outbreaks in England and Wales (Nichols *et al.*, 2009), particularly in relation to cryptosporidiosis which is the most significant water borne disease related to public and private water supplies in the UK (Hoek *et al.*, 2008 and Department of Health, 2008). Warmer temperatures, as well as changes in rainfall, could increase the risk of water-borne diseases in people using surface waters (inland and coastal) for recreational purposes (Zmirou *et al.*, 2003).

Vector reproduction, parasite development and bite frequency generally rise with temperature. Therefore, malaria, tick-borne encephalitis, and dengue fever are very likely to become increasingly widespread due to global warming (Costello *et al.*, 2009 and IPCC, 2007b). There has been recent speculation that this may allow the re-establishment of malaria in Europe and the USA. Although increased temperatures could lead to climatic conditions favourable to increases in the prevalence of certain vector-borne diseases, such as malaria, the environmental and public health infrastructure in the UK would likely prevent the indigenous spread of these diseases (Kuhn *et al.*, 2003 and Hunter, 2003). Currently, there is no conclusive evidence indicating that climate change substantially contributes to tick-borne encephalitis in Europe (Randolph, 2004 and 2010). The risk of new vector species being introduced to the UK is therefore relatively low (Department of Health, 2008).

There is a tendency for the number of cases of food poisoning to rise during the summer when warm weather favours the multiplication of pathogenic micro-organisms (Bentham and Langford, 2001). Higher temperatures as a result of climate change might exacerbate the food borne disease problem (i.e. food poisoning, campylobacter, salmonellosis, *salmonella typhimurium* infections and *salmonella enteritidis* infections) in the UK (Kovats *et al.*, 2004a). However the impact of climate change on this aspect of UK public health is likely to be relatively small compared to other factors such as food hygiene (Lake *et al.*, 2009).

River and coastal flooding, flash floods and windstorms, are associated with a small number of direct deaths and injuries (i.e. from drowning, electrocution, carbon monoxide poisoning¹⁰ and hypothermia) in the UK (see flood and coastal erosion sector report, Ramsbottom *et al.*, 2012). Although the indirect health impacts from floods are difficult to monitor and quantify (partly because people move away from

⁹ This is discussed in more detail in the Water Sector report (Rance *et al.*, 2012).

¹⁰ See for example Daley *et al.*, 2001.

affected areas), there is increasing recognition that the mental stress suffered by affected populations may be substantial (Carroll *et al.*, 2009). Common mental disorders, including anxiety and depression may last for months and possibly even years after the flood event and so the full health burden is rarely appreciated (Hajat *et al.*, 2005 and Ahern *et al.*, 2005). The effect of flooding on the spread of communicable diseases in Europe is thought to be very small.

Climate change may increase human exposures to agricultural contaminants including certain pesticides, fertilizers, bacteria and viruses (Boxall *et al.*, 2009 and Knox *et al.*, 2012). The magnitude of any increases will be highly dependent on the contaminant type. Health risks associated with many pathogens, particulate and particle-associated contaminants could increase significantly.

There is a possibility that current NHS infrastructure, including hospitals, may not be resilient to climate change and related extreme weather events. Floods in particular could cause substantial disruption to NHS services as 7% of hospitals and 9% of surgeries and health centres in England are built in flood risk areas (Environment Agency, 2009). Heatwaves may also cause disruption to the health care sector if indoor temperatures in hospitals and care homes are not appropriately controlled. Exposure of medicines to high temperatures during storage and transit could reduce their efficacy (most licences specify storage below 25°C). In a hot British summer, medicines stored in homes, Primary Care Trusts (PCTs) or hospitals could be exposed to temperatures that might in theory reduce their efficacy (Crichton, 2004). Information Technology (IT) servers overheating and disruption to email communication may occur in PCTs and hospitals during heatwaves. The above events may consequently compromise access to NHS services, as well as health care staff performance and patient recovery.

Although the entire UK health care sector is going to be affected by climate change, certain medical specialities, such as emergency medicine are likely to be more burdened based on their clinical activity, ease of public access, public health roles, and energy/fuel use profiles (Hess *et al.*, 2009). Other medical specialities may also face budgetary impacts, for example due to increased prevalence and severity of heat stress and respiratory diseases. Longer allergy seasons and increased severity of symptoms would lead to higher costs and demands on the NHS for diagnosis and treatment of more complex allergies. Mental health, psychological support and counselling services may experience a rise in demand after extreme weather events such as floods.

In addition to the climate related impacts that affect the UK resident population directly, certain impacts occurring elsewhere may also affect the UK health sector. Coastal flooding, food and water shortages, and changes in the distribution of vector-borne diseases due to climate change in other parts of the world would cause population displacement (Haines *et al.*, 2009). In the medium and long-term, this may indirectly put pressure on NHS resources, due to UK citizens repatriating from overseas and increased immigration. In the short-term, the incidence of imported malaria and dengue to the UK may grow as tourism to endemic countries is continuously expanding (Lee, 2000).

1.3 Background

1.3.1 Introduction to the health sector

The health sector covers the potential change in the health effects to the UK population as a result of climate change. Mainly these effects are anticipated to be negative, with

for example increased temperatures and flood risk leading to an increase in heat related deaths and hospital admissions and flood related deaths, injuries, and numbers of people suffering a mental health effect as a result of a flood. However, there are benefits as a result of climate change, mainly linked to a reduction in cold related deaths and hospital admissions due to increased temperatures in winter.

Basic Health Statistics

- There are typically over 800,000 emergency hospital admissions per year in the UK.
- Over 500,000 people die every year in the UK.
- Approximately half of all deaths are due to diseases of the respiratory or circulatory system.
- The annual cost to the UK economy of ill health amongst working age people is around £100 billion¹¹.

Demographics

Currently approximately 20% of the population is under 16, with 40% 16 to 44 and 20% of pensionable age (Figure 1.1). Over the last 30 years, with a growing population, there have been some noticeable trends in these figures. This is particularly noticeable for the eldest members of society (people aged 85 and over), for which there were approximately 1.4 million people (comprising 460,000 men and 951,000 women) in 2010, accounting for about 2.3% of the total population. Between 1981 and 2010, this age-group increased by approximately 0.8 million (Figure 1.2) (Office for National Statistics, 2011).

The trend of an aging UK population is likely to continue throughout the 21st century. Current projections indicate an increase of 8%-47% of people aged over 85 by the 2050s, with a central estimate of 27%. Non-white ethnic groups are anticipated to increase at greater rates than white ethnic groups. Although the older age groups are anticipated to remain relatively constant across the UK, there is projected to be noticeable trends in the younger age groups. This will include a noticeable reduction in the 25-29 age group in the north, with a noticeable increase in the 15-24 age group in the south (Employers Organisation, 2004¹²).

¹¹ Institute of Occupational Medicine (<http://www.iom-world.org/>)

¹² The Office for National Statistics has not yet produced official population projections for ethnic groups. The data from this study is based on superseded census data; however, the general conclusions reached are unlikely to noticeably change based on any updated official figures.

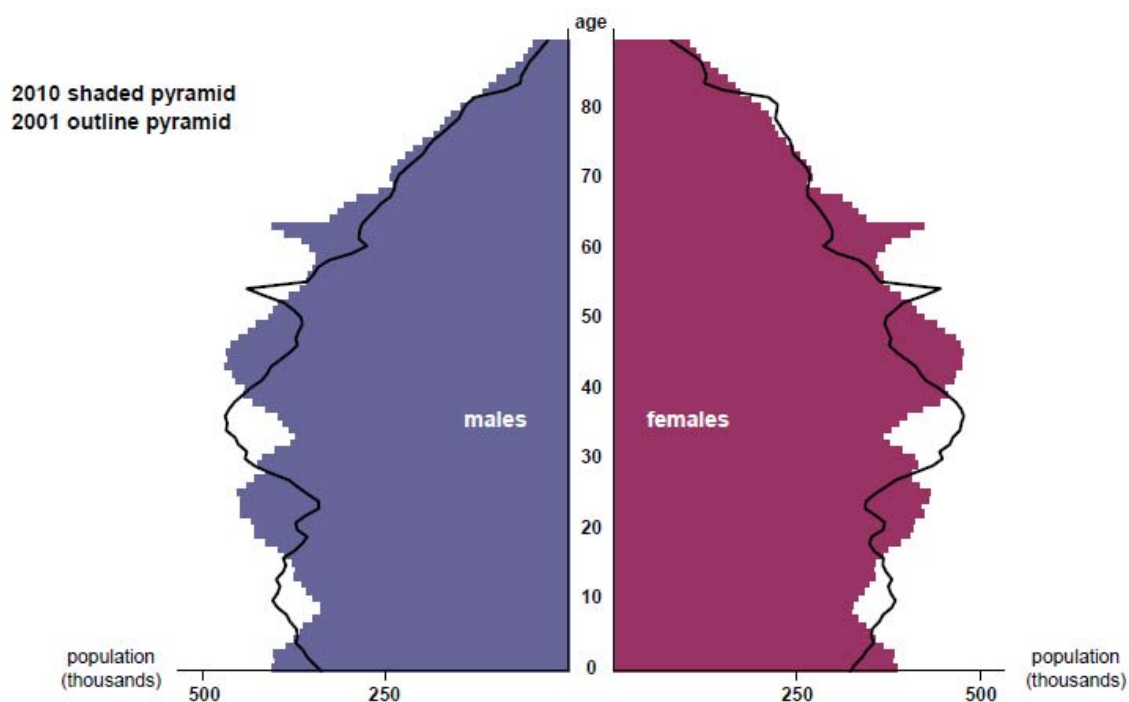


Figure 1.1 Age structure of the UK population pyramid
(Office for National Statistics, 2011)

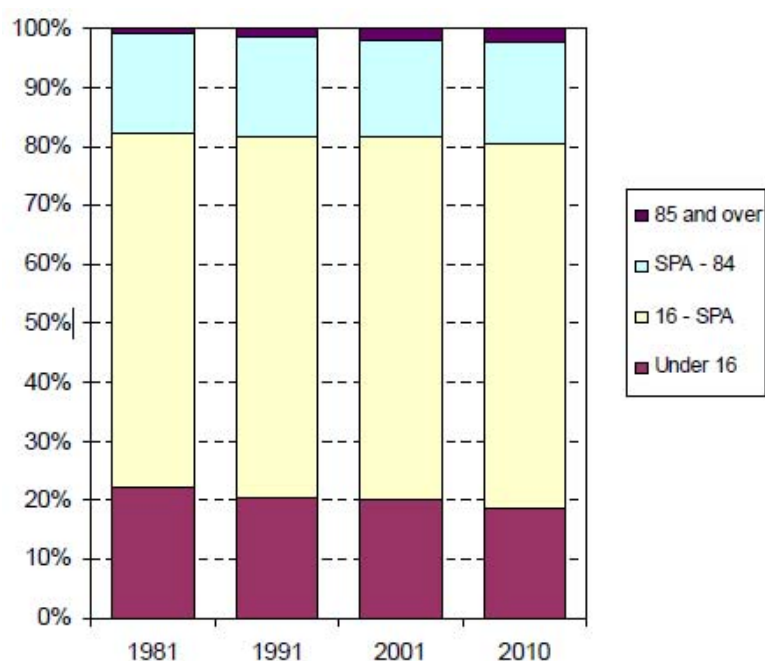


Figure 1.2 UK population by age-group, mid 1981 to mid 2010 (SPA: State Pensionable Age)
(Office for National Statistics, 2011)

Size of the NHS and health sector

Since its launch in 1948, the NHS has grown to become the world's largest publicly funded health service. Although funded centrally, NHS services in England, Northern Ireland, Scotland and Wales are managed separately. While some differences have emerged between these systems in recent years, they remain similar in most respects.

The NHS employs more than 1.7 million people. Of those, just under half are clinically qualified, including 120,000 hospital doctors, 40,000 general practitioners, 400,000 nurses and 25,000 ambulance staff¹³.

The NHS deals on average with one million patients every 36 hours and its budget is over £100 billion. Around 60% of the NHS budget is used to pay staff, a further 20% pays for drugs and other supplies, with the remaining 20% paying for buildings, equipment, training costs, catering and cleaning. Nearly 80% of the total budget is currently distributed by local trusts in line with the particular health priorities in their areas¹³.

The NHS in England is the biggest part of the system by far, catering to a population of 51 million and employing more than 1.3 million people. The Department of Health (DH) is responsible for health protection, health improvement and health inequality issues in England. NHS bodies in England are not part of the DH, but have a close relationship to it as a result of the laws under which they operate (Figure 1.3). In March 2010, there were 10 Strategic Health Authorities (SHAs), 152 Primary Care Trusts (PCTs), 109 NHS Trusts and 129 Foundation Trusts. The NHS White Paper, entitled “Equity and excellence: liberating the NHS”, sets out the Coalition Government’s long-term vision for the future of the NHS.

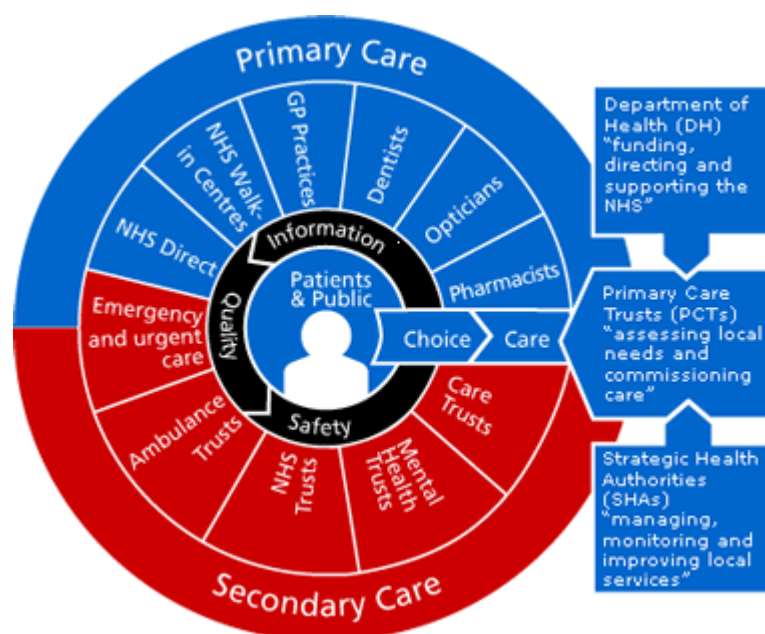


Figure 1.3 NHS structure (May 2010)

Source: NHS¹⁴

The National Health Service in Scotland has around 165,000 staff. The Scottish Government Health Directorates provide the central management of the NHS in Scotland, heading a Management Executive that oversees the work of 14 area NHS boards (see Figure 1.4). These territorial boards plan and deliver health services for people in their area from a total population of around 5.2 million. Services can be hospital or community-based and NHS boards coordinate community health services through Community Health (& Care) Partnerships¹⁵.

¹³ <http://www.nhs.uk/NHSEngland/thenhs/about/Pages/overview.aspx>

¹⁴ www.nhs.uk/NHSEngland/thenhs/about/Pages/nhsstructure.aspx

¹⁵ <http://www.show.scot.nhs.uk/>

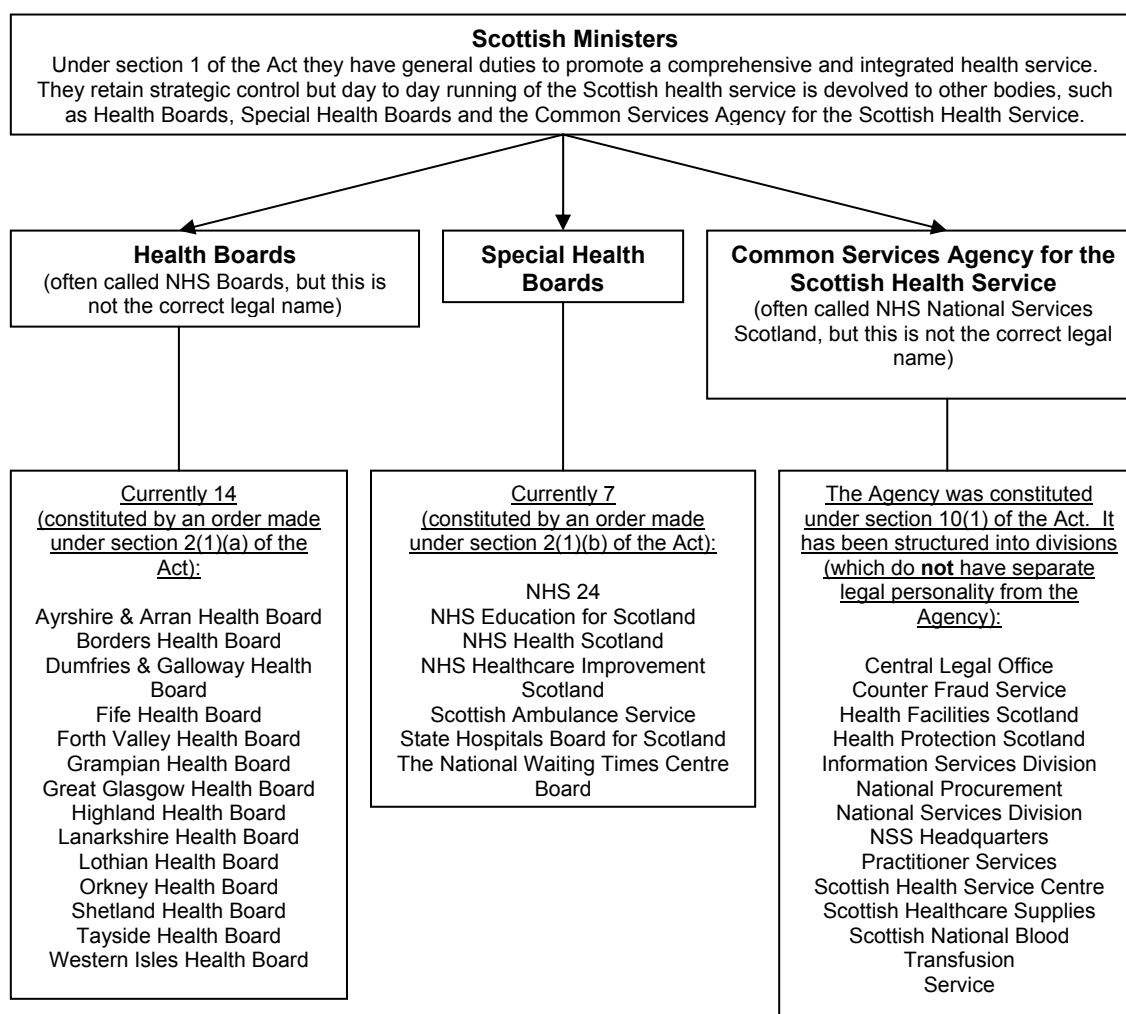


Figure 1.4 Structure of the Scottish Health Service
(under the National Health Service (Scotland) Act 1978)

The National Health Service of Wales provides healthcare to around 3 million people who live in the country. The NHS in Wales is the responsibility of the devolved Welsh Assembly Government. There are almost 91,000 people working for NHS Wales. The Welsh Government allocates resources each year to local health boards and Health Commission Wales to pay for the costs of hospital treatments provided by NHS trusts and other independent healthcare providers¹⁶.

The National Health Service in Northern Ireland has around 67,000 staff. The Health and Social Care Board has the role of developing health and social care services across Northern Ireland. The role of the Health and Social Care Board is broadly contained in three functions: (i) To commission a comprehensive range of modern and effective health and social services for the 1.7 million people who live in Northern Ireland; (ii) To work with the health and social care trusts that directly provide services to people to ensure that these meet their needs; (iii) To deploy and manage its annual funding from the Northern Ireland Executive ensuring that all services are safe and sustainable¹⁷. There are currently 6 trusts in Northern Ireland, providing health and social care services locally and on a regional basis.

¹⁶ <http://www.wales.nhs.uk/>

¹⁷ <http://www.hscni.net/>

1.3.2 Current policy and governance structure

For England, the Department of Health leads the health and social care sector, which includes the National Health Service (NHS), the social care sector and arm's length bodies (ALBs). The policy and governance structure in place in England during this CCRA will change with the introduction of the Health and Social Care Bill 2011. The changes will be phased in, subject to Parliamentary approval by 2013, with flexibility to extend beyond for some organisations.

Current arrangements

The Department of Health (DH) is responsible for the NHS in England and The Secretary of State for Health reports to the Prime Minister. The DH works through England's Strategic Health Authorities (SHAs), which oversee NHS activities in England and each SHA has oversight for NHS trusts in its area (Figure 1.5). NHS Foundation Trusts report directly to Monitor, the independent regulator of NHS foundation Trusts. SHAs and their Primary Care Trusts are responsible for the commissioning of the majority of NHS services.

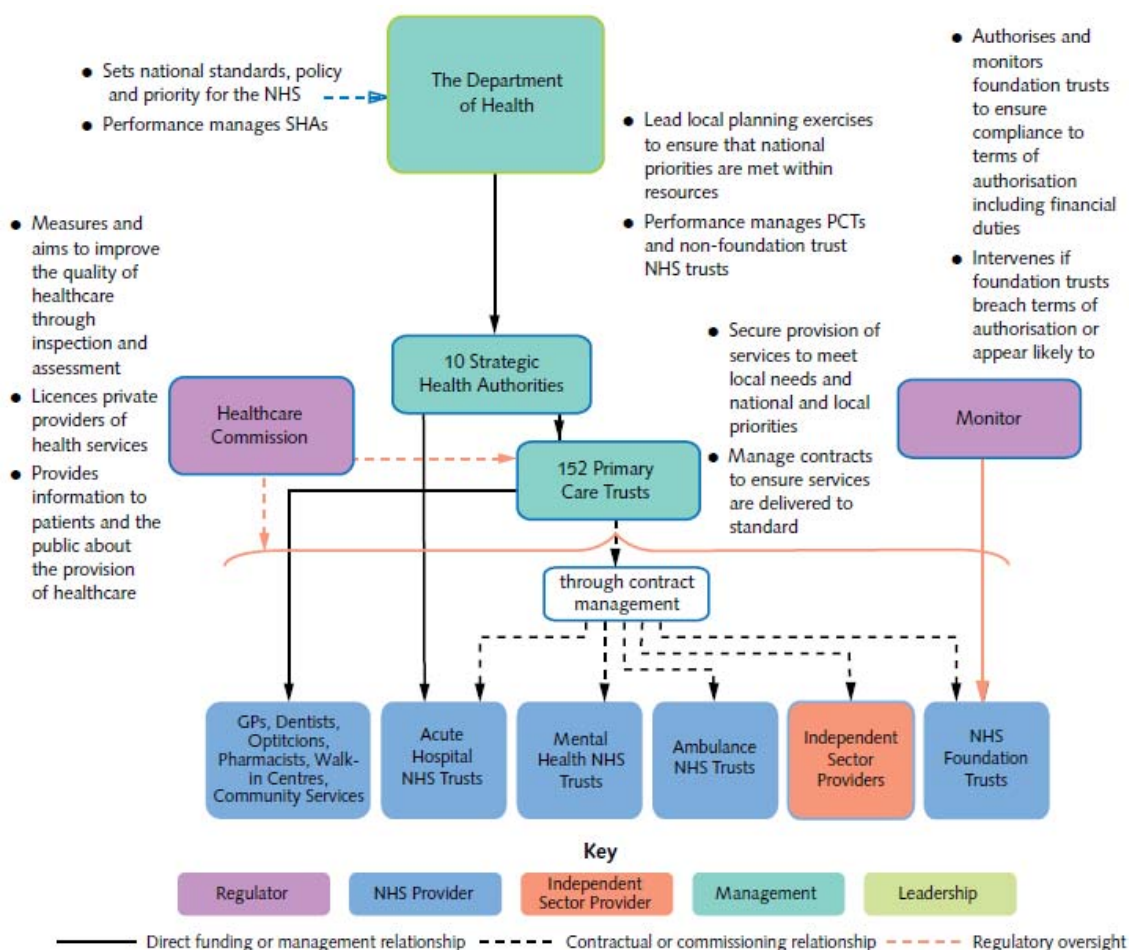


Figure 1.5 Health care delivery chain of the DH working with the NHS
Source: Department of Health, 2010a

In Scotland, the Scottish Government Health Directorate provides the central management of the NHS, and oversees the work of 14 NHS terrestrial Health Boards that plan and deliver health services in their area, along with 8 special NHS Boards.

In Wales health policy is devolved to the Welsh Government. As such, the Welsh Government is responsible for the National Health Service (NHS) in Wales and it therefore has an identity and governance structure that is distinct from its counterparts in the rest of the UK. The NHS delivers services through seven Health Boards and three NHS Trusts.

- Primary care services are provided by general practitioners (GPs) and other health care professionals in health centres and surgeries.
- Secondary care is delivered through hospital and ambulance services.
- Tertiary care is provided by hospitals which treat particular types of illness such as cancer.
- Community care services are usually provided in partnership with local social services, and delivered to patients in their own homes.

In Northern Ireland, health and social care services are provided by six trusts on a local and regional basis. These are the statutory bodies responsible for the management of staff, health and social care services.

The Coalition Government has set out its vision for a modernised NHS in England driven by a new commissioning system focused on improving outcomes for patients. The cornerstone of this system will be local clinical commissioning groups, which will put GPs at the heart of the commissioning process. Clinical commissioning groups will be supported across the country by clinical networks, bringing together experts on particular conditions and service areas, and by clinical senates, bringing together a range of clinical voices across particular parts of the country. At national level, the new NHS Commissioning Board will oversee the new commissioning system and lead the delivery of improvements against the NHS Outcomes Framework (NHS, 2011a).

The size and function of the NHS across the UK makes it a major contributor to climate change mitigation and adaptation. Sustainable delivery of NHS operations can improve the overall quality of life, health and well-being for the wider community and the British public, and save money and valuable resources.

There are also 12 Public Health Observatories (PHOs) working across England, and one each for Scotland, Wales and the combined nations of Northern Ireland and the Republic of Ireland. These produce information, data and intelligence on people's health and health care for practitioners, policy makers and the wider community. The network of nine Public Health Observatories in England continues to work on an agreed work plan. However, the Association of Public Health Observatories¹⁸ has been formally dissolved.

Future arrangements

The Health and Social Care Bill 2011 takes forward the areas of '*Equity and Excellence: Liberating the NHS*' (July 2010), the subsequent Westminster Government response '*Liberating the NHS: legislative framework and next steps*' (December 2010) and the Westminster Government response, published on the 20 June 2011, that require primary legislation. This has been subject to amendment detailed in the Westminster Government's response to the NHS Future Forum recommendations following the Government's listening exercise on the Health and Social Care Bill.

¹⁸ <http://www.apho.org.uk/>

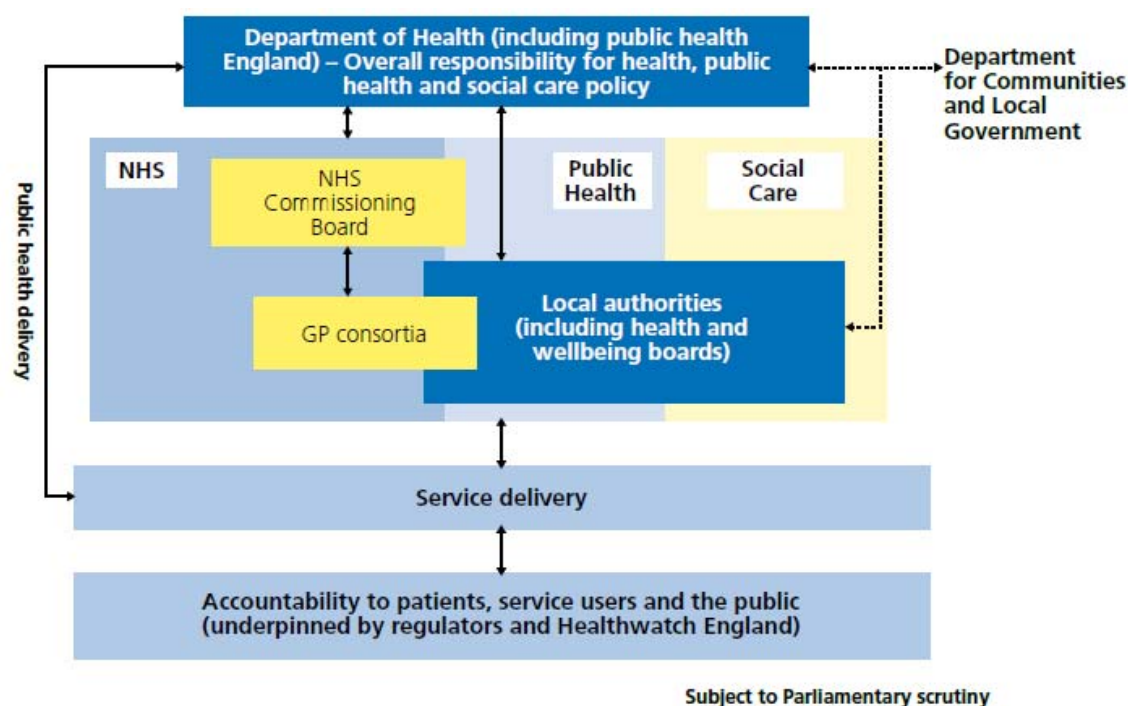


Figure 1.6 New roles for the new and existing organisations in the health sector

Source: Department of Health, 2010b

The new NHS Commissioning Board was created in shadow form in October 2011, will be established as an independent statutory body by October 2012 and take on its full functions in April 2013. There is also important transitions for local government in England as the new arrangements for health and wellbeing boards and the new public health service are tested (DH, 2010b).

- Under the proposed legislation, local authorities will take new public health responsibilities, supported by a ring-fenced budget. Directors of Public Health will lead this work, as the principal adviser on health to the local authority; this new key role will involve for the Directors of Public Health to be:
 - the principal adviser on health to elected members and officials
 - the officer charged with delivering key new public health functions
 - a statutory member of the health and wellbeing board
 - the author of an annual report on the health of the population.
- Local authorities will be supported by a new integrated public health service, Public Health England, which will be an Executive Agency of the Department of Health, and will drive delivery of improved outcomes in health and wellbeing and protect the population from threats to health, including climate change related impacts. Public Health England, which will incorporate the Health Protection Agency, will bring together in one body the diverse range of public health expertise currently distributed across the health system. It will ensure access to expert advice, intelligence and evidence and will provide a focus for the development of new approaches for a resilient health protection service (DH, 2011).

The DH is committed to supporting the NHS in raising the quality and sustainability of the physical environment, operational facilities and service infrastructure. To achieve

this, a wide range of initiatives and partnerships with other government departments, key organisations and professional bodies are in place. Leadership and technical expertise on environmental and sustainable development matters is provided through guidance and advice to the NHS.

For each sector of the CCRA, a high level overview of the policy landscape (related to climate impacts and adaptation) has been undertaken. This includes consideration of which bodies have responsibility within the sector for setting policy or seeing it is enforced, for example one or more Government Department(s), a government agency or a regulator.

The policy response to identified impacts for health for England is given in the Climate Change Plan of the Department of Health (DH, 2010a), which includes a Departmental Adaptation Plan and a Carbon Reduction Delivery Plan. Some specific actions already taken by the Department of Health and associated and devolved administrations bodies with regard to climate change risks are outlined below.

- The Department of Health report on the Health Effects of Climate Change was last updated in 2008 and a further update of this report is currently in preparation. This report considers quantitative aspects of possible impacts of climate change on health, and includes recommendations for public health and future research in this area.
- Separate Heatwave Plans have been issued for England and Wales. Both of these plans which are updated annually aim to protect health and to reduce harm from extreme heat and heatwaves, including advice for relevant bodies and organisations on the protection of vulnerable people.
- The Health Protection Agency has created a Programme Board on Climate Change and Extreme Events with membership including stakeholders from the wider health sector. The role of the Programme Board is to identify gaps in climate change and extreme events activities relevant to the protection of public health and to promote appropriate projects and collaborations to fill these gaps. A workshop titled “Climate change and health protection: looking forward” aiming to examine research and response issues relating to climate change and health protection and explore how to enhance relevant activities in this area was held in London on the 4th October 2010.
- The Health Protection Agency has been working with the Chartered Institute of Environmental Health to establish a Mosquito Watch programme to assist the identification of mosquitoes of concern within the UK and to develop a map of nuisance biting mosquito’s in the UK.
- Many initiatives exist at the sub-national level including a guidance document titled “Health Impact of Climate Change and Promoting Sustainable Communities” produced by the South East Regional Health Group aiming to raise awareness of the health impacts of climate change and a report titled “Health Effects of Climate Change in the West Midlands” produced by a partnership of the West Midlands Climate Change Office; West Midlands Public Health Observatory; Health Protection Agency; Department of Health West Midlands; University of Birmingham; Environment Agency; UK Climate Impacts Programme; Birmingham City Council and Birmingham Climate Change Adaptation Partnership.
- “The Health is Global: An outcomes framework for global health 2011-2015” will focus the UK Government’s efforts to drive forward the global health agenda by 2015. It defines 12 global health outcomes in three overarching areas for action: global health security, international

development and trade. This framework recognises that a wide range of health security threats, including climate change, transcend international boundaries, therefore the UK must be prepared to better predict, avoid and respond to these global health threats.

- Scotland's Climate Change Adaptation Framework - Health and Wellbeing was published in 2009 by the Scottish Government. This provides an overview of key issues in adapting to the consequences of climate change for the health and wellbeing sector in Scotland. The actions outlined provide an indication of the broad range of work planned over the coming years to strengthen resilience of this sector to the impacts of climate change. The first progress report on Climate Change Adaptation in Scotland was laid in the Scottish Parliament on 16 March 2011 along with updated Climate Change Adaptation Framework sector plans, including one on Health and Wellbeing.
- The Institute of Public Health in Ireland has produced "Climate Change and Health: A platform for action", which provides an introduction to the links between climate change and health and aims to inform policy-makers, politicians and the public of the benefits for health from reducing greenhouse gas emissions from food production, transport, energy, and waste. It also highlights the importance of action by the health sector.
- Wales has produced a Climate Change Adaptation Delivery Plan that outlines the actions that Wales are expected to take to address a number of public health issues including increased levels of mortality, food poisoning and risk of new diseases as a result of warmer summers.
- In 2005, the Welsh Government produced guidance called "Designed for Life" (NHS Wales, 2005), which set out a ten year strategic framework for the NHS over the next ten years. By 2015 this framework aims to have in place a NHS which focuses on health and wellbeing, not illness, and which provides fast and effective services which are of a world-class-standard.

Future policy or guidance may be required in certain areas, as for example highlighted in the recommendations for the Pitt Review (2008) in response to the lessons learnt from the 2007 floods in England and Wales, as well as a Department of Health Report (2010c) which recognized the link between climate change and human health. As foodborne illness is also considered in this report, it is important to note that the Food Standards Agency is the lead Department responsible for policy and advice on food safety, including foodborne illness, across the whole of the UK working closely with the HPA.

1.4 Structure of this report

This report describes the methodological steps taken in the health sector analysis. These steps include:

- Introduction
 - Introduces the report, and outlines the health sector and the potential risks within this sector
- Methods
 - Introduces the CCRA and the methods used to assess the impacts, consequences and risks

- Impacts and risk metrics
 - Outlines all the risks outlined within the health sector as well other risks relevant to health from other sectors
- Sector risk analysis
 - Assesses the Tier 2 impacts in the health sector for the different time periods, emissions scenarios and population projections
- Monetisation of metrics
 - Monetises the Tier 2 health impacts
- Adaptive capacity
 - Introduces the adaptive capacity of the sector (an assessment is ongoing)
- Discussion
 - Discussion of the results
- Conclusions.

The report structure broadly follows the risk assessment steps as described in detail in the CCRA Method Report (Defra, 2010b) and as summarised in Chapter 2.

Each section provides a summary of the work undertaken for each step and 'sign posts' additional information that includes stand-alone reports and the additional information contained in Appendices to this report.

2 Methods

2.1 Introduction: CCRA Framework

The overall aim of the CCRA is to inform UK adaptation policy in 2012, by assessing the current and future risks (threats and opportunities) posed by climate change for the UK to the year 2100. The overall approach to the risk assessment and subsequent adaptation plan is based on the UK Climate Impacts Programme (UKCIP) Risk and Uncertainty Framework (UKCIP, 2003). The framework comprises eight stages as shown in Figure 2.1. The CCRA has undertaken Stages 1, 2 and 3 as outlined below. Stages 4 and 5 will be addressed as part of a separate economic assessment of climate adaptation and the remaining stages will be implemented by the UK Government and Devolved Administrations. The framework presents a continual process that can adapt as new evidence and policy emerges; in the case of the CCRA the process will be revisited every five years.

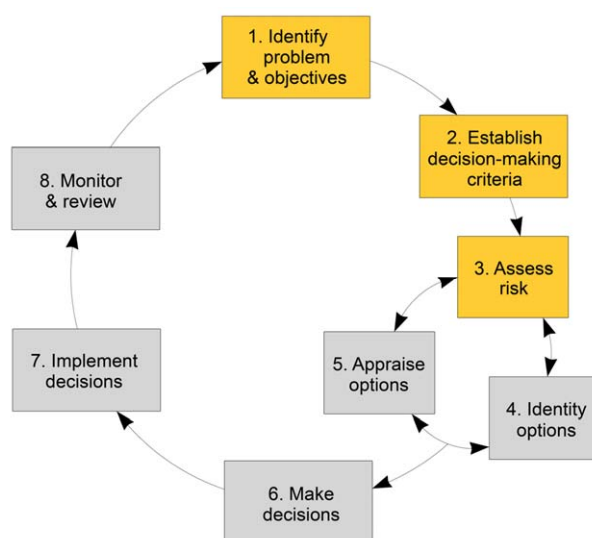


Figure 2.1 Stages of the CCRA (yellow) and other actions for Government (grey)

Adapted from UKCIP (2003).

- Stage 1 is defined by the aim of the CCRA project, to undertake an assessment of the risks (including both threats and opportunities) posed by climate change that will have social, environmental and economic consequences for the UK.
- Stage 2 established decision-making criteria for the study, which were used to inform the selection of impacts for analysis in Stage 3. These criteria are the social, environmental and economic magnitude of consequences and the urgency of taking adaptation action for UK society as a whole.
- Stage 3 covers the risk assessment process. This involved a tiered assessment of risks with Tier 1 (broad level) identifying a broad range of potential impacts and Tier 2 (detailed level) providing a more detailed analysis including quantification and monetisation of some impacts. A list of climate change impacts was developed based on eleven sectors with further impacts added to cover cross-cutting issues and impacts which fell

between sectors. This list of climate change impacts is referred to as the **'Tier 1' list of impacts**. This list contained over 700 impacts – too many to analyse in detail as part of this first CCRA. A consolidated list of the highest priority climate change impacts for analysis was developed and referred to as the **'Tier 2 list of impacts'**. This report presents the risk assessment for Tier 2 impacts.

The background to the framework and the approach used for each of the first three stages is set out in more detail in the CCRA Method Report (Defra, 2010a). This chapter aims to summarise the CCRA method for the risk assessment stage (Stage 3 in the framework above) because this includes the specific steps for which results are presented in this report.

2.2 Outline of the method used to assess impacts, consequences and risks

The risk assessment presented in this report is the focus of Stage 3 in the CCRA Framework (see Figure 2.1). This was done through a series of steps as set out in Figure 2.2. These steps are explained in Sections 2.3 - 2.7 below and are discussed in more detail in the CCRA Method report (Defra, 2010a).

The components of the assessment sought to:

- **Identify and characterise the impacts** of climate change

This was achieved by developing the Tier 1 list of impacts, which included impacts across eleven sectors as well as impacts not covered by the sectors and arising from cross sector links (see Chapter 3).

- **Identify the main risks** for closer analysis

This involved the selection of Tier 2 impacts for detailed analysis from the long list of impacts in Tier 1. Higher priority impacts were selected by stakeholder groups based on the social, environmental and economic magnitude of impacts and the urgency of taking action (see Sections 3.1 and 2.5).

- **Assess current and future risk**, using climate projections and considering socio-economic factors

The risk assessment was done by developing 'response functions' that linked changes in climate with specific consequences based on analysis of historic data, the use of models or expert elicitation. The UKCP09 climate projections and other climate models were then applied to assess future risks. The potential impact of changes in future society and the economy was also considered to understand the combined effects for future scenarios (see Chapter 4 and Section 2.6).

- **Assess vulnerability** of the UK as a whole

This involved:

- i. a high level review of Government policy on climate change in the eleven sectors (see Chapter 1 of this report)
- ii. a high level assessment of the social vulnerability to the climate change impacts

- iii. Defra is undertaking an assessment of the adaptive capacity of the sectors and will report on this later in 2012

- **Report on risks** to inform action

This report presents the results of the risk assessment for the health sector. The results for the other ten sectors are presented in similar reports and the CCRA Evidence Report (CCRA, 2012) draws together the main findings from the whole project, including consideration of cross-linkages, and outlines the risks to the UK as a whole.

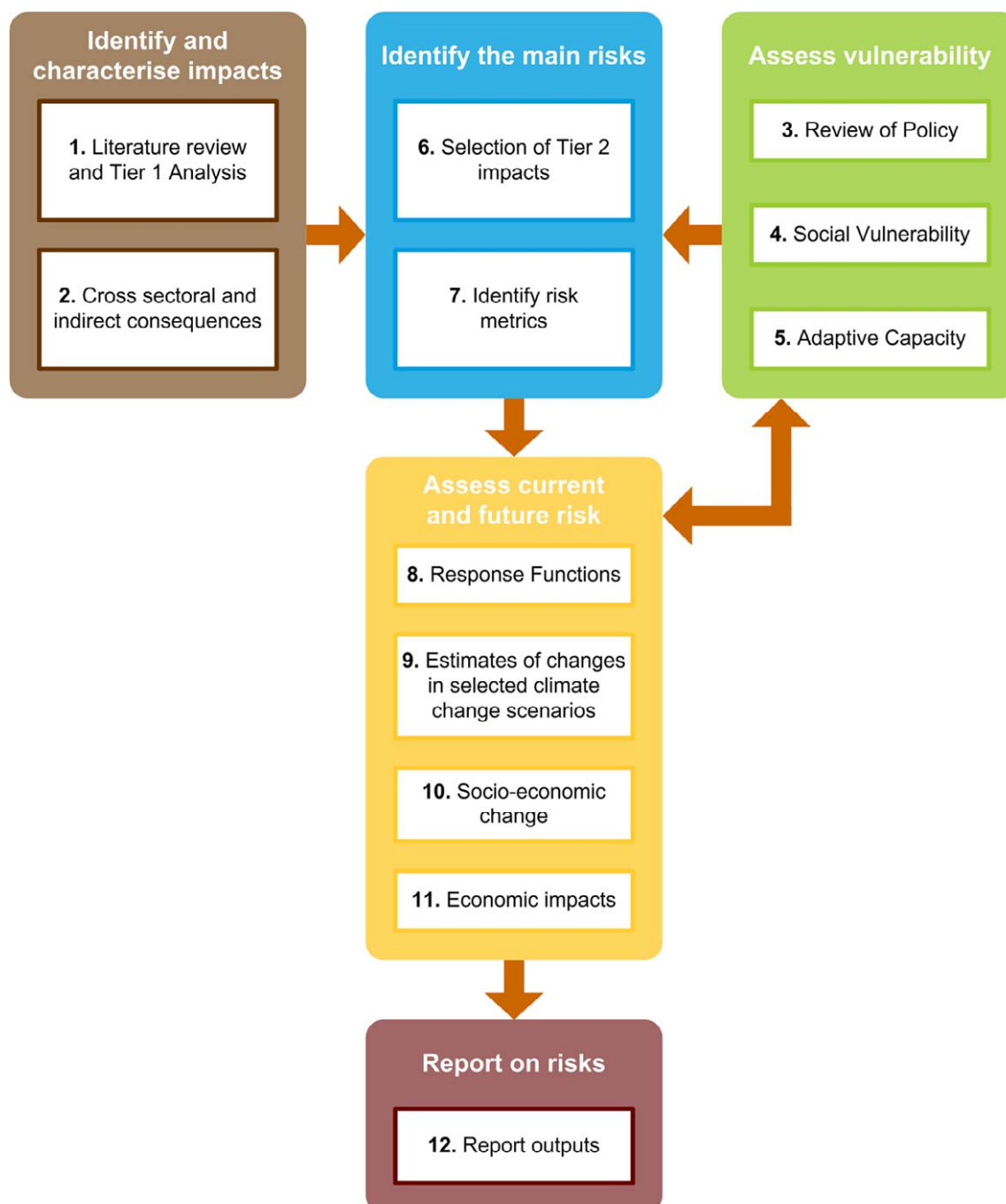


Figure 2.2 Steps of the CCRA method (that cover stage 3 of the CCRA framework: Assess risks)

2.3 Identify and characterise the impacts

Step 1 – Literature review and Tier 1 analysis

This step scoped the potential impacts of climate change on the UK based on existing evidence and collating the findings from literature reviews, stakeholder participation through workshops, correspondence with wider stakeholders and soliciting expert opinion. This work developed the Tier 1 list of impacts (see Appendix 2). The Tier 1 impacts have not been analysed in detail; high level discussion of these impacts is provided in Chapter 3 of this report.

Step 2 – Cross sectoral and indirect impacts

The Tier 1 lists for the eleven sectors in the CCRA were compared and developed further to include cross-sectoral and indirect impacts. This was done by 'Systematic Mapping', (see Section 3.4) which sets out a flow chart to link causes and effects in a logical process. The impacts that were identified in this step were added to the Tier 1 list of impacts.

2.4 Assess vulnerability

Step 3 – Review of Policy

Government policy on climate change develops and changes rapidly to keep pace with emerging science and understanding of how to respond through mitigation and adaptation. This report includes an overview of selected relevant policy in Chapter 1 as this provides important context for understanding how risks that are influenced by climate relate to existing policies. This information will be expanded in the Economics of Climate Resilience project and the National Adaptation Programme.

Step 4 – Social Vulnerability

The vulnerability of different groups in society to the climate change risks for each sector was considered at a high level through a check list. The completed check list for the health sector is provided in Appendix 5. This information is provided for context; it is not a detailed assessment of social vulnerability to specific risks. Note that this step is different from Step 10, which considers how future changes in society may affect the risks.

Step 5 – Adaptive Capacity

The adaptive capacity of a sector is the ability of the sector as a whole, including the organisations involved in working in that sector, to devise and implement effective adaptation strategies in response to information about potential future climate impacts. The adaptive capacity of the health sector is subject to an investigation that will be reported on later in 2012.

2.5 Identify the main risks

Step 6 – Selection of Tier 2 impacts

The Tier 1 list of impacts for each sector that resulted from Steps 1 and 2 (see above) were consolidated to select the higher priority impacts for analysis in Tier 2. Firstly, similar or overlapping impacts were grouped where possible in a simple cluster

analysis. Secondly, the Tier 2 impacts were selected using a simple multi-criteria assessment based on the following criteria:

- the social, economic and environmental magnitude of impacts
- overall confidence in the available evidence
- the urgency with which adaptation decisions needs to be taken.

Each of these criteria were allocated a score of 1 (low), 2 (medium) or 3 (high) and the impacts with the highest scores over all were selected for the Tier 2 analysis. The scoring for each sector was carried out based on expert judgement and feedback from expert consultation workshops (or telephone interviews). Checks were carried out to ensure that a consistent approach was taken across all the sectors. The results of the scoring process are provided in Appendix 3.

Step 7 – Identifying risk metrics

For each impact in the Tier 2 list, one or more risk metrics were identified. Risk metrics provide a measure of the consequences of climate change, related to specific climate variables or biophysical impacts. For example, premature deaths as a result of an increase in mean and/or extreme temperatures. The risk metrics were developed to provide a spread of information about economic, environmental and social consequences. The metrics have been referenced using the sector acronym and a number; the health sector metrics are referenced as HE1, HE2 etc.

2.6 Assess current and future risk

Step 8 – Response functions

This step established how each risk metric varied with one or more climate variables using available data or previous modelling work. This step was only possible where evidence existed to relate metrics to specific climate drivers, and has not been possible for all of the tier 2 impacts. This step was carried out by developing a 'response function', which is a relationship to show how the risk metric varies with change in climate variables. Some of the response functions were qualitative, based on expert elicitation, whereas others were quantitative.

Step 9 – Estimates of changes in selected climate change scenarios

The response functions were used to assess the magnitude of consequences the UK could face due to climate change by making use of the UKCP09 climate projections. This step used the response functions to provide estimates of future risk under three different emissions scenarios (high carbon emissions, A1FI; medium emissions, A1B; low emissions, B1; see <http://ukclimateprojections.defra.gov.uk/content/view/1367/687/> for further details) and three future 30-year time periods (centred on the 2020s, 2050s and 2080s) for three probability levels (10, 50 and 90 percent, see <http://ukclimateprojections.defra.gov.uk/content/view/1277/500/> for further details), associated with single or combined climate variables. The probability levels are cumulative and denote the degree of confidence in the change given; for example 90% suggests that it is thought very unlikely that the change will be higher than this; 50% suggests that it is thought equally likely that the change will be higher or lower than this; and 10% suggests that it is thought very unlikely that the change will be lower than this. 90% does not mean that the change is 90% likely to occur, for example.

All of the changes given in the UKCP09 projections are from a 1961-1990 baseline. For the health sector, these were adjusted to give a current day baseline.

The purpose of this step is to provide the estimates for the level of future risk (threat or opportunity), as measured by each risk metric.

Step 10 – Socio-economic change

It is recognised that many of the risk metrics in the CCRA are influenced by a wide range of drivers, not just by climate change. The way in which the social and economic future of the UK develops will influence the risk metrics. Growth in population is one of the major drivers in influencing risk metrics and may result in much larger changes than if the present day population is assumed. For some of the sectors where this driver is particularly important, future projections for change in population have been considered to adjust the magnitude of the estimated risks derived in Step 9.

For all of the sectors, a broad consideration has been made of how different changes in our society and economy may influence future risks and opportunities. The dimensions of socio-economic change that were considered are:

- Population needs/demands (high/low)
- Global stability (high/low)
- Distribution of wealth (even/uneven)
- Consumer driven values and wealth (sustainable/unsustainable)
- Level of Government decision making (local/national)
- Land use change/management (high/low Government input).

The full details of these dimensions and the assessment of the influence they have on the health sector is provided in Chapter 4. Note that this step is different from Step 4, which considers how the risks may affect society; whereas this step considers how changes in society may affect the risks.

Step 11 – Economic impacts

Based on standard investment appraisal approaches (HM Treasury, 2003) and existing evidence, some of the risks were expressed as monetary values. This provides a broad estimate of the costs associated with the risks and is presented in Chapter 5 of this report. A more detailed analysis of the costs of climate change will be carried out in a study on the Economics of Climate Resilience¹⁹.

2.7 Report on risks

Step 12 – Report outputs

The main report outputs from the work carried out for the CCRA are:

- The eleven sector reports (this is the sector report for the health sector), which present the overview of impacts developed from Tier 1 and the detailed risk analysis carried out in Tier 2.
- The Evidence Report, which draws together the main findings from all the sectors into a smaller number of overarching themes.
- Reports for the Devolved Administrations for Scotland, Wales and Northern Ireland to provide conclusions that are relevant to their country.

¹⁹ <http://www.defra.gov.uk/environment/climate/government/>

3 Impacts and Risk Metrics

A preliminary overview of the potential impacts of climate change on the Health sector was provided in the CCRA sector scoping report (Vardoulakis, 2010). A wide range of 41 overlapping impacts and consequences were identified for the health sector during the Tier 1 assessment. A full list of these impacts and consequences from the Tier 1 assessment are given in Appendix 2.

Following a health sector workshop, held on the 26th May 2010, there was a consolidation of these impacts and consequences which enabled this list to be reduced down to 29 impacts, which are outlined in Table 3.1 below, together with the score from the scoring exercise (see Appendix 3).

Table 3.1 Health sector tier 1 consolidated impacts

Climate effect	Impact	Consequence	Comment
Summer temperature	Temperature mortality (summer)	Increased demands on health and adult care service	Score > 30
Predominantly rainfall and sea level rise	Extreme weather event mortality (flooding and storms)	Increased demands on health and adult care service	Score > 30
Increased average temperatures	Increase in frequency and intensity of Summer air pollution (ozone)	Increase in cases of mortality and morbidity linked to respiratory disease and associated hospital admissions	Score > 30
Summer temperature	Temperature morbidity (summer)	Increased demand on health and adult care services	Score > 30
Predominantly rainfall and sea level rise	Extreme weather event injuries (flooding and storms)	Increased demands on health and adult care service	Score > 30
Increase in average temperature	Longer pollen season and more days with high pollen counts	More people suffering with hay fever and pollen asthma	Score > 30
Cloud cover and UVB radiation	Sunlight/UV exposure	Increased demands on health and adult care service	Score > 30
Predominantly rainfall and sea level rise	Increase in flooding of properties	Increased psychological well-being affecting mental health	Score > 30
Winter temperature	Temperature mortality (winter)	Reduced demands on health and adult care service	Score > 30
Winter temperature	Decline in frequency and intensity of winter air pollution episodes	Decrease in associated mortality and morbidity	Score > 30
Winter temperature	Reduced winter temperature morbidity	Reduced demands on health and adult care service	Score > 30
Extreme weather events	Increase in demand for emergency medicine	Overwhelming of public services	Score > 30
Milder and wetter winters	Algal/fungal growth in buildings	Impact on respiratory conditions	Score > 30
Extreme weather events	NHS infrastructure failure	Potential impact on safety of hospital wards etc	Score > 30

Climate effect	Impact	Consequence	Comment
Predominantly rainfall and sea level rise	NHS property damage	Disruption to hospitals, clinics, GP offices etc	Score > 30
Temperature and rainfall	Increased prevalence and survival of certain arthropods such as ticks and mosquitoes	Vector borne diseases	Score > 30
Increased average temperatures	Increase in certain water borne diseases such as <i>cryptosporidium</i> and deterioration in quality of surface waters	Health impacts such as diarrhoea and nausea/vomiting	Score > 30
Extreme weather events	Increase in social disruption	Exacerbate inequalities in communities raising tensions between different social groups	Score > 30
Summer temperature	Multiplication of pathogenic micro-organisms	Increase in food borne diseases	Score = 17
Extreme weather events	Transport network failure	Increased demands on health and adult care service	Score = 17
Predominantly increased winter rainfall, but also other climate variables	Increase in indirect human exposure to agricultural contaminants	Health risks leading to increased burden on health and care services	Score = 17
Summer temperature	Exposure of medicines to high temperatures	Reduction in medicine efficacy	Score = 17
Milder winters	Traffic accidents	Changed burden on emergency services during the winter	Score = 17
Extreme weather events	Impact on NHS staff work and working conditions	Reduction in NHS staff performance	Score = 17
Extreme weather events	Patient recovery rates in hospitals may be compromised	Increased demands on health and adult care service	Score = 17
Increased maximum summer temperatures	Disruption to building maintenance work	Impact on NHS services	Score = 17
Increase in average temperatures	Change in available food, diets etc	Potential increase in healthy eating	Score = 17
Increased temperatures and reduced cloud cover	Increased outdoor activity	Increased sunlight exposure enhancing vitamin D levels and related health benefits	Score < 17
Change in weather extremes and severity	Change in levels of mobile care and support services	Increased demands on health and adult care service	Score < 17

3.1 Impact selection

Of the impacts within the health sector, a number scored above the selected threshold of 30. However, several of these were deemed too uncertain to assess due to limited published evidence and very complex relationships with a wide range of socioeconomic

and behavioural factors loosely associated with climate change. Time and resource constraints also meant that it was not possible to analyse all of these risks in detail. The selected risks taken forward for analysis are therefore given below. Impacts excluded from the analysis are outlined in Section 3.3. A comprehensive scoping study of the risks associated with climate change for the UK health sector has been presented separately (Vardoulakis, 2010).

3.2 Health risk metrics assessed in this report

Metrics for CCRA were considered at the health sector workshop and discussed with a number of experts at the Health Protection Agency and the London School of Hygiene and Tropical Medicine. The pros and cons of different metrics were considered by the project team vis-à-vis the characteristics of good metrics as in Box 3.1 below. The metrics chosen for the health sector are given in Table 3.2 below, and discussed in more detail in Sections 3.2.1 to 3.2.9.

Table 3.2 Health sector: Climate change impacts and risk metrics²⁰

Tier 2 impact	Risk metrics
Temperature mortality (heat)	HE1 Excess mortality (based on daily mean temperature and population)
Temperature morbidity (heat)	HE2 Effects of increased summer temperatures on hospital patient days (semi-quantitative)
Extreme weather event (flooding and storms) mortality	HE3 Flood and storm related deaths (increased risk to people using data from the floods sector)
Summer air pollution (ground-level ozone)	HE4a Excess mortality based on ground level ozone, baseline mortality and population
	HE4b Excess respiratory hospital admissions based on ground-level ozone, baseline morbidity and population
Temperature mortality (cold)	HE5 Averted mortality (based on daily mean temperature, baseline mortality and population)
Temperature morbidity (cold)	HE6 Effects of increased winter temperatures on hospital patient days (semi-quantitative)
Sunlight/UV exposure	HE9 Skin cancer cases (potentially linked to changes in UVB levels of radiation) (qualitative)
Effect of floods/storms on mental health	HE10 Mental stress caused by flooding and storms (based on GHQ-12) (semi quantitative)
Extreme weather event (flooding and storms) Injuries	HE7 Flood and storm related injuries (increased risk to people using data from the floods sector)

²⁰ The numbering of the impacts was carried out before the selection of the Tier 2 Impacts was finalised. This explains the absence of HE8 (assessment of the health effects of pollen/allergens) which did not make the Tier 2 list. HE7 is reported on after HE10 throughout this report as it did not make the Tier 2 list, yet has been assessed as a simple response function to HE3 was identified.

Box 3.1 Assessment of “good” metrics

For national risk assessment, ‘good’ metrics are likely to have a number of criteria, i.e. they:

- Are sensitive to climate but also allow the disaggregation of climate and socio-economic effects;
- Provide a measure of changing probability or consequences relevant to a baseline, so historical data are required to establish the current situation;
- Can be presented at the national and regional scales, based on high quality data that are collected and held by Government departments, agencies or research institutes. The use of Government data should provide consistency between sectors and allow the metrics to be repeatable in subsequent CCRA cycles;
- Reflect economic, environmental and social consequences of climate change; some metrics may be monetised but others may simply indicate the areas affected or consequences for vulnerable groups of society;
- Are relevant/have legitimacy to the relevant Government policy.

3.2.1 HE1 – Temperature mortality (heat)

As temperatures increase, mainly during summer months, this can have a subsequent effect on the number of premature deaths as a result of heat related illnesses (i.e. cardio-vascular and respiratory diseases). These deaths tend to increase above a set temperature threshold, with the threshold and rate of increase varying between regions.

There have been a number of studies undertaken recently looking at the effect of heat related illnesses on mortality, and this data was made available for this study. However, this work has concentrated on England and Wales, and few if any studies have been done for Scotland and Northern Ireland.

Temperature mortality (heat-related) has therefore been addressed by assessing the change in mortality rate based on published exposure response functions, threshold temperatures and regional time series data on temperature and daily death counts.

3.2.2 HE2 – Temperature morbidity (heat)

As temperatures increase, mainly during summer months, this can have a subsequent effect on the number of hospital admissions as a result of heat related illnesses. Hospital admissions attributable to heat are more difficult to attribute than those under heat related deaths. However, there are indications that the numbers of patient days as a result of heat is approximately proportional to the numbers of deaths attributable to heat.

For this metric, a proportional relationship has been assumed between patient days and heat related mortality. This relationship has been chosen based on limited published work on this subject, and therefore results should be interpreted with caution.

3.2.3 HE3 – Extreme weather event (flooding and storms) mortality

As levels of flooding increase, there will be an increase in the level of risk and hence potential mortality rates of people affected by both fluvial and coastal flooding. This risk can be related to the number of people at significant risk of flooding²¹ identified in the flood and coastal erosion sector report (Ramsbottom *et al.*, 2012). In addition to fluvial and coastal flooding, there is an additional risk during storms associated with increased coastal wave action linked to increases in sea levels.

Baseline mortality rates due to flooding may be difficult to determine due to the relatively low and clustered mortality rates within the UK, specifically in relation to coastal events for which no known recorded flood deaths have occurred since the major North Sea flood event of 1953.

With UKCP09 projections showing little change in levels of storm activity, changes in extreme weather event mortality due to storms is considered to be small, apart from those deaths in coastal regions where an increase in sea levels would lead to increased periods of wave activity nearshore during storms. Storm deaths are therefore assumed to not change, apart from those related to coastal wave activity.

Extreme weather event flooding has therefore been assessed by considering the change in the number of people at significant risk of flooding as defined in the flood and coastal erosion sector report (Ramsbottom *et al.*, 2012) linked to current day best estimate baseline figures²². For the additional risk associated with coastal wave activity, this has been assessed by considering the change in the period of time that storm conditions are likely near the coastline, defined as a function of the time above mean high water springs (MHWS), correlated to best estimates of current day baseline figures.

3.2.4 HE4 – Summer air pollution (ozone)

Ground-level ozone is a secondary pollutant, which means that it is not directly emitted from pollution sources but it is formed by a series of chemical reactions between nitrogen oxides, volatile organic compounds and oxygen in the presence of sunlight. Ozone is also an important greenhouse gas because of its direct radiative forcing in addition to its indirect radiative forcing effect due to its impact on the productivity of natural vegetation (Royal Society, 2008). Increased concentrations of ground-level ozone could lead to significant reductions in regional plant production and crop yields. Ground-level ozone can directly affect human health. Acute exposure to ozone may cause irritation to the eyes and nose and very high levels can cause damage to the airway lining.

Mainly in spring and summer months, during periods of anti-cyclonic weather conditions associated with low winds, increased sunlight and warm temperatures, there can be a noticeable increase in ground-level ozone. This can lead to increases in daily mortality and hospital admissions linked to respiratory diseases (Pattenden *et al.*, 2010). Air quality monitoring networks exist around the UK, and these provide ground-level ozone data that can be used together with published exposure-response

²¹ Significant risk of flooding is defined as a 1.3% chance of flooding in any one year (a return period of 75 years).

²² Pluvial flooding was not considered in the floods and coastal erosion sector report. However, the response function for fluvial flooding is related to a current day baseline for all types of death due to inland flooding. As fluvial flooding would be expected to be the major cause of death as a result of inland flooding, the omission of pluvial flooding from this metric would only reduce the confidence in the projections given, and it could not be stated whether these estimates could be larger or smaller as a result.

coefficients, and population and mortality data sets to assess the potential impact of ozone on public health.

It is a very complex task to assess future effects of climate change on ground-level ozone as the metric is non-linearly related to future anthropogenic (from transport and industry) and biogenic emissions. The estimation of this risk is therefore based on published model results indicating how levels of ozone could change by the end of the current century due to climate change and published exposure-response coefficients indicating the percentage change in impact on health per $10\mu\text{g}/\text{m}^3$ change in daily ozone levels.

3.2.5 HE5 – Temperature mortality (cold)

As temperatures increase this can have a subsequent effect on the number of deaths put back, or more specifically premature deaths avoided. There have been a limited number of studies undertaken looking at the effect of cold weather on mortality in the UK, however, the methods developed are similar to those developed for heat related mortality. Again, these studies have concentrated on England and Wales, with few if any studies existing for Scotland and Northern Ireland.

Cold-related mortality has therefore been assessed in the same way as heat-related mortality.

3.2.6 HE6 – Temperature morbidity (cold)

Within winter months, as temperatures increase this will almost certainly result in a reduction in the number of hospital admissions due to cold related illnesses. Hospital admissions are more difficult to attribute due to cold than to heat, with many of these due to infectious diseases such as influenza and pneumonia, complicated in the future by other factors such as people spending more time outdoors in winter periods.

Taking into account these complicating factors, estimates for this metric are considered difficult to determine. A tentative semi-quantitative assessment based on a proportional relationship between cold related deaths and hospital patient-days derived from a study by Donaldson *et al.*, (2002) has therefore been carried out, and these results should be treated with caution.

3.2.7 HE9 – Sunlight/UV exposure

As exposure to UV radiation is increased, levels of skin cancers and cataracts would be expected to increase. The amount of UV radiation which reaches the surface of the earth is dependent on a number of factors, the main one of which is the amount absorbed by the stratospheric ozone layer. However changes in cloud cover in the future, as well as social behaviour and changes to UVB radiation flux²³ will also affect exposure at ground level.

The effect of climate change on UV radiation exposure is difficult to assess based on the contributing factors outlined above together with probable increased outdoor activity due to higher summer temperatures and lower levels of clothing. However, for no change in social behaviour there is limited evidence that the change in the risk of melanoma due solely to climate change can be correlated to the change in the mean

²³ Radiation flux is a measure of the flow of radiation from a given radioactive source. Although UVB radiation is not covered by UKCP09 projections, for this report estimates have been made based on shortwave and longwave wavelength projections of 10-200nm and 500-2,500nm respectively.

annual UV radiation flux, a climate variable that has been assessed within UKCP09. The difficulties in assessing population exposure to UV in the future in addition to the uncertainty due to using the UV radiation projections from UKCP09 rather than just UVB radiation projections (which can be linked to skin cancer) mean that a quantitative assessment would be unreliable. Similarly, it was not possible to quantify any health benefits associated with increased exposure to sunlight (e.g. vitamin D levels).

This metric was therefore not assessed quantitatively in this report.

3.2.8 HE10 – Effects of floods/storms on mental health

As levels of flooding increase and storm conditions change due to climate change, there will almost certainly be an increase in the number of people suffering mental health problems as a result. For mental health effects, the increase in floods defined by the flood and coastal erosion sector report (Ramsbottom *et al.*, 2012), enables a change in the relative risk due to flooding to be determined. Climate change effects due to storms are uncertain (i.e. they could increase or decrease) and are difficult to quantify. However, this effect is expected to be small in comparison to floods, and was therefore considered to make no noticeable difference to this metric. In addition, Ramsbottom *et al.*, (2012) do not consider pluvial flooding, which will result in the projections given in this report being underestimated. They also consider England and Wales only.

In determining baseline rates of mental health, a number of scales now exist that measure changes in the mental health condition of people due to various causes. These include the post traumatic stress scale, and several versions of the general health questionnaire. The shortest version of the general health questionnaire, termed the GHQ-12, has commonly been used in flood studies to assess the effect of flooding on mental health. As this is now an established method of assessing mental health effects due to severe weather events, including flooding, this questionnaire has been used to assess the number of people who suffer a mental health problem due to flooding. This is assessed as the number of people who go from a GHQ-12 score of below 4 to 4 or above as a direct result of the flood. This is then linked to the number of people projected to flood on a yearly basis from the floods and coastal erosion sector report (Ramsbottom *et al.*, 2012).

3.2.9 HE7 – Extreme weather event (flooding and storms) injuries

This metric is very closely related to the metric for extreme weather event (flooding and storms) mortality. Rates of injuries would be expected to be proportional to the number of deaths recorded, however, the baseline rates would be more difficult to quantify. This is made more difficult due to the definition of “what is an injury”?

In measuring this metric, a direct relationship has been identified linking number of individuals who suffer an injury requiring medical attention from a hospital admission (i.e. definition of an injury for the basis of this report) to the number of fatalities. This ratio has been estimated based on officially recorded statistics of past flood events. It should also be noted that in addition to injuries obtained, there may also be a consequential impact on working incapacity benefits (not considered in this report), including for some individuals not classified as having been injured.

For the same reasons as given in Section 3.2.3, this metric has been considered solely due to injuries as a result of extreme weather event flooding²².

3.3 Health risk metrics not assessed in this report

3.3.1 Food borne diseases

There is a tendency for the number of cases of food poisoning to rise during the summer when warm weather favours the multiplication of pathogenic micro-organisms (Bentham and Langford, 2001 and Box 3.1). Higher temperatures as a result of climate change might exacerbate the food borne disease problem (e.g. food poisoning, Salmonellosis, *salmonella typhimurium* infections and *salmonella enteritidis* infections) in the UK (Kovats *et al.*, 2004a). Given the current level of food poisoning notifications, an increase of 1°C, would result in an approximate 4,000 additional notifications²⁴, although due to under reporting, the real level of additional cases could be around nine times this figure (Stanwell-Smith, 2008). Approximately 19 million days are lost every year due to infectious intestinal diseases, 11 million of which are amongst people of working age (based on research by Tam *et al.*, 2011). Based on the Medium Emissions Scenario, this indicates a 1-7%, 5-14% and 8-21% increase in notifications by the 2020s, 2050s and 2080s respectively. Despite this, the impact of climate change on this aspect of UK public health is likely to be relatively small compared to other factors such as improved food hygiene (Lake *et al.*, 2009).

Box 3.1 The effect of rising temperatures on food poisoning (adapted from Stanwell-Smith, 2008)

The food poisoning risk will increase with climate change, accelerating the already established seasonal variation:

- increased multiplication of pathogens at high temperatures e.g. Salmonella growth occurs above 7°C, optimum at 37°C and Campylobacter growth increases above 30°C.
- higher temperatures also increase rate of infection in animals (e.g. multiplication of bacteria in animal feeds), thus adding risk to the food chain.
- change in food eating behaviour e.g. more barbecues and outdoor eating.
- studies have shown that food poisoning rates correlate with temperature a month earlier, consistent with time taken for food chain to be affected and cases to emerge.
- a mean temperature increase of 1°C (expected within the next 30 years or so) is estimated to increase food poisoning by 4.5%, with a higher risk of that due to Salmonella of approximately 12.5% (Kovats *et al.*, 2004a). An increase of 2°C would increase food poisoning notifications by approximately 9.5%, while an increase of 3°C would raise them by approximately 14.8% (Bentham, 2008b).
- The evidence is sufficiently strong for public warnings about food poisoning to be considered during hot weather periods: Salmonella is strongly related to temperature in the range 7-37°C and the common threshold for the one week lag effect in the study of 13 European countries (Kovats *et al.*, 2004a) was 6°C.

²⁴ There are currently in the region of 100,000 reported cases of food poisoning cases in the UK every year, NHS (2011b).

3.3.2 Vector borne diseases

Vector reproduction, parasite development and bite frequency generally rise with temperature. Therefore, malaria, tick-borne encephalitis, and dengue fever are very likely to become increasingly widespread in certain parts of the world (mainly in tropical and sub-tropical climates) due to projected rises in temperatures (Costello *et al.*, 2009 and IPCC, 2007b). However, future outbreaks of certain vector borne diseases such as malaria, would still be expected to be rare and limited in number in Europe (Rogers *et al.*, 2008).

The risk of new vector species being introduced to the UK is relatively low (Medlock *et al.*, 2005 and Rogers *et al.*, 2008), although British citizens visiting vector-borne endemic countries overseas would be expected to be at higher risk. Lyme disease, for example, may present local problems in the UK, but the increase in their overall impact of the disease would probably be small and mainly dependent on agricultural and wildlife management practices. There is also no conclusive evidence indicating that climate change substantially contributes to tick-borne encephalitis in Europe (Randolph, 2004 and 2010).

Although as stated above British citizens visiting vector-borne endemic countries overseas would be at higher risk to vector borne diseases, changes in the regional climate of Northern Europe may also lead to an increased risk of the introduction of new diseases to the UK. This could be due to immigration and international travel, with the arrival of affected persons in the UK; an outbreak domestically, due to imported vectors (such as insects) or person-to-person spread; or through the import of contaminated food products to the UK. However, it is important to note that the relevance of environmental change to patterns of disease depends on the susceptibility of local populations to the disease, the robustness of local food and water safety measures, vector control measures and communicable disease surveillance and control arrangements (e.g. vaccination programmes, legislation) (Foresight, 2011).

Prompt action to any outbreaks will reduce the chances of endemic malaria transmission in the UK, and it is likely that the public health infrastructure in the UK would prevent the indigenous spread of these diseases (Kuhn *et al.*, 2003 and Hunter, 2003).

3.3.3 Water quality and water borne diseases

Zoonotic gastro-intestinal pathogens present a human disease burden. Approximately a third of the UK population suffer infectious intestinal disease each year (>16 million cases) and there are about 2 GP consultations for every 100 person years (Tam *et al.*, 2011), costing the economy over £750 million (Wheeler *et al.*, 1999)²⁵. These pathogens have evolved and circulate in animal reservoirs with human infection occurring through exposure via a number of different pathways including food, the environment (direct/indirect contact with animals and their faeces) and water (drinking or recreational contact). This can result in disease outbreaks, in particular cryptosporidiosis which is the most significant water borne disease related to public and private water supplies in the UK (Hoek *et al.*, 2008; Nichols and Kovats, 2008).

A number of factors impact upon the human burden attributable to these pathogens including anthropogenic and environmental influences. Environmental factors include climate change, which may lead to an increasing frequency of high intensity rainfall events that permit mobilisation of pathogens from faecal material into watercourses, resulting in increased transmission to animals and humans. This was noted by Nichols

²⁵ This figure is probably in the region of twice as large now based on the recent research by Tam *et al.*, (2011).

et al., 2009, who observed a strong correlation between heavy rain events and drinking water-borne disease outbreaks in England and Wales. Other changes may be associated with de-carbonisation of agriculture to mitigate against greenhouse gas emissions, while changes in rural visit patterns may also have an additional effect on zoonotic transmission (McGuigan *et al.*, 2010).

Drinking water may be contaminated with pathogens before or after treatment from a variety of sources including livestock, feral animals or infected humans present in the catchment (Smith *et al.*, 1995). While chlorination is an effective disinfectant against most water-borne pathogens, *Cryptosporidium* oocysts can remain infectious in the environment for prolonged periods and are resistant to normal drinking water disinfection treatments. Preventing oocyst transmission via physical removal is therefore necessary to reduce potential human exposure.

The water industry and public health agency response to *Cryptosporidium* contamination of municipal drinking water has focussed on establishing effective multiple barrier water treatment systems to eliminate this pathogen from drinking water supplies. Indeed, most public drinking water supplies have effective forms of water treatment capable of significantly reducing the concentration of *Cryptosporidium* in final tap water. These include coagulation, rapid gravity filtration (RGF), dissolved air flotation (DAF) and more recently, membrane filtration (Goh *et al.*, 2005).

Inadequate disinfection and/or filtration of drinking water may expose consumers to a risk of infection from water-borne disease and has previously resulted in large outbreaks of cryptosporidiosis and *Escherichia coli* O157, particularly in North America (MacKenzie *et al.*, 1994; Clark *et al.*, 2003; Olsen *et al.*, 2002). In Scotland for example, there have been several outbreaks of cryptosporidiosis and *E. coli* O157 which have been associated with failures in the treatment of public and private drinking water supplies (Mukherjee, 2002; Licence *et al.*, 2002).

For the UK, the majority of drinking water supplies, especially in major urban areas, have effective forms of water treatment capable of significantly reducing the *Cryptosporidium* load in final drinking water. However, there are a number of rural communities served by drinking water supplies, where current treatment is inadequate at removing *Cryptosporidium* oocysts. This is more prevalent in Scotland where approximately 3% of the population are on a private water supply as opposed to England and Wales where it is less than 2%, and Northern Ireland where it is less than 1%. With these areas commonly frequented by farmed and/or wild animals, which harbour zoonotic pathogens such as verotoxin-producing *Escherichia coli* (VTEC) and *Cryptosporidium*, the risks are high, particularly following periods of heavy rain (Ogden *et al.*, 2001).

In Scotland in particular, there is an intense and disproportionate public interest in the microbial quality of drinking water, largely due to a number of high-profile outbreaks of cryptosporidiosis and incidents resulting in boil water notices (Mukherjee, 2002; NHS Scotland, 2001). However, most cases of zoonotic gastro-intestinal disease are sporadic and private water supply consumers, who are most at risk, perceive that the risk of microbial contamination is low and/or that they have acquired immunity to these pathogens (SGHD, 2009). With water safety programmes in place for public water supplies, rural and private water supplies are most at risk. Considering UKCP09 projections, by the 2020s it is unlikely that the number of cases of cryptosporidiosis or VTEC associated with drinking water should significantly change. For the 2050s and 2080s, projected temperature increases may have a bearing on pathogen survival on land and in drinking water (Chief Medical Officer, 2001). The evidence for this statement however is sparse and it may be that augmented UV effects (see Section 4.6) have a greater effect on pathogen survival (Hader *et al.*, 2011). It is therefore not possible to predict how climate change may affect waterborne disease but given the likely increase in population, it is reasonable to assume that more people may live in

rural environments and drink water from a private water supply which may be contaminated. Furthermore, increased flooding events may result in overflow of sewage discharge where there is bypass of sewage treatment plants therefore recreational use of water may become more of a public health risk. A rise in temperature of water bodies can also result in an increase in various plankton blooms, a number of which are directly or indirectly hazardous to human health. These include Cyanobacteria and *Pfiesteria piscicida* which amongst other things can cause respiratory problems and skin and eye inflammation/irritation. Recreational water use could therefore increase the risk of water-borne diseases in people using inland and coastal waters (Zmirou *et al.*, 2003). However, the epidemiological evidence of infectious disease associated with recreational water contact is limited, and this type of exposure is unlikely to cause a large disease burden in the UK population (Hunter, 2003). The potential for any epidemic outbreak of disease is also considered rare in developed countries such as the UK (Malilay, 1997).

3.3.4 Agricultural contaminants

Humans are potentially exposed to a number of agriculturally derived chemicals and pathogens in the environment (air, soil, water and sediment) by a number of different routes. This not only includes consumption of food (both crops and livestock) exposed to contaminants through the food chain, as well as via groundwater and surface waters used for drinking, but also from direct contact with water bodies or agricultural soils through for example, recreational use (Boxall *et al.*, 2009).

Although attributing health effects due to agricultural contaminants to the general population is often inconclusive, several studies have associated different health outcomes with exposure to chemicals from agriculture. These include Parkinson's disease, linked to exposure to pesticides (Ascherio *et al.*, 2006), and a number of medical disorders linked to chlorophenoxy herbicide exposure (Stillerman *et al.*, 2008). This also includes water borne diseases from the contamination of water supplies with animal waste leading to *Cryptosporidium* transmission, as outlined above.

Apart from the direct impacts of agricultural contaminants on human health, there are also a number of indirect impacts. These are outlined in detail in Boxall *et al.*, 2009), but include:

- A change in the chemical controls used in agriculture, partly linked to changes in abundance and seasonal activity of agricultural pests and diseases (e.g. Bloomfield *et al.*, 2006) as well as the effectiveness of pesticides (Patterson, 1995) is likely to lead to a significant increase and a change in the type of pesticides used.
- Increased temperatures and increased frequency of waterlogged pastures could lead to increased housing of animals resulting in an enhanced need to store and dispose of manures.
- New pathogens, vectors or hosts could lead to increased use of biocides and veterinary medicines (Kemper, 2008).
- Changes in weather (e.g. greater rainfall levels in winter) could result in increased or new pathways between contaminated and uncontaminated areas. This could have implications for residue levels in food crops and animals (e.g. Casteel *et al.*, 2006).
- Projected increased levels of precipitation in the winter will increase the levels of contaminants to water bodies (also see water borne diseases above).

- Estimated lower river flows (Rance *et al.*, 2012) would lead to higher levels of contaminants particularly for rivers draining impermeable catchments. This would threaten effluent dilution, resulting in greater pathogen loading.
- Levels of spray will change as wind speeds change. However, the level is likely to be small, and the direction uncertain as projections of winds over the current century are uncertain, and are unlikely to change noticeably (Sexton and Murphy, 2010).
- Uptake to plants of chemicals from soils is uncertain. Although a projected warmer climate can enhance evapo-transpiration and uptake, any changes will probably be offset by projected increases in levels of carbon dioxide that could reduce the activity of plant stomata and reduce plant transpiration. However, in general, the effect of climate change on plant uptake of chemical contaminants is likely to be small.

Overall, it is likely that under a changing climate, levels of, and subsequent human exposure to agricultural contaminants are likely to increase. A likely increase in the use of pesticides as crop diseases become more prevalent will increase levels of pesticide applied to food items. The transport of pesticides into water bodies is also likely to increase noticeably. In addition, intensification of agriculture is likely to result in increased disease pressures and greater use of antibiotics and disinfectants, which in turn could result in the selection of more antibiotic-resistant pathogens. Changes in climate (e.g. warmer conditions and wetter winters and drier summers), could result in the emergence of new pathogens, or the increased incidence of existing diseases. Although existing drinking water treatment and monitoring will likely prevent high human exposure levels, human exposure to pathogens in food items may increase, although the magnitude of this increase will be highly dependent on the contaminant type. Changes in the UK agricultural environment due to climate change can, however, be managed for the most part, and it is likely that there will not be a seriously increased risk for human health.

3.3.5 Pollen and allergens

Higher temperatures may cause an earlier and possibly longer pollen season. More days with high pollen concentrations would result in more people with hay fever and pollen asthma (Sommer *et al.*, 2009). The effects of climate change, including increased levels of CO₂ and changes in plant distribution through range shifts and invasions (see Knox *et al.*, 2012, Moffat *et al.*, 2012 and Brown *et al.*, 2012) as well as the introduction of new and/or novel crops could affect the exposure of the population to aeroallergens and increase sensitisation. Increased exposure to aeroallergens (which would vary regionally) may increase the likelihood of developing allergic rhinitis or asthma in sensitised individuals and an aggravation in patients already symptomatic.

A longer pollen season, and changes to the distribution of plant species noted above may also result in changes to pollen related food allergies. Some food allergies (especially fruits) are linked to pollen allergy (either because of similarities between the proteins in the pollen and in the fruit or from the association between birch tree pollen allergy and some food allergies). If there are more, or more-prolonged periods, of pollen production, then there is a risk of more people developing related food allergies linked to plant-derived foods such as apples, stone fruits, celery, carrot, nuts and soybeans (Vieths *et al.*, 2002; Geroldinger-Simic *et al.*, 2011).

However, there is currently insufficient quantitative evidence for establishing the impact of climate change on aeroallergens including pollen and the associated risks for public health and NHS service in the UK.

3.3.6 Winter air pollution

Winter air pollution episodes are likely to decline in frequency and intensity partly as a result of warmer temperatures. Higher winter temperatures are expected to result in reduced atmospheric stability and consequently less air pollution stagnation events. Although warmer and potentially windier winters are likely to result in a reduction in winter air pollution, projections of winds over the current century are uncertain and are unlikely to change noticeably (Sexton and Murphy, 2010). The likely decrease in winter air pollution episodes will be associated with a proportional decrease in mortality and morbidity (Anderson *et al.*, 2008).

Apart from climatic effects, winter air pollution episodes are also likely to further decline due to projected reductions in atmospheric emissions (e.g. traffic-related) of particulate matter (PM₁₀), nitrogen oxides (NO_x) and Volatile Organic Compounds (VOCs) due to future tightening of both fuel and vehicle emission legislation. The effect of the projected changes in atmospheric emission on winter air pollution is likely to be much larger than any effects associated with changing climatic conditions.

3.3.7 Demand for respiratory, mental health and emergency medicine

Emergency medicine will very likely experience a large change in demand for its services over and above current annual levels as a result of climate change. This is likely to result in an increase in levels and variety of demand during extreme weather events, such as floods and heatwaves. Climate change may affect the prevalence and severity of allergic and respiratory illness through increases in the frequency, spatial distribution and concentrations of airborne allergens (Schmier and Ebi, 2009). Other expected health effects include heat related illness such as respiratory illnesses (Patz *et al.*, 2005), ischaemic heart disease and cerebro-vascular disease (Hassi *et al.*, 2005). In addition, there will likely be an amplification of weather-related disease patterns and shifts in their distribution, as well as likely increases in water and food borne diseases (Hess *et al.*, 2009). This will result in an increase in pre-hospital care activities (primary health care services) as well as a likely increased pressure on emergency medical services, particularly during extreme weather events.

Anxiety and depression associated with population displacement (e.g. due to flooding), and indirect health effects from interruptions of medical and psychiatric care, are also major concerns (Hess *et al.*, 2009). Health effects will vary by region and will disproportionately affect certain populations, particularly the elderly and young, those with pre-existing medical conditions, and the socially and economically marginalized. Patients with mental health concerns, particularly exacerbations of psychiatric disease, have an increased vulnerability to the hazardous exposures associated with climate change, not only from their diminished capacity but also as a result of increased psychotropic medication use, several classes of which predispose patients to heat-related illness and death via sweating impairment (Hess *et al.*, 2009).

3.3.8 Medicine efficacy

Manufactured drugs are in general licensed for storage at temperatures up to 25°C (US Pharmacopeia, 2000). During emergency use, these medicines are often stored in cupboards or bags for use on home visits (Crichton, 2004), and in a potential warmer climate, could be exposed to temperatures greater than this limit, more often, and for greater periods of time.

Based on an assessment of storage of medicines during an English heatwave between 4 to 15 August 2003, medicines were noted to be routinely exposed to temperatures above 25°C, and little attempt was made to control storage temperatures of medicines (Crichton, 2004). This could have consequences for the efficacy of medicines. For example, the capsules of certain brands of cefalexin degrade rapidly in hot conditions, and this can cause serious fluctuations in absorption (Molokhia, 1984). Ampicillin, erythromycin, furosemide for injection and benzilpenicillin can also significantly reduce their efficacy when stored for long periods at high temperatures, as well as aspirin and diclofenac tablets (Ballereau *et al.*, 1997 and Risha *et al.*, 2003).

3.3.9 Algal / fungal growth in buildings

The increased frequency of extreme weather events associated with climate change can lead to higher occurrence of mould indoors by producing favourable conditions for mould growth. The combination of damp damage due to flooding of domiciles and increasing temperatures can result in favourable conditions for mould to proliferate in the built environment (Burge, 2002) and can become a health hazard for both returning residents and remediation workers (Ratard, 2006; Bloom *et al.*, 2009). The chemical and biological content of flood water and properties of construction materials used in buildings determine the extent of the health risk presented due to algal and fungal growth in buildings following flooding (Taylor *et al.*, 2011). The ability to control indoor temperature, humidity and ventilation are the key factors in reducing fungal spore levels and improving indoor air quality.

3.3.10 Infrastructure failure

Transport, communications and power generation infrastructure may be compromised during extreme weather events such as floods, storms and heatwaves (Defra 2011, Royal Academy of Engineering 2011). NHS infrastructure could also be directly affected by floods, storms and heatwaves. For example, IT server overheating and disruption to email communication may occur in PCTs and hospitals during heatwaves. Such incidents could seriously compromise access to NHS services. Healthcare delivery will rely in part on the adaptive capacity of hospital infrastructure that is required to respond to the predicted physical and health-related impacts of climate change (Loosemore *et al.*, 2011).

3.3.11 Building maintenance

Building maintenance work usually carried out during summer time may be disrupted due to more frequent and intense heatwaves. This could disrupt NHS property maintenance and affect the delivery of related services. Thermal comfort for patients and staff could be adversely affected.

3.3.12 NHS property damage

There is a risk that current NHS infrastructure, including hospitals, may not be resilient to climate change and related extreme weather events. Floods in particular could cause substantial disruption to NHS services as 7% of hospitals and 9% of surgeries and health centres in England are built in flood risk areas (Environment Agency, 2009). Heatwaves may also cause disruption to the health care sector if indoor temperatures in hospitals and care homes are not appropriately controlled.

3.3.13 Transport network failure

There are a number of climate factors which are likely to impact on the operation of the national transport network. In winter, adverse conditions associated with wetter weather and increased incidence of flooding could lead to disruption to the operation of road and rail networks and airports. Landslides may increase in future, in association with increased rainfall, and this could provide obstructions for transport networks (Arkell and Darch, 2006). The potential for road traffic accidents may increase during periods of heavy rain in the future. Sea level rise and coastal flooding could impact adversely on shipping operations. During summer, increased temperatures are likely to affect the transport network, through incidence of vehicle overheating on roads and damage to road surfaces, which could cause congestion; and heat-related damage to railway infrastructure could causing delays and cancellations (Chapman *et al.*, 2008).

It is possible that potentially warmer winters in future might lead to decreased risk of transport network disruption due to ice and snow. There would also be fewer road traffic accidents associated with warmer winters in future due to smaller snow and ice amounts, although cold weather impacts are likely to continue to affect transport networks in the UK significantly for the foreseeable future (Defra, 2011). The impact of climate change on the transport sector is addressed in detail in the transport sector risk assessment report (Thornes *et al.*, 2012).

3.3.14 Traffic accidents

A future changing climate is likely to have an effect on the number of traffic accidents as a result of a number of factors, the main ones of which are outlined below. On the Cabinet Offices' National Risk Register (Cabinet Office, 2008) this impact is highlighted as a medium relative impact of low relative magnitude.

- Warmer weather
 - This is likely to lead to more vehicle breakdowns due to overheating of engines with resultant disruption to travel (Cabinet Office, 2008).
 - Increased wear and tear of road surfaces (Cabinet Office, 2008).
- Wetter winters
 - Greater and more intense rainfall levels in winter will lead to an increased risk of traffic accidents due to reduced visibility leading to more difficult driving conditions, as well as localised flood areas as a result of low areas and/or an overwhelmed drainage system.
- Drier summers
 - Drier summers will increase the risk of landslide, with a subsequent increase in risk to transport links, as well as directly, traffic accidents (Thornes *et al.*, 2012).
- Greater sea levels / wave heights
 - An increase in mean sea levels will result in more regular coastal flooding and erosion, and flooding to greater depths and volumes. Combined with greater wave activity nearshore, this will increase the risk to traffic accidents for coastal roads due to flooding, erosion, and impact by overtopping waves (Ramsbottom *et al.*, 2012).
- Mist / Fog
 - An increase in levels of mist or fog will increase the potential for more traffic accidents. However, currently it is not known whether levels of

mist or fog are likely to increase or decrease as a result of climate change, and by how much.

- Frost / Snow
 - Higher temperatures in the colder months will result in reduced periods of icy conditions as well as less periods when visibility is reduced by ice/condensation on windscreens. Combined with reductions in snowfall, which are projected to reduce by 80-95% in most parts of the UK by the 2080s under the medium emissions scenario (Jenkins *et al.*, 2009), traffic accidents would be expected to reduce due to frost and snow.
- Winds / Storms
 - There are currently about six wind-associated deaths in the UK, with approximately 150 non-fatal injuries, a large proportion of which are associated with traffic accidents. However, projected changes in wind speeds and storms are uncertain, but likely to show little change. It is likely therefore that the change in risk due to winds/storms in the future is likely to be small.

3.3.15 NHS staff performance

NHS staff performance may be compromised during extreme weather events. Particularly during heatwaves, NHS staff may underperform if indoor temperatures are not appropriately controlled. Floods may also affect negatively the ability to get to work and the performance of NHS staff who live or work in flood risk areas. IT equipment and power failures due to extreme weather will also compromise NHS staff performance.

3.3.16 Patient recovery rates

Patient recovery may be compromised during extreme weather events, particularly during heatwaves, if indoor temperatures in hospitals and care homes are not appropriately controlled.

3.3.17 Social disruption

Mental stress, violent behaviour and suicides increase during hot weather (Page *et al.*, 2007). Death from cocaine overdose is more likely on hot days (Marzuk *et al.*, 1998), as well as ambient temperature and heat waves are strongly correlated with increases in violent crime and associated injuries (Anderson, 1987). Longer and warmer summers will encourage more outdoor activity, more recreational alcohol consumption, and the potential for more violence in the future.

Increased night-time temperatures can also lead to heat stress and sleep deprivation, with a potential increase in social unrest. This is particularly the case in urban areas where the Urban Heat Island effect can raise night-time temperatures significantly (Capon and Oakley, 2012).

3.3.18 Healthy eating

Health risks related to the safety and availability of imported and locally produced foods may increase. Food standards in exporting countries could become compromised due

to climate change pressures. Shortages and high prices of imported healthy foods (fruits and vegetables) may affect the diet of the UK population, potentially exacerbating health inequalities.

3.3.19 Increased outdoor activity

Working, exercising or playing outdoors during extreme weather events such as heatwaves, floods and windstorms will increase the health risks for those exposed. These may be construction workers, people exercising regularly outdoors (sports persons and amateur athletes), and young children who could be adversely affected by heat stress, and higher ozone and pollen levels. Commuters and professional drivers will also be negatively affected by high temperatures, increased air pollution and flooding events. This could exacerbate the prevalence and severity of allergic and respiratory disorders, including childhood asthma. It is reasonable to expect increased numbers of people spending recreational time outdoors during warmer summer weather in the future, which would increase exposure to heat, air pollution and UV radiation. The main health impacts of this are likely to include respiratory and cardiovascular effects due to air pollution and heat exhaustion, sunstroke and sunburn. However, there will also be a number of health benefits linked to a healthier lifestyle, and exposure to cleaner air in countryside locations and a resultant positive contribution to human well being, as well as increased exposure affecting vitamin D levels. People most at risk of adverse health effects would be those exercising or working outdoors during high temperatures. Warmer weather may lead to increased swimming and bathing outdoors, which could lead to more exposure to water borne disease, although there would be benefits of increased physical activity. There is also a risk of exposure to infectious diseases, and high UV levels resulting from more overseas travel in the future.

3.3.20 Mobile care and support services

Mobile care and support services include ambulances, transportation of patients and organs, and visits by NHS staff. Potential problems in the future will be mainly due to transport network and infrastructure problems and traffic accidents. Adverse weather conditions such as flooding could also increase disruption to mobile support services and could endanger lives and limit the supply of medicines and the delivery of urgent health care to patients.

Ambulance response times can be adversely affected by severe weather. In December 2010 all ambulance trusts in England (and in Scotland, Wales and Northern Ireland) failed to meet NHS targets. Category A ambulance calls, which include the most serious life-threatening conditions, have a target of 75% within an eight minute response time. In December 2010 the average was only 62% with one region only achieving 49%. Statistics on response times are published annually by the NHS (National Audit Office, 2011), and further research is required to assess the impact of different severe weather incidents on response times.

3.4 Cross sectoral impacts

There are a number of cross-sectoral impacts identified via the systematic mapping (step 2, Section 2.3) that showed linkages to the health sector. The largest numbers of these are linked to four main impacts which were noted as:

- Human illness or morbidity

- Includes a number of impacts linked to various diseases, pollution, contamination, air quality, mental health, etc.
- Conflict
 - Conflict caused by a number of issues including changes to supplies of water or food, oil, environmental conditions, construction activities, weather disruption, flood risk etc.
- Death or injury
 - Change in the number of deaths or injuries due to changes in weather conditions as well as consequential effects such as changes to flood risks and traffic accidents etc.
- A changed demand for health care services
 - A change in the numbers and/or levels of illness, death, injury or morbidity will have a consequential impact on the demand for health care services.

In addition, there are a number of consequential impacts related to these impacts that impact across other sectors. The most obvious of these are within the Business/Industry/Services sector, where an increase in levels of illness, morbidity, death or injury for example will have a noticeable impact on the workforce as well as other areas such as the tourism sector.

The main linkages to these four impacts are given below. The systematic maps for these four impacts for the health sector are given in Appendix 4.

Human illness or morbidity

There are a number of cross-sectoral impacts identified that could have an impact on levels of human illness or morbidity, and these are outlined below:

- A change to the natural environment, including forestry regions would probably change levels of outdoor activity. This could either increase or reduce outdoor activity, leading to levels of change in human wellbeing, as well as levels of exposure to UV radiation and vitamin D. These cross sectoral impacts were identified via a number of sectors including Forestry and Biodiversity.
- A reduction in the survival of new trees could reduce the green space effectiveness of urban areas, reducing the cooling effect as well as feelings of wellbeing. This was mainly identified within the Built Environment sector, but was also linked to the Forestry and Biodiversity sectors.
- Changes to plant growth would affect levels of outdoor activity with the same consequences as outlined above. This was identified by the Agriculture sector, as well as the Biodiversity and Forestry sectors.
- An increase in sea temperatures would increase water based activities and outdoor activity with the same consequences as outlined above. This would also increase the risk of exposure to non native species that are anticipated to be more prevalent in a changing climate. This was identified within the Marine and Fisheries sector.
- A change in the levels of volatile organic compounds would lead to a change in the quality of outdoor air. This was identified within the Business/Industry/Services sector, although it has been identified as an impact across a range of sectors (Built Environment, Forestry etc).

- Changes in levels of runoff or storm activity would change levels of contaminant mobilisation, and hence potential pollution levels. This was identified within the Built Environment sector.
- There is projected to be an increase in urban heat, increasing risk of heat stress. This was identified within the Built Environment sector.
- A projected increase in the water penetration of buildings leading to an increase in pests and moulds would increase levels of human illness or morbidity. This was identified within the Built Environment sector.

Conflict

Most direct consequences of climate drivers were noted to lead to the potential for a potential “change” in levels of conflict. The most noticeable of these were in relation to flooding (identified across most sectors), but could also include a change in levels of airborne dust from the Built Environment sector as well the number of convective storms leading to an increased frequency of lightning strikes, as identified by the Energy sector.

Human death/injury

A general increase in levels of flooding from all sources, as well as lightning strikes identified above would be expected to increase the risk of human death or illness. These were identified across most sectors.

Demand for health care service

Although no additional cross-sectoral impacts were identified for this impact across all sectors, the large number of cross-sectoral impacts noted above as a result of a changed risk to human health, or risk of death or injury all had a consequential impact of a changed demand on health care services. This was noted for several sectors, but was covered within the health sector.

3.5 Health risk metrics assessed in other reports

In addition to the impacts assessed as part of the health sector, a number of other sectors include metrics that are linked to the health sector. These relevant metrics are listed in Table 3.3, with further details of these impacts and the assessment carried out below.

Table 3.3 Climate change impacts in other sectors that are linked to health

Sector	Tier 2 impact	Risk metric
Built Environment	BE1 – Urban heat island effect	Qualitative assessment based on change in mean average minimum summer temperature
Built Environment	BE3 – Overheating of buildings	The number of days for which the maximum external air temperature reaches or exceeds 26°C
Built Environment	BE5 – Effectiveness of green space	Total area of green space to change in relative aridity
Built Environment	BE9 – Demand for heating	Variation in household space heating energy demand with change in heating degree days

Sector	Tier 2 impact	Risk metric
Business, Industry and Services	BU10 – Loss of staff hours due to high internal building temperatures	Fall in productivity relative to the variation in temperature above 26°C
Energy	EN2 – Cooling demand	Demand response against temperature
Floods and Coastal Erosion	FL12 – Number of hospitals at significant risk of flooding	Change in risk due to change in fluvial and/or coastal flood probabilities
Marine	MA1a – Harmful algal blooms	Incidents of non-compliance with EC Directives
Marine	MA1b – Disease hosts and pathogens (water quality)	Water Quality in shellfish waters
Marine	MA1 – Disease hosts and pathogens (human illness)	Incidents of related human illness
Water	WA6 – Population affected by a supply-demand deficit	Supply demand balance models

3.5.1 BE1 – Urban heat island effect

The existence of the Urban Heat Island (UHI) effect within cities is now well established as a result of temperature monitoring in and around cities, and the temperature at the centre of a large city can be several degrees higher than in the surrounding rural areas. Several factors contribute to the development of this urban microclimate, which is likely to become more pronounced due to increasing temperatures associated with climate change. There is greater absorption and storage of short-wave solar radiation by the urban fabric during the day. This energy is then re-emitted at night as long-wave radiation. Surface water from rainfall is normally drained away and is therefore not available for evaporative cooling in paved areas. Anthropogenic heat emissions, such as exhaust air from air-conditioning systems, also act to increase the local air temperature in densely populated city centres. The UHI effect is most pronounced at night, which means that during heatwaves, there can be little relief from raised temperatures in urban areas (Tomlinson *et al.*, 2011). Over prolonged periods of hot weather, this can have an impact on health, particularly in vulnerable populations.

During the August 2003 heatwave, temperatures in central London were noted to be 10°C higher than that in surrounding rural areas. This heatwave led to large number of excess deaths in the UK, the greatest proportion of which occurred in southern England, with a particularly high death rate in London. (There was far greater loss of life in Paris and elsewhere in Europe). By the 2050s, such hot summers are projected to be much more frequent events, occurring perhaps every 2 to 3 years (Stott *et al.*, 2004).

Although external temperatures are higher within the Urban Heat Island, increasing the risk of building overheating, green and blue infrastructure can help cool urban areas. Thus the UHI effect is closely linked to both building overheating and to the availability and effectiveness of urban green space.

3.5.2 BE3 – Overheating of buildings

Historically within the UK, building design has been driven by the need for indoor thermal comfort in winter and more recently, by a desire for winter energy efficiency. Overheating and indoor thermal comfort in summer has not been regarded as a problem. This is in contrast to other regions of the world, such as the Mediterranean, where the vernacular architecture is adapted to minimize the impact of summer temperatures, through the use of small windows, exposed thermal mass and external shading devices.

Overheating risk depends partly on climatic factors, primarily external temperature and incident solar radiation. Hence there is a geographical variation; the risk in central Scotland is lower than in south-east England. Within dense urban areas, the risk of overheating is further exacerbated by the Urban Heat Island effect, which increases external temperatures. Increasing temperatures and a higher incidence of summer heatwaves due to climate change would increase the risk of building overheating.

The risk of overheating also varies considerably from building to building, as well as with position within a building. The internal performance of a building during hot weather depends on multiple factors such as orientation, air-tightness, insulation, thermal mass, ventilation strategy and whether the façade is shaded or highly glazed.

There is evidence that some types of building, such as highly insulated lightweight buildings and buildings with heavily glazed facades, are already vulnerable to summer overheating. Without planned adaptation to implement appropriate passive cooling measures, there is the further risk that the Urban Heat Island effect and the resulting building overheating would be exacerbated by widespread use of air-conditioning.

At home, the general effects on people of building overheating are likely to be increases in discomfort and difficulty in sleeping. Elsewhere, building overheating will make working conditions uncomfortable, leading to a reduction in productivity. This would affect commercial buildings including offices and other types of buildings, for example schools and hospitals.

3.5.3 BE5 – Effectiveness of green space

Green and blue infrastructure, such as parks, open spaces, rivers and water bodies, has a dual function in combating the Urban Heat Island effect. Firstly their inherent cooling, and for green infrastructure, shading capacity reduces the heat vulnerability of the surrounding area. Secondly, it provides valuable climate refuges, to which local residents can go for temporary respite from extreme heat. There is also an important association between access to green spaces and better mental and physical health (Department of Health Heatwave Plan for England).

Green infrastructure can take many forms from large open spaces such as parks to smaller scale features such as domestic gardens and street trees. In recent hot summers, drying out of green space has been observed, for example the parched grassland in Hyde Park in 2006. Under prolonged hot, dry conditions, evapo-transpiration of the green space slows down, eventually shutting down if the vegetation becomes completely parched. Consequently, the cooling effect of the green space is effectively switched off. Without planned adaptation, this could become an ever more frequent occurrence as summers become hotter and drier. This has clear consequences for the Urban Heat Island and overheating, and subsequent human health effects.

3.5.4 BE9 – Demand for heating

Currently, winter energy efficiency is the focus of both new-build design and retrofit/refurbishment programs, such as the Carbon Emissions Reduction Target (CERT) programme and the “Warm Front” scheme. However, with future warmer winters, a reduction in heating demand is expected. This will reduce the risk to the vulnerable members of society, with a likely reduction in levels of winter morbidity and mortality with a consequential reduction in demand on health and social care services. Reductions in energy demands for heating is likely to have a positive effect on local air quality during winter as less power production is required locally. Potential problems in delivering energy supplies to the public could occur if infrastructure is damaged by adverse weather such as flooding in the future (Defra, 2011). This could impact on cold related health impacts if heating demands are not met in vulnerable populations.

3.5.5 BU10 – Loss of staff hours due to high internal building temperatures

Changes in climate will clearly influence both the heating and cooling energy demand within buildings. Modern factory buildings are more vulnerable to climate change as a result of their design characteristics, through increased ambient air temperatures, and reduced cloud cover (increasing UV radiation), as well as heat created by plant and machinery and IT equipment and lighting. In the specific case of cooling requirements, longer, drier summer periods may cause overheating in naturally ventilated buildings and affect the capacity of low energy cooling systems to provide comfortable conditions across all building types. These changes may have knock-on implications for worker health and safety and cause increased absenteeism, as well as reduced productivity and product quality.

3.5.6 EN2 – Cooling demand

Temperatures are confidently expected to rise and hence the demand for cooling (for air conditioning, IT infrastructure) can be expected to also rise. In some cases this can be offset by other means, such as building design, but the scope of this is limited due to existing building stock.

The demand for cooling could have significant impacts for society if it is not met. This was demonstrated for example by the heatwave of 2003, which claimed a large number of lives across Europe largely as a result of vulnerable people being unable to keep cool. Similar to impact BU10 above, failure to meet cooling demand could also have implications for worker health and safety and increased absenteeism, as well as reduced productivity and product quality.

3.5.7 FL12 – Number of hospitals at significant risk of flooding

As winter rainfall is likely to increase and mean sea levels are projected to rise, the risk of fluvial and coastal flooding will increase. This will raise the probability of flooding to individual properties, including hospitals. At present, the Environment Agency estimates that 7% of hospitals and 9% of surgeries and health centres are built in flood risk areas (Environment Agency, 2009). As levels of flooding also rise, hospitals not previously at risk of flooding may enter the flood risk zone increasing the number of properties considered to be at a significant risk of flooding. Potential health impacts associated with increased flood risks for hospitals include the disruption associated with moving patients to safer buildings, reduced recovery time, increased time to reach

operational hospitals in emergency situations, and power failures. As well as the hospital infrastructure being affected by flooding, transport problems may lead to staff shortages, and energy supplies may be affected.

3.5.8 MA1a – Harmful algal blooms

Harmful Algal blooms (HABs) via their toxins can cause the deaths of fish, sea birds, marine mammals and humans. Economically they have the potential to render shellfish unfit for human consumption if they are exposed to them. They are also important in relation to bathing water quality and tourism.

During recent years there has been an apparent increase in the occurrence of HABs in many marine and coastal regions (FAO, 2006). Around the UK and Ireland, a strong regional distribution has been observed for toxic HAB species and impacts which are more regularly detected along the Irish South and West coasts and in Scotland. Such observations raise concerns over the potential for increased HABs within UK waters.

Climate change has the potential to heighten the incidence of HABs in UK waters via a number of different biophysical drivers, and changing future societies in terms of population, wealth or value systems may impact upon HABs either reducing or exacerbating effects. For example, increasing populations may place greater pressure on existing sewage and runoff systems causing increased nutrient runoff in coastal waters and therefore frequency of HAB blooms.

3.5.9 MA1b – Disease hosts and pathogens

Effect on water quality

Projected changes in rainfall patterns and temperature pose significant problems for the occurrence of microbial pathogens (e.g. viruses, bacteria, protozoa) in the marine environment and this could have an effect on human health. Climate change driven heightened precipitation events (i.e. flash flooding) increases the risk of waterborne disease outbreaks; also increases in water related pathogens may relate to warmer summer temperatures (Murphy *et al.*, 2009).

This may increase the occurrence of water-borne disease outbreaks in the UK (see Section 3.3.3), including cases of gastrointestinal and respiratory illness, ear and wound infections which have been reported following bathing (Fleisher *et al.*, 1996 and Oliver, 2005).

Effects on human illness

Vibrio vulnificus and *Vibrio parahaemolyticus* infections are currently not frequently reported either in the UK or in Europe (European Commission Health & Consumer Protection Directorate-General, 2001), but there is increasing evidence to suggest that the frequency of reporting and illness is increasing coincident with sustained periods of warming (Baker-Austin *et al.*, 2009 and Martinez-Urtaza *et al.*, 2010). *V. parahaemolyticus* causes acute Gastroenteritis. It is highly dependent on seawater temperature with rapid proliferation occurring at seawater temperatures above 16°C. UKCP09 models suggest increasing sea temperature of several degrees in the coming decades. Sustained warming events (>20°C) are the most significant risk factor associated with *Vibrio* outbreaks.

Studies at the Centre for Environment, Fisheries and Aquaculture Science (Cefas) show pathogenic *V. parahaemolyticus* is present in seafood from the UK during summer months. The frequency and seriousness of these isolations is increasing.

Increasing temperatures are virtually certain to also increase the range and prevalence of *V. vulnificus* and other marine *Vibrio* species in the UK. Infections of *V. vulnificus* are currently rare (less than 100 per year in the USA), but carry highest mortality rates of any bacterial pathogen - if treatment is delayed more than 36 hours then the mortality rate is 100%.

3.5.10 WA6 – Population affected by a supply-demand deficit

The impacts of climate change on water supply-demand deficits (when water resource zones fall into deficit) and the population affected is assessed as part of the Water sector analysis (see Rance *et al.*, 2012). To address these deficits, demand or supply-side management measures need to be implemented. In very extreme cases demand-side measures may be introduced (e.g. the use of standpipes) which result in the disruption of water supplies to homes and businesses. This could subsequently have health implications, particularly for vulnerable groups including those that require large amounts of water for a medical condition, the elderly, the ill and the very young.

As well as households, public services such as schools and hospitals are large users of water from public water supply. Any disruption of supply for these essential services would have significant consequences, and maintaining these supplies is a priority in water company drought plans and emergency plans.

4 Sector Risk Analysis

4.1 Introduction

This section considers the change in risk for each impact considered in the health sector. Response functions have been determined for each impact based on current and ongoing research in these areas. This indicates how an impact is likely to change based on changes in (for example) mean temperatures and mean changes in sea levels. Although there has been an aim to produce response functions to a climate variable, in some cases such as changes in summer air pollution due to ozone, it is not possible to have a direct response function related to any climate variable. In these cases, expert elicitation and published reports have been used to investigate the future response of the selected risks to a changing climate. Consequence functions for heat and cold mortality as well as morbidity have been presented together due to the similarity of the response functions and the analysis techniques.

Extreme weather event flooding (flooding and storms) injuries²⁶ was initially excluded from this assessment (Section 3.2.9), as it was considered too difficult to assess. However, a review of available data on flood injuries and results presented in the Flood Risks to People research (Defra/Environment Agency, 2003 and 2006) indicated that a simple relationship between flood related mortality and injuries could provide a high level estimate. This has therefore been used in this study.

Based on the response functions defined, the UKCP09 projections have been applied to the response functions to indicate the likely change in the 2020s, 2050s and 2080s under the current population and the low, principal and high population changes (see Office for National Statistics, 2009). These have been applied for the current socio-economic baseline and three different emission scenarios (see below). A detailed assessment of future changes in the age distribution of the population, the main socio-economic effect for health apart from population, has not been carried out, although the additional socio-economic factors that affect each metric are outlined as appropriate in each section.

The UKCP09 low, medium and high emissions scenario projections were considered at the 10%, 50% and 90% probability levels (p_{10} , p_{50} and p_{90}) for each risk for the 2050s and the 2080s. In addition, the medium emission scenario was considered for the 2020s at the same probability levels (see Section 2.6).

The UKCP09 variable projections considered in this report are:

- Changes in mean annual temperature (degrees Celsius)
- Projections of regional changes in mean sea levels (taking into account isostatic rebound)
- Change in seasonal average precipitation
- Changes in mean annual net surface shortwave and long wave flux.

²⁶ No formal agreed definition appears to be given in relation to extreme event injuries. For the basis of this report therefore this is defined as the number of injuries sustained during an event that requires medical attention from a hospital admission.

For each metric a scorecard is given at the start of each section to indicate the confidence in the estimates given and the level of risk or opportunity. Confidence is assessed as high (H), medium (M) or low (L). Risks and opportunities are scored either high (3) medium (2) or low (1) (shown to the right). These are given for the lower (l), central (c) and upper (u) estimates for the 2020s, 2050s and 2080s. Further information is provided in Appendix 3. Where estimates are uncertain, or no data is available, this is stated in the scorecard.

M	Confidence assessment from high (H) to low (L)
3	High opportunity (positive)
2	Medium opportunity (positive)
1	Low opportunity (positive)
1	Low risk (negative)
2	Medium risk (negative)
3	High risk (negative)

4.2 HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)

4.2.1 Introduction

This analysis is mainly based on two papers, Hajat *et al.*, (2007) who considered both heat and cold related deaths over the period 1993-2003, and Armstrong *et al.*, (2010) who considered just heat related deaths over the period 1993-2006. Both papers considered an epidemiological time series of daily mortality rates and daily mean or maximum temperatures for the ten government administrative regions for England and Wales (shown in Appendix 7, Figure A7.1). Armstrong *et al.*, (2010) also showed how the exposure-response functions developed could be extended to cover locations (e.g. Scotland and Northern Ireland) where no response functions exist.

Based on the analysis carried out, both Hajat *et al.*, (2007) and Armstrong *et al.*, (2010) presented regional current-day exposure-response functions (including confidence bands) linking excess daily mortality (heat related), or premature deaths, correlated against daily mean or maximum temperature, population and a baseline mortality rate for each region. Hajat *et al.*, (2007) also showed the same relationship for cold related mortality, or premature deaths avoided.

For this analysis, it is assumed that these current-day exposure-response functions do not change over the rest of the century, as there is insufficient published evidence on the effects of autonomous and planned adaptation on temperature-related mortality.

4.2.2 Methodology

Hajat *et al.*, (2007) obtained data on all deaths recorded between 1993 and 2003 for all regions of England and Wales from the Office for National Statistics, with postcode information on the death certificate used to link the deaths to 2001 census output areas.

Linking these records to coincident mean temperature daily time series for a representative location for each region (available from the British Atmospheric Data Centre) enabled investigations to be made on sub-groups of people to highlight whether certain groups were at increased risk due to exposure to hot or cold weather. Daily ambient levels of PM₁₀ and ozone and weekly reports of laboratory confirmed influenza A and influenza B activity were also collected from the National Air Quality

Monitoring Network and the Centre of Infection at the Health Protection Agency respectively and incorporated into the regression models so as to eliminate short term effect between temperature and mortality due to air pollution levels and influenza epidemics.

The heat relationship was modelled using temperatures correlated against deaths on the same day, and the day before death (0-1 day lag). The cold relationship was modelled using temperatures correlated against deaths on the same day, and up to 13 days later (0-13 day lag). This is because the effects of low temperatures can be more delayed than for high temperatures (Braga *et al.*, 2001).

The analysis of Hajat *et al.*, (2007) was repeated for heat by Armstrong *et al.*, (2010) who extended the data set analysed to 2006 and also investigated the combined effect of humidity and temperature on heat stress. However, Armstrong *et al.*, (2010) did not consider the effects of air pollution or influenza epidemics considered by Hajat *et al.*, (2007). They also considered a four month summer period of June to September.

Both studies modelled the effects of temperature by a linear threshold model, indicating a log-linear increase in risk above or below respective thresholds for heat and cold. However, the choice of heat threshold varied between papers with Hajat *et al.*, (2007) taking the threshold at the 95th percentile of daily mean temperature and Armstrong *et al.*, (2010) at the 93rd percentile of daily mean temperature²⁷. The selection of the threshold affects the resultant slopes, with the higher threshold of Hajat *et al.*, (2007) generally resulting in steeper slopes²⁸. Hajat *et al.*, (2007) took a cold threshold at the 5th percentile of daily mean temperature. This indicated an approximate log-linear relationship with risk below this threshold.

4.2.3 Linear Threshold Model

Linear threshold models were used by both Hajat *et al.*, (2007) and Armstrong *et al.*, (2010) to model heat and (cold effects) and involved the fitting of a log-linear increase in risk above (or below) a threshold. This is a well established epidemiological methodology in the assessment of heat and cold related deaths, as demonstrated for example in Curriero *et al.*, (2002), Hajat *et al.*, (2007) and Knowlton *et al.*, (2007).

This gives a relative risk (*RR*), defined as the ratio of deaths that occur under a heat or cold effect relative to the baseline mortality rate as:

$$RR = \exp(b\Delta T) \quad (4.1)$$

where:

b = heat/cold exposure response slope

ΔT = difference between mean daily temperature and threshold

Hajat *et al.*, (2007) investigating the effects of heat and cold related deaths indicated that the regional threshold for heat was at the 95th percentile of the mean daily temperature (with a 0-1 day lag), and for cold at the 5th percentile of the mean daily temperature (with a 0-13 day lag). Further work by Armstrong *et al.*, (2010) on a summer period of June to September indicated that the regional heat threshold was at the 93rd percentile. Less published evidence is available on the cold threshold for all cause mortality, with Keatinge *et al.*, (1997) using a threshold of 18°C for London and

²⁷ Thresholds refer to the full year daily time series, not just summer (or winter) months.

²⁸ The "slope" gives a measure of the change in relative risk above (heat) or below (cold) the threshold for a one degree change in temperature. It is approximately linear for small increases (or decreases) above (or below) the threshold, within about 5% for a 2°C increase (or decrease) above (or below) the threshold.

Donaldson *et al.*, (2002) a single threshold of 15.6°C for the whole UK. To maintain consistency within the analysis, the methodology for heat and cold related mortality defined by Hajat *et al.*, (2007) was initially used in this study. However, the 5th percentile threshold (Hajat *et al.*, 2007) which corresponds to mean daily temperatures of 1.8-4.3°C in different UK regions was considered too low²⁹ and therefore cold related mortality was recalculated for a range of 60th-90th temperature percentiles (corresponding to regional temperatures of 9.6-18.7°C). In addition, a full sensitivity analysis of the effect of threshold on cold related mortality was carried out, Section 4.2.7.1. Based on equation (4.1), the heat and cold related mortality risks used in this study were given by equation (4.2) below. The baseline figures are given in Appendix 6, Table A6.4.

$$D = \left(\frac{P}{100,000} \right) * M * ERC \quad (4.2)$$

where:

D	=	heat/cold related deaths
P	=	population
M	=	baseline non-accidental mortality rate per 100,000 of population
ERC	=	exposure response coefficient of mortality for a given change in same-day temperature exposure

$$ERC = \exp(b\Delta T) - 1 \quad (4.3)$$

Baseline non-accidental mortality was based on version 10 of the International Classification of Diseases (ICD10), WHO (2010) for mortality since 2001, and version 9 (ICD9) before this date (see Appendix 6, Table A6.1). These baseline figures for each region are given in Appendix 6, Tables A6.4. The heat and cold slopes for England and Wales are given in Appendix 6, Tables A6.2 and A6.3.

There are a number of key assumptions in relation to the linear threshold models, and these are outlined below:

- The regional heat and cold-related mortality thresholds and exposure-response coefficients have been assumed to remain unchanged in the future. This is of course a simplifying assumption since regional populations are likely to partially acclimatise to generally increasing temperatures through gradual physiological and planned adaptation (increased use of air conditioning, heat health warning systems, etc.), (Knowlton *et al.*, 2007 and Hajat *et al.*, 2010b). There is much debate in the scientific literature as to how adaptation can be modelled. Methods proposed include shifting of the exposure-response relationship by certain degrees or using a “surrogate” city whose present climate best approximates the estimated climate of a target city in the future (Gosling *et al.*, 2009). However, there is no generally accepted methodology for accounting for autonomous and planned adaptation to heat/cold.
- The methodology assumes a static population structure, which does not take into account the projected aging of the UK population. Although it is recognised that elderly people are most at risk from temperature related mortality, there is limited information on age specific exposure-response relationships. A number of studies have also shown greater vulnerability to heat in women (Hajat *et al.*, 2007). It is expected that autonomous and

²⁹ Personal communication with Dr Paul Wilkinson, London School of Hygiene and Tropical Medicine.

planned adaptation will compensate (at least partially) the negative effect of population aging on temperature related mortality in the UK.

- The methodology of the present study assumes constant regional baseline mortality rates (i.e. no seasonal fluctuation) which remain unchanged in the future. In reality, mortality baseline rates vary within a year (with generally higher mortality rates in winter compared to summer) and between years. However, this assumption is unlikely to have a significant effect on the results.
- This study does not explicitly account for an additional heatwave effect (i.e. the effect of continuous days of exceptional heat) on daily mortality, as this is likely to be relatively small compared to the estimated overall burden of heat on mortality (Hajat *et al.*, 2007).

Factoring the relative risk (equation 4.1) for London using the population and baseline mortality figures given in Appendix 6, Figure 4.1 below shows the heat and cold related mortality (showing the 5th, 60th and 90th temperature thresholds for cold) relationship for London superimposed on the daily death records for London over the period 1993 to 2006³⁰. The time series of daily deaths and temperature are those used by Armstrong *et al.*, (2010).

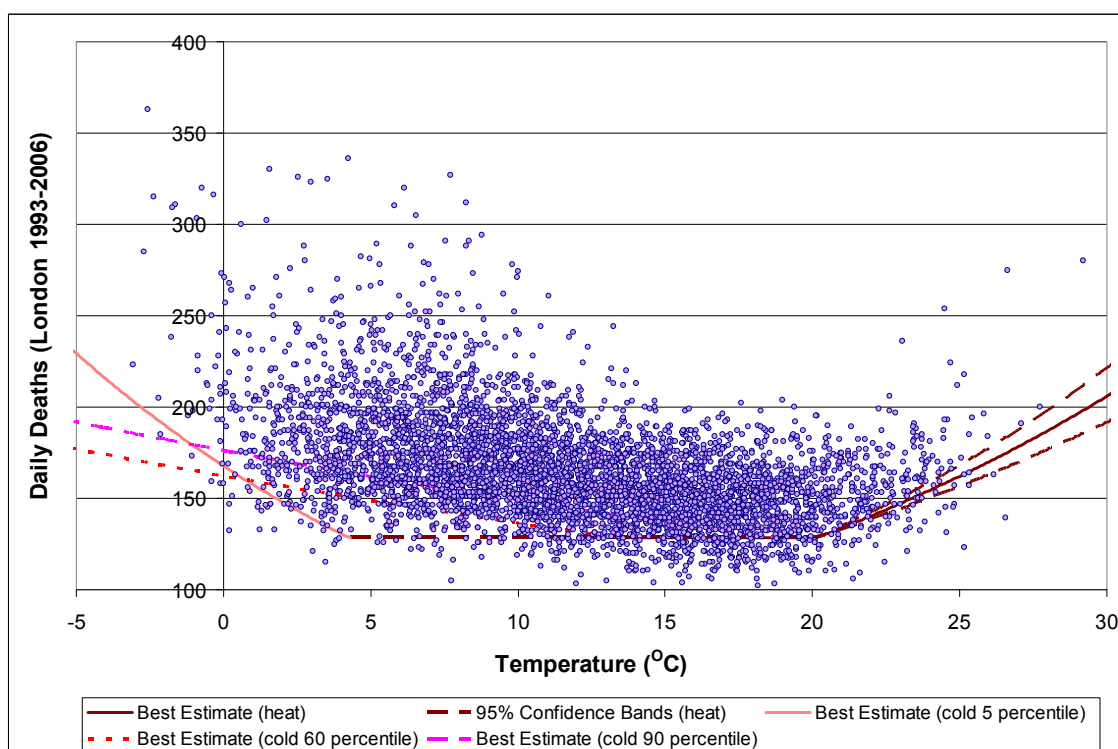


Figure 4.1 Heat and cold related exposure response functions against daily deaths for London (1993-2006)

³⁰ It should be noted that baseline estimates for Wales and the English regions exclude deaths due to external causes and those whose normal residence is not in England or Wales. This figure would therefore exclude the death of any non-UK tourist, or any person from Scotland or Northern Ireland. All baseline estimates will also inherently exclude a proportion of residents from England and Wales who die abroad. However, little change would be expected as most deaths would be anticipated to be amongst the elderly who are very likely to die near their residence.

4.2.4 Temperature time series

The temperature time series used for England and Wales in this analysis is the same time series as used by Armstrong *et al.*, (2010). To determine these regional temperature time series, all available valid temperature time series for stations reporting on 75% of days between 1993 and 2006 was downloaded from the British Atmospheric Data Centre. Armstrong *et al.*, (2010) combined these monitoring station series, weighted based on the populations nearest each station to give one mean series for each region. The AIRGENE algorithm (Ruckerl *et al.*, 2007), was used to avoid spurious fluctuations due to missing data.

For Scotland and Northern Ireland, mean averaged regional data was obtained from the Met Office. The data for Scotland was provided for the regions of East, West and North Scotland. These were combined based on population density to provide a single Scotland time series (see Appendix 6, Table A6.6). Similar data was also obtained for Wales and the English areas. For mean temperatures, a comparison of the Met Office data against the data sets provided by Armstrong *et al.*, (2010), showed a high level of correlation (typically 0.99 or higher). Armstrong's time series was also between 0% and 9% larger due to their time series being more heavily weighted towards stations in urban areas where temperatures are higher. The differences were also noticeably greatest in the more northern regions (e.g. the North-East and North-West), and the most mountainous and sparsely populated region (Wales). Mean temperature time series for Scotland and Northern Ireland were therefore assessed by increasing the mean averaged regional values by 4%.

4.2.5 Linear threshold models for Scotland and Northern Ireland

No published information on temperature-mortality thresholds or slopes is available for Scotland and Northern Ireland. However, Armstrong *et al.*, (2010) indicates an approximate linear relationship between mean summer temperature and heat slope. Despite these suggested relationships for heat only, and published only for heat slopes corresponding to the 93rd percentile of temperature, the same relationship was assumed to hold for the 95th percentile.

A similar relationship for cold slope was investigated, however, a poor correlation was observed.

Figure 4.2 shows these relationships using Hajat's analysis, also shown on this graph are Armstrong's results.

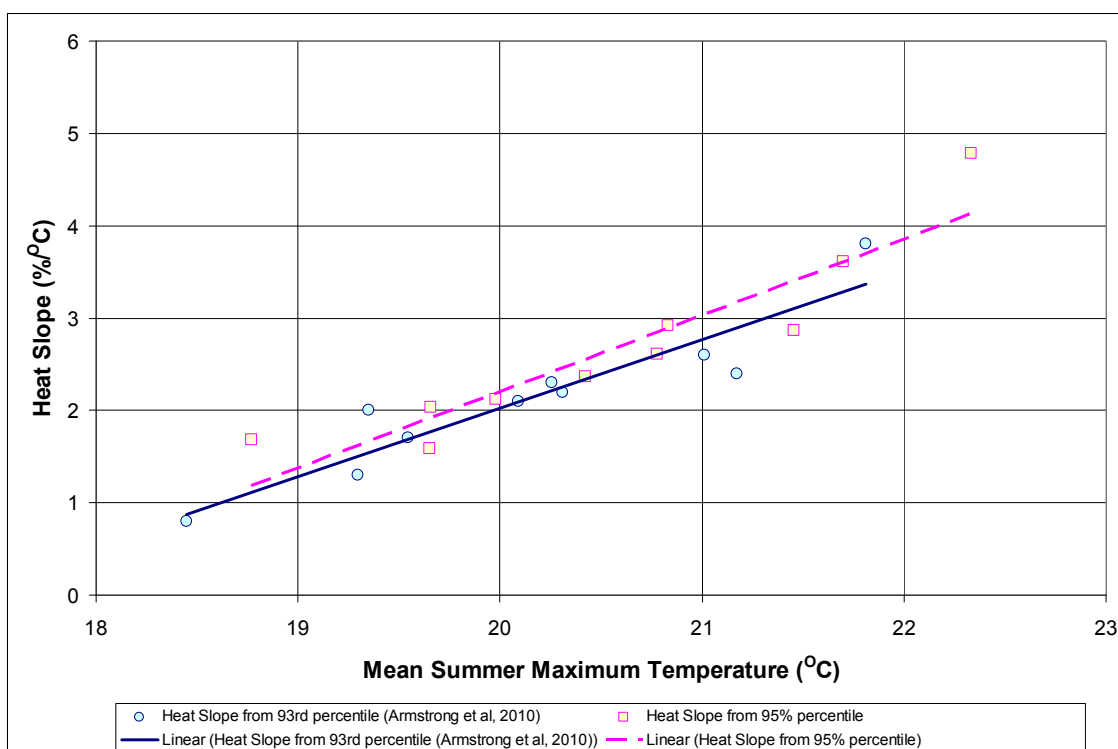


Figure 4.2 Maximum temperature against heat slope (%/°C) based on Armstrong (2010) 93rd percentile and Hajat *et al.*, (2007) 95th percentile

For Northern Ireland, and in particular Scotland where temperatures are typically lower than the rest of the United Kingdom, we are extrapolating beyond the range of results given in Figure 4.2. Armstrong³¹ however indicated that these relationships were only applicable in the ranges shown. Therefore for Scotland and Northern Ireland, the heat and cold slopes corresponding to the North-East and North-West respectively were used. These regions were considered the most representative of Scotland and Northern Ireland, and would be anticipated to provide a conservative estimate of heat and an over-estimate for cold related mortality (see Table A6.2, Appendix 6).

4.2.6 Socio-economic influence

Heat and cold affected deaths are a function of several factors, including the age distribution of the population, levels of deprivation (especially in relation to cold related deaths), and social capital (i.e. social networks and contacts). This could have an effect on the baseline mortality rates given in Table A6.4, as well as the heat and cold mortality slopes and thresholds.

However, the relationship between temperature related mortality, deprivation and social capital is very complex and not possible to characterise within this assessment. It is also believed that there is limited published research in this area (Wolf *et al.*, 2010, Hajat *et al.*, 2007, Wilkinson *et al.*, 2004). For the purpose of this assessment, baseline mortality rates, as well as temperature related mortality slopes and thresholds are assumed to remain unchanged in the future, and heat and cold related mortality are therefore considered to be solely proportional to population sizes.

³¹ Personnel communication with Ben Armstrong, Professor in Epidemiological Statistics - London School of Hygiene and Tropical Medicine, 8th October 2010.

4.2.7 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE1	Temperature mortality (heat)	H	2	2	3	2	3	3	3	3	3
HE5	Temperature mortality (cold)	M	3	3	3	3	3	3	3	3	3

To estimate the heat and cold related deaths due to future changes in the climate, the temperature time series outlined in Section 4.2.4 was assumed to increase uniformly for each scenario by the mean increase in temperatures given in Appendix 6, Table A6.5. As stated in Section 4.2.1, the heat and cold slopes and thresholds were assumed not to change. For all regions, the mortality relationship defined by equation (4.2) was used to determine premature deaths (heat) and premature deaths avoided (cold). For England and the regions, the daily death time series used in the Armstrong *et al.*, (2010) study was used to determine excess mortality attributable to the effects of heat or cold. For heat, comparison against Armstrong's results showed differences of between 1-2%, which is consistent with round-off differences for published values. Determination of excess mortality rates based on regional baseline mortality rates or regional daily death counts for Wales and the English regions showed minor differences, and gave confidence that either methodology was robust. Hajat's analysis on the daily death time series was therefore used to estimate the effect on mortality due to heat, with cold determined based on the 60-90th percentiles outlined in Section 4.2.3 (also see Section 4.2.7.1). The temperature time series for Scotland and Northern Ireland were determined as outlined in Section 4.2.4.

Tables A7.1 to A7.3 show the results of this analysis for heat related mortality for the current day demographics. Tables A7.4, A7.5 and A7.6 show the results of this analysis for cold related mortality for the current day demographics. Results for premature deaths (heat) and premature deaths avoided (cold) are given for the low, principal and high population projections for the 2020s, 2050s and 2080s based on the population projections given in Table A6.6 in Appendix 6, and in Tables A8.1 to A8.18 of Appendix 8.

These results are summarised for the UK in Figures 4.3 and 4.4 below. These results are relative to the estimated current baseline figures for premature deaths (heat) and premature deaths (cold) shown in Table 4.1.

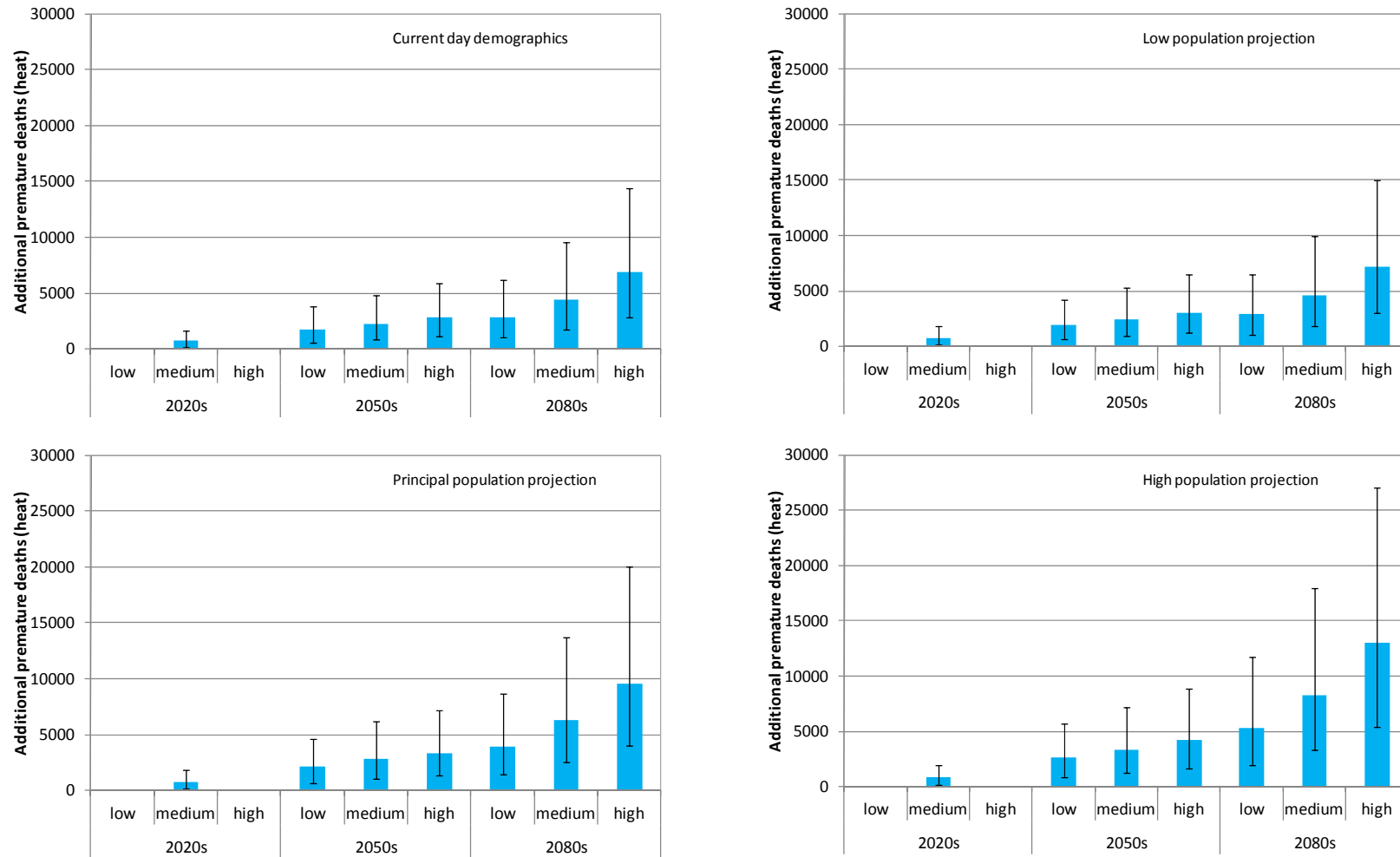


Figure 4.3 Additional premature deaths (heat) per year for the UK (baseline period: 1993-2006)
(regional breakdown given in Tables A7.1-A7.3 and A8.1-A8.9)

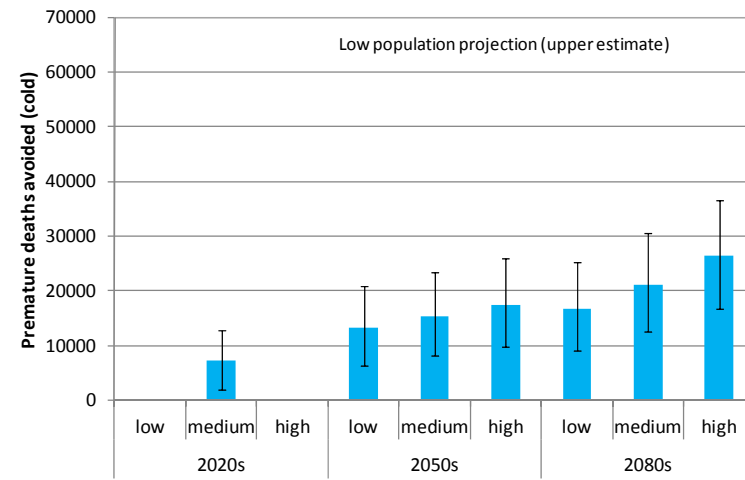
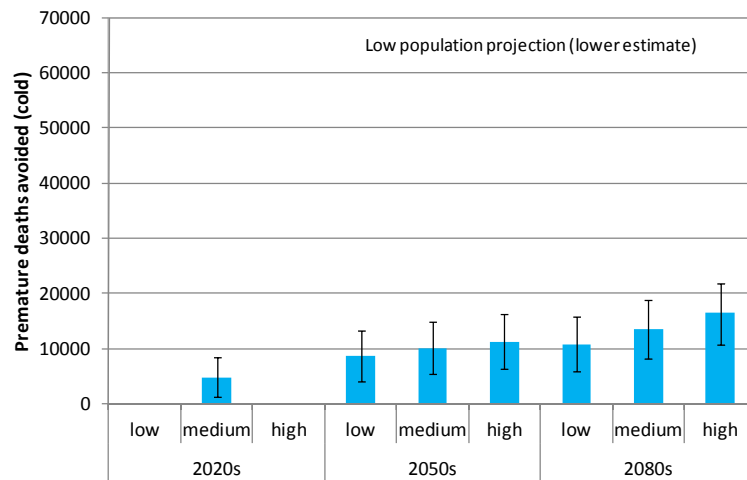
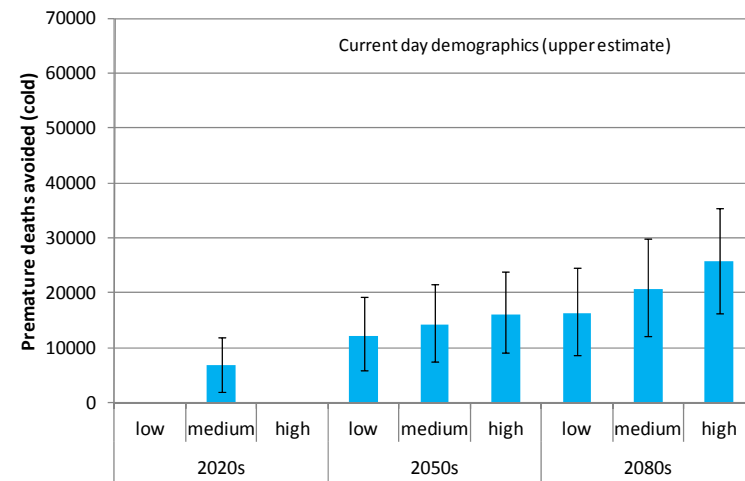
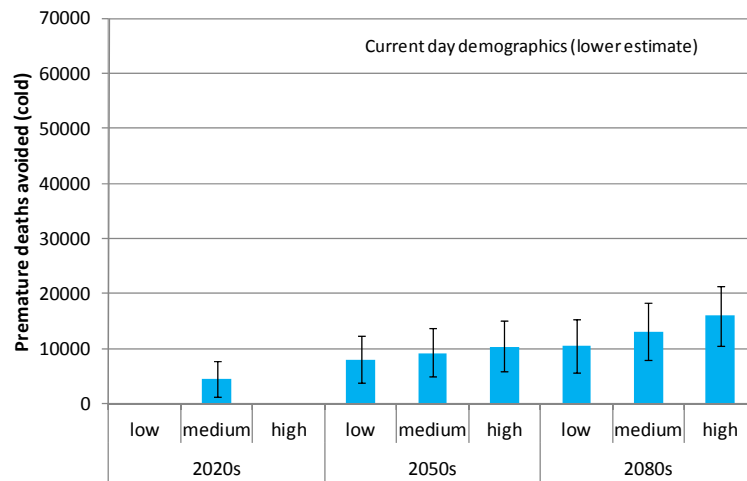


Figure 4.4a Premature deaths avoided (cold) per year for the UK (baseline period: 1993-2006) – current day demographics and low population projection
(regional breakdown given in Tables A7.4-A7.6, A8.10, A8.13 and A8.16)

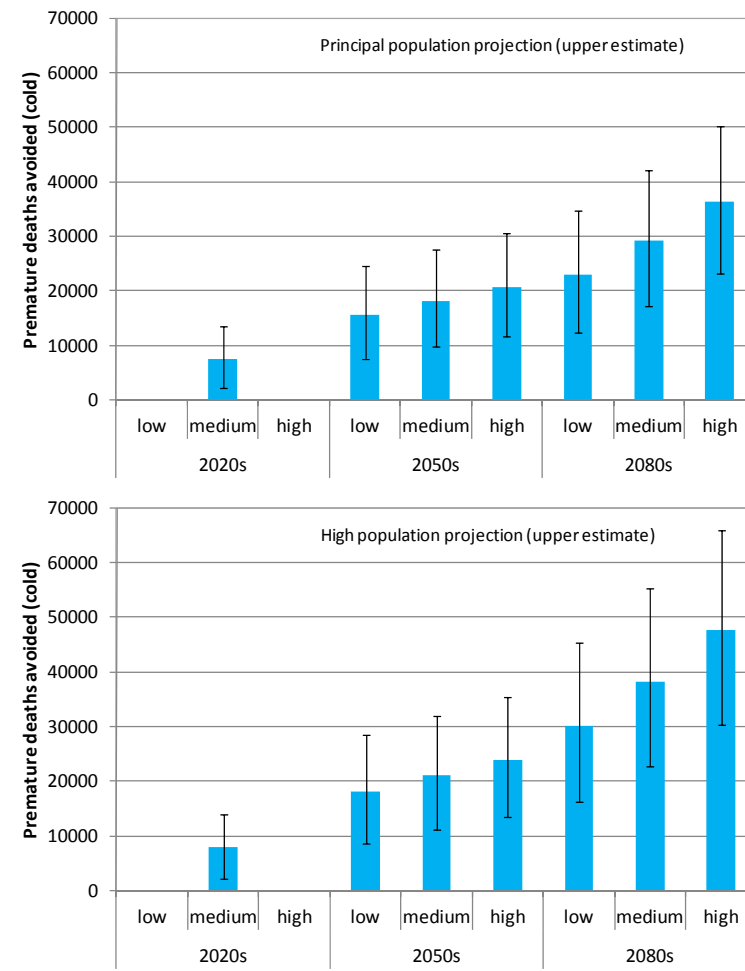
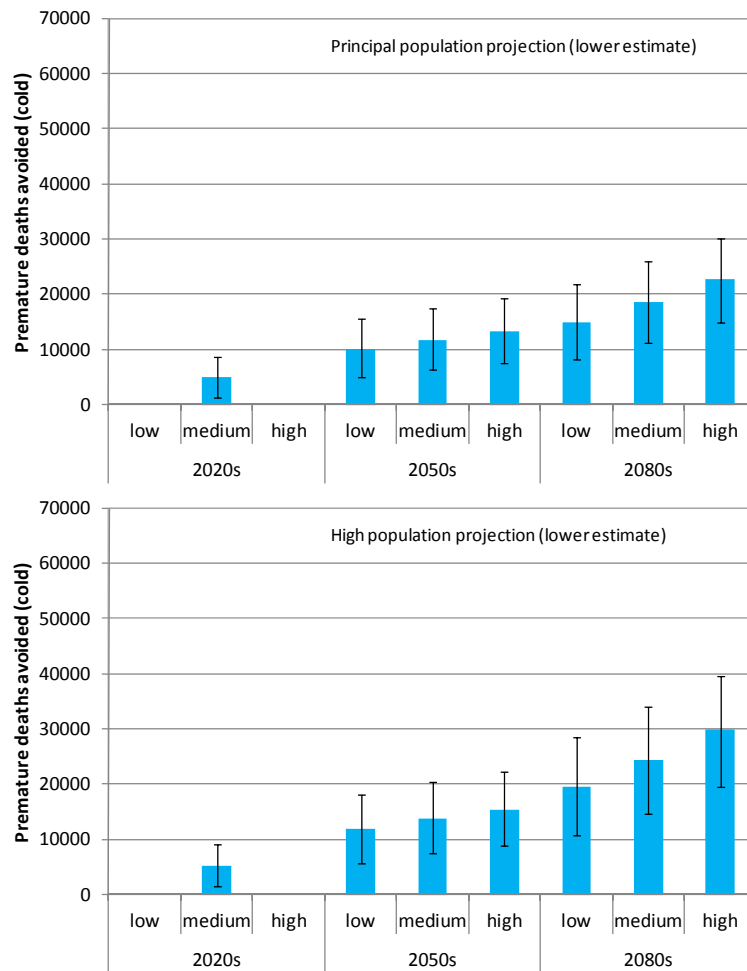


Figure 4.4b Premature deaths avoided (cold) per year for the UK (baseline period: 1993-2006) – principal and high population projections
(regional breakdown given in Tables A8.11, A8.12, A8.14, A8.15, A8.17 and A8.18)

Table 4.1 Baseline premature deaths (heat) per year and premature deaths (cold) for each region (baseline period: 1993-2006)

Admin Region	Heat	Cold
South-West	83	3,180 to 6,826
South-East	160	3,303 to 7,201
London	207	2,664 to 6,127
East of England	140	2,494 to 6,193
West Midlands	122	2,515 to 5,841
East Midlands	82	1,955 to 4,255
North-West	116	2,593 to 5,626
North-East	31	887 to 2,150
Yorkshire and Humber	76	1,965 to 4,403
Wales	37	1,785 to 3,506
Scotland	68	1,789 to 4,202
Northern Ireland	19	469 to 1,025
UK	1,142	25,598 to 57,355

4.2.7.1 Sensitivity analysis

Temperature-related mortality (heat)

Heat-related mortality was calculated based on a uniform increase of daily mean temperatures observed over the period 1993-2006. As mentioned in Section 4.2.3, this does not take into account the potentially increased frequency of heatwaves during summertime which has been predicted for the northern hemisphere by certain authors (Jones *et al.*, 2008). A relatively simple way of assessing the potential impact of a higher frequency of heatwaves on mortality is by using a baseline period that includes more such events. To do that, we have selected a four year period (2003-2006) that includes two major heatwave years (2003 and 2006) for the UK. Following exactly the same methodology described in Section 4.2.3, we have calculated the excess heat-related deaths per year for the UK summarised in Table 4.2. These mortality estimates for the baseline period of 2003-2006 are 18-33% higher than the corresponding values shown in Figure 4.3 (baseline period of 1993-2006).

Table 4.2 Additional premature deaths (heat) per year for the UK for the different emission scenarios (baseline period: 2003-2006) – heatwave scenario

Scenario	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				768	2,285	4,956	1,377	3,687	7,851
Medium	172	948	2,198	1,124	2,919	6,168	2,283	5,658	11,638
High				1,469	3,629	7,476	3,712	8,611	16,967

Temperature threshold

It should be noted that the temperature related mortality figures calculated with the above methodology are very sensitive to the selection of the threshold above or below which heat or cold related deaths occur. In the case of heat related mortality, the daily

mean temperature thresholds reported by Hajat *et al.*, (2007) for different UK regions range between 17.7°C in the North East and 20.4°C in London, while a single threshold value of 18.6°C was reported in an earlier study for the whole UK population by Donaldson *et al.*, (2002). These thresholds are broadly consistent with the daily maximum temperature thresholds for deaths attributed to heat in England and Wales reported in a recent study by Armstrong *et al.*, (2010), and the daily mean temperature threshold for cardiovascular disease deaths in London reported by the same author, Armstrong (2006).

In the present study, we have adopted heat mortality thresholds that correspond to the 95th percentile of daily mean temperatures (lags 0-1) for each region following the methodology of Hajat *et al.*, (2007). This resulted in threshold values and associated heat mortality estimates broadly consistent with those reported by Donaldson *et al.*, (2002) and Armstrong *et al.*, (2010). These are around 1,100 total heat-related deaths per year (UK) for the current climate, around 1,850 deaths in the 2020s, around 3,400 deaths in the 2050s, and around 5,600 in the 2080s based on the central estimate of the medium emissions scenario.

The total cold-related deaths calculated for thresholds corresponding to the 5th percentile of daily mean temperatures (lags 0-13) following the same methodology (Hajat *et al.*, 2007) were around 1,700. This figure, which corresponds to daily temperature thresholds of 2.9-4.2°C in different UK regions, is much lower than the approximately 80,000 cold-related deaths reported by Donaldson *et al.*, (2002) who assumed a daily mean temperature threshold of 15.6°C.

However, the 5th percentile threshold (Hajat *et al.*, 2007) was considered too low as noted in Section 4.2.3 and therefore cold related mortality was recalculated for a range of 60th-90th temperature percentiles (corresponding to regional temperatures of 9.6-18.7°C).

An even higher threshold of 22.3°C for cardiovascular disease deaths attributed to cold in London was reported by Armstrong (2006). Given the limited amount of published evidence and the lack of consistency with the Donaldson *et al.*, (2002) study, we have carried out a sensitivity analysis using thresholds corresponding to a wide range of daily mean temperature percentiles (from 5th to 90th)³². The results summarised in Figure 4.5 indicate that the current total cold-related mortality levels could be as high as 57,400 deaths for daily mean temperature thresholds of 14.1-18.7°C in the different UK regions (90th percentile). The corresponding reductions in cold-related mortality for the 90th percentile would be in the region of 7,000 by the 2020s, 13,000 to 17,000 deaths by the 2050s and 17,000 and 25,000 deaths by the 2080s for the central estimate of the medium emissions scenario.

³² The cold exposure response slopes were produced specifically for this study by Dr Shakoob Hajat at the London School of Hygiene and Tropical Medicine based on his previous assessment in Hajat (2007).

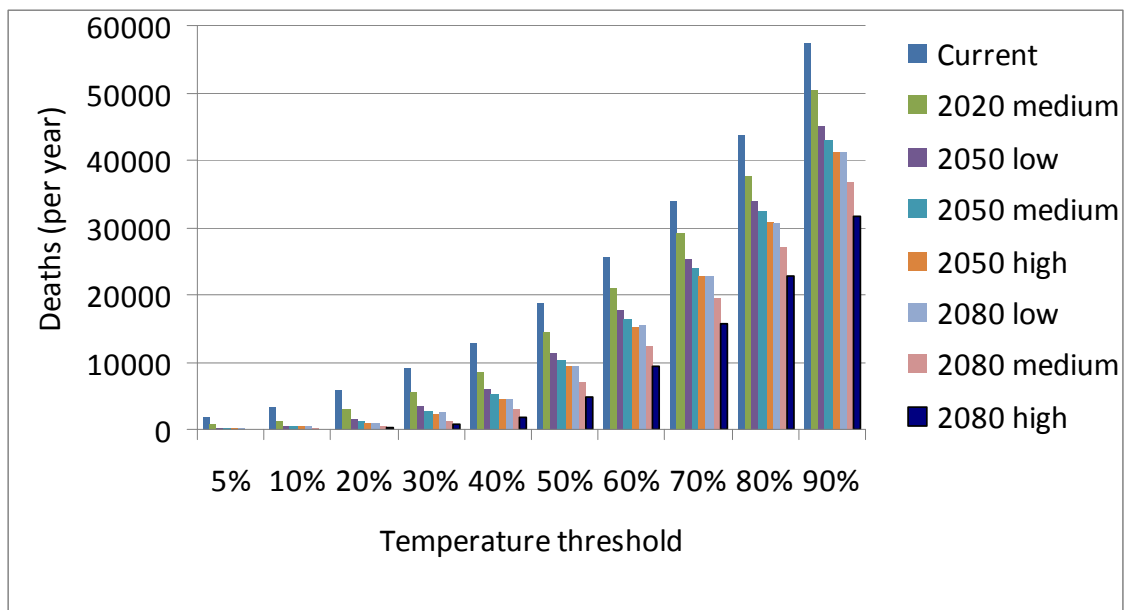


Figure 4.5 Cold related mortality estimates against different thresholds for the central estimate (p_{50})

4.3 Temperature morbidity

4.3.1 Heat (HE2)

There is certain evidence that both very high and very low temperatures have an impact on a range of morbidity outcomes. Morbidity rises in hot weather, particularly for the elderly, very young and sick people (Vassallo *et al.*, 1995). Elderly people are vulnerable to heat stress, especially those in hospital or long-term care institutions. Vulnerability to heat in old age is linked to intrinsic changes in the regulatory system or to the presence of drugs that interfere with normal homeostasis³³ (Department of Health, 2002).

Heatwaves (i.e. continuous days of exceptional heat) in particular have been shown to increase respiratory and cardiovascular illnesses (Patz *et al.*, 2005). Exposure to high temperatures during heatwaves may cause dehydration partly attributable to certain side-effects of drugs (e.g. impaired thermoregulation and suppressed thirst) (Stoellberger *et al.*, 2009), heat cramps caused by fluid and electrolyte imbalances often caused by exertion, heat exhaustion, and heat stroke which can result in organ failure, brain damage or death. Heatwaves have also been linked to mental stress, violent behaviour and suicides which increase during hot weather (Page *et al.*, 2007). There is some evidence that alcohol consumption and accidents (road traffic accidents, drowning, etc.) increase during hot weather periods (Kovats and Hajat, 2008 and Morabito *et al.*, 2006). The risk factors associated with heat stress are summarised in Table 4.3.

³³ The ability to adjust ones internal environment to maintain a stable equilibrium.

Table 4.3 Risk factors for heat stress (DH, 2002)

Risk factor	Comments
Extreme old age	>80 years
Dependency	Bedridden>semi-dependent>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, gastrointestinal and septicaemia

In a study of 12 US cities with both hot and cold climates, Schwartz *et al.*, (2004) found that hospital admissions for all heart disease increased with average temperature on the same day and the day before admission. Donaldson *et al.*, (2002) reported an estimate of around 800 heat-related deaths occurring in the UK per year in the 1990s, accompanied by approximately 80,000 days of additional NHS hospitalisation³⁴. According to the same study, a medium-high climate change scenario would result in an estimated 2,800 heat-related deaths per year and 280,000 days per year of additional NHS hospitalisation in the UK in the 2050s. This would represent an increase of approximately 250% for both heat-related deaths and hospitalisations per year compared to 1990s climate conditions. However, these increases are likely to be overestimates in the long-term since they ignore physiological acclimatisation and adaption to climate change (e.g. passive cooling, behavioural change, etc.) which are expected to reduce the impact of hot weather. Estimates are also based on analysis across the whole year without correction for season. However, with a heat threshold of 18.6°C, there are few days outside the June-August summer period when temperatures exceed this threshold (on average, less than two days per year), and 80-90% of these would occur in September.

Kovats *et al.*, (2004b) reported that the impact of hot weather on mortality is not paralleled by similar magnitude increases in hospital admissions in the UK, possibly because many of the heat-related deaths occur before the sufferers come to medical attention. In the Kovats *et al.*, (2004b) study there was no clear evidence of a relationship between total emergency hospital admissions and high ambient temperatures, although there was evidence for heat related increases in emergency admissions for respiratory and renal disease in children under 5 years of age, and for respiratory disease in the above 75 age group. During the heatwave of 3 August 1995, hospital admissions showed a small increase of 2.6% (95% CI, 2.2 to 7.6), while daily mortality rose by 10.8% (95% CI, 2.8 to 19.3). Preliminary analyses of the impact of the 1995 heatwave in England and Wales suggested that excess mortality was proportionally higher in more deprived populations (Donaldson *et al.*, 2002). These conclusions confer with observations from the severe Chicago heatwave of 1995, where many of the deaths were of people living alone or who had limited social contact, (Semenza *et al.*, 1996).

³⁴ Morbidity data on in-patient hospital days were calculated from NHS admission data for England (1995-1996) and Wales (1996-1997) and from the average length of stay in hospital for all except psychiatric patients.

Knowlton *et al.*, (2009) reported 16,166 excess emergency department visits and 1,182 excess hospitalizations in California during a severe heatwave in 2006. They observed elevated relative risks of emergency department visit for heat-related causes, with young children under 4 years of age and the elderly, above 65 years of age being most affected. Emergency department visits showed significant increases for acute renal failure, cardiovascular diseases, diabetes, electrolyte imbalance, and nephritis. Knowlton *et al.*, (2009) also reported significantly elevated relative risks for hospitalizations for heat-related illnesses, acute renal failure, electrolyte imbalance and nephritis.

During the August 2003 heatwave there were an estimated 2,000 more deaths in England and Wales than for the same period averaged between 1998 and 2002. Most of the excess deaths were concentrated in the south east of England, particularly in London. Increased mortality was seen in all age groups, but most notably in the elderly above 75 years of age. However, hospital admissions in London showed no increase for those under the age of 75 (Johnson *et al.*, 2004).

From the above studies, it can be concluded that generally hotter climatic conditions and more frequent and intense heatwaves are likely to cause an increase in patient-days per year in hospital in the UK due to heat-related illness (i.e. hospital admissions attributable to high temperatures but not necessarily diagnosed as hyperthermia, heat stroke, etc.). The rate of change is more uncertain than that of heat-related mortality (probably because many heat-related deaths occur before the sufferers come to medical attention), and little work has been carried out in this area. However, Donaldson *et al.*, (2002) indicates a linear relationship between heat related mortality and heat related patient-days which they calculated as 1 death for every 102 patient days in hospital. Although this figure can be considered highly uncertain due to the very limited published evidence, it is the only known indication of an exposure-response function for this metric in the UK. Nevertheless, the empirical relationship between heat-related deaths and hospital patient days per year in the UK obtained from the Donaldson *et al.*, (2002) study has been used to make quantitative estimates of heat related morbidity.

Heat related morbidity is therefore tentatively determined by multiplying the heat related mortality deaths outlined in Section 4.2.3 by 102.

4.3.2 Cold (HE6)

Epidemiological evidence has indicated a causal relationship between mortality and cold weather. The most important diseases associated with cold-related excess mortality and morbidity are ischaemic heart disease, cerebro-vascular disease and respiratory disease (Hassi *et al.*, 2005).

Donaldson *et al.*, (2002) reported an approximate 25% decrease in cold-related mortality and morbidity (from 80,000 cold-related deaths per year in the 1990s to 60,000 in the 2050s, and from 8.2 million patient-days of hospitalisation per year in the 1990s to 6.1 million in the 2050s) due to progressively milder temperatures associated with a medium-high climate change scenario. This is based on the same 102 patient days of hospitalisation to every 1 cold related death adopted for heat related hospitalisations.

Many winter deaths and hospitalisations are due to infectious diseases such as influenza and pneumonia³⁵. It has been suggested that increases in mean

³⁵ The increase in infectious diseases in the winter months is not known. However, many authors (e.g. Eccles, 1996) have theorised that this is due to increased proximity to others, therefore increasing risk, and is not due to cold weather.

temperatures will encourage people to spend more time outdoors and increase indoor ventilation which may reduce infectious disease transmission (McGeehin and Mirabelli, 2001). It should also be noted that excess winter morbidity may be affected by socio economic status with impacts being greater in those unable to afford heating for their house or using a car (Watkins *et al.*, 2001).

Due to the limited published evidence on quantitative exposure-response relationships and the inherent problems outlined in trying to indicate individual hospital admissions to a cold related disease, even on a statistical basis, no reliable estimate of cold related hospital admissions can be made. Nevertheless, the empirical relationship between cold-related deaths and hospital patient days per year in the UK obtained from the Donaldson *et al.*, (2002) study has been used to make quantitative estimates of cold related morbidity.

Cold related morbidity is therefore tentatively determined by multiplying the cold related mortality deaths outlined in Section 4.2.3 by 102.

4.3.3 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE2	Temperature morbidity (heat)	H	1	2	3	2	3	3	3	3	3
HE6	Temperature morbidity (cold)	M	3	3	3	3	3	3	3	3	3

Temperature morbidity due to higher temperatures has been assessed as the increased number of heat related hospital-patient days and the reduced number of cold related hospital-patient days. This is estimated as proportional to the number of deaths due to higher seasonal temperatures.

For the different scenarios, time periods and regions, Figures 4.6 (heat) and 4.7 (cold) indicate how the number of hospital patient days are likely to change due to increased seasonal temperatures. Due to the level of confidence in the projections, only results for the 50% probability level for the UK only are shown.

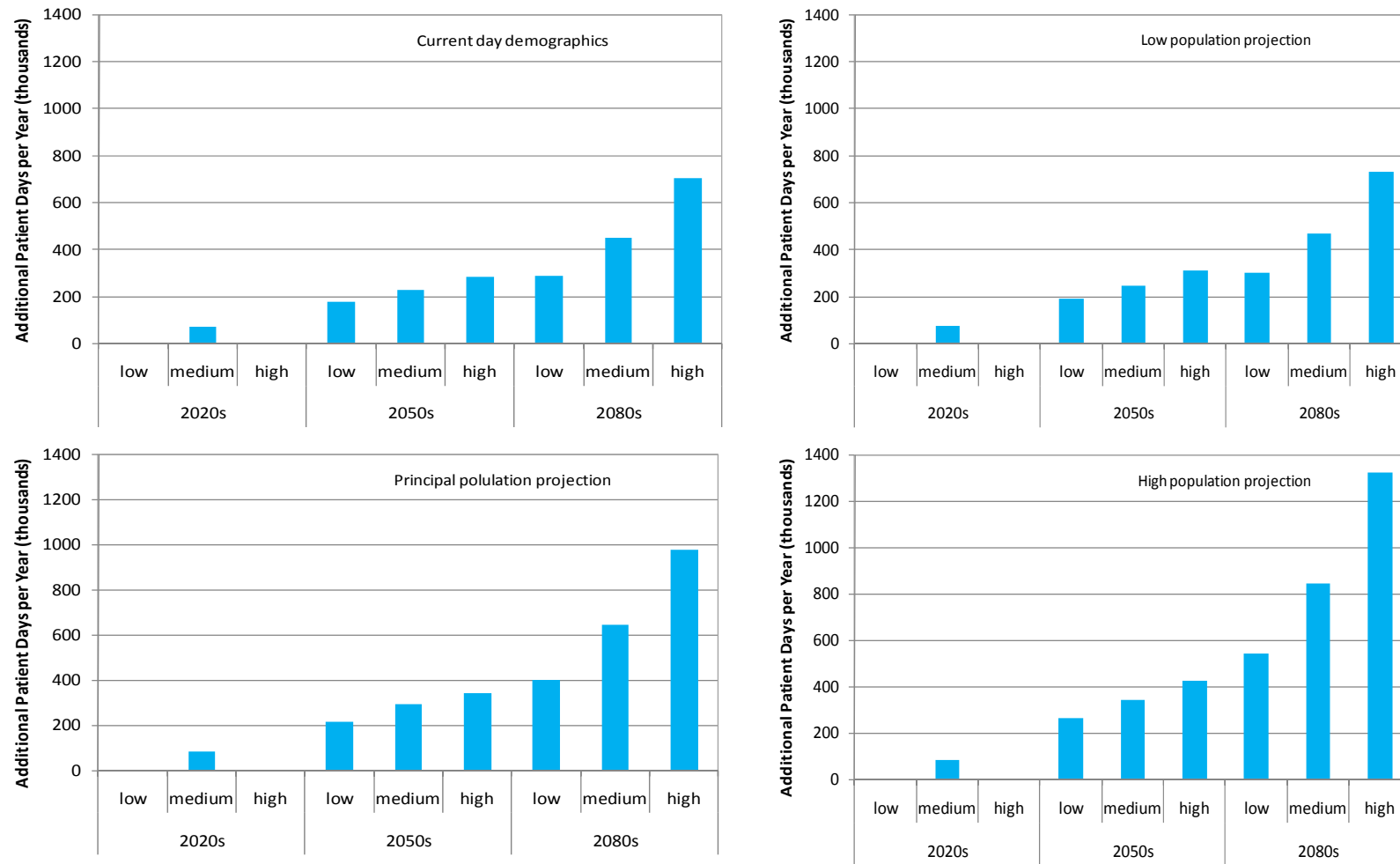


Figure 4.6 Annual additional patient days per year (p₅₀) due to increased high temperatures (thousands) – tentative estimates (baseline period: 1993-2006)

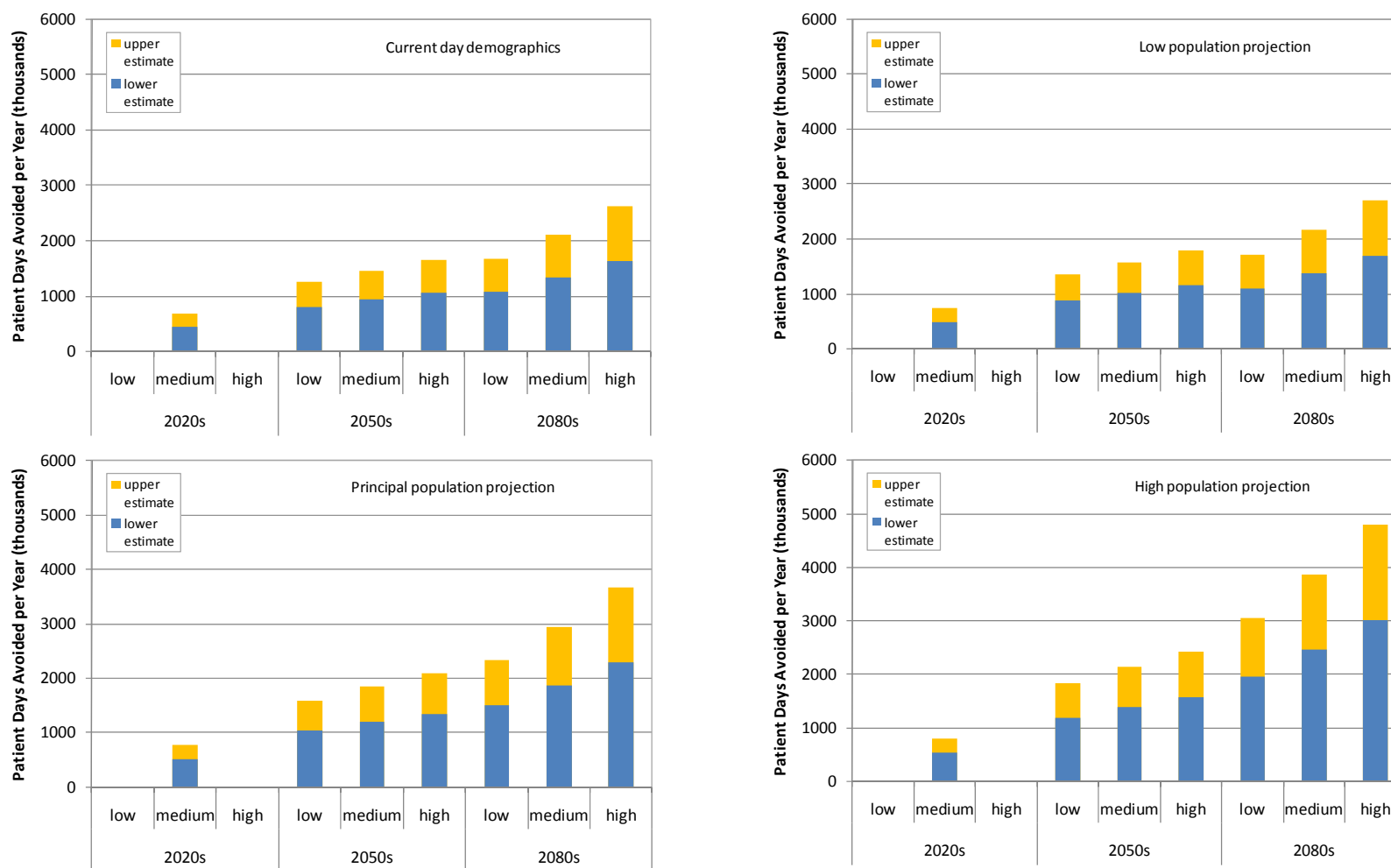


Figure 4.7 Annual patient days avoided per year (p_{50}) due to increased low temperatures (thousands) – tentative estimates (baseline period: 1993-2006)

4.4 HE3 – Extreme weather event (flooding and storms) mortality

4.4.1 Introduction

Flood events in the UK that lead to a large number of deaths³⁶ are few and far between, and are heavily driven by the type of flood event and/or warning and the local characteristics of the area. However, based on past flood events, indications are that flood related mortality can be significant for very extreme individual events. For example, the 1953 North Sea tidal surge and resultant coastal flood that affected the east coastline of England resulted in 307 UK fatalities and in total over 2000 along Northern European coastlines (Baxter 2005). The Lynmouth flash flood disaster of 1952 resulted in 34 fatalities, and a large number of injuries, even though a relatively few number of properties, approximately 400, were affected (Penning-Rowsell *et al.*, 2005)³⁷.

However despite these figures, and with a general increase in the number and probable severity of floods over the last century (Defra/ Environment Agency, 2003), aggregate data for Europe³⁸ indicates that flood related fatalities have declined in this period (Defra/Environment Agency, 2003). This apparently contradictory statement is heavily linked to improvements in flood forecasting, particularly in relation to coastal flooding, as well as communication via several media (European Environment Agency, 2005). The potential for a repeat of the extreme storm tide levels of 1953 for example would be known about for about three days in advance, with confident estimates within about 24 hours. Warnings and if appropriate evacuations of those affected (see also Section 4.4.3) would be in place before any risk was imminent (see Section 4.4.2 and also European Environment Agency, 2005).

In terms of understanding the current level of risk therefore, an estimate has to be made based upon events over the last century, but recognizing that there have been significant developments with respect to improving flood defences, particularly since the North Sea tidal surge event of 1953, which was the impetus for a significant investment in flood defences, particularly on the east coast³⁹. This makes an estimate of current risk from extreme events at a national scale not a simple task.

A review of historic flood events and the Flood Risks to People research (Defra/Environment Agency, 2003) indicates that the number of deaths (or injuries)

³⁶ A flood death is defined as any death that can be considered to have taken place as a result of a flood, whether as a direct or indirect result (see for example Health Protection Agency (2010). This would include for example the case of a farmer who in May 2009 committed suicide, as a result of several incidents, but for which the underlying cause could be considered to be the continual flooding of his rare breed's farm.
http://www.getsurrey.co.uk/news/s/2073454_distraught_farmer_had_threatened_suicide_inquest.

³⁷ The vulnerable are particularly at risk as a result of extreme event flood events. For the 1953 flood event for example, a large number of deaths occurred amongst inhabitants of post-war prefabricated buildings, bungalows and chalets, with the highest mortality rate among the elderly. For Jaywick, where the highest number of deaths were recorded relative to the population size for example, 82% of those who died were aged 60 or over and of the remainder, 50% were either disabled or in the advanced stages of pregnancy. Only one person was identified who was either not considered in a vulnerable group, or who did not die as a result of a trying to rescue others (Baxter, 2005).

³⁸ A database of reported mass disasters around the world is kept on the EM-DAT disaster database, <http://www.emdat.be/>. Over the period 1980 to 1999, inland flood and landslide related deaths and injuries were given as 1.3 and 5.7 for every 10,000,000 population respectively for Western Europe, McMichael *et al.*, (2002). As this database only considers criteria where either 10 or more people are killed, 100 people reported affected, a call made for international assistance or a declaration of a state of emergency, this database excludes a large percentage of the type of flood events expected to lead to death (or injury) for a large number of UK events. However, this database does help in indicating a potential lower limit for an annual estimate of flood and storm related deaths and injuries.

³⁹ See <http://www.environment-agency.gov.uk/homeandleisure/floods/38317.aspx> for more details.

from flooding can be taken as being approximately proportional to the number of people at risk of flooding. In addition, there is a risk due to increased wave activity at the coast as a result of projected increases in sea levels. These are storm related deaths, although it should be emphasised that these are a direct result of increased wave activity linked to projected increases in sea levels, not storms which UKCP09 suggest remain relatively unchanged over the coming century⁴⁰.

In assessing the number of fatalities linked to flood events, there is a clear link to the type of flood event and the number of fatalities. Defra/Environment Agency (2003) and French *et al.*, (1983) indicate that flash floods similar to that which occurred in 1952 at Lynmouth, which come with little or no warning, would result in a high casualty rate (see also European Environment Agency, 2005). Although this was not demonstrated at Boscastle in 2004, this was considered unusual and if a similar event occurred again with no warning, there might be some fatalities.

However, for a different type of flood event which arises as a result of long periods of rainfall over large areas for a sustained period of time (which is typical for the UK), a lower mortality rate would be expected. This is because people are more aware, there is more warning time, flood velocities are lower and damage limitation measures (e.g. evacuations) are put in place. This was demonstrated for example by the widespread floods in the UK in 2007, Section 4.4.2 below, where despite almost 50,000 properties flooded, only 13 fatalities were recorded (approximately 1 fatality for every 8,000 people affected).

4.4.2 Selected Extreme Flood Events in the UK since 1990

Towyn Flood 1990 In February 1990, high winds combined with a high spring tide resulted in the sea wall at Towyn being breached, with flooding to 2,800 homes. Despite the late warning to the residents there were no fatalities. This was one of the most severe coastal flood events to affect the UK coastline since 1953.

Easter 1998 Floods A stationary band of heavy rain falling on already saturated land over the Midlands area of the UK on 9th and 10th April 1998 resulted in extensive flooding with over 4,200 homes and businesses affected, approximately 2,000 of which were in Northampton. Five deaths were directly attributed to this flood event.

Autumn Floods of 2000 A high level of rainfall over England throughout the autumn of 2000, combined with the wettest 12 month period in England and Wales since records began in 1766 brought widespread flooding to England and Wales over several periods in October and November of this year. In total about 10,000 homes and 700 businesses were flooded at 700 locations, some more than once. It has been reported that up to nine fatalities were directly attributable to these floods, although different organisations give different figures (Defra / Environment Agency, 2003).

Boscastle Flood of 2004 On 16th August 2004, the villages of Boscastle and Crackington Haven in Cornwall suffered extensive damage as a result of flash flooding caused by heavy rainfall falling over the previous eight hour period. Approximately 1000 people were affected, with over 70 properties flooded (five of which were demolished). Although no fatalities occurred during this flood, the severe flood conditions recorded and the damage that took place would normally have been expected to have led to some fatalities.

Carlisle Flood of 2005 Heavy rains on 7th January 2005 in the high lands above Carlisle led to severe flooding in Carlisle on the following day, as well as flooding in

⁴⁰ See http://ukclimateprojections.defra.gov.uk/images/stories/Tech_notes/UKCP09_Storm_technote.pdf.

Appleby, Cockermouth and Keswick. This caused widespread disruption of the transport system. Approximately 1800 homes were flooded and 3 people died.

UK wide floods of 2007 During the summer of 2007, there were a series of destructive floods that took place in various places across the UK. The most severe floods occurred across Northern Ireland and Yorkshire, as well as a large area bounded between South Wales, the Midlands and Oxfordshire. The May to June period of this month was the wettest since records began in 1776. During this period, approximately 48,000 properties were flooded and there were 13 recorded fatalities.

Cumbria Flood of 2009 Throughout November and December of 2009, significant flooding across the UK led to a series of floods affecting large parts of the UK, as well as Ireland. The worst of these floods was in Cumbria where a number of towns and villages were affected, with approximately 1,000 properties flooded. A number of bridges collapsed, one of which led to the death of a police officer, the only fatality as a result of this flood.

4.4.3 Expected number of fatalities as a result of flooding and storms under a changing climate

From Ramsbottom *et al.*, (2012), results are presented which outline the number of people at risk due to inland (fluvial) and coastal inundation under current conditions and for the different social economic scenarios. Review of historic flood data indicates that relationships can be derived between the number of fatalities or injuries and the number of properties flooded.

This is also indicated by Frieser *et al.*, (2005), who presented an approximate linear correlation between people exposed and fatalities as shown in Figure 4.8. The high ratio of fatalities to people exposed in this figure relates to locations where deep flooding occurred and/or little or no warning was given to the residents at the time of the flood. Many UK floods are a lot less extreme, and with in general more advance food warnings in place, and possibly with better quality houses and a more responsive population, an average UK ratio would be expected to be significantly lower.

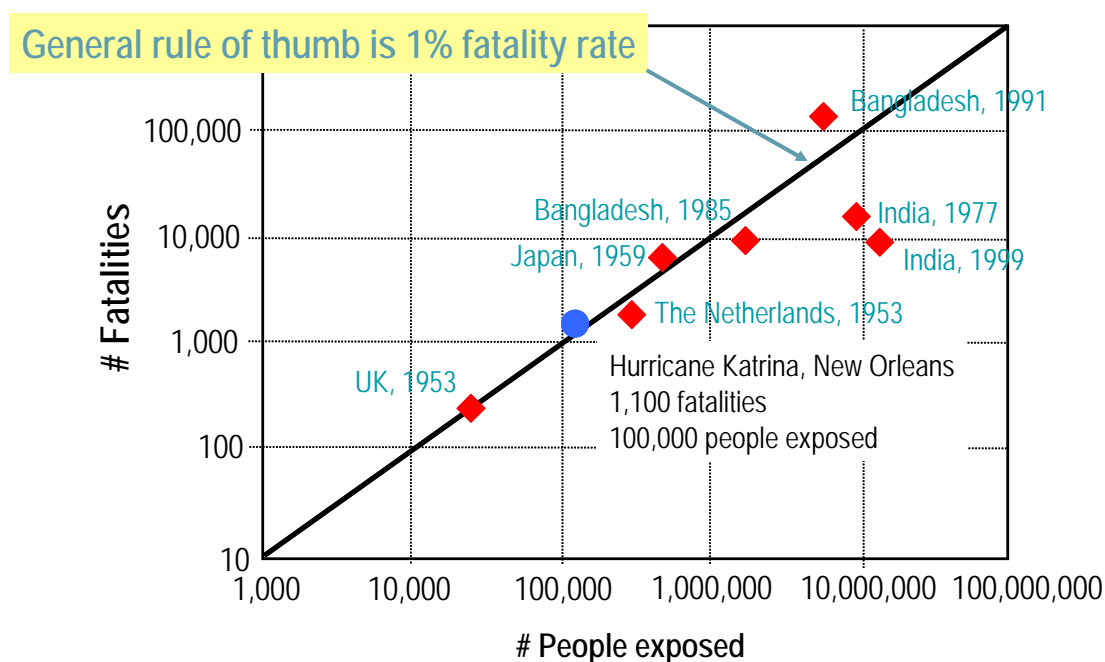


Figure 4.8 Relationship between people exposed and fatalities
Source: Frieser *et al.*, (2005)

Linking these conclusions together therefore, the response function for fatalities due to flooding is taken as being directly proportional to the number of people at risk in any particular year. As the information on flood related data is so sparse, and heavily dependent on topography, as well as for coastal locations exposure and access, it is not feasible to try and break these figures down regionally.

From an assessment of the significant fluvial flood events since 1998, fatalities tend to occur during periods of flash floods. These floods, which can come with little warning and with high velocity waters can catch people unaware, and often cause death to individuals as a result of their actions. Male deaths predominate in these instances as they often occur during rescue operations or similar in high velocity waters. Risk of death is also greater amongst the elderly as noted for the 1953 flood by Baxter, (2005). Currently in the region of 700,000 properties in England and Wales are at significant risk of fluvial flooding⁴¹ on an annual basis (Ramsbottom *et al.*, 2012).

An assessment of the flood events outlined above, together with other past major UK flood events (e.g. Lynmouth) as well as recent flash flood events in Western Europe from the EMDAT database indicates an average mortality rate due to fluvial and pluvial flooding of approximately 3 per year. In view of the potential for very severe flash floods, as well as more minor flood events⁴², some of which may not be widely reported, or necessarily attributed to extreme flood events, an average fatality rate of between 5 and 10 per year is likely. A fatality rate of 8 per year has therefore been adopted for this report⁴³.

For coastal flooding, an average fatality rate is much more difficult to establish. Fatalities related to coastal flooding would be expected to be more widespread relative to number of properties affected, as flood waters tend to cause more rapid inundation. Fatalities would also be expected to come in small groups, with only a few very extreme events leading to large loss of life such as demonstrated by the 1953 flood event.

In trying to establish a baseline mortality rate therefore, recent flood events have been considered for the North Wales and North West coastlines where annual maxima sea level records exist from Hilbre Island since 1854⁴⁴, see Figure 4.9. This location has been chosen as annual maxima sea levels can be considered over a 156 year period (with records available in 140 of these years), and as there have been three significant high sea level events within the North Sea Basin in relatively recent times (i.e. 1990 to 2002). High tides along this stretch of coastline also occur within about an hour of each other, so would be expected to be subject to similar storm conditions.

⁴¹ Significant risk of flooding is defined as a 1 in 75 chance of flooding in any one year.

⁴² A few isolated deaths occur every year that can be directly linked to significant, although not necessarily extreme floods. In February 2011 for example, a woman was swept to her death on the North Yorkshire Moors by a river swollen by heavy rainfall as she tried to negotiate a ford (http://news.bbc.co.uk/1/hi/england/north_yorkshire/8540789.stm). Other deaths can occur that initially may not be considered related to flood events. For example, amongst the 13 recorded fatalities of the summer 2007 floods was the death of a father and son at Tewksbury Rugby Club overcome by fumes as they tried to clear flood water from the basement (<http://news.bbc.co.uk/1/hi/uk/6911778.stm>). A further example of this is the case of a woman who died on 25th August 2020, 18 days after being flooded at her West Hampstead flat. Despite the time delay between the flood occurring and her death, it was reported that her death by kidney failure was as a direct result of an infection picked up from the sewage that flooded her flat during the flood (http://www.camdennewjournal.co.uk/archive/n061103_8.htm).

⁴³ It should be noted that the Environment Agency and Defra have no formal criteria for a flood death, but collate information from situation reports completed after each flood. These are usually limited to persons who are swept away or drown near their own homes, but may not include examples such as those given in the previous footnote.

⁴⁴ Annual maxima records were obtained from Jeremy Benn Associates (1998), with records updated based on recorded sea levels obtained from the Proudman Oceanographic Laboratory. Additional port readings were also obtained from Silloth (which covered the tide event of 1990), as well as Workington, Whitehaven (subsequently not used) and Barrow. Known corrections were also applied to the Jeremy Benn Associates (1998) records and the Workington data set as outlined in Hames *et al.*, (2004).



Figure 4.9 Location plan showing sea level measurements around the North West and North Wales coastline

Figure 4.10 shows these annual maxima records recorded at the 12 locations considered around the Irish Sea. These records have been standardised by equation 4.4 which enables direct comparison of different time series. The time series have also been de-trended by 3.4mm/year^{45} based on a linear best fit line through the long duration Hilbre Island annual maxima time series.

⁴⁵ This figure is higher than published figures for past sea level rises, as for example demonstrated in IPCC (2007) and taking into account isostatic rebound (Shennan and Horton, 2002). However, this will give more weight to earlier events and will therefore give more confidence that recent high sea level events are relative to a consistent datum, greater than previously recorded sea level events since 1854.

$$HTF = \left(\frac{\eta_{CD} + (2009 - year) * 0.034}{HAT - LAT} \right) \quad (4.4)$$

where:

HTF = high tide factor (non-dimensional)

η_{CD} = recorded annual maxima for year (to Chart Datum)

HAT = highest astronomical tide

LAT = lowest astronomical tide

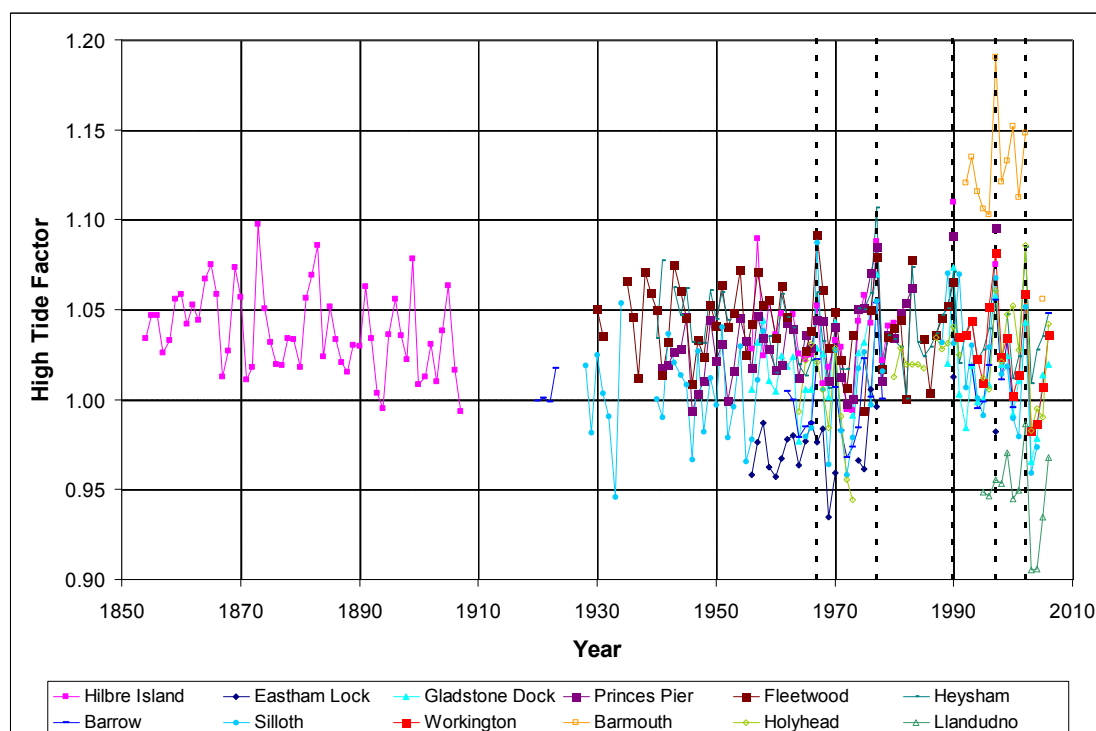


Figure 4.10 Annual maxima recorded around the North Wales and North West coastline since 1854

Annual maxima records are factored by the relationship given by equation 4.4

Considering these time series records, five of the eight largest high sea levels have been recorded in the last 50 years, which were in 1967, 1977, 1990, 1997 and 2002 (indicated in Figure 4.10 above by the dashed vertical lines)⁴⁶. The last three of these have occurred in the last 20 years, and over a short 12-year time frame.

Examining these records indicates that the highest sea levels relative to mean sea levels over the periods available were probably 1967 for Cumbria, 1967 or 1977 for Morecambe Bay, 1990 for Liverpool Bay and the eastern part of the North Welsh coastline, and 2002 for the western part of the North Welsh coastline. This tends to demonstrate the extreme nature of the 1990 flood event at Towyn, which relative to standardised sea levels, is the largest recorded sea level in 118 years where sea levels are available in this region.

For the western part of the North Welsh coastline, the highest sea levels recorded at Barmouth and Holyhead showed the greatest differences between the highest and next highest recorded annual maxima sea levels based on equation 4.4 (and noticeably higher than locations further to the east). Although only 12 years of annual maxima

⁴⁶ The other years where significant sea levels were recorded were in 1873, 1883 and 1958.

records are available for Barmouth, and only two of the large event years noted above, Holyhead has 36 years of annual maxima records, only missing 1977 of the recent large events noted. This would indicate that the extreme event of 2002 for this part of the coastline was at least of a similar return period to the 1990 event for Liverpool Bay.

Considering these two large events along the North Wales coastline, it is likely that events with return periods in excess of 100 years and possibly significantly greater have occurred since 1990. The event of 1990 is well known as it caused the failure of the seawall at Towyn. The event of 2002 was probably of a greater return period for this part of the coastline than the 1990 event was for Towyn. Significant flooding occurred at a number of places, including Dundalk in Ireland (Duffy, 2010), however no major seawall failures took place, and no known loss of life occurred.

A number of other large sea levels have probably occurred at a number of other locations around the UK coastline since 1953, however, with the significant improvements in flood warnings and communications noted above, early evacuations and flood defence measures have prevented major loss of life. In addition, examination of the EMDAT database outlined above highlights 338 flood related deaths in Western Europe since 1953, none of which appears to be related to coastal flooding.

Current day average yearly risk to people is therefore probably low, and cannot be directly related to the figures outlined in Figure 4.8. The risk is also more related to very rare extreme events, possibly of a return period of 1,000 years⁴⁷ or greater affecting large populations (possibly greater than 500,000) where deaths would probably be more as a result of problems of evacuation or a refusal to evacuate, as indicated for example by Sorensen (1991), Drabeck (1991), Sharma *et al.*, (2009) and HR Wallingford (2010).

These events would be exacerbated by the underlying assumption in the flood and coastal erosion sector report (Ramsbottom *et al.*, 2012) that defences are maintained in their present condition but not raised. This means that coastal floods will almost certainly become more frequent. For example, a flood event with a present day annual probability of 0.5% (1:200) could be an annual event by the 2080s, although this is highly dependant on region.

These kinds of events could potentially lead to thousands of deaths, although on an average yearly timescale, only indicating a small average yearly rate, possibly in the region of about 2 to 5 per year. A baseline rate of 3 deaths per year has therefore been assumed for this analysis.

Figures 4.11 and 4.12 show the response functions for coastal and fluvial flooding. These are based on results presented in the floods and coastal erosion sector report (Ramsbottom *et al.*, 2012) for metric FL6⁴⁸. These figures show the relative risk⁴⁹ of mortality for coastal (R_c) and fluvial (R_f) flooding which are defined as the expected number of fatalities in the future relative to a relative change in peak fluvial flows and mean rises in sea levels. The response function for fluvial flooding does not include pluvial flooding. However, this is not expected to noticeably affect the results for the reasons given in Section 3.2.3.

⁴⁷ Potential severe flood events would be known about at least 3 days in advance. These would be monitored, with estimates improving nearer the event, indicating the size and timing of any significant storm surge together with the timing of high tide conditions.

⁴⁸ Metric FL6 of the Flood Sectors report considers the number of properties at significant risk of flooding for both fluvial and tidal flooding (pluvial data was not considered due to a lack of suitable data). Figures 4.11 and 4.12 are therefore based on the assessment for this metric assuming a direct correlation between probability of flood risk and probability of mortality. Further details of how these figures were obtained can therefore be obtained from this report.

⁴⁹ Relative risk in all cases in this section is a non-dimensional term that gives the change in risk relative to the current day. Therefore for example, a relative risk of 1.2 corresponds to a 20% increase in risk in the future relative to today.

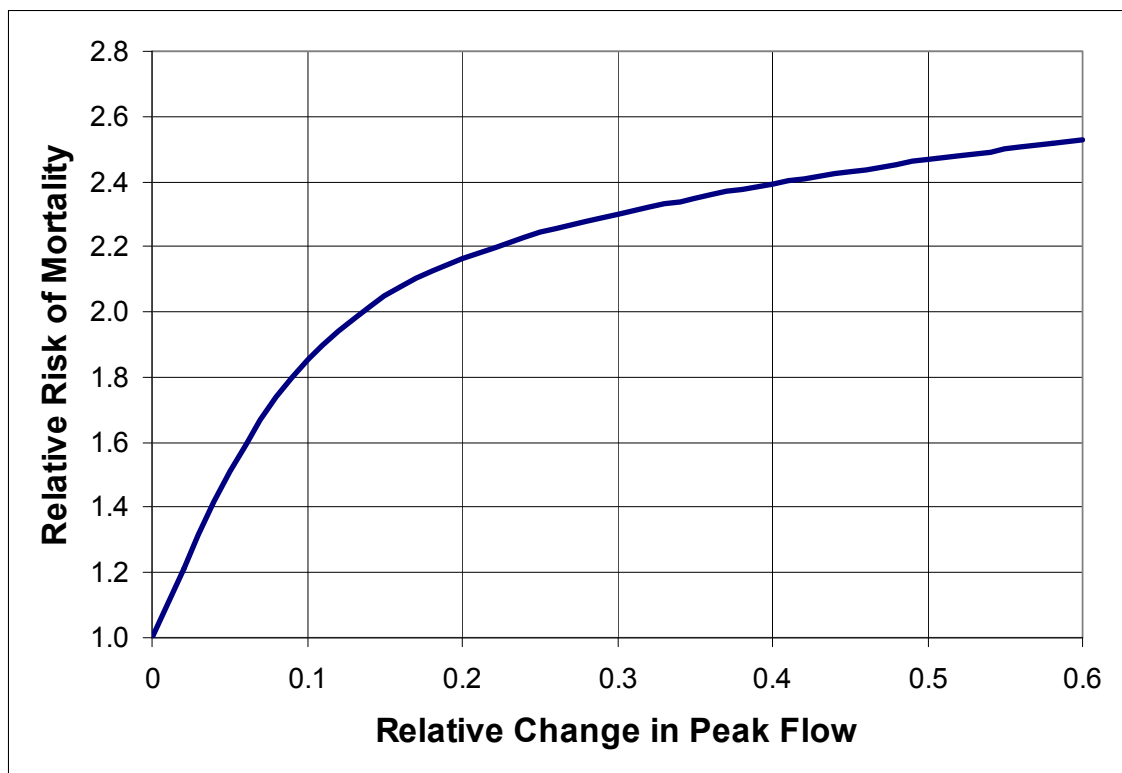


Figure 4.11 Relative risk of mortality due to change in relative peak fluvial flows

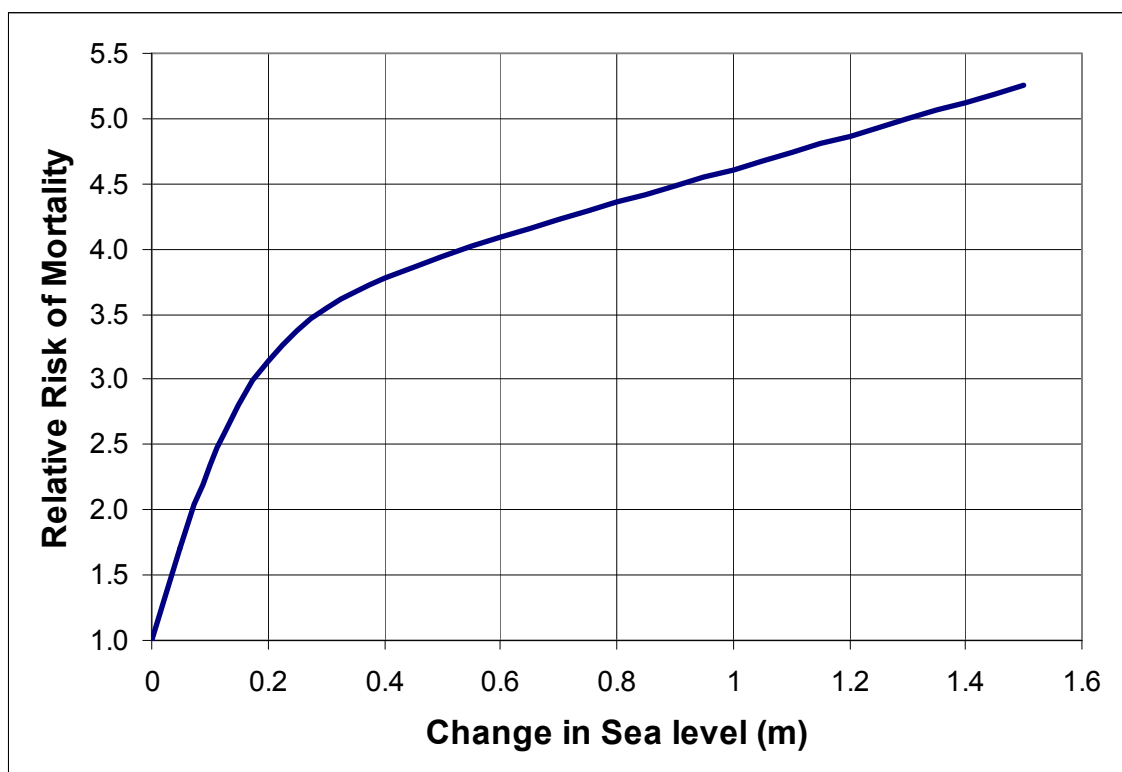


Figure 4.12 Relative risk of mortality due to change in sea levels

4.4.4 Expected Number of Fatalities due to Coastal Wave Action during Storms

As part of an unofficial data gathering process for the Violent Overtopping of Waves at Seawalls Project (<http://www.vows.ac.uk/>), deaths due to overtopping of water of seawalls or land recorded in the media has been kept⁵⁰. These records, kept over a short duration of less than 2 years, indicated that between March 2003 and November 2005, 14 fatalities were recorded as a result of wave action during storms nearshore. An assessment of these records, shown in Table A6.7 indicates that approximately 11 of these deaths could be considered as a result of storm activity, as opposed to accidental death. Considering the record duration this equates to a current day estimate of approximately 7 deaths per year due to storm activity. Although only a limited sample, other cited events over the period October 1999 to February 2002 identified 12 fatalities over this time period, equivalent to approximately 6 deaths per year based on the presumption that all of these deaths relate to storm conditions. The baseline rate of fatalities due to storms has therefore been taken as 7.

For future risk, fatalities would be expected to be related to the increase in wave activity nearshore, which in turn due to depth limited effects, can be considered a function of sea level rise (see for example Townend, 1994). An assessment of the records, given in Table A6.7, indicates that fatalities tend to occur near high water, and for all of these events noted, predicted high water was near mean high water springs (MHWS). Taking MHWS as the baseline for significant wave activity, an estimate can therefore be made for a location of the period of time that sea levels exceed current MHWS, and therefore the change in risk due to rising sea levels associated with climate change.

To assess this risk for the UK, Figure 4.13 shows the change in relative risk due to sea level rise for all UK standard ports as defined by the Admiralty Tide Tables (2010). The relative risk is defined as the period of time that sea levels exceed current MHWS for a given increase in mean sea levels, relative to the period of time that sea levels exceed current MHWS for no increase in sea levels. This indicates that as sea levels rise, relative risk increases exponentially. Figure 4.13 shows how this relative risk changes for a few defined ports, together with an estimate of the average for the UK as a whole. This is given as:

$$R_o = \exp(4slr) \quad (4.5)$$

where:

R_o = relative risk of fatality

slr = eustatic⁵¹ increase in sea level

⁵⁰ Personal communication with Professor William Allsop, Technical Director HR Wallingford.

⁵¹ Rise in sea level relative to a stationary datum. This is different to a sea level rise measured at (for example) a tide gauge which would measure sea level rise relative to the location, which may be affected by isostatic rebound.

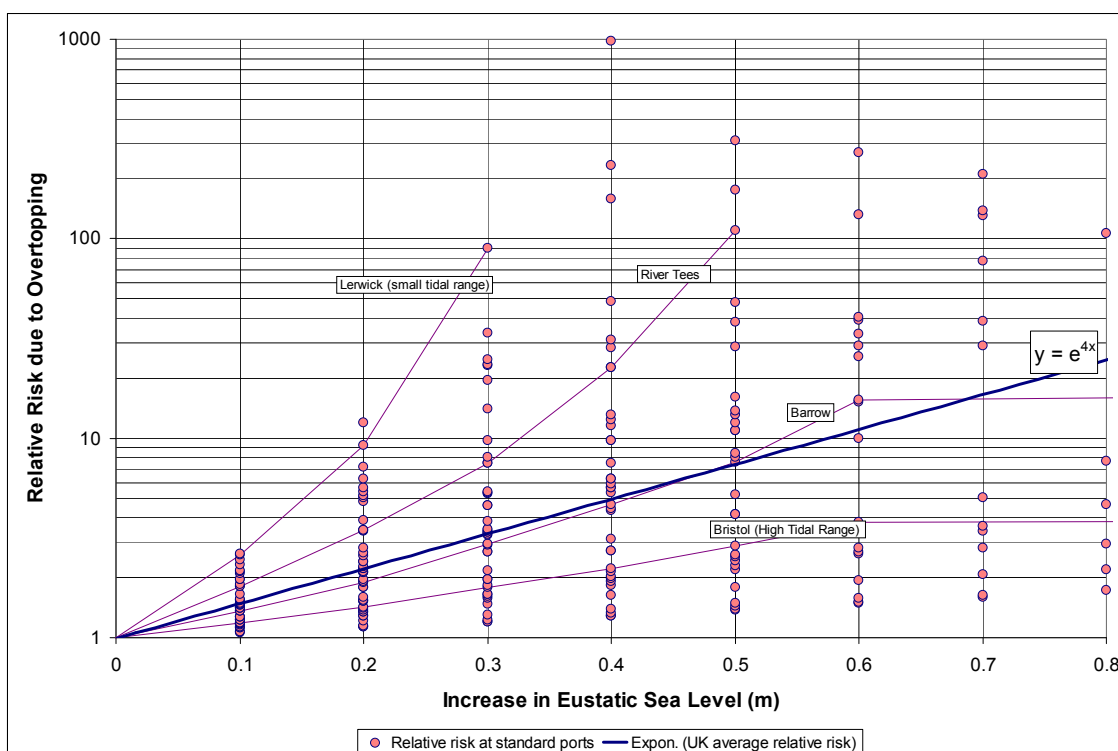


Figure 4.13 Change in relative risk of fatalities due to overtopping of seawalls relative to changes in eustatic sea levels

Future relative rates of coastal fatalities due to wave activity are therefore given by equation 4.5. These deaths which are as a result of storm activity, are referred to as storm related deaths, despite the change being as a result of projected increases in sea levels, not storms which UKCP09 suggests will remain relatively unchanged over the coming century⁴⁰.

4.4.5 Socio-economic influence

Flood related deaths as a result of a changing climate are a function of several factors including individual's age, the topography or exposure of a site, deprivation levels etc. Flood related deaths are also more common among males for the reasons outlined in Section 4.4.3, as well as the elderly as noted for the 1953 floods by Baxter (2005). However, the small number and inconsistent number of deaths reported as a result of extreme flood events means that it is unlikely that mortality rates could be based on anything other than exposure risk to the population as a whole. The socio-economic influence on this metric is therefore assessed solely based on change in population. With flood deaths related to number of properties at risk, residency rates are also assumed to remain constant at 2.36 people per property as given by the 2001 census⁵². However, there are suggestions that these residency rates could decrease by about 10% by the 2030s (Communities and Local Government, 2009).

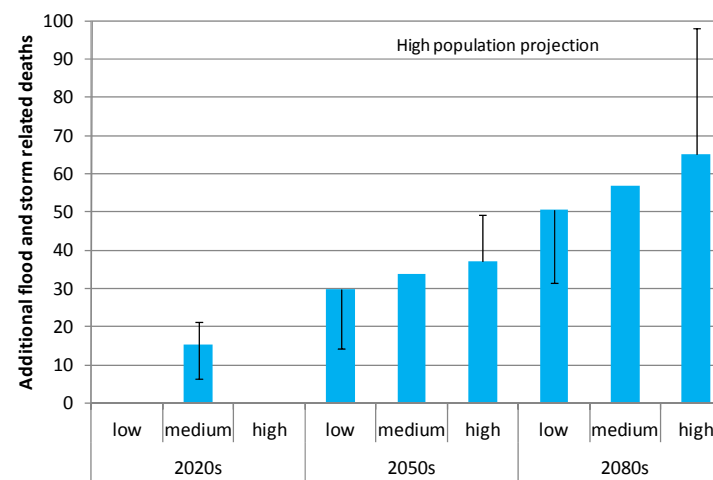
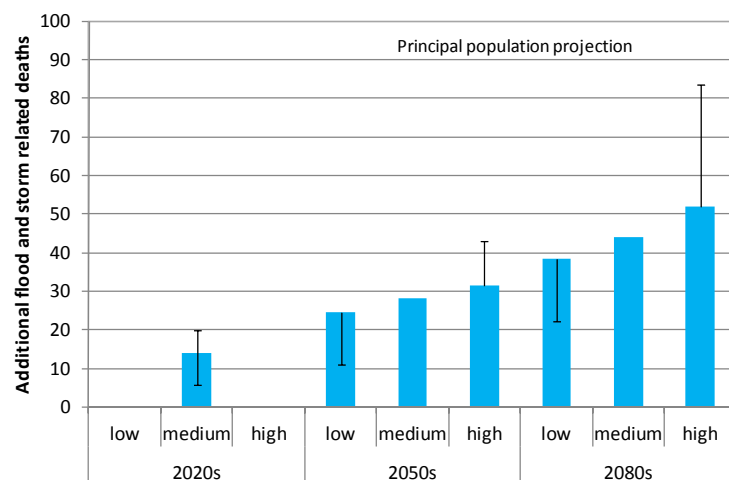
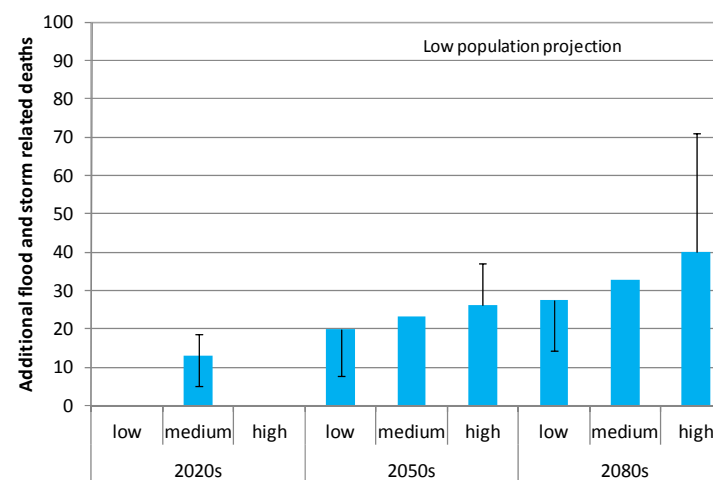
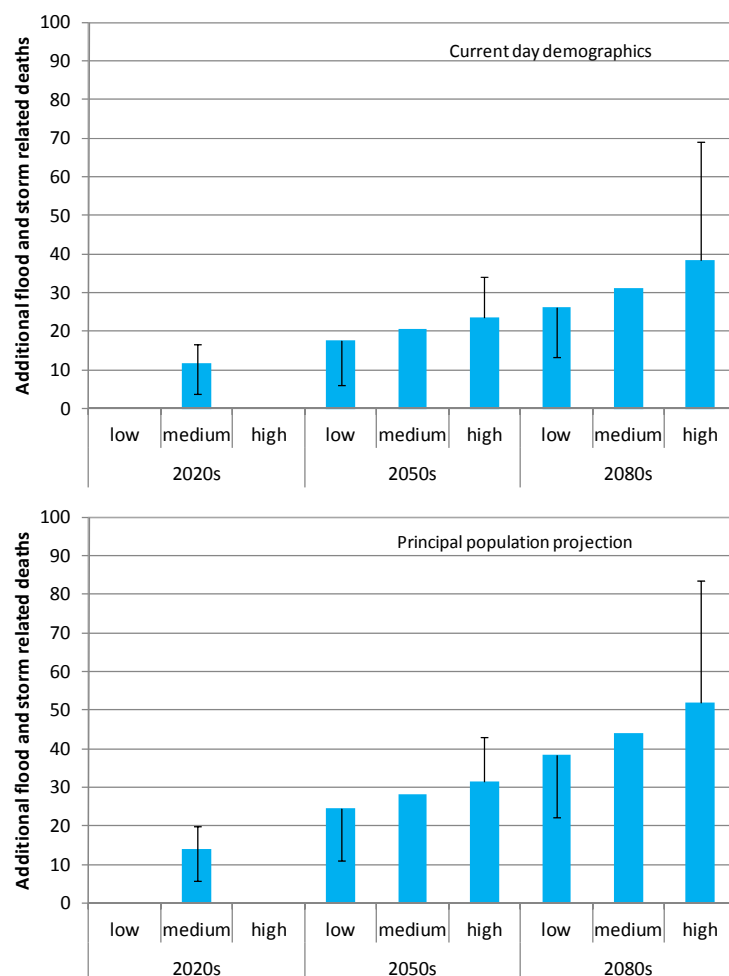
⁵² Source : <http://www.statistics.gov.uk/census2001/profiles/commentaries/housing.asp>.

4.4.6 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE3	Extreme weather event (flooding and storms) mortality	M	1	2	2	2	2	2	2	2	2

Flood related deaths as a result of a changing climate are assumed to be proportional to the number of people at risk due to inland or tidal flooding. For flood related deaths due to increased coastal wave activity during storms, these are assumed to increase exponentially in relation to changes in mean sea levels. Changes in death rates due to non coastal storm activities are assumed to be negligible. No attempt has been made to break estimates for these figures down regionally for the reasons given in Section 4.4.3. Baseline rates for deaths due to extreme event flooding and storms are therefore given as 18 per year.

For the different scenarios, time periods and probability bands considered, Figure 4.14 gives the estimated number of deaths due to future extreme event flooding and storms.



The error bars show the results that were assessed in the Health Sector report. These were only considered for a selection of risks, and those considered are shown.

Figure 4.14 Annual additional flood related deaths due to extreme event flooding and storms

4.5 HE4 – Summer air pollution (ozone)

4.5.1 Introduction

Elevated concentrations of ground-level ozone are produced during summer photochemical smog episodes, caused by the interaction of oxides of nitrogen and volatile organic compounds in the presence of sunlight, and these can have detrimental effects on human health leading to an increase in respiratory hospital admissions and premature deaths.

The key influences on ambient ozone concentration are well understood (see for example NEGTA, 2001). However, these combine in different ways, and levels are very much dependent on a number of factors, of which the key ones are given below (Stedman and Kent, 2008).

- The regional scale photochemical production of ozone during the summer period. Generally this has the greatest impact in the south-east of the United Kingdom which is influenced by the continental sources of precursor emissions and subject to a higher frequency of air mass transport from these regions than the rest of the UK (PORG, 1997 and NEGTA, 2001). This varies significantly on a yearly basis due to differing weather patterns, and there has been a gradual decline in peak ozone concentrations over recent years due to reductions in the emissions of precursor species in the European regions.
- Although Nitrogen Oxides (NO_x) are one of the precursors to ozone formation in very polluted areas, an excess of NO_x can start to react with ozone and destroy it. This has the effect that in urban areas, ozone levels are generally lower than in surrounding rural areas.
- Topography affects levels of ozone (PORG, 1997 and Coyle *et al.*, 2002). Surface ozone concentrations are lower at higher altitudes where NO_x concentrations are very low.
- The gradual yet varying increase in hemispheric background ozone concentrations (Derwent *et al.*, 2005), influences the temporal trends in ozone and how the spatial distribution of ozone concentrations varies over time.

4.5.2 Methodology (baseline ozone impact)

The spatial pattern of ground-level ozone concentrations varies across the UK based on the metric illustrated and due to variations in the weather and changes in emissions. Using empirical measurements based models for three distinct years of 1995, 2003 and 2005, Stedman and Kent (2008) estimated the effect on human health for these three years which represented distinct variations in ozone levels. These represented years where there were higher (2003) and lower (2005) photochemical ozone concentrations, and a year (1995) with higher photochemical ozone concentrations combined with higher urban NO emissions. This assessment used population weighted means (using the UK 2001 census) on a 1x1km grid, updating results of annual mean ozone concentrations originally presented by Coyle *et al.*, (2002) which used an empirical method to incorporate the impacts of topography and local NO emissions. Ozone measurements were based on the UK Air Quality Archive, available

at a number of locations around the UK at www.airquality.co.uk. Details of the data capture and the ozone mapping are given in Stedman and Kent (2008).

In assessing the effects of ground-level ozone on public health, the metric considered was the annual average of the daily maximum of the running 8 hour mean. This is used as a “basic metric” for many of the health metrics and also used for Defra’s air quality indicator, and influenced by the magnitude of local nitrogen oxide (NO_x) emissions.

This ozone metric for the UK has been very kindly provided for this study by John Stedman.

4.5.3 Analysis (baseline figures)

As the health impacts of ground-level ozone are very much dominated by the ambient ozone concentrations in urban areas (see Box 4.1 below), this assessment has used the ozone maps for 1995, 2003 and 2005 provided by Stedman, combined with population density on a 1*1km grid to give population-weighted means of the metric considered. Population has been determined based on the 2001 census⁵³. Using the three ozone maps of 1995, 2003 and 2005 gives a broad range of ozone levels typically expected, and therefore are anticipated to give a level of confidence in the changes in future ozone effects.

The health impact has been estimated by multiplying the population-weighted mean by a dose response coefficient, expressed as a percentage change in the health impact per 10µg/m³ change in ozone and by a baseline rate of the health impact in the absence of ozone pollution (Knowlton *et al.*, 2007 and Stedman and Kent, 2008). This can be expressed as:

$$I = \beta \sum_{i=1}^r \sum_{j=1}^{n_i} [O_3]_j P_j \overline{B}_i \quad (4.6)$$

Where:

I	=	health impact
β	=	dose response coefficient slope (see below)
r	=	region
n_i	=	population square (within region)
$[O_3]$	=	annual mean of the daily maximum of the running 8 hour mean ozone concentration
P_j	=	population density
\overline{B}_i	=	baseline mortality or morbidity rate for region (see below)

The baseline rates, details of which are given in Appendix 6, Table A6.4 with further details in Section 4.2.3, have been determined based on published mortality statistics and respiratory hospital admission data and population projections for the relevant years available from the Office for National Statistics. These published baseline rates

⁵³ For each census output area, the total number of people was divided by the area to get a density per km². This figure was then adjusted depending on the number of 1km grid points that lay within the output area and to make the total population in the grid squares equal to the census population.

inevitably include an effect of ozone on mortality and morbidity. Assuming for simplicity that this effect corresponds to 20 µg/m³ (10 ppb) of ozone throughout the UK, then adjusted baseline rates have been calculated as:

$$\bar{B}_i = \bar{N}_i \frac{100}{101.4} \quad \text{for respiratory hospital admissions, and}$$

$$\bar{B}_i = \bar{N}_i \frac{100}{100.6} \quad \text{for premature deaths}$$

Where \bar{N}_i are the unadjusted mortality and morbidity rates for each region.

This also assumes that there is a linear non-threshold relationship between ozone and the above health outcomes. An exposure-response function of 0.7% per 10µg/m³ was taken for daily maximum 8 hour ozone for respiratory hospital admissions. This is the figure recommended by the Department of Health (1998). An exposure response function of 0.3% per 10µg/m³ was taken for daily maximum 8 hour ozone for premature deaths. This is the figure recommended by a World Health Organisation meta-analysis (2004).

Box 4.1 Definition of Urban / Rural Areas

Rural and Urban Areas have been defined based on definitions of urban/land classifications given by the Office for National Statistics (England and Wales) (ONS, 2004), Scottish Government and Northern Ireland Statistics and Research Agency.

These are:

<u>Location</u>	<u>Dwelling</u>	<u>Urban / Rural</u>
England and Wales	Urban Population > 10,000	Urban
England and Wales	Town and Fringe	Rural
England and Wales	Village Hamlet and Isolated Dwellings	Rural
Scotland	Large Urban Areas (over 125,000 people)	Urban
Scotland	Other Urban Areas (over 10,000 to 125,000 people)	Urban
Scotland	All Other Areas	Rural
Northern Ireland	Urban (Bands A-E)	Urban
Northern Ireland	Rural (Bands F-H)	Rural

Sources

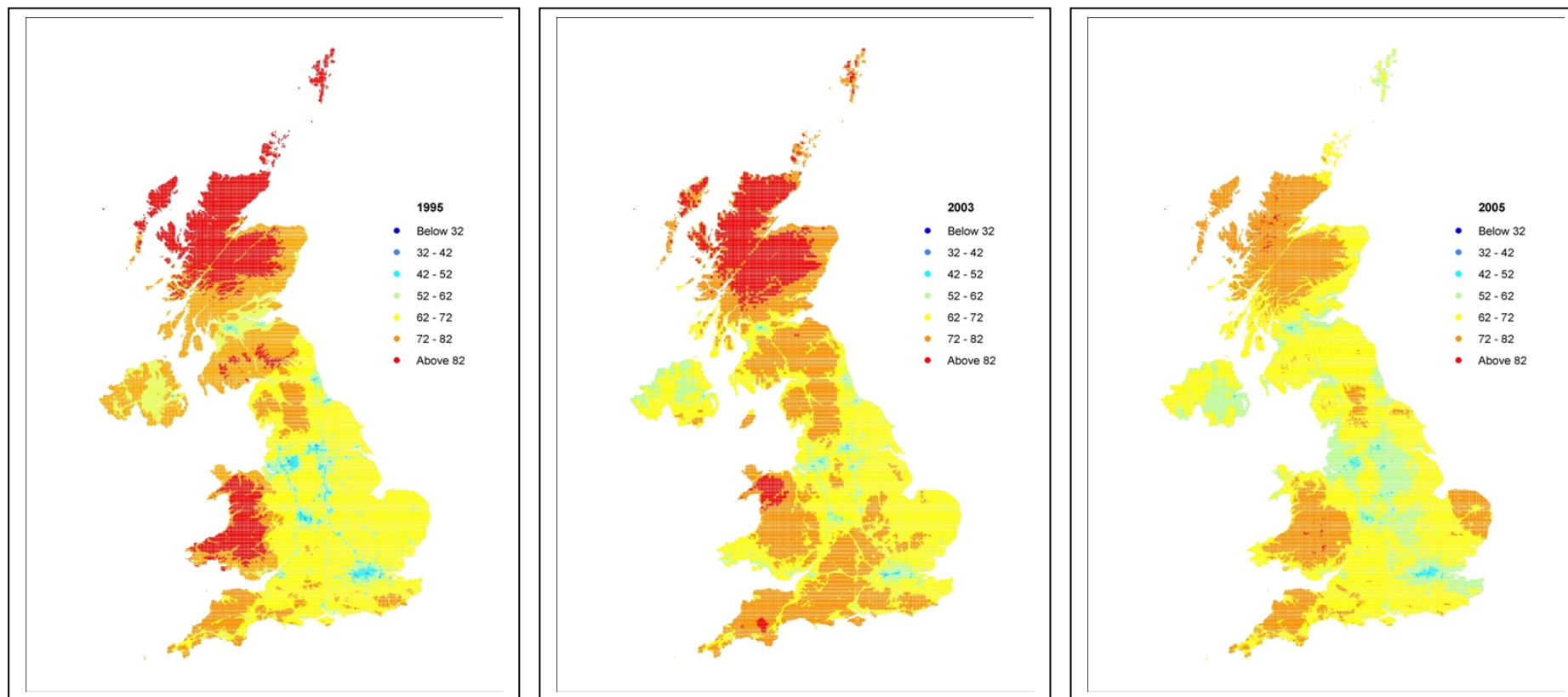
<http://www.ons.gov.uk/about-statistics/geography/products/area-classifications/rural-urban-definition-and-la-classification/rural-urban-definition/index.html>

<http://www.scotland.gov.uk/Topics/Statistics/About/Methodology/UrbanRuralClassification>

<http://www.nisra.gov.uk/geography/default.asp10.htm>

There have been suggestions of a specific threshold, with 100 ug/m³ (or 50 ppb) being the most commonly quoted value, below which ozone concentrations do not cause harm to human health (Stedman and Kent, 2008). The World Health Organisation (WHO) however concluded in 2004 that it was not possible to define an unequivocal no-effect threshold for the whole population. In this study we have used a linear non-threshold exposure-response model which is less sensitive to ozone peak concentrations compared to other threshold models proposed in literature (Pattenden *et al.*, 2010).

Using the ozone map produced by Stedman and Kent (2008), Figure 4.15 shows the modelled ozone metric for 1995, 2003 and 2005 for the annual mean of the daily maximum of the running 8 hour ozone concentration. This figure indicates the effect of the hemispheric background, with upland areas tending to have the highest levels of ozone (e.g. Scottish highlands), with a significant decrement in urban areas (e.g. London).



(a) : 1995

(b) : 2003

(c) : 2005

Figure 4.15 Annual mean of the daily maximum of the running eight hour mean ozone concentration ($\mu\text{g}/\text{m}^3$)
Adapted from Stedman and Kent, 2008

Comparison of the results for this analysis against those given by Stedman and Kent (2008) are shown in Table 4.4. These show small differences for premature deaths, although noticeably larger results for additional (or brought forward) respiratory hospital admissions. This is in the main due to the larger baseline rates used for this metric which on a national basis are about 40% larger than those used by Stedman and Kent, (2008).

The regional breakdown for these baseline estimates is given in Appendix 7, Table A7.7.

Table 4.4 Baseline estimates of the health impacts of mapped ozone
Comparison of UK results by Stedman and Kent (2008) and this study

	1995		2003		2005	
	Stedman and Kent (2008)	CCRA	Stedman and Kent (2008)	CCRA	Stedman and Kent (2008)	CCRA
Premature deaths						
0 μgm^{-3} cut-off	10,143	9,368	10,943	10,107	10,283	9,501
Respiratory Hospital Admissions (additional or brought forward)						
0 μgm^{-3} cut-off	23,428	33,098	25,276	35,727	23,751	33,571

4.5.4 Analysis (future projections)

The effect on future ground-level ozone concentrations due to climate change is an extremely complex metric, and future changes in temperature, specific humidity, wind speed and direction, cloud cover, solar radiation, heat flux and precipitation would all be anticipated to have a significant effect on future levels.

Very few, if any, studies have incorporated all the feedbacks between projected ozone and climate in a combined model of chemistry, transport emissions and climate (Cape, 2008). Although current trends are not uniform, there is some indication that background ozone levels over the mid-latitudes of the Northern Hemisphere have risen over the last three decades of the 20th century, and that this rise was in the range of approximately 0.5-2% per year, with rising trends being steeper in the 1970s and 1980s compared to the 1990s (Vingarzan, 2004).

Future changes in ozone at urban scale (directly affecting population exposure in urban areas) mainly depend on precursor emissions control (especially reductions in local NO_x emissions) and changes in ozone background levels. The reduction in the titration⁵⁴ effect of ozone by locally emitted NO is expected to cause an increase in urban ozone levels. A modelling study has shown that annual mean ozone concentrations at an urban location in central London are expected to more than double within the 2000-2050 period assuming an 0.3% per year increase of ozone background levels mainly due to reductions in projected NO_x emissions (and without considering the effect of climate change on urban ozone) (AQEG, 2009).

Meleux *et al.*, (2007) have used a chemistry transport model to show a pronounced regional variability of ozone in Europe, with the largest effects of climate change on ozone concentrations occurring over England, Belgium, Germany and France. The

⁵⁴In this context, "titration" means the chemical reaction of ozone with nitric oxide. This reaction removes ozone from the lower atmosphere.

temperature driven increase in biogenic emissions⁵⁵ appeared to enhance the ozone production and isoprene was identified as the most important chemical factor in the ozone sensitivity. Anthropogenic emissions and initial/boundary chemical conditions were kept the same for the present day and the scenario simulations, so as to isolate the effects of climate change on ozone. This study has also shown that summer ozone levels in future climate projections are similar to those observed during the exceptionally warm and dry European summer of 2003.

A recent modelling study by Athanassiadou *et al.*, (2010) considered projected changes in annual average ozone levels for London and Glasgow for plausible climates in 100 years from baseline years of 1971, 1976, 1981 and 1986. The study shows that the effect of climate change alone (assuming no changes in emission levels) is likely to cause annual mean ozone increases within the period of 1980s-2080s of about 5.2 ppb (20.0%) and 1.6 ppb (5.6%) in rural areas around London and Glasgow respectively, while the corresponding changes in urban concentrations are predicted to be about 4 ppb (33.0%) and 0.9 ppb (7.4% - not statistically significant).

In the present assessment, an approximate increase of annual mean ozone concentrations of 7-33% and 5-20% in urban and rural areas of the UK, respectively, due to climate change only has been assumed by the 2080s. In particular, excess mortality and respiratory hospital admissions associated with population exposure to ozone has been calculated under the following scenarios:

1. Increase of annual mean ozone (ppb) by 5% in rural and 7% in urban areas
2. Increase of annual mean ozone (ppb) by 13% in rural and 20% in urban areas
3. Increase of annual mean ozone (ppb) by 20% in rural and 33% in urban areas.

To estimate the equivalent change in annual mean daily max eight hour ozone (O_3) concentrations, annual mean O_3 has been plotted against annual mean daily max 8 hour O_3 concentrations observed at 13 rural and six urban background monitoring stations (including London and Glasgow) over the period 1990-2009, Figure 4.16. Linear and non-linear regression analyses were carried out to derive functions relating the two ozone metrics. The following power law relationships were finally used in the calculations as they yielded the highest correlation coefficients:

$$\text{Rural areas:} \quad [O_3]_{8\text{hour}} = 4.55[O_3]_{\text{annual}}^{0.61} \quad (4.7)$$

$$\text{Urban areas:} \quad [O_3]_{8\text{hour}} = 2.73[O_3]_{\text{annual}}^{0.77} \quad (4.8)$$

⁵⁵ Biogenic emissions are the emissions of volatile organic compounds from vegetation. These generally increase at higher ambient temperatures.

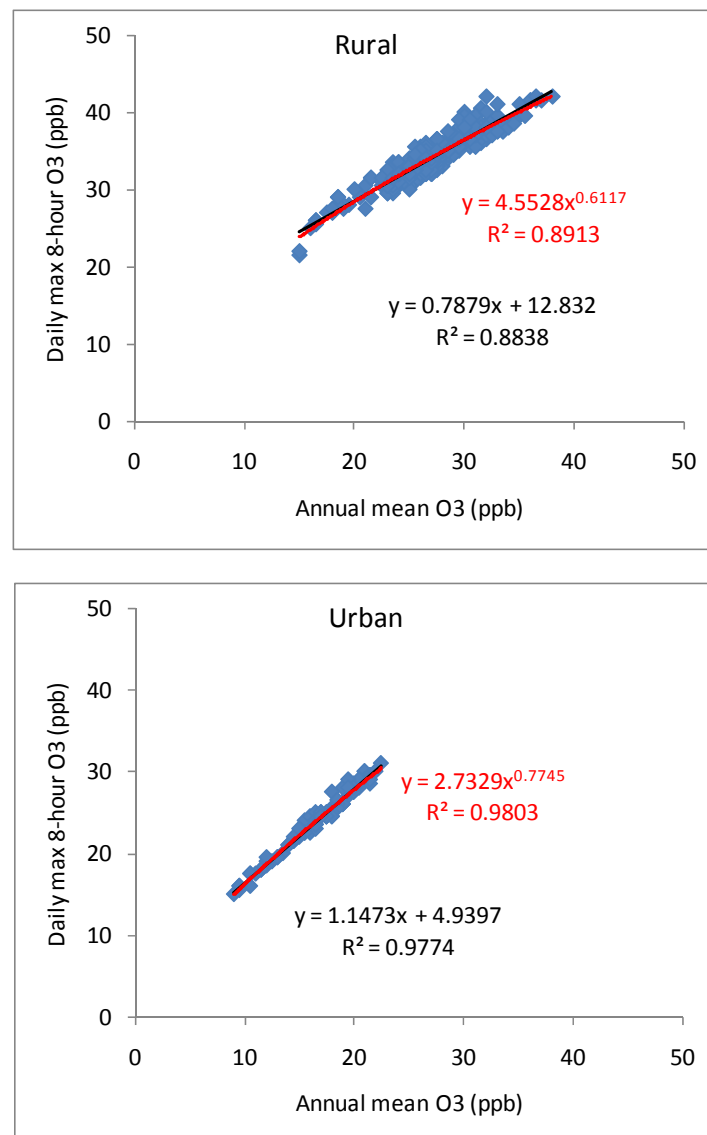


Figure 4.16 Annual mean O₃ against annual mean daily maximum eight hour O₃ concentrations for 13 rural and 6 urban background monitoring stations over the period 1990-2009

Given the lower confidence in the ozone projections for urban areas based on the study by Athanassiadou *et al.*, (2010), the above analysis was repeated using the more reliable rural ozone projections throughout the UK⁵⁶. In this case, the three scenarios are:

4. Increase of annual mean ozone (ppb) by 5% in rural and urban areas
5. Increase of annual mean ozone (ppb) by 13% in rural and urban areas
6. Increase of annual mean ozone (ppb) by 20% in rural and urban areas.

It should be noted that changes in ground-level ozone concentrations due to climate change are not going to be uniform in all urban or rural areas of the UK. Athanassiadou *et al.*, (2010) have shown that O₃ increases as a result of climate change are likely to be substantially larger in the London area compared to the Glasgow area. However, these spatial variability patterns are currently uncertain and have not been taken into account in the present assessment.

⁵⁶ Personal communication with Dr Dick Derwent.

The nature of ozone projections and its complex non-linear relationship between emissions and temperatures as well as its countrywide variation mean that it is not possible to produce a response function linked to a single climate variable. No response functions have therefore been presented in this report. In addition, there is no relationship between the projections by Athanassiadou *et al.*, (2010) and other time periods not considered. Future climate related effects linked to ozone are therefore only presented for the three scenarios highlighted earlier for the 2080s.

4.5.5 Socio-economic influence

Within this assessment, ozone related deaths and respiratory hospital admissions are expressed solely as a function of the exposure-response function, annual mean of the daily maximum 8 hour ozone concentrations, population density and the baseline mortality rate (Section 4.5.3). Although the baseline mortality rates may change, as already discussed in Section 4.2.3, the main socio-economic effect on future deaths and respiratory hospital admissions due to ground-level ozone concentrations is the change in regional populations. Other socio-economic effects such as changes in smoking and chronic obstructive pulmonary disease have not been considered.

The socio-economic influence has therefore been considered solely based on the projected changes in population.

4.5.6 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE4a	Summer air pollution (ozone) - deaths	M	No data						3	3	3
HE4b	Summer air pollution (ozone) - hospital admissions	M	No data						3	3	3

Future levels of ozone concentrations is a complex relationship between future levels of emissions of ozone precursors (mainly NO_x and VOCs), as well as synoptic weather conditions and high temperature episodes. As stated in Section 4.5.4, a response function linked to any climate variable is therefore difficult to estimate. Previously published work on ozone projections has also only considered plausible climates for the 2080s for the time periods considered in this report. Interpolation of results to the 2020s and 2050s is not possible from these results.

This analysis has therefore only considered estimates for the 2080s based on annual mean ozone concentrations projections on a UK wide 1km x 1km grid for 1995, 2003 and 2005. These years are anticipated to give the likely range of levels of ozone concentration for the reasons outlined in Section 4.5.2.

Using a linear non-threshold exposure-response model, Table 4.5 shows the baseline annual estimates of premature deaths and additional (or brought forward) respiratory hospital admissions on a regional basis for the three “baseline” years considered. This is for no change in ozone precursors emissions, and is a regional breakdown of the figures given in Table 4.4. Figures 4.17a and 4.17b show the premature deaths and

additional (or brought forward) respiratory hospital admissions for the two sets of three scenarios considered for the 2080s.

Table 4.5 Baseline estimates of premature deaths and additional (or brought forward) respiratory hospital admissions due to ozone in 1995, 2003 and 2005

Region	Premature Deaths			Respiratory Hospital Admissions		
	1995	2003	2005	1995	2003	2005
South West	938	990	946	3,195	3,374	3,223
South East	1,341	1,404	1,309	4,319	4,524	4,219
London	686	772	705	3,095	3,481	3,180
East of England	891	933	908	2,926	3,064	2,981
West Midlands	828	913	866	2,884	3,181	3,017
East Midlands	667	734	666	2,413	2,655	2,409
North West	1,097	1,200	1,104	3,965	4,339	3,990
North East	440	456	456	1,627	1,687	1,686
Yorkshire and Humberside	790	831	795	2,861	3,011	2,882
Wales	583	597	596	1,863	1,907	1,903
Scotland	882	1,039	926	2,826	3,330	2,966
Northern Ireland	226	237	225	1,128	1,180	1,119
United Kingdom	9,368	10,107	9,501	33,098	35,727	33,571

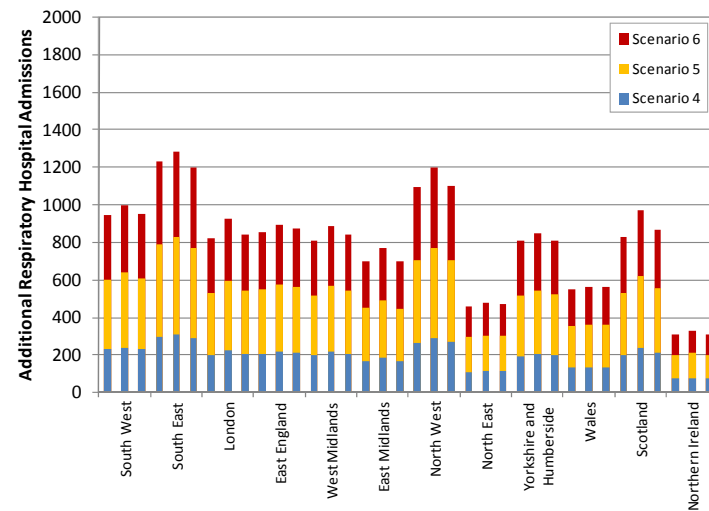
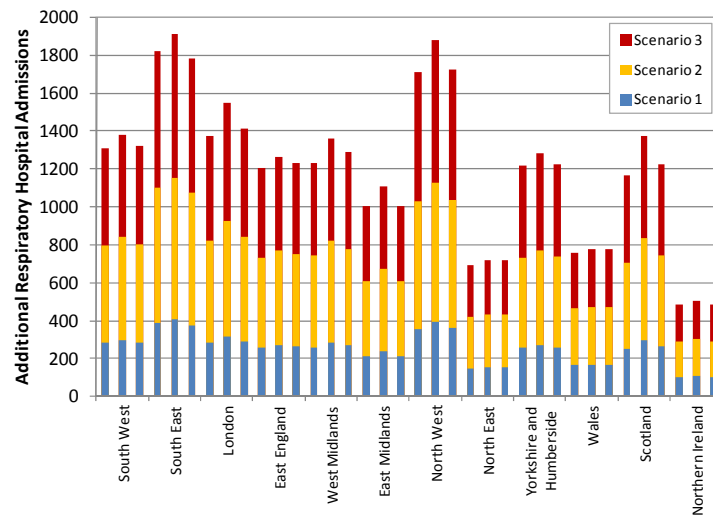
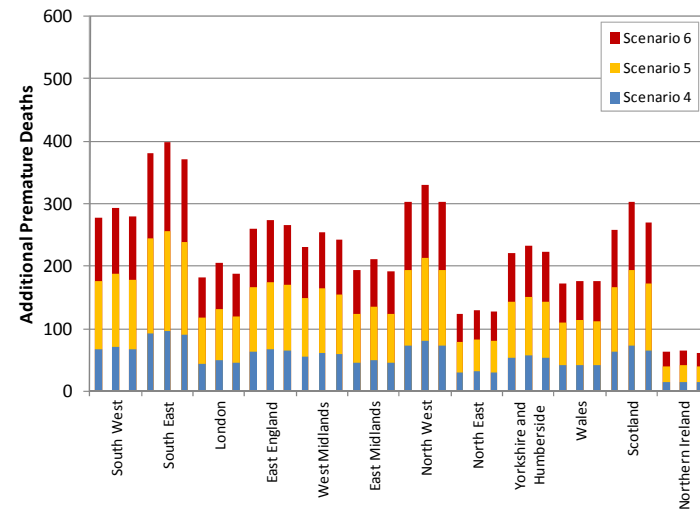
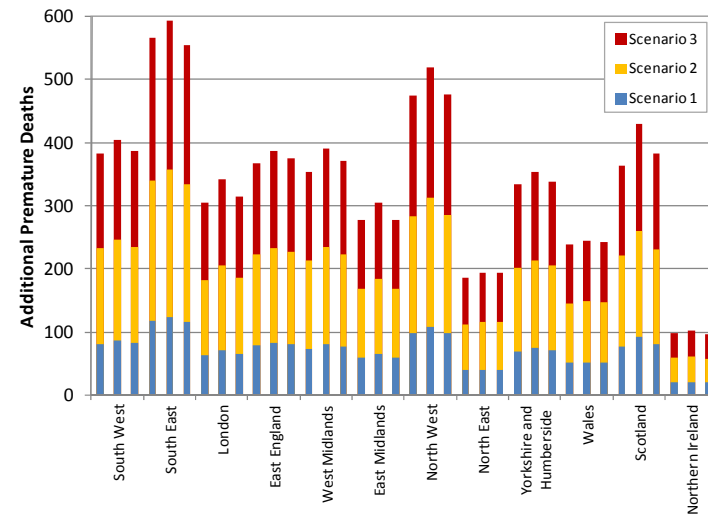


Figure 4.17a Effect of future levels of ozone for the 2080s on additional premature deaths and respiratory hospital admissions per year (current day demographics, regional estimates)
(see also Tables A7.8 and A8.19-A8.21)

Note : The three lines shown for each region represent the changes based on the different representative years, i.e. 1995, 2003 and 2005.

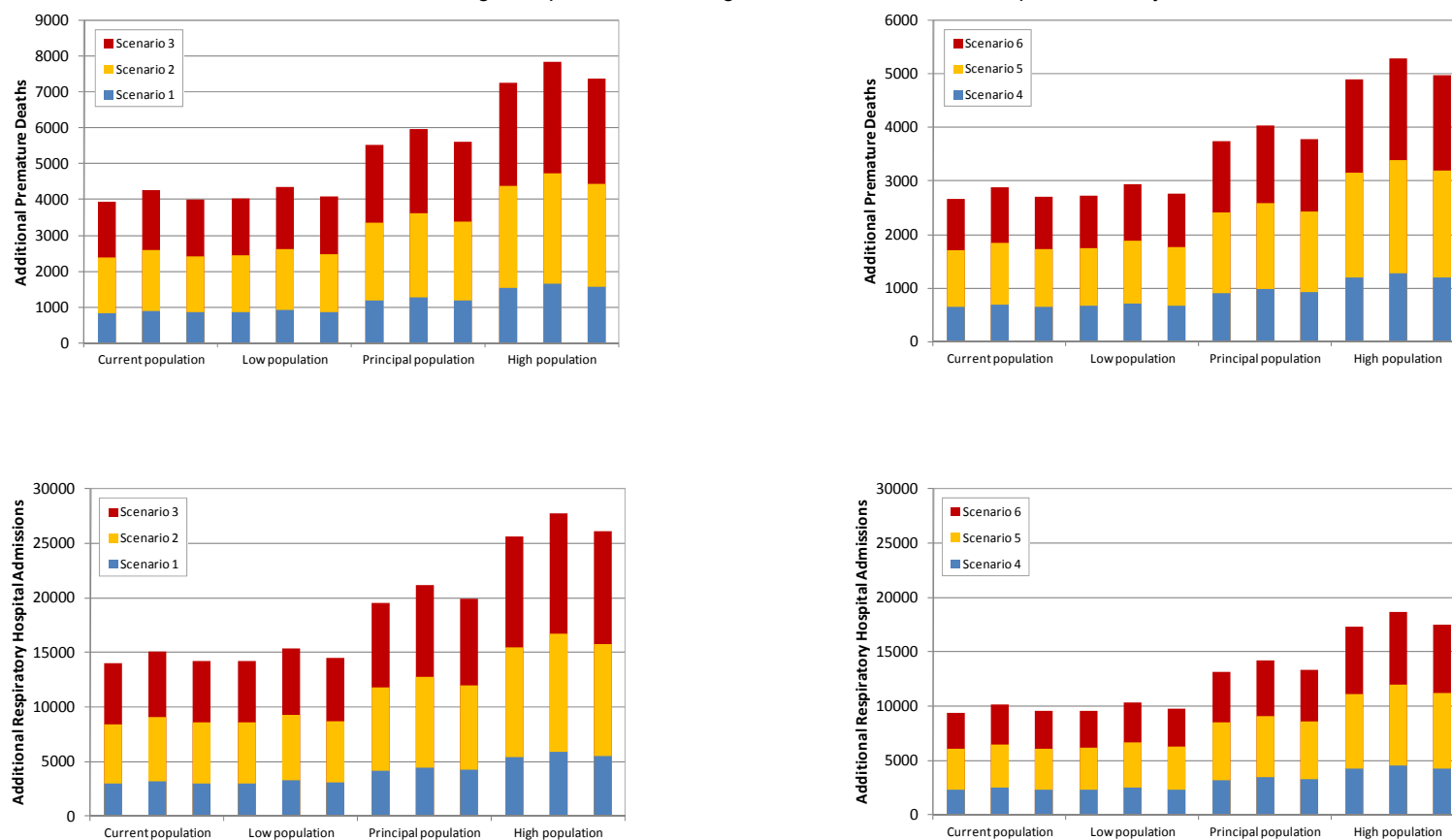


Figure 4.17b Effect of future levels of ozone for the 2080s on additional premature deaths and respiratory hospital admissions per year (UK estimates)
(see also Tables A7.8 and A8.19-A8.21)

Note : The three lines shown for each population projection represent the changes based on the different representative years, i.e. 1995, 2003 and 2005.

4.6 HE9 – Sunlight/UV exposure

4.6.1 Introduction

The most common diseases linked to ultraviolet radiation (UVR)⁵⁷ exposure are skin cancers and cataracts as well as other less common detrimental health effects including sunburn, photodermatoses, photoaggravation of inflammatory skin disorders and immunosuppressive effects on the skin⁵⁸. The most serious of these effects are skin cancers, which are either melanoma⁵⁹ (MSC) or non-melanoma skin cancers (NMSC), consisting of basal cell carcinoma (BCC), squamous carcinoma (SC), and merkel cell carcinoma (MCC).

Apart from MCC, MSCs are the least common type of skin cancer, with 10,672 new cases diagnosed in 2007 (Cancer Research UK, 2009). However, these are the most fatal with 2,067 reported deaths in 2008 (Cancer Research UK, 2010). For NMSCs, over 84,550 cases were registered in the UK in 2007 (Cancer Research UK, 2010); however registration is incomplete (particularly for basal cell carcinomas), and Toms (2004) and Holme *et al.*, (2000) estimates that there are at least 100,000 diagnosed cases each year. Apart from MCC, survival rates for NMSCs are high, particularly for the most common of these, BCC, which accounts for less than 0.1% of recorded deaths due to cancer each year. SC is more aggressive and accounted for most of the 491 deaths recorded in the UK in 2008 due to NMSCs (Cancer Research UK, 2010).

Health benefits of UV exposure include the synthesis of vitamin D, and although UV exposure may exacerbate inflammatory skin conditions it also has some therapeutic effects. It has long been known that vitamin D is required to maintain a healthy skeleton through a process of calcium metabolism and the main source of vitamin D is through exposure to UVB radiation, with diet playing a minor role. There is some weak evidence for a possible role for vitamin D protecting against some cancers (National Radiological Protection Board, 2002). Furthermore, moderate exposure to sunlight has been generally associated with improved mental and physical health (Holick, 2001). Both negative and positive effects of increased sunlight/UV radiation exposure are difficult to quantify. It should be noted that the risk of malignant skin tumours as a result of UV exposure is currently considered to be of a greater consequence⁶⁰.

4.6.2 Effect of UV Radiation on health

Humans have two major organ systems whose cells and other tissues are commonly exposed to UV radiation via sunlight. These are the skin and the eye. The cells/tissues exposed in the skin are the epidermis and the dermis. For the eye it is principally those associated with the cornea, the iris and the lens. Exposure to sunlight can have severe and differing health effects, dependent on the type of UV exposure and the period of time that exposure occurs over, and these are outlined below:

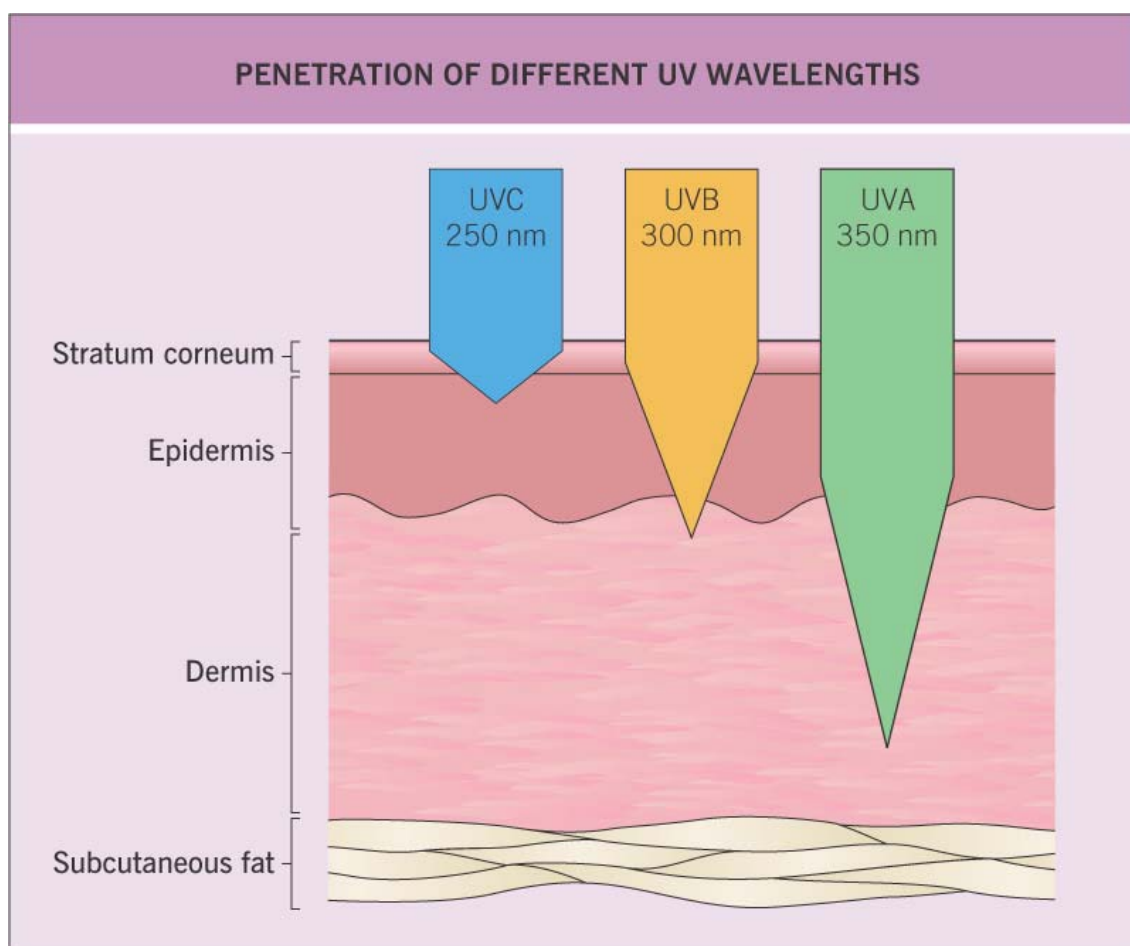
⁵⁷ UV radiation is divided into UVC (100-280 nm), UVB (280-315 nm) and UVA (315-400 nm) radiation. Practically all of the UVC and much of the UVB radiation are absorbed by the stratospheric ozone layer, and about 95% of the UV radiation that reaches the earth's surface is UVA. The main risk to health is from UVA and UVB radiation.

⁵⁸ Personal communication with Dr Ruth Asher Consultant Dermatopathologist, John Radcliffe Hospital in Oxford.

⁵⁹ Melanoma is commonly referred to as malignant melanoma.

⁶⁰ Bentham (2008a) indicates that only modest levels of exposure are required to maintain adequate vitamin D levels. Advice from the Governments Chief Medical Officer Sir Liam Donaldson is also to reduce exposure to the sunlight, not increase it.

- Depth of skin penetration is linked to wavelength (Anderson and Parrish, 1981 and Bruls *et al.*, 1984). UVB radiation causes the most significant solar mutagenesis of the epidermis layer (Besaratnia *et al.*, 2008 and Figure 4.18), and is the main driver leading to skin cancer.
- There is evidence that UV can lead to an increase in cataracts (Wolff, 1995 and EPA, 2010). Radiation in the range of 305-400 nm can penetrate the cornea and is strongly absorbed by the lens. Epidemiological evidence suggests that UVR may contribute to the cause of human cataracts through damage to lens proteins and cells (National Radiological Protection Board, 2002).
- UVB can result in immunosuppressive effects in the skin (Poon *et al.*, 2005), which can have health effects if they coincide with the entry of an infectious agent, or the development of a cancer cell. The relative significance of UVA in immunosuppression is, however unknown (Poon *et al.*, 2005).
- UVA and UVB cause sunburn, with immediate erythema caused as a result of UVA. Short term exposure to UVB can also cause photokeratitis, the ocular equivalent of sunburn. The effects of UVB are usually not immediate, typically occurring 6-12 hours after UVB exposure.



From Bologna, Jorizzo & Rapini: Dermatology 2e. © 2008 Elsevier, Ltd.

Figure 4.18 Depth of penetration of different wavelengths of UV radiation into the human skin

Source: Bologna *et al.*, 2008

UVB exposure linked to MSC and NMSCs is considerably the most important health effect linked to sunlight / UV radiation exposure. UV radiation effects on eyes and immunosuppressive effects and sunburn, as well as the positive vitamin D effects are therefore not considered further.

4.6.3 Current and Future UVR radiation and the Effect on Skin Cancers

The amount of UV radiation which reaches the surface of the earth is largely determined by how much is absorbed by the stratospheric ozone layer. Since the mid 1970s, the stratospheric ozone layer began to be depleted due to the anthropogenic release of chlorine and bromine containing chemicals, and this led to reductions in stratospheric ozone of up to 8% per decade and a corresponding increase in UV exposure in Europe over the last few decades (European Environment Agency, 2000). The Montreal Protocol in 1984 acted to limit the release of chemicals including CFCs, to allow for recovery of the ozone layer. However, the lifetime of these destructive chemicals means that this process is likely to take a number of decades and levels of stratospheric ozone are not expected to reach pre-1980 levels until 2050 (UNEP, 2010). There are further complexities in predicting stratospheric ozone recovery including effects of volcanic eruptions, interactions with the climate system and changes in other atmospheric gases, which may disrupt or modify the process of ozone recovery.

It is unclear what the effect of climate change will be on stratospheric ozone recovery in terms of chemical, radiative and dynamical processes (UNEP, 2010). However, Hegglin and Shepard (2009) have indicated that under the IPCC medium emissions scenario, the clear-sky UVR index would increase by approximately 9% in northern high latitudes over the period 1965 to 2095 due to changes in stratospheric circulation. Changes in cloud cover in the future are also uncertain but a decrease in summertime cloud levels would imply an increase in levels of UV radiation exposure (see also Section 4.6.4). Although the effect of climate change on UV radiation exposure in terms of stratospheric ozone recovery and cloudiness level is difficult to predict, it is likely that increased summertime temperatures in the UK will encourage more outdoor activities and lighter clothing in the future, and this will increase the health risk of exposure to UV radiation to the UK population. People occupationally exposed to solar UV radiation, including farmers, construction workers and some public service workers may be at higher risk of developing skin cancer (Young, 2009), although studies indicate that current risk is lower relative to the rest of the population (Autier *et al.*, 1994 and Elwood and Jopson, 1997).

4.6.4 UV radiation risk for health

Although the amount of UV radiation that reaches the surface of the earth is largely determined by how much is absorbed by the stratospheric ozone⁶¹ layer (Section 4.5.3), the main determinants of UV exposure linked with MSC and NMSC and linked to climate change are cloud cover, periods of time spent outdoors, changes in the mean annual flux and temperature changes. These effects on UV radiation over the current century are:

- Levels of cloud cover are anticipated to show noticeable changes over the current century. Based on UKCP09 best estimate projections for the

⁶¹ MSC rates are approximately 3-4 times greater in Australia and New Zealand than they are in the UK. This is because the ozone layer in this part of the world is very thin, therefore increasing levels of surface UVR.

summer (UKCP09, 2009), these could be as high as a 20% reduction in the south by the 2080s. Schafer *et al.*, (1996), Chen *et al.*, (2004) and Lee *et al.*, (2004) all investigated the effect of cloud cover on UVB radiation, indicating that UVB radiation was noted to reduce by approximately 70% for overcast skies, 40% for 80-90% cloud cover, 25% for 60-70% cloud cover and 20% for 40-50% cloud cover.

- Projected warmer summers are anticipated to result in people generally spending more time outdoors, therefore exposing themselves to greater levels of UV radiation. Horton (2004), based on beach users in East Anglia indicated that the time spent on the beach was strongly correlated to estimated levels of UVB exposure, with a significant negative association with the area of the body covered by clothing. This could be particularly significant for the south where cloud cover could reduce and net surface UVB flux is projected to increase (see point below).
- Fears *et al.*, (2002) assessing non-Hispanic white patients in Philadelphia and San Francisco clinics indicated that an increase in the average annual UVB flux was associated with an exponential increase in melanoma risk. For the 10% level, this was given as an increase of 19% (5-35% 95% CI) for men and 16% (2-32% 95% CI) for women. UKCP09 (2009) indicate a slight increase in net surface UVB flux⁶² by the end of the century for Southern England (up by approximately 10% by the 2080s for the high emissions scenario at the 90% probability level), reducing further north⁶³.

The main risk to individuals for MSC and NMSC is linked to the mean annual flux that they receive over a lifetime, rather than the cumulative flux (Fears *et al.*, 2002). However, before even the effect of climate change is considered, this “changed” baseline risk is extremely difficult to estimate. Changes in the behaviour of individuals and the population in terms of occupation, leisure and lifestyle will probably be the main driver to changes in the health effect. These measures are extremely difficult to quantify, and it is not known if there is any quantifiable research indicating what these changes may be, and how the risk changes due to different levels of exposure as indicated by Autier *et al.*, (1994) and Elwood and Jopson (1997). However, considering the work by Fears *et al.*, (2002) and the potential for greater outdoor activity in warmer summers, an increase in melanoma risk of up to 20% could be possible by the end of the century. This is particularly the case for the most southerly parts of the UK where the increase in UVB flux is anticipated to be at its greatest, and where the potential for lower levels of cloud cover and higher temperatures would be anticipated to further increase periods of time spent outdoors. However, this estimate is highly uncertain, as it mainly relates to a study carried out in a different environment, with further evidence for greater exposure based on longer periods of time spent outdoors.

4.6.5 Socio-economic influence

There are a number of socio-economic factors that need to be considered in future estimates of MSC and NMSC cases linked to climate change. These include:

- Approximately 75% of NMSCs occur in people aged 60 or over, and this is a fairly consistent pattern across the regions. With the predicted age shift

⁶² Net surface wave flux is a measure of the total amount of radiation that flows through a unit area per unit time at the Earth's surface (see also Section 3.2.7).

⁶³ UKCP09 do not do projections corresponding directly to the wavelength of UVB radiation. However, an assessment of projections for net surface shortwave and longwave flux, which encompass the wavelengths for UVB radiation has been used to estimate the likely projections for UVB radiation.

in populations, this is expected to result in an increase in tumour incidents in the UK (Diffey and Langtry, 2005). This is partly indicated in Figure 4.19 which shows the probability and cumulative density functions (pdf and cdf) for MSC and NMSC deaths for England and Wales against age for ICD-10 codes C43 (MSC) and C44 (NMSC)⁶⁴. This indicates for example that approximately twice as many people die as a result of MSC and NMSC at age 65 than at age 50 (from pdf plot), and that approximately 40% of NMSC deaths occur in people aged 70 or over (from cdf plot). These density functions were noted to show little variation on a regional basis.

- Based on the changing age structure of the country (Smith *et al.*, 2005), and an assessment of Figure 4.19, skin cancer deaths are likely to increase. However, this assumes that the response function for MSC and NMSC does not change, which is inconsistent with an ageing population.
- Cases of MSC have a positive correlation with affluence (Quinn *et al.*, 2001). Indications are that currently cases of melanoma are about twice as likely in affluent areas than for the most deprived areas (Quinn *et al.*, 2001 and ISD 2010). The reasons for these differences are not known, however, if linked to travel abroad typically where higher sun exposure is experienced, then this gap is likely to narrow in the future as more people travel abroad, and therefore increase overall rates of MSC.
- MSC is more common in women than men, with a ratio of about 5 to 4. The Cancer Atlas of the UK indicates that these ratios do not vary significantly on a regional basis (Cancer Research UK, 2010).
- Incidents rates of MSC are typically above average for Southern England, and below average for Northern England. The main exceptions to the general trend of “lower rates in the north” and “higher rates in the south” are for Scotland and Northern Ireland. The high rates for these regions may be as a result of better ascertainment of cases, or due to a larger proportion of fair-skinned people in these areas (Cancer Research UK, 2010).
- Fairer skinned individuals show the highest rates of MSC (Cancer Research UK, 2010).
- Melanoma is rare in black people often occurring on parts of the body (e.g. soles of feet) not exposed to sunlight. Non-white ethnic groups are anticipated to increase at greater rates than white ethnic groups. The current population of these groups is also considerably younger on average than for the white population. These are also more highly concentrated in the south where future UVB exposure is anticipated to increase at the largest rate (Employers Organisation, 2004¹²).
- There is anticipated to be a future increase in population in the south relative to the north. However, these changes will almost certainly vary for different age groups, with a noticeable reduction in the 25-29 age group in the north, and a noticeable increase in the 15-24 age group in the south. The 50-64 age group is anticipated to remain relatively constant across the UK (Employers Organisation, 2004¹²).
- Melanoma incidence is currently increasing by about 5% per year in the UK. This is believed to be linked to increased foreign travel and increased use of sunbeds (Cancer Research UK, 2010).

⁶⁴ Source : Published statistics obtained from the National Statistics Office for 2006 and 2007.

- There is strong evidence that heavy occupational exposure currently reduces risk of melanoma, and that risk is at its highest for intermittent levels of exposure. This was based on an assessment of 35 case-control studies by Elwood and Jopson (1997), for all known published studies at the time of this paper.
- The number of holiday weeks spent annually in sunny resorts and sunbathing during the hot hours of the day is strongly correlated to melanoma risk. Length of holidays showed a strong correlation to level of awareness as well as risk of melanoma, Autier *et al.*, (1994).
- Ecological studies consistently indicate long latency periods of years or decades from an exposure of an individual to increased levels of UVB to a melanoma diagnosis as noted by a review of studies by Whiteman *et al.*, (2001). This means that increased exposure during childhood could increase the risk to individuals suffering from melanoma when they are in their thirties or forties (i.e. 20-30 years later).

Effective adaptation measures, such as public awareness campaigns informing the public about the health risks associated with excessive UV radiation exposure and promoting protective measures may also help reduce the burden of disease as a result of changing behavioural trends.

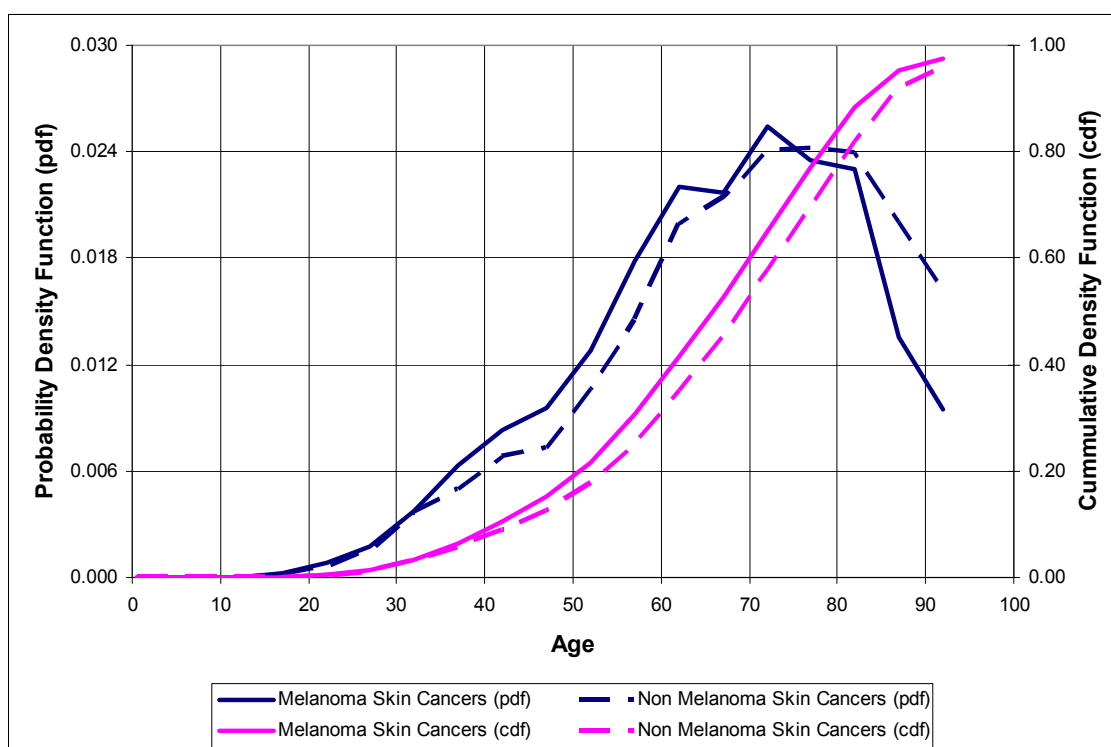


Figure 4.19 Probability density of melanoma and non melanoma deaths against age for England and Wales

4.6.6 Sunlight/UV response function

The future change in the numbers of skin cancer cases per year is related to the change in risk of skin cancer due to the change in the mean annual flux. Fears *et al.*, (2002) based on his work on non-Hispanic whites in America indicate how this change in risk could be assessed for melanoma cases. However, the variance linked to a

number of unknown factors, including the main variable, time spent outdoors, means that it is difficult to quantify how this risk may change in the future. This is particularly the case considering the expected recovery in the stratospheric ozone layer. Also, as stated in Section 4.6.4, despite the extensive nature of this study, it is based on a group of individuals in a quite different environment.

These considerations go only part-way towards assessing this risk, as social behaviour will almost certainly change due to projected increased temperatures (e.g. increased time spent outdoors and lighter levels of clothing, particularly in the south where increased levels of UVB exposure are projected to be at their greatest). It is therefore not possible to quantify these aspects. Considering the results by Fears *et al.*, (2002), with the current ratio of cases to deaths remaining constant, MSC cases could increase by up to 20% by the 2080s in the south. However, this relationship would be expected to be less strong for NMSC, as the evidence for this is less clear⁶⁵. The probability of greater periods of time spent outdoors as alluded to for example by Horton (2004) would also lead to a likely, although unquantifiable increase.

With the various factors outlined above, as well as the driving factor of future human behaviour in response to projected warmer weather, it is not possible to estimate a reliable response function for this metric. This metric is also further complicated by expected increased detection rates and improved levels of treatment.

4.6.7 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE9	Sunlight/UV exposure	L	1	1	1	2	2	2	2	2	2

UVB exposure linked to MSC and NMSC is considered the most important health impact linked to sunlight/ UV exposure. Changes in the number of MSC and NMSC cases and deaths linked to climate change is therefore the only effect linked to sunlight/UV exposure which was subject to an initial quantitative analysis for this report. The beneficial effect of moderate sunlight exposure on mental and physical health (e.g. improved levels of vitamin D) has not been quantitatively assessed due to the lack of published quantitative evidence.

As outlined so far in this chapter, a relationship between future levels of skin cancers and climate change as a result of a change in levels of UVB is an extremely complex relationship, driven more by changes in social behaviour rather than any climate effect. Improved detection rates and better treatment of cancer cases is likely to mean that percentage mortality will decrease in the future and it is unclear as to how to incorporate this consideration into a quantitative analysis. Other uncertainties include the projected UVR for the future climate of the UK, since UKCP09 do not specifically refer to UVB radiation. The effect of climate change on the recovery of stratospheric ozone is a further area of uncertainty. With all these uncertainties in mind, it was decided that no reliable quantitative estimate of future UV related health impacts could be made in this report.

⁶⁵ Personal communication with Dr Ruth Asher Consultant Dermatopathologist, John Radcliffe Hospital in Oxford.

4.7 HE10 – Effect of floods/storms on mental health

4.7.1 Introduction

The documentation of the mental effects of flooding and storms has increased in recent years, with this covered in a number of recent influential papers such as Frumkin and McMichael (2008) and Costello *et al.*, (2009). The publication of the 2007 Intergovernmental Panel on Climate Change (IPCC) assessment report (Confalonieri *et al.*, 2007) also included a section on the human (including mental) health effects of winds, storms and floods.

However, despite this recent activity, and the broad recognition that the mental health effects of climate change is very likely to be significant across the range of climate effects, such effects have only been discussed in very broad terms, and often by those not actively involved in mental health research or policy (Page and Howard, 2010). Mental health effects of flooding are also often under-recognized (Costello *et al.*, 2009) despite the enhanced preparedness since, for example, several major flood events in the UK in the 1940s, and the well documented 1953 flood. Important knowledge gaps also exist in relation to long-term anxiety and depression, as well as the indirect effects on mortality and the use of health care services following a severe weather event (Kovats and Hajat, 2008).

Examples following Hurricane Katrina in 2005 showed how even in a western society, mental health problems can become intractable (Kessler *et al.*, 2008), and how medical and psychiatric care can diminish dramatically for those with a pre-existing mental illness in the immediate aftermath of a significant flood event (Weisler *et al.*, 2006). Indirectly, forced migration due to (for example) low lying coastal areas becoming uninhabitable, would lead to an increased burden of mental health problems. This was demonstrated for those with a pre-existing serious mental illness for “complex” emergencies (e.g. armed conflicts) by Jones *et al.*, (2009), and could become an issue in areas such as along the River Humber, where large areas of land are particularly at threat due to relatively small increases in mean sea levels (Ramsbottom *et al.*, 2012).

Within the UK, of the studies carried out on the mental health effects of severe weather, limited research has been carried out in relation to “non” flooding events (with the exception of a study linking suicide rates with hot weather, Page *et al.*, (2007), and most reports are dominated by fluvial flooding. Floods are considered to be the most important climate change related meteorological events in the UK that would be expected to impact on mental health. This study therefore only considers adverse mental health effects due to flooding. Effects due to changes in storms resulting from climate change are uncertain and likely to be small when considered against flood effects, and are therefore not assessed further.

4.7.2 Effect of flooding on mental health

Adverse psychiatric effects and illness in the aftermath of flooding and other climate related effects have been documented (Norris *et al.*, 2002 and Reacher *et al.*, 2004), and are strongly related to the type and nature of the flooding that takes place. Pre-existing mental health conditions such as depression or adverse social circumstances such as living alone or having limited social contact can also greatly increase levels of anxiety or depression following a flood episode, which can be delayed over a period of several months (Ginexi *et al.*, 2000, Tunstall *et al.*, 2006 and Hajat *et al.*, 2003).

Several studies have also found an association between pre-existing psychiatric disorder and subsequent post traumatic stress disorder (PTSD) following natural disasters (Breslau and Peterson 2010, Kessler 1999, Koren *et al.*, 1999, McMillen *et al.*, 2002, North *et al.*, 1994a and 1994b, and Smith 1990). The psychologically healthy are also more resilient to repeat floods, which Ferraro *et al.*, (2003) indicated may be due to an inoculation effect as a result of previous experiences. Those with more resources and other social factors (community/social support, marriage status, income, education, etc) are also less likely to develop PTSD (Green *et al.*, 1985, Solomon *et al.*, 1988, Breslau *et al.*, 1997, Kessler *et al.*, 1999 and Ursano *et al.*, 1999).

Based on a literature review of the evidence therefore, the main effects on mental health are outlined below. These include infections, diseases⁶⁶ and illnesses, etc, that can as a consequence exacerbate or cause levels of mental illness⁶⁷.

- Severe flood events can lead to a small increase in post-traumatic stress disorder (Galea *et al.*, 2005), a condition most commonly associated with flash flooding as indicated by Verger *et al.*, (2003).
- General psychological distress increases substantially in the aftermath of flooding (Reacher *et al.*, 2004). This includes people who do not fulfil criteria for a discrete disorder such as PTSD or depression but who nevertheless have been adversely affected psychologically.
- Immediate and delayed problems caused by flooding include unmasking cognitive impairment and provoking of depressive and anxiety disorders (Marshall *et al.*, 2007 and Hayes *et al.*, 2009) and the presentation of Somatoform disorders⁶⁸ (Van Den Berg *et al.*, 2005). There is also some new evidence that alcohol disorders may be exacerbated in those with a previous history of alcohol misuse, e.g. relapses in the previous abstinent (North *et al.*, 2010).
- Displacement is a well recognized trigger for psychological problems (Fullilove 1996), as well as damage to property (Scottish Government 2007 and Keane 1998) and dealing with repair work after the flood (Tapsell and Tunstall 2001). This is particularly the case for those who have lived in the same place for a long time (Phifer *et al.*, 1988).
- There is some evidence of medium to long-term impacts on behavioural disorders in young children affected by natural disasters (Durkin *et al.*, 1993 and Boksaczanin 2000 and 2002).
- Theoretically, any increase in infectious disease may lead to increased psychological distress or disorder. However, this risk is limited in countries such as the UK where the likelihood of post-flooding infectious disease epidemics is low (Page and Howard, 2010).
- An increase in respiratory and diarrhoeal diseases (Miettinen *et al.*, 2001, and Wade *et al.*, 2004).

Many of these problems do not present themselves immediately, and some are restricted to certain types of flood. For example, the flooding of Oxfordshire in 2007 (see Section 4.7.3) caused by a gradual increase in water levels on land triggered quite

⁶⁶ The risk of floods increasing communicable diseases appears to be relatively infrequent in the UK (Hajat *et al.*, 2003).

⁶⁷ General psychological distress increases substantially in the aftermath of flooding (Reacher *et al.*, 2004). This includes people who do not fulfil criteria for a discrete disorder such as PTSD or depression, but who nevertheless have been adversely affected psychologically.

⁶⁸ Somatoform symptoms are physical symptoms for which no underlying biomedical explanation can be found.

a different set of problems than those that would be associated with other forms of flooding. These were mainly related to delayed psychological symptoms due to damage to property as well as social isolation and displacement (Tunstall 2007 and Tunstall *et al.*, 2006), with some cases not materialising until up to nine months later. No cases of PTSD were noted in this incident of gradual increase in water levels on land, as PTSD is a condition more common amongst victims of flash flooding (see above).

4.7.3 Case studies

Lewes Flood of 12th October 2000

Following three days of exceptionally heavy rain on already saturated ground, subsequent overtopping of the River Ouse caused flooding of the town of Lewes on 12th October 2000, with 613 residential and 207 business properties flooded. 227 randomly selected residents from 103 of these flooded properties (representing 42% of flooded properties) as well as 240 from non-flooded properties (representing 2% of non flooded properties) were interviewed nine months later by Reacher *et al.*, (2004), who compared mental health conditions, as well as reported gastrointestinal and other illnesses from the flooded and non-flooded households⁶⁹.

For adults, Reacher *et al.*, (2004) identified a fourfold increase (48% of flooded residents against 12% of non flooded residents) of psychological distress, defined as a score of 4 or above as measured by the 12-item General Health Questionnaire (GHQ-12)⁷⁰, for those in flooded properties against those in non-flooded properties, which was most noticeably for those with pre-existing physical illnesses, a well recognized link (Reid and Wessley, 2001). This was a significant increase, although it was not clear whether these results in general were as a result of the flooding, or subsequent events over the subsequent nine month period. Risk estimates for physical illness were also reported to decline after adjustments were made for psychological distress. However, no clear trend was apparent for risk of psychological distress relative to number of days displaced from home despite this being recognized as a cause of stress (Fullilove 1996). Interviews relating to children did not take place, so it was not possible to measure any change in psychological distress for children.

These results will have been affected by the high level of temporary resettlement required at Lewes. Of the 613 residential properties flooded, 397 (65%) were evacuated and became vacant after the flood. Of these, 127 (20% of the total residential properties flooded) were still vacant nine months after the flood.

West Oxfordshire floods of 2007

For the summer 2007 floods (see Section 4.4.2), Hayes *et al.*, (2009) considered the effect on older adults living in West Oxfordshire under the care of a community mental health team. This indicated that for those affected by the flood, 9 out of 87 (about 10%) suffered deterioration in mental health as a direct consequence of the flood. This rose to 1 in 3 (36%) when a difficult rescue was experienced. Two new individuals were also referred as a consequence of the floods, and overall 11 new clinical problems

⁶⁹ A potential limitation of this study was that responses were only obtained from those who were contactable by phone, and who had a recognizable telephone number. Although response rate for those contacted was high in households randomly selected, it is possible that flooded individuals normally resident at addresses for which no contact number was available could have been worse affected, which could result in an underestimate of the risks highlighted.

⁷⁰ At a cut-off of 4, the GHQ-12 was noted by Bashir *et al.*, (1996) as having a 0.81 positive predictive value, defined as the proportion of patients with positive tests who are correctly diagnosed, for diagnosing depression and anxiety defined by ICD-9 for those attending general practice surgeries. This level has therefore been used in several UK studies to define significant psychiatric morbidity.

were triggered, with presentation from immediate to up to nine months later. In addition to the general deterioration in mental health of some of the individuals, logistical problems, such as closure of roads and flooding of re-housed residents caused additional problems, as well as the inability of some people with dementia to remember their full names and to identify their property.

Health effects of flooding on 30 locations in England and Wales

Tunstall *et al.*, (2006) analysed the physical and psychological health effects of fluvial flooding for residents of 30 locations in England and Wales that had flooded since January 1998 both during and after the flood event. 983 individuals of 18 or over were interviewed whose homes had been flooded above floor level. Similarly, 527 individuals from the same areas whose homes had not flooded were interviewed as a “control”. No more than one individual was interviewed from any one address.

All respondents were asked to complete the GHQ-12 for current conditions, and for flooded respondents retrospectively for the personal “worst health time” in respect of the flood. A Post Traumatic Stress Scale (PTSS), (Scott and Dua, 1999) was also used to measure PTSD, including measures of the frequency, severity and duration of individual symptoms and symptoms overall.

From the results, 64% of flood victims were found to have scores on the General Health Questionnaire 12-scale indicative of mental health problems (scores of 4 or higher) at their worst time after the event, compared with 25% with this score at the time of the interview. For 56% of flood victims, health had improved since the flood event, however, 19% recorded no change.

From the PTSS score, 15% were reported as suffering from at least a mild level of PTSD, with 5% of these scored at a high level and 2% at an extreme level. These levels compare favourably with figures of 15-20% reported by Beck and Franke (1996) for people studied after natural disasters. Few studies of flooded households have used the PTSS scale (see also Section 4.7.5).

Overall, Tunstall *et al.*, (2006) suggested that the effects of flooding on the mental health of some victims are enduring and not just long-term, and that this burdens adds significantly to the strain on medical services, as well as potentially disrupting the capacity of health care systems to respond to the health crises (Ohl and Tapsell, 2000).

4.7.4 Socio-economic influence

A number of key socio democratic factors are noted with regards to mental health effects of flooding and/or storms.

- Research has shown that floods and other disasters impact on men and women in different and distinct ways (Enarson and Hearn-Morrow, 1998, Fordham 1998, Morrow 1999 and Tapsell and Tunstall, 2001). Women tend to suffer more, which qualitative research indicates is because women have the main responsibility for, and probably a greater emotional investment in the home as well as the key responsibility for the children and/or elderly (Tapsell *et al.*, 2003). However, this may also be due to the fact that women more readily admit feelings of stress, anxiety and/or depression and to seek medical help in the aftermath (Tapsell and Tunstall 2001).
- Those with a poor health status prior to a flood event were noted to show a more serious decline related to those who did not suffer from poor health prior to the event. This was noted in all the case studies outlined above as well in a number of studies outlined in Sections 4.7.1 and 4.7.2.

- Tunstall *et al.*, (2006) noted that those renting property experienced more health problems at the time of the flood than those owning or buying. Homeowners were also noted to be much more likely to have contents insurance which would help them with the financial consequences of a flood, and would exacerbate the health effects of those with no or limited insurance cover (Fordham and Ketteridge, 1995).
- Age was noted to have weak influence on the mental health effects of floods. However this conclusion reached by Tunstall *et al.*, (2006) could be influenced by the most severely affected having died or moved into residential care since the flood. Tunstall *et al.*, (2006) also suggests an inbuilt resilience amongst the elderly who had been through the trauma of the 2nd World War.

4.7.5 Conclusions

The mental health impact of flooding varies due to a number of factors including the severity of the flooding, its nature (fluvial, flash, coastal etc), time of day, timeliness of warning, emergency preparedness and existing social and economic structures.

Although both Hayes *et al.*, (2009) and Tunstall *et al.*, (2006) indicate a noticeable relationship between severity of flooding and psychological distress, there is little literature evidence to indicate how these differing factors would affect mental health, and even whether these effects can be attributed to the flood event itself (Ohi and Tapsell, 2000). However, analysis of the Great Midwest Floods in the USA between June and August 1993 (McMillen *et al.*, 2002), indicated that where severe stress is observed, due to for example the death of a close family friend or relative, or the witnessing of a death or injury, levels and amounts of psychological stress are noticeably increased.

Attempts to quantify estimates of the effect on mental health are hampered by the varying definitions used in different studies (Hajat *et al.*, 2003), including the GHQ-12 and PTSS noted in this report. The GHQ-12 used by Reacher *et al.*, (2004) and Tunstall *et al.*, (2006) gave a mental health effect due to flooding if a change in the GHQ-12 from below 4 to 4 or above was noted after the flood event. Based on this methodology, Reacher *et al.*, (2004) indicated 36% of flooded residents went from a GHQ-12 score of below 4 to 4+ as a result of the flooding of Lewes, a similar figure to that found by Tunstall *et al.*, (2006). The PTSS scale used by Tunstall *et al.*, (2006) is believed to be the only UK based study to use this scoring, and has therefore been excluded from this assessment.

For the summer 2007 floods, about 10% of older adults with pre-existing mental health problems living in Oxfordshire and affected by the floods suffered deterioration in mental health (Hayes *et al.*, 2009). However, this assessment was for those at risk of flooding, and included (for example) a large number of elderly people moved as a precautionary measure who may not have necessarily been flooded. For those where difficulty of evacuation was experienced, this rose to 36%. This is the same figure as noted by Reacher *et al.*, (2004), although for a specified sub-set of the population. However, it is not known how these effects were quantified.

Several socio demographic factors pre-dispose to mental health difficulties following floods, in particular prior health problems. This was noted by several authors as outlined in Section 4.7.2, as well as the case studies outlined above. For example, three times more interviewees with a prior psychiatric disorder suffered PTSD after the Great Midwest Floods in 1993, than those without a prior psychiatric disorder.

A further factor to consider in the case studies is that, in most cases, respondents were being asked to recall events that in some cases had occurred up to 5 years previously (e.g. Tunstall *et al.*, 2006). This could lead to problems of recall bias (Power 1988). However, in qualitative research which followed health effects that participants attributed to flooding over a four year period, participants showed good recall and were generally found to be consistent in their reporting (Tapsell *et al.*, 2003).

Although the retrospective use of the GHQ-12 constitutes a relatively new approach to assess the mental health effects of those flooded, it is currently probably the most appropriate way to assess this condition. It is also widely used, well validated and easy to administer. Mental health effects of flooding is therefore assessed by the number of people who may go from a GHQ-12 score of below 4 to 4 and above as a result of the flooding.

Little research has been carried out on the mental health effects of storms within the UK. However, the effects due to flooding are anticipated to be the most significant effect, and the latest projections from UKCP09 (2009) indicate that on a UK basis, storms as a result of climate change are likely to show a negligible change. The effect on mental health due to climate change is therefore only considered due to flood related events.

The impact due to flooding is estimated based on results from Reacher *et al.*, (2004) and Tunstall *et al.*, (2006) showing that about 36% (a range of 30-40% is considered in this report) of those flooded are likely to go from a GHQ-12 score of below 4 to 4 and above. This estimate is only based on two studies which cover more serious flood events, although the percentage for flash flood events would possibly be higher. Averaged across all flood events, including the majority of less newsworthy floods where levels of flooding are low, this is likely to be an over-estimate. The West Oxfordshire Floods of 2007, Hayes *et al.*, (2009), have not been considered as this only considers a sub-set of the population (older adults) and no quantifiable measurements were outlined.

An approximate number of people who are likely to suffer psychological distress due to flooding can be obtained by multiplying this rate by the number of people who are predicted to flood every year. The number of people at significant risk of flooding, has been used for this calculation (obtained from Ramsbottom *et al.*, 2012, see Section 4.4.3). The response functions for increase in a GHQ-12 score of below 4 to 4 or above are therefore the same as for relative risk of mortality shown for peak fluvial flows and changes in sea levels shown in Section 4.4.3, Figures 4.11 and 4.12. These figures are therefore not reproduced here. As an approximate 30-40% range is given, only results for the best estimate (p₅₀) are calculated.

4.7.6 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
HE10	Effects of floods/storms on mental health	M	3	3	3	3	3	3	3	3	3

Similar to flood related deaths, the effect of floods / storms on mental health as a result of a changing climate are as noted in Section 4.7.5 to be proportional to the number of

people at risk due to fluvial or tidal flooding. For the same reasons as for extreme event flooding, no attempt has been made to break these figures down regionally.

This metric has been assessed as the number of people who go from a GHQ-12 score of below 4 to 4 or above as a result of a flood event. This is assessed as being between 30-40% of those flooded each year. These results are given in Figure 4.20. Socio-economic effects have been considered solely based on the change in population.

It should be noted that the results given in Figure 4.20 relate to England and Wales only, as no results for future flood risk relating to Scotland and Northern Ireland were available for this assessment (Ramsbottom *et al.*, 2012). Pluvial flooding was also not included in the assessment carried out by Ramsbottom *et al.*, (2012), which would also be expected to increase the estimated given in this report.

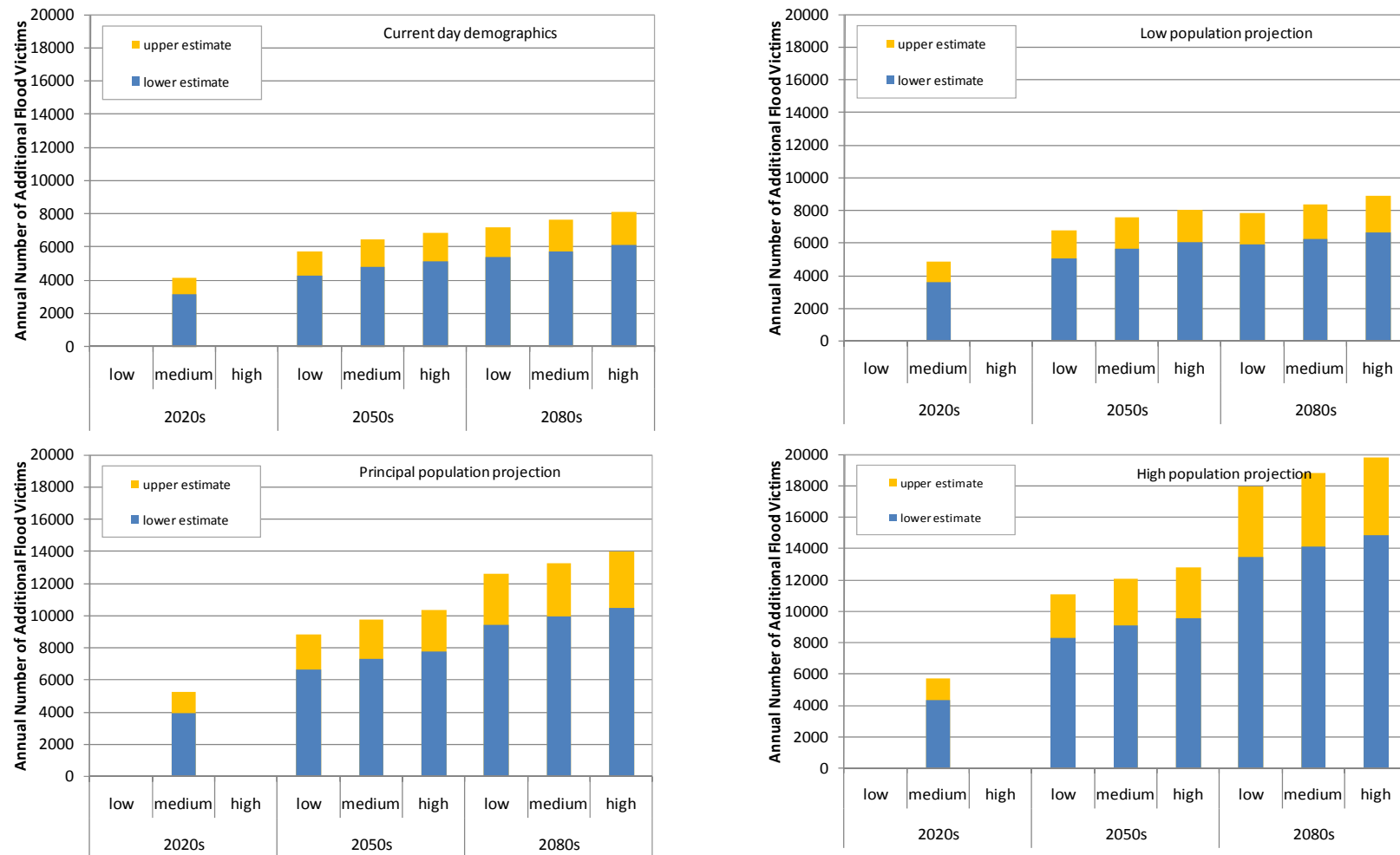


Figure 4.20 Annual number of additional flood victims who go from a GHQ-12 score of below 4 to 4 or above as a result of climate change (p_{50} estimates only) – England and Wales only

4.8 HE7 – Extreme weather event (flooding and storms) injuries

Little evidence exists that indicates how many people are at risk of injury as a result of extreme flooding, particularly in relation to coastal flooding. This is because injuries can be difficult to quantify, and often levels of injuries are not reported, or difficult to associate with a flood event⁷¹. However, despite this some evidence does exist, and an attempt to quantify injuries has been given by Defra/Environment Agency (2003). This has been used together with information from recent floods to establish a relationship between extreme weather event flooding and injuries.

The methodology proposed by Defra/Environment Agency (2003), outlines a means of determining how many people could potentially die or be injured due to an extreme flood event related to a number of factors including distance from the river or coast, level of flood warning, speed of onset and the nature of the flooded area.

To demonstrate this methodology it was applied to three flood events, the Norwich flood of 1912, the Lynmouth flood of 1952 and the Gowdall flood of 2000. These predicted that for Lynmouth, approximately a quarter of those injured would die, whereas for Norwich and Gowdall, approximately 1 in 20 of those injured would subsequently die.

The Lynmouth flood of 1952 is atypical of most extreme flood events that have occurred since the 1950s, with a high mortality rate relative to the number of properties flooded as discussed in Section 4.4.1. The initial indication based on the Norwich and Gowdall floods is that approximately 20 times more injuries would occur than deaths. In phase 2 of this report (Defra/Environment Agency, 2006), application of the methodology to 5 flood events indicated that this ratio was of the order of 15 injuries to every 1 death.

For the flood events outlined in Section 4.4.2, little if any published information is available on the number of people that were injured as a result of these floods. However, the Environment Agency⁷² does indicate that 70 injuries were sustained as a result of the Carlisle flood in 2005, giving an injury to fatality ratio of approximately 20.

Based on the methodology outlined in Defra/Environment Agency (2003) and the reported injuries for the Carlisle flood of 2005, a simple linear relationship between injuries and floods is assumed with 20 injuries for every 1 death. This same relationship is also presumed for coastal related deaths where no known information is available. This gives a baseline injury rate of 160 per year for inland flood events, and 200 per year for coastal flood events. The response functions are therefore the same as given in Figures 4.11 and 4.12 and equation (4.5), but with the baseline rates for injuries outlined above.

4.8.1 Socio-economic influence

Flood related injuries are likely to have the same socio-economic influences as noted for flood related deaths outlined in Section 4.4.5. For the same reasons as outlined in Section 4.4.5 therefore, flood related deaths for the socio-economic influence are only considered based on the change to the population as a whole. The ratio of flood

⁷¹ This is explored in detail in Health Protection Agency (2010) which outlines the many factors that could result in an injury as a result of a flood.

⁷² Source : <http://www.environment-agency.gov.uk/research/planning/109005.aspx>

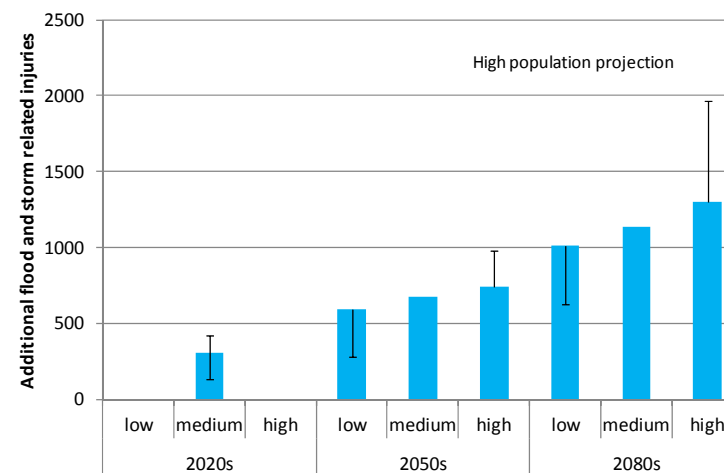
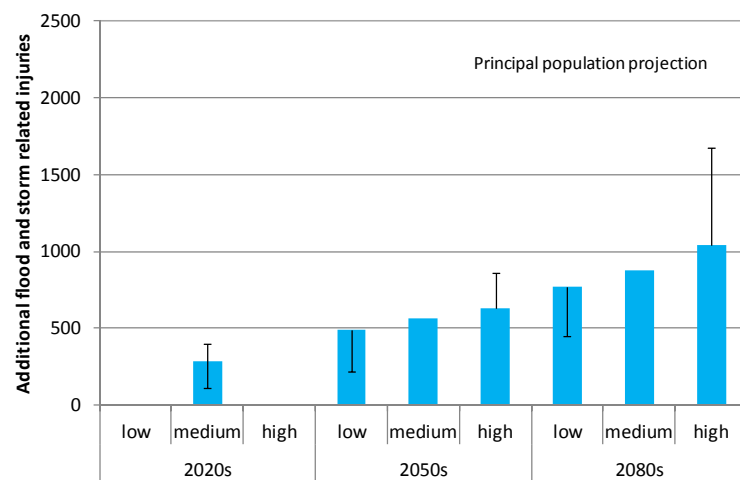
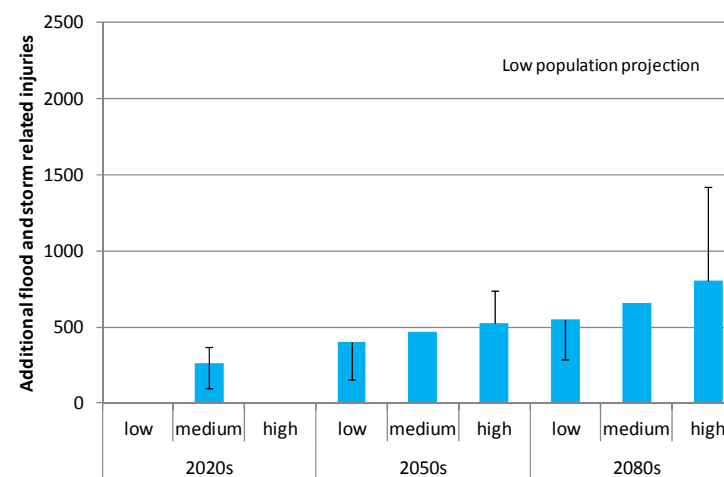
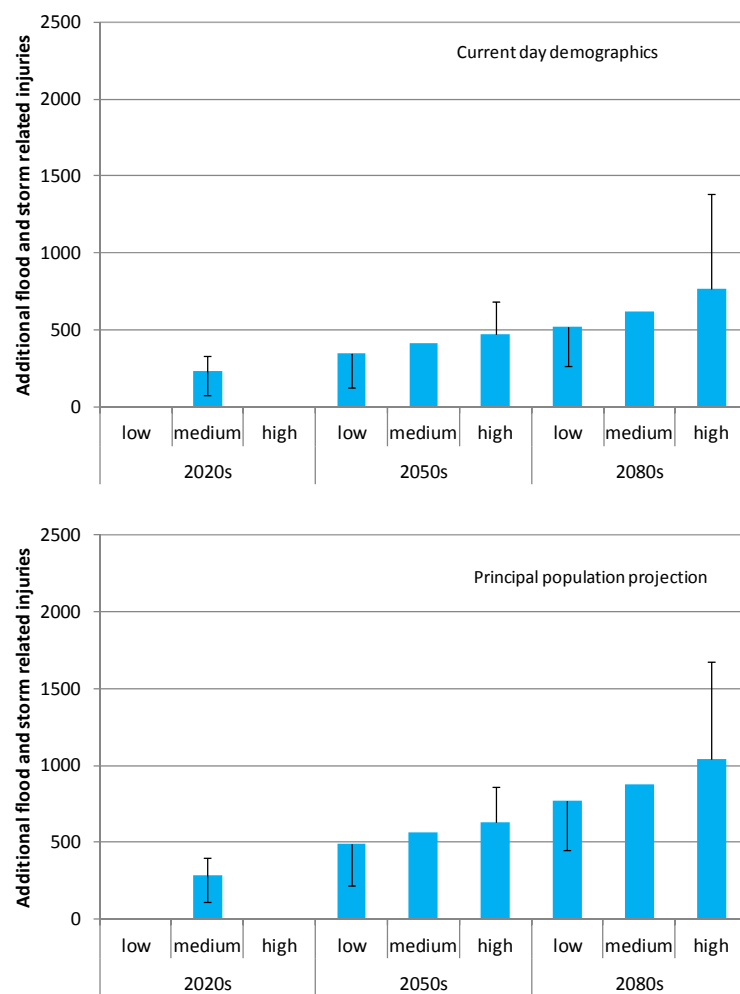
related deaths to injuries outlined above is also assumed to remain constant, as are future residency rates.

4.8.2 Results

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			L	c	U	l	c	u	l	c	u
HE7	Extreme weather event (flooding and storms) injuries	M	1	1	1	1	2	2	1	2	2

Flood related injuries as a result of a changing climate are assumed to be proportional to the number of deaths due to inland and coastal flooding as outlined in Section 4.8, as well as coastal wave activity nearshore during storms, exponentially related to changes in mean sea levels. No attempt has been made to break these figures down regionally for the reasons given in Section 4.4.3. Baseline rates for extreme weather event (flooding and storms) injuries are therefore given as 360 per year.

For the different scenarios, time periods and probability bands considered therefore, Figure 4.21 gives the estimated number of injuries due to future extreme event flooding and storms.



The error bars show the results that were assessed in the Health Sector report. These were only considered for a selection of risks, and those considered are shown.

Figure 4.21 Annual additional flood related injuries due to extreme event flooding and storms

5 Monetisation of Metrics

5.1 Summary

Climate change adaptation decisions that are designed to reduce climate change risks inevitably involved making trade-offs concerning the use of scarce economic resources. To the extent that economic efficiency is an important criterion in informing such decision-making, it is useful to express climate change risks in monetary terms, so that they can be:

- Assessed and compared directly (using £ as a common metric) and
- Compared against the costs of reducing such risks by adaptation.

For the CCRA, a monetisation exercise has been undertaken to allow an initial comparison of the relative importance of different risks within and between sectors. Since money is a metric with which people are familiar, it may also serve as an effective way of communicating the possible extent of climate change risks in the UK and help raise awareness.

Where possible, an attempt has been made to express the size of individual risks (as described in this report) in monetary terms (cost per year) however, due to a lack of available data it has sometimes been necessary to use alternative costs (repair or adaption) to provide an estimate. A summary of the results are provided in Table 5.1.

A variety of methods have been used to determine the costs. In broad terms, these methods can be categorised according to whether they are based on:

- Market prices (MP)
- Non-market values (NMV) or
- Informed judgement (IJ).

Informed judgement has been used where there is no quantitative evidence and was based on extrapolation and/or interpretation of existing data.

In general terms, these three categories of method have differing degrees of uncertainty attached to them, with market prices being the most certain and informed judgement being the least certain. It is important to stress that the confidence and uncertainty of consequences differs. Therefore, care must be taken in directly comparing the results. Whilst we attempt to use the best monetary valuation data available, the matching-up of physical and monetary data is to be understood as an approximation only.

Further, it is important to highlight that some results are presented for a scenario of future climate change only, whilst others include climate change under assumptions of future socio-economic change. It is apparent that the different population scenarios have a trivial effect on the scale of the results compared with the impact of climate change across the time periods. However, taking into account the change in population structure we would expect that the results for those metrics principally affecting the elderly (e.g. HE1, HE2, HE5 and HE6) the results may be expected to be twice as high as the estimates presented here.

Table 5.1 Summary of results in £million per annum

(2010 prices, no uplift or discounting) – climate change signal only (current socio-economics) – relative change from baseline period. Medium p50 scenario

Risk metrics	2020s	2050s	2080s	Estimation Method	Confidence ranking	Notes
HE1 Excess heat-based mortality	L	M	M	Non-Market Value Welfare impact cost	L	Assume no acclimatisation. Do not include urban heat island and heatwave impacts. Do not include benefits of cooling associated with rising energy costs (see Built Environment sectoral report reference). No age structure changes included.
HE2 Excess heat-based morbidity	M	H	H	Adaptation costs (medical treatment costs (Market Prices)) included in overall welfare cost (Non-Market Value/ Market Prices)	M	Same as HE1
HE3 Flood related deaths	M	M	M	Welfare impact cost (Non-Market Value)	L	Links directly with floods sectoral risk assessment.
HE4a Excess mortality based on ground level ozone and population	L	L	M	For 2020s & 2050s (IJ); For 2080s welfare impact cost (Non-Market Value)	L	Same as HE2
HE4b Excess respiratory hospital admissions from ground level ozone	L	L	L	Adaptation costs (medical treatment costs (Market Prices)) included in overall welfare cost (Non-Market Value/ Market Prices)	M	Same as HE2
HE5 Excess cold-based mortality	+M	+H	+H	Welfare impact cost (Non-Market Value)	L	Assume no acclimatisation.
HE6 Excess cold-based morbidity	+H	+H	+VH	Adaptation costs (medical treatment costs (Market Prices)) included in overall welfare cost (Non-Market Value/ Market Prices)	M	Same as HE5
HE7 Flood related injuries	M	M	M	Adaptation costs (medical treatment costs (Market Prices)) included in overall welfare cost (Non-Market Value/ Market Prices)	M	Same as HE3
HE9 Skin cancer cases	L	L	M	Informed Judgement	L	-
HE10 Mental stress caused by flooding	L	L	L	Adaptation costs (medical treatment costs (Market Prices)) included in overall welfare cost (Non-Market Value/ Market Prices)	L	Same as HE7

Note: - signifies a negative impact or loss; + signifies benefits or cost reductions.

Impact cost ranking: L = £1-9m/pa M = £10-99m, H = £100-999m, VH= £1000m+

Monetisation Confidence Ranking:

Ranking	Description	Colour code
High	Indicates significant confidence in the data, models and assumptions used in monetisation and their applicability to the current assessment.	
Medium	Implies that there are some limitations regarding consistency and completeness of the data, models and assumptions used in monetisation.	
Low	Indicates that the knowledge base used for monetisation is extremely limited.	

5.2 Introduction to health monetisation

The monetisation of health risks requires the identification of the components that comprise changes in welfare, which can be summed to give the total welfare change. In general, three components are needed to estimate the total welfare change, i.e. the total effect on society:

- *Resource costs* i.e. medical costs paid by the health service in a given country or covered by insurance, and any other personal out-of-pocket expenses made by the individual (or family).
- *Opportunity costs* i.e. the cost in terms of lost productivity (work time loss (or performing at less than full capacity)) and the opportunity cost of leisure (leisure time loss) including non-paid work.
- *Dis-utility* i.e. other social and economic costs including any restrictions on or reduced enjoyment of desired leisure activities, discomfort or inconvenience (pain or suffering), anxiety about the future, and concern and inconvenience to family members and others.

The aim is to express the risk in terms of its effects on social welfare, as measured by the preferences of individuals in the affected population. Individual preferences are expressed in two, theoretically equivalent, ways. These are:

- The minimum payment an individual is willing to accept (WTA) for bearing the risk or
- The maximum amount an individual is willing to pay (WTP) to avoid the risk.

There are also other issues (beyond this scoping analysis) in terms of impacts that have non-marginal effects on the UK economy, the treatment of distributional variations in impacts, and the aggregation of impact cost estimates over sectors and time.

There is a long tradition of the valuation of health endpoints in the UK, for use in cost-benefit analysis. Currently, guidance is given in documents produced by Department of Transport, Department of Health and Defra. It is highlighted, however, that values that currently exist may not express accurately the willingness-to-pay (WTP) that individuals might express, e.g. to avoid an increase in mortality risks from climate change. More specifically, existing values are derived often in the context of the work-place (wage-risk studies) that estimate the willingness to accept (WTA) a higher wage rate in accordance with a greater risk of accidental death. Alternatively, attention has been given to the valuation of fatal transport accidents, the frequency of which might be expected to change with e.g. the introduction of new transport infrastructure.

Both the transport and workplace examples of contexts differ from the climate change context and so may be expected to result in different WTP values. The principal differences are:

- **The length of life-time lost on average through the impact.** Whereas the impact of premature death in the road or work context can be expected to be on an individual of average age within the population and therefore result in the loss of about 35 years of life, climate change impacts are typically likely to lead to a loss of life of only a few weeks, months or years.
- **Size of the risk change.** The physical impact report suggests that the annual risk change associated with climate change may be 20-4 whilst the risk valued in the transport accident context is typically 10-3.
- **Context specificity.** The nature of the risk is perceived to be different according to the degree to which exposure to the risk is voluntary, the extent to which the potential impact is perceived to be controllable, and the size of the impact (in terms of number of deaths resulting). For example, premature death as a result of a road accident may be perceived to be more voluntary to a death that results from climate change.

We have addressed these differences in the following ways. First, since the length of lost life time is thought to be germane to the monetary values used, we adopt the Value of Life Year (VOLY) metric that explicitly recognises the change in length of lifetime as a result of the climate change risk. This contrasts with the use of the Value of a Prevented Fatality (VPF) used in transport appraisal. Second, we have reviewed the literature to see whether there is any evidence that a) the size of the risk change affects the willingness to pay on anything other than on a unit linear basis, and b) whether context influences WTP for a given type of health impact. In both cases, no evidence was available to justify adjustment of the unit values currently applied in Government appraisal.

5.3 Adaptation

It is highlighted that all the non-fatal (morbidity) risks considered in this analysis include unit value estimates for the resource cost component of welfare costs, as identified above. In the current context these costs can be interpreted as adaptation costs since they are incurred following the occurrence of the health risk. We assume that these medical treatment costs comprise part of the adaptation baseline in this sector.

Treatment of adaptation more generally is described in the earlier sections of the report. It is emphasised that physiological acclimatisation is not considered in the estimation of the heat-related risks. The general principal that the sectoral authors have adopted is to assume no planned adaptation additional to what is in place at the present time.

The following sub-sections review the monetary data available to us with respect to these risks and provide justifications for their adoption. Given the huge range of uncertainties, this is not a precise exercise. As a consequence, whilst it was attempted to use the best monetary valuation data available, the matching-up of physical and monetary data is to be understood as approximate, only.

5.4 Presentation of results, uplifts and discounting

Consistent with other sectors, the results below are presented in terms of constant 2010 prices) for the three time periods considered in the CCRA i.e. the 2020s, 2050s and 2080s. The results are presented in this way to facilitate direct comparison.

At this stage, we have therefore not presented the values below as a present value or equivalent annual cost. However, the use of the values in subsequent analysis, for example in assessment of the costs and benefits of adaptation options to reduce these impacts, would need to work with present values. For this, the values below would need to be adjusted and discounted. The HM Treasury Green Book recommends 3.5% discount rates/factors (HM Treasury, 2007) noting that for longer time periods as assessed here, this requires the use of a declining discount rate scheme.

The climate scenarios are those adopted across the CCRA i.e. the UKCIP09 scenarios: low, medium and high. No specific mitigation scenario additional to what the UK government has committed to has been used in the sectoral analysis. For each climate scenario, a probabilistic density function (pdf) has been generated; the CCRA has used data from the 10% (p_{10}), 50% (p_{50}) and 90% (p_{90}) of this pdf, and results are presented for these three data points on the climate scenario pdf. Four population projections are adopted: current; low; principal, and high.

The results are reported on an annual basis.

5.5 HE1 – Temperature mortality (heat)

5.5.1 Outputs from the Risk Assessment

Estimates are made of the number of additional premature deaths for the UK for the different emission scenarios assuming no future change in the population. The numbers of additional deaths are also estimated for three population projections: low, principal and high. The number of additional deaths is estimated as those due to the impacts of future climate change only, i.e. assuming current population, and for future climate change and socio-economic change i.e. assuming alternative population projections.

5.5.2 Methodology and unit values to be adopted

Valuation of mortality, (or fatality), focuses solely on the disutility welfare component; specifically the valuation of changes in the risk of death in a given time period. This is commonly expressed through the metric of a Value of a Prevented Fatality (VPF), also known as the Value of a Statistical Life (VSL). These metrics are already widely used in Government appraisal and cost-benefit analysis, for example in transport appraisal. An alternative metric, the Value of a Life Year (VOLY), is also suggested for use in contexts such as air quality regulatory impact analysis where it is likely that the shortening of life time associated with a change in mortality risk is thought to be relatively small (Defra, 2007). It is stressed that there is some debate in the literature as to the relative merits of these two metrics. Current best practice has been to use both metrics, at least in sensitivity analysis (see Watkiss and Hunt, forthcoming).

The search for appropriate unit values relies on the available literature. Since there are no values currently recommended for use in Government guidance for the climate change context, we are obliged to transfer unit values.

The most relevant context would appear to be that of air quality regulation, in which the Interdepartmental Group on Costs and Benefits (Defra, 2007) has made recommendations on the appropriate unit values to apply. This guidance is particularly relevant, given guidance that it is important that the length of life time should be material in the valuation of mortality impacts⁷³. The IGCB suggests a VOLY-equivalent of £60,000⁷⁴. In order to incorporate length of life time into our monetary estimates we have assumed that each additional death is associated with a loss of four months, the mid-point of a suggested range of two to six months⁷⁵.

It is stressed that the results below are based on the physical impact estimates provided earlier in this sectoral report. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below. The numbers below do not include physiological acclimatization (a form of autonomous adaptation), i.e. the fact that future population will naturally adjust to future higher temperatures. It is highlighted that previous studies that have included this adjustment (Kovats *et al.*, 2006 and Watkiss *et al.*, 2009), derive very much lower estimates of physical and economic impacts. However, it is also highlighted that the climate change data used does not account for elevated temperatures in urban areas, i.e. from any urban heat island effects, and therefore may underestimate effects, particularly in major cities. It is also stressed that there are more complex issues in the acclimatization, lag phases, etc that may mean that heat and cold related effects need to be treated differently, in terms of quantification and valuation. The results also do not account for other socio-economic factors (e.g. income growth, age profile or age specific mortality rates) that might affect relative risks.

There are some cross-sectoral linkages that affect these results and that are important when aggregating risks between sectors. The most important of these is the increased cooling demand and energy use with the built environment/energy analysis. The assumption of ownership and usage of air conditionings greatly reduces the effects of temperature on health outcomes to heat (Ostro *et al.*, 2010) and would thus be expected to reduce the estimated risks.

5.5.3 Results and discussion

The results are presented in Tables 5.2 – 5.6.

Table 5.2 shows the monetary value of additional mortality impacts under the three climate scenarios, given current population, i.e. in the absence of future socio-economic change. No acclimatisation or increased adoption of air conditioning is assumed. Tables 5.4 - 5.6 show equivalent results under low, principal and high population projections adopted in Section 4.2, i.e. combining future climate and future socio-economic change. It is stressed that these combined effects are not due only to climate change alone. Table 5.3 presents the monetary totals for the English Regions and the Devolved Administrations, for the medium climate scenario and principal population projection.

It is clear from Table 5.2 that as climate change develops over the course of the century the size of the heat-related mortality risks increase significantly, so that the increased welfare cost in the 2080s is at least five-six times higher than that in the 2020s, whilst doubling between the 2050s and 2080s. Contrasting Tables 5.2 and 5.4 – 5.6, it is apparent that the different population projections have a smaller effect on the

⁷³ John Henderson, Department of Health, personal communication

⁷⁴ Noise & Health – Valuing the Human Health Impacts of Environmental Noise Exposure” The Second Report of the IGCB(N)

⁷⁵ Dr Sotiris Vardoulakis, Health Protection Agency and sectoral report author, personal communication

scale of the results compared with the impact of climate change across the time periods.

Table 5.2 Valuation of life years lost (heat) per year for the UK for the different emission scenarios, current population, baseline period 1993-2006

(£m, annual, 2010 prices), no acclimatisation

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				25	54	102	37	79	157
Medium	13	28	51	32	65	125	53	115	233
High				38	78	150	80	172	347

Table 5.3 Valuation of life years lost (heat) per year for the English regions for the medium emission scenario, principal population, baseline period 1993-2006

(£M, Annual, 2010 Prices), No Acclimatisation

Administrative Region	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	1.3	2.8	5.1	4.1	8.5	16.9	7.8	17.3	36.3
South East	2.1	4.6	8.4	6.7	14.1	26.8	13.1	28.3	56.3
London	2.3	4.7	8.4	6.9	14.0	26.5	13.1	28.1	55.9
East of England	1.9	4.2	7.5	5.9	11.8	21.9	11.3	23.6	46.4
West Midlands	1.4	3.2	5.9	4.0	8.2	16.1	7.4	15.9	33.4
East Midlands	1.1	2.3	4.1	3.0	5.9	10.9	5.6	11.6	22.9
North West	1.4	3.1	5.7	3.1	6.6	12.8	5.5	12.4	25.7
North East	0.4	0.9	1.7	1.0	2.1	4.0	1.8	4.0	8.1
Yorkshire and Humber	1.1	2.4	4.2	2.8	5.5	10.2	5.2	10.8	21.6
England	12.9	28.2	51.1	37.5	76.7	146.1	70.8	152.0	306.4

Table 5.4 Valuation of life years lost (heat) per year for the UK for the different emission scenarios, low population, baseline period 1993-2006

(£m, Annual, 2010 Prices), No Acclimatisation

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				27	58	112	38	83	163
Medium	14	30	55	35	71	136	56	120	243
High				42	85	164	83	179	362

Table 5.5 Valuation of life years lost (heat) per year for the UK for the different emission scenarios, principal population, baseline period 1993-2006

(£m, annual, 2010 prices), no acclimatisation

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				30	64	123	51	110	218
Medium	14	31	57	41	84	161	77	165	334
High				46	94	180	111	239	482

Table 5.6 Valuation of life years lost (heat) per year for the UK for the different emission scenarios, high population, baseline period 1993-2006

(£m, annual, 2010 prices), no acclimatisation

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				38	80	153	69	149	295
Medium	15	33	60	48	98	187	101	217	438
High				57	117	224	150	324	651

A sensitivity using VSL estimates (a value of £1.79m, as used by Department for Transport) is presented below, for the UK level analysis, where no socio-economic (population) change is included. Thus, apart from the valuation metric, it is equivalent to Table 5.2 above. Clearly, the results in Table 5.7 are much higher than the earlier table.

Table 5.7 Valuation of premature fatalities (heat) per year for the UK for the different emission scenarios, current population, baseline period 1993-2006

(£m, annual, 2010 prices), no acclimatisation

Scenario	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				1,036	3,110	6,878	1,862	5,074	11,173
Medium	230	1,280	2,990	1,517	3,994	8,648	3,108	7,897	17,084
High				1,988	4,991	10,604	5,108	12,332	25,785

5.6 HE2 – Temperature morbidity (heat)

5.6.1 Outputs from the risk assessment

The HE2 risk metric estimates the number of hospital admissions attributable to heat. Temperature morbidity due to higher temperatures has been assessed as the increased number of heat related hospital-patient days. These totals are estimated as being proportional to the number of deaths due to high summer temperatures. It is recognised, however, that these estimates are very uncertain and are, in all likelihood, underestimates of the true extent of heat-related morbidity impacts, many of which may be serious but which do not result in hospital admissions but which have significant effects on the welfare of affected individuals.

5.6.2 Methodology and unit values to be adopted

Previous economic analysis in UK Government, by the Interdepartmental Group on Costs and Benefits in the context of air quality regulation, has assessed the economic costs of hospital admissions. Defra (2007) assume that hospital admissions (HA), whether resulting from respiratory or cardio-vascular illness, are valued equivalently.

Based on Department of Health (1999), Defra (2007) estimates the total resource cost, and per patient-day of an HA to be £2,423, and £266 (2010 prices), respectively. In its central estimates, Defra (2007) assumes that since most respiratory hospital admissions (RHAs) are borne by the retired population, no productivity losses and

associated costs are incurred as a result of RHAs. In accordance with IGCB recommendations, total WTP for HA patient-days is then assumed to be £625 (£350 and £900 constitute lower and upper bounds around this central estimate) in 2010 prices.

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below. Further, the issues raised in relation to HE1 above, notably the urban temperature effects and other socio-economic factors including age profile, and the cross-sectoral overlap with cooling are highlighted.

5.6.3 Results and discussion

Tables 5.8 and 5.9 present the monetary results for heat-related morbidity using current population as the baseline (climate change only), and the three population projections adopted in Section 4.3 (i.e. with climate change under future socio-economic change (population)), respectively. No acclimatisation is assumed.

When comparing the two tables, as with HE1, it is clear that climate change, rather than socio-economic change, accounts for the majority of the additional cost of morbidity. Across the population projections, the uncertainty appears to increase in the furthest time period, where the result for the high emissions scenario is approximately double that for the low emission scenario.

Table 5.8 Monetary value of annual additional patient days in UK per year due to increased temperatures (£m, annual, 2010 prices)

Current population, baseline period 1993-2006 – tentative estimates

Emission scenario (p ₅₀)	2020s	2050s	2080s
Low		111	181
Medium	46	142	281
High		178	439

Table 5.9 Monetary value of annual additional patient days in UK per year due to increased temperatures (£m, annual, 2010 prices)

Population projections, baseline period 1993-2006 – indicative estimates

Population projection	Emission scenario (p ₅₀)	2020s	2050s	2080s
Low	Low		121	188
	Medium	49	156	294
	High		194	459
Principal	Low		134	252
	Medium	51	183	404
	High		215	612
High	Low		166	340
	Medium	54	213	530
	High		266	828

5.7 HE3 – Extreme weather event (flooding and storms) mortality

5.7.1 Outputs from the risk assessment

As described in Section 4.4.1, flood related deaths as a result of a changing climate are assumed to be proportional to the number of people at risk due to fluvial or tidal flooding. For coastal wave activity during storms, deaths are assumed to increase exponentially in relation to changes in mean sea levels. A baseline rate for deaths due to extreme event flooding and storms in the UK was given in Section 4.4 as 18 per year.

5.7.2 Methodology and unit values to be adopted

The metric to be valued is the number of fatalities resulting from floods. Thus, the VPF (VSL) is the relevant monetary metric. The UK Department of Transport uses a VPF in its economic appraisal of accident fatalities in the UK. As documented in unit 3.4.1 of webtag (<http://www.dft.gov.uk/webtag/>), this value is currently £1.79 million (2010 prices). It is highlighted that this assumes the values are readily transferable to the floods context, which does involve a number of important contextual differences, not least the involuntary risk, as well as the size of the risk change. The value that is currently quoted in Defra guidance is £1.49million⁷⁶. We therefore adopt this latter value in this analysis.

⁷⁶ Defra (2008) Defra Flood and Coastal Defence Appraisal Guidance: Social Appraisal

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below.

5.7.3 Results and discussion

The monetary totals for climate-induced flood related deaths are presented in Tables 5.10 and 5.11. Whilst Table 5.10 shows the results using current population (i.e. climate change only on current conditions), those in Table 5.11 are based on a range of population projections, thus include the effects of climate change, with socio-economic change. The results are presented for a range of climate scenarios and distributions, depending on the time period. Current levels of flood defences are assumed to not change in the risk assessment.

In both tables, the number, and welfare cost, of fatalities increases further into the future, and across the climate scenarios from low to high. As with HE1, the climate signal is more important than the population signal in determining the size of the additional cost. It is also notable that the range of uncertainty expressed by the results across the probability distribution function (p10 - p90) within a given emission scenario is substantial, the latter being a factor of four greater than the former in the 2020s.

Table 5.10 Monetary value of annual additional flood related deaths per year due to extreme event flooding and storms, future climate change with current population (£m, 2010 prices)

2020s			2050s					2080s				
Med.	Med.	Med.	Low	Low	Med.	High	High	Low	Low	Med.	High	High
p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀
6	17	25	9	26	31	35	51	20	39	47	57	103

Table 5.11 Monetary value of annual additional flood related deaths per year due to extreme event flooding and storms, future climate change, with future socio-economic change (population), population projections (£m, 2010 prices)

Population projection	2020s			2050s					2080s				
	Med.	Med.	Med.	Low	Low	Med.	High	High	Low	Low	Med.	High	High
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀
Low	8	20	28	12	30	35	39	55	21	41	49	60	106
Principal	9	21	30	16	37	42	47	64	33	57	66	77	125
High	10	23	32	21	44	50	55	73	47	76	85	97	146

5.8 HE4a – Summer air pollution (ozone) - deaths

5.8.1 Outputs from the risk assessment

Section 4.5.4 reports that previously published work on ozone projections has only considered plausible climates for the 2080s for the time periods considered in this report. Interpolation of results to the 2020s and 2050s is not possible from these results. The analysis of this risk metric has therefore only considered estimates for the 2080s based on annual mean ozone concentrations derived on a UK wide grid for 1995, 2003 and 2005. Using empirical measurement-based models for these three distinct years, Stedman and Kent (2008) estimated the effect on human health for these three years which represented distinct variations in ozone levels. These represented years where there were higher (2003) and lower (2005) photochemical ozone concentrations, and a year (1995) with higher photochemical ozone concentrations combined with higher urban NO emissions. Thus, these years provide historical analogues of the health impacts that may be expected to be typical in the 2080s.

In the present assessment, described in Section 4.5.4, six scenarios have been considered for the 2080s which are outlined below.

1. Increase of annual mean ozone (ppb) by 5% in rural and 7% in urban areas
2. Increase of annual mean ozone (ppb) by 13% in rural and 20% in urban areas
3. Increase of annual mean ozone (ppb) by 20% in rural and 33% in urban areas
4. Increase of annual mean ozone (ppb) by 5% in rural and urban areas
5. Increase of annual mean ozone (ppb) by 13% in rural and urban areas
6. Increase of annual mean ozone (ppb) by 20% in rural and urban areas.

5.8.2 Methodology and unit values to be adopted

In line with the treatment of ozone in the air quality methodology described in Defra (2007), the mortality risk valuation is based on a shortening of life expectancy of 2- 6 months (we assume the mid-point of 4 months) in poor health, and has a central VOLY unit value of £15,000 (2005 prices, or £16,900 in 2010 prices).

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below. Of particular importance are the high uncertainty of the net effects of climate change on ozone concentrations, and the future socio-economic baseline of ozone pre-cursor emissions (the “with policies” scenario, for air quality and also low carbon futures), which are not accounted for in the analysis below.

5.8.3 Results and discussion

Table 5.12 presents the mortality ozone impacts in monetized terms. Whilst the choice of historical analogues and population projection do not result in much variation in the

aggregate figures, the choice of ozone scenario makes a significant difference (of up to a factor of five for any given climate scenario).

Table 5.12 Effect of future levels of ozone for the UK for the 2080s

Additional premature deaths per year based on ozone scenarios using 1995, 2003 and 2005 analogues, and alternative population projections – valuation (£m, annual, 2010 prices)

Population projection	Ozone scenario	Mortality		
		1995	2003	2005
Current	1	5	5	5
	2	13	15	14
	3	22	24	23
	4	4	4	4
	5	10	10	10
	6	15	16	15
Low	1	5	5	5
	2	13	15	14
	3	22	24	23
	4	4	4	4
	5	10	11	10
	6	15	17	16
Principal	1	7	7	7
	2	19	20	19
	3	31	34	32
	4	5	6	5
	5	14	15	14
	6	21	23	21
High	1	9	9	9
	2	25	27	25
	3	41	44	41
	4	7	7	7
	5	18	19	18
	6	28	30	28

5.9 HE4b – Summer air pollution (ozone) - respiratory hospital admissions

5.9.1 Outputs from the risk assessment

In the present assessment, described in Section 4.5.4, six scenarios have been considered for the 2080s which are outlined below.

1. Increase of annual mean ozone (ppb) by 5% in rural and 7% in urban areas
2. Increase of annual mean ozone (ppb) by 13% in rural and 20% in urban areas
3. Increase of annual mean ozone (ppb) by 20% in rural and 33% in urban areas
4. Increase of annual mean ozone (ppb) by 5% in rural and urban areas
5. Increase of annual mean ozone (ppb) by 13% in rural and urban areas
6. Increase of annual mean ozone (ppb) by 20% in rural and urban areas.

5.9.2 Methodology and unit values to be adopted

Defra, (2007), assume that hospital admissions (HA), whether resulting from respiratory or cardio-vascular illness, are valued equivalently. Based on Department of Health (1999), Defra (2007) estimates the total resource cost, and per patient-day of an HA to be £2,423, and £266, respectively⁷⁷. In its central estimates, Defra (2007) assumes that since most RHAs are borne by the retired population, no productivity losses and associated costs are incurred as a result of RHAs. In accordance with IGCB recommendations, total WTP for HA patient-days are then assumed to be £625 (£350 and £900 constitute lower and upper bounds around this central estimate). A number of other methodological issues are relevant.

5.9.3 Results and discussion

Table 5.13 presents the morbidity (RHA) ozone impacts in monetized terms. It is clear that the mortality impacts reported above are larger than the RHA impacts by approximately an order of 2-3. Whilst the choice of historical analogues and population projection do not result in much variation in the aggregate figures, the choice of ozone scenario makes a significant difference (of up to a factor of 5 for any given climate scenario).

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below.

⁷⁷ Converted to 2010 prices assuming 3% annual inflation rates

Table 5.13 Effect of future levels of ozone for the UK for the 2080s

On “additional” respiratory hospital admissions per year based on ozone scenarios using 1995, 2003 and 2005 analogues and alternative population projections – valuation (£m, annual, 2010 prices)

Population projection	Ozone scenario	Respiratory hospital admissions		
		1995	2003	2005
Current	1	2	2	2
	2	5	6	5
	3	9	9	9
	4	1	2	1
	5	4	4	4
	6	6	6	6
Low	1	2	2	2
	2	5	6	5
	3	9	10	9
	4	1	2	1
	5	4	4	4
	6	6	6	6
Principal	1	3	3	3
	2	7	8	8
	3	12	13	12
	4	2	2	2
	5	5	6	5
	6	8	9	8
High	1	3	4	3
	2	10	10	10
	3	16	17	16
	4	3	3	3
	5	7	7	7
	6	11	12	11

5.10 HE5 – Temperature mortality (cold)

5.10.1 Outputs from the risk assessment

Estimates are made of the number of deaths avoided in the UK for the different emission scenarios assuming current population, as well as under three alternative population projections.

5.10.2 Methodology and unit values to be adopted

The method used to estimate the monetary value of mortality avoided is the same as that adopted in HE1. Hence, we convert the number of premature deaths reported in Section 4.2 to life years using the same assumption, i.e. that each death resulted in a

loss of lifetime of six months. We then apply the unit value, the VOLY of £33,800 (2010 prices), as recommended in Defra (2007).

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier physical impacts analysis, and these should be considered in interpreting the estimates below.

5.10.3 Results and discussion

The results are presented in Tables 5.14 – 5.17. Table 5.14 shows the monetary value of additional mortality impacts under the three climate scenarios, given current population (i.e. climate change only). Tables 5.16 - 5.18 show equivalent results under low, principal and high population projections adopted in Section 4.2, i.e. with future climate and socio-economic change. Table 5.15 presents the monetary totals for the English Regions and the Devolved Administrations, for the medium climate scenario and principal population projection. No acclimatisation is assumed.

It is clear from Table 5.14 that as climate change develops over the course of the century the size of the cold-related mortality benefits increase significantly, so that the welfare cost in the 2080s is approximately three times higher than that in the 2020s. Contrasting Tables 5.14 and 5.16 – 5.18, it is apparent that the different population projections have a small effect on the scale of the results compared with the impact of climate change across the time periods. It is also notable that the range of uncertainty expressed by the results across the probability distribution function (p_{10} - p_{90}) within a given emission scenario is substantial, the latter being at least a factor of two greater than the former in each of the three time periods.

Table 5.14 Valuation of life years gained (cold) per year for the UK for the different emission scenarios, current population

Baseline period 1993-2006 (£m, annual, 2010 prices)

Scenario	2020			2050			2080		
	p_{10}	p_{50}	p_{90}	p_{10}	p_{50}	p_{90}	p_{10}	p_{50}	p_{90}
Low				188	304	428	242	377	517
				290	475	674	374	591	824
Medium	114	204	298	220	340	469	303	452	598
	174	315	464	341	531	742	473	713	975
High				248	374	507	377	535	670
				385	586	807	591	855	1139

Table 5.15 Baseline valuation of life years gained (cold) per year for the regions

Baseline period 1993-2006 (£m, annual, 2010 prices)

Admin Region	Cold		
South West	95	to	205
South East	99	to	216
London	80	to	184
East of England	75	to	186
West Midlands	75	to	175
East Midlands	59	to	128
North West	78	to	169
North East	27	to	65
Yorkshire and Humber	59	to	132
Wales	54	to	105
Scotland	54	to	126
Northern Ireland	14	to	31
UK	768	to	1721

Table 5.16 Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), low population

Baseline period 1993-2006 (£m, annual, 2010 prices)

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				204	329	462	248	386	530
				314	513	729	385	607	846
Medium	122	218	318	239	367	507	312	464	613
	187	337	496	369	575	803	487	733	1001
High				269	404	548	387	549	687
				417	634	873	608	880	1170

Table 5.17 Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), principal population

Baseline period 1993-2006 (£m, annual, 2010 prices)

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				240	388	545	341	531	729
				370	605	859	529	834	1163
Medium	130	234	341	297	390	538	463	518	686
	200	362	532	391	609	851	543	818	1118
High				317	477	646	533	755	945
				491	748	1029	836	1209	1608

Table 5.18 Valuation of life years gained (cold) per year for the UK for the different emission scenarios, with future socio-economic change (population), high population

Baseline period 1993-2006 (£m, annual, 2010 prices)

Scenario	2020			2050			2080		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
Low				279	450	633	447	697	955
				430	703	997	694	1094	1524
Medium	133	239	348	327	503	694	562	836	1105
	204	369	542	506	787	1098	878	1321	1804
High				368	553	750	698	990	1239
				570	868	1194	1096	1585	2108

5.11 HE6 – Temperature morbidity (cold)

5.11.1 Outputs from the risk assessment

The HE6 risk metric estimates the number of hospital admissions attributable to cold. Temperature morbidity due to rising winter temperatures has been assessed as the reduced number of cold related hospital-patient days. These totals are estimated as being proportional to the reduction in the number of deaths due to higher winter temperatures.

5.11.2 Methodology and unit values to be adopted

The method used to estimate the monetary value of mortality avoided is the same as that adopted in HE2. Hence, we multiply the estimated number of patient-days attributable to climate change, reported in Section 4.3, by the unit value of £625 recommended in Defra (2007).

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below.

5.11.3 Results and discussion

Tables 5.19 and 5.20 present the monetary results for heat-related morbidity using current population as the baseline, and the three population projections adopted in Section 4.3, respectively.

When comparing the two tables it is clear that climate change – rather than population – accounts for the majority of the additional cost of morbidity across the range of scenarios. There is considerable uncertainty in these results as expressed by the range of estimates for each emission scenario, generally of a factor of 2 to 4, and, indeed, for individual points on the climate pdf.

Table 5.19 Monetary value of annual reduction of patient days per year due to Increased winter temperatures

Baseline period 1993-2006 (£m, 2010 prices), current population

Low emission scenario			Medium emission scenario			High emission scenario		
2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
-	508	985	80	588	1176	-	664	1363
-	781	1565	120	907	1904	-	1030	2266

Table 5.20 Monetary value of annual reduction of patient days per year due to increased winter temperatures

Baseline period 1993-2006 (£m, 2010 prices), with future socio-economic change population projections

Population Projection	low emission scenario		medium emission scenario			high emission scenario	
	2050s	2080s	2020s	2050s	2080s	2050s	2080s
Low	550	689	305	636	861	719	1054
	846	1070	464	983	1353	1116	1683
Principal	645	939	319	746	1173	842	1435
	991	1457	485	1151	1841	1306	2290
High	748	1230	334	865	1537	977	1882
	1150	1910	507	1336	2414	1516	3002

5.12 HE7 – Extreme weather event (flooding and storms) injuries

5.12.1 Outputs from the risk assessment

As stated in Section 4.8, flood related injuries as a result of a changing climate are assumed to be proportional to the number of deaths due to fluvial and coastal flooding, as well as for coastal wave activity during storms, exponentially related to changes in mean sea levels. Baseline rates for deaths due to extreme weather event injuries in the UK are therefore given as 360 per year.

5.12.2 Methodology and unit values to be adopted

The empirical evidence on the valuation of injuries is very sparse; valuation data relating to accidents are almost entirely derived for fatal accidents in the work-place (see e.g. Viscusi and Aldy, 2003). Commonly, the empirical evidence is expressed in terms of a ratio - between a fatal and non-fatal injury. Values for injuries in the UK are utilized in the context of transport appraisal by the Department of Transport. The values are reported in webtag (<http://www.dft.gov.uk/webtag/>) in unit 3.4.1. The disutility component of non-fatal injuries is valued using ratios between non-fatal (serious and slight) and fatal injuries of 13:100 and 1:100, respectively. In Table 5.21 below, we have applied these ratios to the central VPF of £1.79m, also derived from webtag. The resource and opportunity cost components have been estimated directly. The average totals account for the relative frequency of serious and slight injuries. The values for road transport accidents are presented in Table 5.21, below. Values for rail accidents

are very similar. We therefore adopt these values, specifically the total of £72,338, rounded to £72,000, in the CCRA analysis.

Table 5.21 Summary of non-fatal injury values per year by welfare component. (£, 2010)

Injury Severity	Opportunity Costs	Disutility	Resource costs	Total
Serious	23,658	232,700	14,333	270,691
Slight	2504	17,900	1,061	21,465
Average	11,606	58,175	2,557	72,338

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below.

5.12.3 Results and discussion

Table 5.22 and Table 5.23 show the monetized results for non-fatal injuries relating to flooding and storms that result under future climate and population projections.

As with previous risks, those results generated using the population projections, in Table 5.22, are higher than those using current population levels in Table 5.21. The tables show that the climate sensitivity changes the size of the results by up to a factor of 5 and is more important as a determinant of the overall range than population projections. It is also clear that there is large uncertainty across a given climate scenario as well as between scenarios for a given time period, typically of a factor of 2 to 4.

Table 5.22 Monetary valuation of additional flood related injuries per year due to extreme event flooding and storms (current population)

(£m, annual, 2010 prices)

2020s			2050s					2080s				
Med	Med	Med	Low	Low	Med	High	High	Low	Low	Med	High	High
p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀
6	17	24	9	25	30	34	49	19	38	45	56	100

Table 5.23 Additional flood related injuries per year due to extreme event flooding and storms with socio-economic change (population projections)

Valuation (£m, annual, 2010 prices)

Population projection	2020s			2050s					2080s				
	Med	Med	Med	Low	Low	Med	High	High	Low	Low	Med	High	High
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₅₀	p ₅₀	p ₉₀
Low	7	19	27	11	29	34	38	54	21	40	47	58	102
Principal	8	20	29	16	36	41	46	62	32	55	63	75	120
High	9	22	31	21	43	48	54	71	45	73	82	94	141

5.13 HE9 – Sunlight/UV exposure

5.13.1 Outputs from the risk assessment

Section 4.6.2 argues that UVB exposure linked to melanoma skin cancer and non melanoma skin cancer is considered the most important health impact linked to sunlight / UV exposure. However, as outlined in Section 4.6, a relationship between future levels of skin cancers and climate change as a result of a change in levels of UVB is an extremely complex relationship, driven more by changes in social behaviour rather than any climate effect. In addition, improved detection rates and better treatment of cancer cases is likely to mean that percentage mortality will decrease in the future and it is unclear as to how to incorporate this consideration into a quantitative analysis. Other uncertainties include the projected UVR for the future climate of the UK, since the UKCP09 do not specifically refer to UVB radiation, the wavelength that is the main driver leading to skin cancers. The effect of climate change on the recovery of stratospheric ozone is a further area of uncertainty. With all these uncertainties in mind, it was decided not to provide quantitative estimates of future UV related health impacts in this report.

5.13.2 Methodology and unit values to be adopted

With no quantification of the incidence of skin cancer attributable to climate change, we rely on expert judgement as to how significant the future risks of this health impact under climate change scenarios are likely to be. We use an Impact Cost Ranking comprising of four rankings. These are: L = £1-9m/pa M = £10-99m, H = £100-999m, VH= £1000m+.

As a way of orientating the expert judgement it is useful to identify the number of cases of skin cancer per year that would be required to reach the Medium (M) ranking. We are able to do this because there is some data available to calculate a unit value per case of skin cancer. The following paragraphs outline this data before calculating the numbers of cases implied by moving from the Low to Medium cost ranking.

There is little empirical evidence on which to base unit WTP values for cases of skin cancer. As far as we are aware, no WTP values are used in UK public appraisal. As a result, we review the international literature and draw out some conclusions with regard to possible unit values. The literature addresses the three components of welfare change separately. Consequently, we review this literature according to these three components.

Medical treatment costs

Serup-Hansen *et al.*, (2004), estimated the direct and indirect costs of skin cancer (non-melanoma type, ICD code C44) in Denmark. They assume that all patients are treated within one year and that non-melanoma is non-fatal. Costs of hospital services are based on the prevalence approach while costs for primary care services are based on incidence approach. Some 70% of patients are treated in primary care sector only, whilst 30% are additionally referred to treatment in hospital. Average primary care sector costs are £110 per case whilst costs for the 30% that require combined primary and secondary care sector treatment are £1,007.

Dickie and Gerking (1996) also report estimates made by the US EPA (1985) of medical treatment costs associated with non melanoma skin cancer, of a range of £4,590 to £8,055, significantly higher than those reported by Serup-Hansen *et al.*, (2004).

On the basis of this evidence we adopt £1,115 as a central unit value estimate, with a range of £110 - £8,055.

Loss of productivity

The study by Serup-Hansen *et al.*, (2004) used expert judgment to estimate that, on average, inpatient hospital services took 4.5 days, followed by 14 days of incapacity from the work-place. One-third of a day is assumed to be lost for each outpatient hospital visit. Based on a productivity loss of £65 per day, average production loss was estimated to be £610 per skin cancer patient. It was assumed that these costs were levied during the first year following diagnosis. We adopt the unit value of £610 per skin cancer case.

Welfare costs

The literature review identified only two studies from which it is possible to identify the willingness to pay to avoid a case of skin cancer. Both of the studies were undertaken in the US; further details of these studies are given in Table 5.24.

The studies by Dickie, Gerking and Agee (1991) and Dickie and Gerking (1996) estimated marginal willingness to pay for reduction of skin cancer risk on a sample of 291 respondents from Wyoming and California, using a private good i.e. sunscreen. The first study reports that the marginal willingness to pay for a 1% reduction in skin cancer risk lies in the £2.8 - £5.9 range for each of six age groups applying a 5% discount rate, £2.2 - £2.6 if applying a 10% discount rate and £1.7 - £2.2 with a 15% discount rate. These values roughly equate to a range of £175 to £590 per case of skin cancer avoided if we assume that the WTP for 1% is linear and proportional for all subsequent risk reductions prior to entire risk elimination.

In the second study results from a WTP regression were used to compute option price estimates to reduce the risk of skin cancer for low, medium and high income households with different levels of initial perceived risk of getting skin cancer. Option prices for a five percentage point reduction in risk ranged from £44 to £66 for low income households, from £45 to £67 for medium income households and from £52 to £73 for high income households. These values are equated to a value per case of skin cancer avoided of between £820 and £1,385.

Whilst the temporal and spatial transfer issues that arise in suggesting this range of values for the UK are likely to be significant, we are forced to proceed with this range in the absence of other evidence. We adopt a central unit value of £700, as an approximate mid-point between the ranges derived by the two Dickie *et al.*, (1991 and 1996) studies, with a range of £170 - £1,385 to be used in sensitivity analysis. Total WTP over the three welfare components is therefore £2,425 (central), with a range of £890 to £10,050.

Table 5.24 Studies that estimate the WTP to avoid skin cancer

Study ref. (data year if known)	Peer reviewed	Good valued	Location	Valuation method	Sample size	Results (mean £2010)
Dickie, Gerking & Agee (1991)	Yes	1% redn. of lifetime risk of skin cancer	US	CV	291	170-590 per case of skin cancer
Dickie & Gerking (1996)	Yes	5% redn. of lifetime risk of skin cancer	US	CV	291	820-1,385 per case of skin cancer

5.13.3 Results and discussion

The central unit value for a case of skin cancer is £2,425. In order to reach the lower limit of the medium cost ranking, this unit value implies that an additional 4,200 cases would be generated annually as a result of climate change.

With in the region of 100,000-120,000 skin cancer cases per year, an approximate 4% increase due to climate change alone would be required to reach the medium cost ranking. Based on the work by Fears *et al.*, and the change in levels of UVB exposure likely by the end of the current century (see Sections 4.6.4 and 4.6.6), the medium cost ranking could be reached by the 2080s. The medium cost ranking has therefore been assigned for the 2080s, with the low cost ranking for the 2020s and the 2050s.

5.14 HE10 – Effects of floods/storms on mental health

5.14.1 Outputs from the Risk Assessment

Finally, the analysis has considered valuation estimates for mental stress caused by flooding. Similarly to flood related deaths, the effect of floods / storms on mental health as a result of a changing climate are assumed to be proportional to the number of people at risk due to fluvial or tidal flooding outlined in Section 4.7. This metric has been assessed as the number of people who go from a GHQ-12 score of below 4 to 4 or above as a result of a flood event, which is estimated as being between 30-40% of those flooded each year.

5.14.2 Methodology and unit values to be adopted

As above, in order to express the impacts in monetary terms, unit values for psychological stress are derived, composed of the three welfare components: medical costs; the costs of lost productivity, and disutility. It is assumed that these component costs are independent of each other and so can be straightforwardly summed.

Medical and productivity costs

Since the psychological stress of flooding most frequently manifests itself in terms of mild depression (Reacher *et al.*, 2004), cost estimates associated with the treatment of this illness are estimated. It is assumed that this broadly equates with the health quality indicator GHQ-4 utilised in the quantification of mental health impacts. The cost of treating depression has previously been studied in terms of comparing the cost-effectiveness of different drug treatments, and a wide range of studies have examined the cost-effectiveness of different drugs. Bower *et al.*, (2000), the only identified study to cost mild depression, investigates the cost-effectiveness of three types of treatment, notably non-directive counselling, cognitive behaviour therapy and general practitioner care for patients with depression in the UK. The results for a four month period of treatment from Bower *et al.*, (2000) are reported in Table 5.25 and include direct and indirect costs. The direct costs include treatment costs whilst the indirect costs identified are the cost of production losses based on employment status, weeks worked, wage rate and time lost from work through illness. An assumption is made that the psychological stress lasts for eight months, the average length of a depression period (Klein and Wender, 1993), and that there is a four month treatment period.

Table 5.25 Per case mean costs of treating depression (£, 2010)

Resource use Costs at 4 months	GP care	Cognitive behaviour therapy	Non-directive counselling
Direct costs:			
Primary care	103	64	60
Drugs	21	8	11
Outpatient services	156	51	38
Inpatient services	104	3	63
Protocol therapy	0	212	228
Travel costs	4	5	11
Total	388	342	409
Total indirect costs	611	455	707
Total societal costs	1000	800	1115

Source: Bower *et al.*, (2000)

The total per-case treatment and labour opportunity costs for cognitive behaviour therapy and non-directive therapy identified in Table 5.25 are rounded and define a range to be applied to the mild depression end-point, within which the GP care cost is found. A central value is derived by taking the simple mean of these three values. This equates to £970.

Disutility

The cost-based value neglects any valuation of the “pain and suffering” component of the total willingness-to-pay to avoid this illness. One study, Floyd *et al.*, (2003) has addressed the valuation of this component. The study, using a contingent valuation survey, confirmed that flooding caused physical effects in the short-term and psychological effects in the short and longer-terms. Psychological effects included memory of the stress from flooding and damage, and the stress of recovering after an event, including that arising from settling claims with insurers and dealing with builders and repairers.

The study asked two groups of respondents for their willingness to pay (WTP) to avoid the stress impacts of flooding: those who had previously been flooded and those who had not been flooded but whose property was currently at flood risk. Unfortunately the unpublished study provides incomplete evidence of the WTP to avoid flood-incurred stress. A single value of £225 per household per year is presented, with no accompanying statistical information. There appears to be no other study that has been undertaken and whose results could be used to test convergent validity. However, the value has been adopted in official Defra appraisal guidance (Defra, 2004). The single result from Floyd *et al.*, (2003) is therefore transferred directly to the current context. It is therefore assumed that the psychological effects valued in this study are equivalent, in welfare terms, to mild depression, whose treatment and productivity costs are estimated above. These are then converted from household totals to person-equivalents by dividing by 2.36 - the average number of people per household as determined by the 2001 census (see Section 4.4.5). The unit value is therefore £94. The total rounded WTP over the three welfare components is £1,065.

It is stressed that the numbers below use the physical impact estimates provided earlier in this chapter. A number of important issues are associated with these estimates, as reported in the earlier analysis, and these should be considered in interpreting the estimates below.

5.14.3 Results and discussion

Table 5.26 shows the monetized results of the mental health risks associated with climate change-induced flooding and storms under alternative population and climate scenarios. It is assumed that flood defences are maintained at current levels.

Table 5.26 shows ranges for each climate/population combination, reflecting the uncertainty in the epidemiology relating to this risk. The data presented shows that the population projections have a similar-sized effect on the variation over time to the climate signal. Assuming constant population, the climate signal increases the total welfare cost by a factor of four over the three time periods.

Table 5.26 Additional people who go from a GHQ-12 score of below 4 to 4 or above as a result of extreme event flooding or storms, future climate change (current population), and with alternative population projections – England and Wales

Valuation (£m, annual, 2010 prices)

Population projection	2020s	2050s			2080s		
	Medium	Low	Medium	High	Low	Medium	High
Current	3 - 5	5 - 6	5 - 7	6 - 8	6 - 8	6 - 8	7 - 9
Low	4 - 5	6 - 7	6 - 8	7 - 9	6 - 9	7 - 9	7 - 10
Principal	4 - 6	7 - 10	8 - 11	8 - 11	10 - 14	11 - 15	11 - 15
High	5 - 6	9 - 12	10 - 13	10 - 14	15 - 20	15 - 21	16 - 22

6 Adaptive Capacity

6.1 Overview

Adaptive capacity considers the ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Ballard, 2009, after IPCC, 2007a). This can be considered as having two components; the inherent biological and ecological adaptive capacity of ecosystems and the socio-economic factors determining the ability to implement planned adaptation measures (Lindner *et al.*, 2010). Considering adaptive capacity is essential for adaptation planning and the CCRA project has included work in this area that will contribute to the ongoing Economics of Climate Resilience study and the National Adaptation Programme. The CCRA work on adaptive capacity focuses on structural and organisational adaptive capacity and this chapter provides an overview of the assessment approach. The subsequent sections of this chapter provide an overview of the findings from other work on adaptive capacity in the health sector that has been carried out.

The climate change risks for any sector can only be fully understood by taking into account that sector's level of adaptive capacity. Climate change risks can be reduced or worsened depending on how well we recognise and prepare for them. The consequences of climate change are not limited to its direct impacts. Social and physical infrastructure, the backdrop against which climate change occurs, must also be considered. If such infrastructure is maladapted, the economic, social or environmental cost of climate impacts may be much greater; other consequences could also be considerably more detrimental than they otherwise might have been. Avoiding maladaptation is one outcome of high adaptive capacity; high adaptive capacity lowers the negative consequence of climate impacts. Conversely, low adaptive capacity increases the negative consequences.

6.2 Assessing structural and organisational adaptive capacity

The methods used for assessing structural and organisational adaptive capacity in the CCRA are based on the PACT framework⁷⁸. The work included a preliminary literature- and expert interview-based assessment of all eleven sectors in the CCRA. This was followed by more detailed analysis for the following sectors:

- **Business, Industry and Services** (focusing on the finance sector)
- **Transport** (focusing on road and rail)
- **Built Environment** (focusing on house building)
- **Health**
- **Biodiversity and Ecosystem Services**
- **Water**

⁷⁸ PACT was developed in the UK as one of the outcomes of the ESPACE Project (European Spatial Planning: Adapting to Climate Events) <http://www.pact.co/home>.

Structural adaptive capacity

The extent to which a system is free of structural barriers to change that makes it hard to devise and implement effective adaptation strategies to prepare for future impacts. This covers issues such as:

Decision timescales: This considers the lifetimes of decisions, from their conception to the point when their effects are no longer felt. The longer this period is, the greater the uncertainty as to the effects of climate change impacts. Cost-effective adaptation becomes harder. Potential climate impacts also become more extreme over longer timescales. This means that a greater scale of adaptation may need to be considered, and that the barriers to adaptation resulting from 'lock-in' to maladapted processes become more pronounced (Stafford-Smith *et al.*, 2011). Adaptive capacity is therefore lower, and maladaptation more likely, when long-lasting decisions are taken.

Activity levels: This considers what opportunities are there for adaptation, and on what scale. The frequency with which assets are replaced or created determines how many opportunities there will be to take action which increases adaptive capacity⁷⁹. In addition, when a lot of asset replacement and/or new investment is expected, there will be more chances to learn from experience, which increases adaptive capacity.

Maladaptation: This evaluates the effect of decisions already made on adaptive capacity. Long-term previous decisions which have reduced adaptive capacity are often difficult or expensive to reverse. Such decisions were made either before climate change was recognised as an issue, or more recently as a result of poor organisational capacity. Such maladaptation makes implementing effective strategies much harder.

Sector (or industry) complexity: This refers to the level of interaction between stakeholders within an industry, or with outside industries and groups, that is required to facilitate effective decision-making. Complexity is higher (and adaptive capacity lower) when many stakeholders are involved in decision-making and when their agendas (e.g. their financial interests) differ substantially.

Organisational adaptive capacity

Organisational adaptive capacity is the extent to which human capacity has developed to enable organisations to devise and implement effective adaptation strategies. Effective adaptation requires decision-making that takes account of an uncertain future and avoids locking-out future options that might be more cost-effective if climate impacts become more severe, or arrive more rapidly, than expected. The PACT framework used to assess this recognises different levels of adaptation. This framework is arranged in a hierarchy of 'Response Levels' ('RLs'), as set out below, of increasing capacity⁸⁰. These levels do not supersede one another; instead, each one builds on the experiences and practices built up in the previous response level. Organisations may need to be active on all levels for an effective adaptation programme. An RL4 organisation focused on breakthrough projects still needs to be stakeholder-responsive, for example.

RL1: Core Business Focused: At this level, organisations see no benefit from adapting; if change is required of them, it should both be very

⁷⁹This differs from 'Decision timescales' because investment in a sector is not continuous but varies over time, with periods of high investment being followed by periods of little or no investment.

⁸⁰ The PACT framework contains six response levels: those cited are the most relevant to the adaptation field.

straightforward to implement and also incentivised, e.g. through ‘carrots’ and ‘sticks’.

RL2: Stakeholder Responsive: At early stages of adaptation, organisations lack basic skills, information, processes and also skilled people; they need very clear advice and information plus regulations that are straightforward enough to help them get started.

RL3: Efficient Management: As organisations begin to professionalise adaptation, they become more self-directing, able to handle short term impacts up to 10 years (Stafford-Smith *et al.*, 2011). They need professional networks, best practice guidelines, management standards, etc.

RL4: Breakthrough projects: When impacts beyond 10 years need to be considered, organisations may need to consider more radical adaptation options. As well as high quality support from scientists, they may need support with the costs of innovation.

RL5: Strategic Resilience: Adapting a whole region or industry for long-term climate impacts of 30 years or more requires lead organisations to develop very advanced capacity that is able to co-ordinate and support action by a wide range of actors over programmes that are likely to last for many years.

6.3 Adaptive Capacity in the Health Sector

There is evidence that population acclimatisation and adaptive capacity can influence the level of certain health risks associated with climate change. For example, people can become gradually acclimatised to higher temperatures and there are indications that European regions with hot summers do not have significantly higher annual heat-related mortality rates than cold regions (Keatinge *et al.*, 2000). Knowlton *et al.*, (2007) estimated that acclimatization effects (e.g. increased use of air conditioning and gradual physiological adaptation) reduced regional increases in summer heat-related premature mortality in the New York City region by approximately 25%. However, there is currently much debate about how to model acclimatisation to climate change (Gosling *et al.*, 2009).

Public health protection measures such as warning systems, health alerts, public awareness campaigns and home-based prevention advice can help reduce the health risks of higher temperatures associated with climate change (Hajat *et al.*, 2010a); providing these is a sign of capacity to adapt to short term climate risks. An example is given by the Heatwave Plan for England, which was initially launched in 2004 and is updated yearly. This contains guidance for the general public, and the health and social care sector on protecting vulnerable people from the effects of heat. Similar air pollution and ozone forecasts and alerts, including relevant health advice, are commonly issued by local authorities and other organisations.

However, longer-term adaptation actions may have substantial financial implications for the health sector. For example, wider deployment of cooling systems in hospitals, care homes, etc. would probably come at a high economic and environmental cost (due to capital investment and energy consumption costs). Hospitals, surgeries and care homes will therefore almost certainly need to invest in refurbishment, procurement and regeneration plans that account for changes in temperature and extreme weather events. In particular, NHS infrastructure within flood risk areas may need to temporarily close down and eventually relocate. Certain medical specialties, such as respiratory medicine, emergency medicine and mental health, are likely to experience a rise in

demand due to higher occurrence of high ozone episodes, heatwaves and floods. Meeting these needs will require long-term planning and investment in the health sector.

Therefore, the ability of the health sector to design and implement climate change adaptation strategies will depend on the availability of resources, as well as on the perceived magnitude and urgency of the risks.

A comprehensive discussion on barriers and enablers for adaptation in the health sector has been presented by Vardoulakis (2010).

7 Discussion

A number of key risks to the health sector have been analysed within the CCRA, the “Tier 2” risks. This section discusses the outcomes of this assessment, outlining the evidence and the uncertainty in the outcomes, as well as the gaps in and limitations of the analysis carried out. In addition to the discussion on the Tier 2 risks, a brief discussion is also given on the remaining “Tier 1” risks to highlight the evidence gaps for these risks.

7.1 HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)

There are a number of sensitivities that could affect estimates of future heat or cold related mortality. The most significant of these is the threshold chosen for the exposure-response function. This is particularly the case for cold related mortality, where there is limited published evidence on thresholds in the UK and the estimates given can vary by a factor of 10 or more dependent on the threshold chosen (see section 4.2.7.1). For heat related mortality, more research has been carried out in the UK and there is a clearer consensus on the most appropriate temperature threshold. Published research indicates that variation in the estimate of heat related deaths is within a factor of about two.

Further uncertainty factors to be considered are the age structure of the future population and any autonomous or planned adaption to a gradual increase in mean temperatures. A change in the temperature distribution, particularly in the extremes, is also a factor which has not been taken into account in this assessment. Elderly people are more susceptible to extreme temperatures; however, little evidence is available to quantify this risk for different age groups. It is also unclear from UKCP09 projections how extremes are likely to change relative to mean temperatures. An increase in mortality as a result of an ageing population cannot therefore be estimated. However, this increase is likely to be compensated to a certain extent by a decrease in mortality due to autonomous (e.g. physiological) and planned adaptation (e.g. use of air conditioning, heat health warning systems, etc) of the population to a warmer climate. A population that adapts fully to increasing temperatures would result in no noticeable change in heat related premature deaths and cold related premature deaths avoided due to a simple shift in the distribution of temperatures. A more gradual adaptation would reduce heat related premature deaths, although levels are very much dependent on the extent of autonomous and planned adaptation.

Although estimates in this report have been given for the Devolved administrations and the English regions, there will be noticeable variations within these regions. The Urban Heat Island (UHI) effect for example can result in temperatures several degrees higher in the centre of a large city than the surrounding rural areas. These differences are particularly large during stable anti-cyclonic conditions in summer, and at night (Capon and Oakley, 2012). In London for example during the 2003 heatwave, the UHI was recorded as 9°C (Capon and Oakley, 2012). The raised daytime temperatures would be expected to increase mortality risks in urban areas. Higher night time temperatures would contribute to heat stress (Dousset *et al.*, 2011) and therefore also raise the mortality risk.

For Scotland and Northern Ireland no known heat and cold slopes related to any thresholds have been published. Also, regional average temperature time series only were available, rather than the more appropriate population weighted time series used

in the studies by Armstrong *et al.*, (2010) and Hajat *et al.*, (2007). The time series for these locations were therefore factored by a conservative 4% based on investigations of the regional average against the population weighted averages for other locations in England and Wales, with the response functions for Scotland and Northern Ireland assumed to be the same as for North-East and North-West respectively. The combination of these two factors is likely to result in an under-estimate in the projections for premature deaths, yet an over-estimate for premature deaths avoided.

7.2 HE2 – Temperature morbidity (heat and cold)

Limited published research has been carried out into temperature morbidity, defined as the additional patient days in hospital per year due to heat, or the reduction of the number of patient days in hospital per year due to cold. Research indicates that additional hospital patient days increase in hot and cold spells, although this does not necessarily show a direct correlation to temperature related deaths. In addition, the UHI will increase heat stress within cities, and increase risks in these areas (see Section 7.1). These relationships are uncertain as it is likely that many temperature related deaths occur before the sufferers come to medical attention. However, the study by Donaldson *et al.*, (2002) has inferred a direct correlation between temperature related deaths and hospital patient days. The evidence for this relationship is not published, and with little collaborative evidence for this relationship (together with some possible contradictions by other studies) this evidence should be treated with caution.

7.3 HE3 – Extreme weather event (flooding and storms) mortality

As noted in section 4.4.1, coastal flood related deaths in the UK that lead to a large number of fatalities are few and far between. The 1953 flood is by far the most significant coastal flood event in living memory, with 307 casualties in the UK. Indeed, since the Bristol Channel flood of 1607, there has perhaps been on average one flood event per century that has led to large loss of life (in the region of 100-1000 fatalities), resulting in an historic average annual death rate due to coastal flooding probably in the region of at least 1-10 people per year. Outside of these coastal flood events, direct loss of life is rare. There are no known deaths due to coastal flooding in the UK since 1953, and prior to this, no known reliable figures of deaths due to coastal flooding are available. The rarity of deaths due to coastal flooding combined with the significant improvements in coastal defences and communications since the 1953 flood, means that estimates of deaths due to coastal flooding are difficult to determine. The estimate given in this report of 2-5 deaths per year, with a best estimate of 3, was based on expert elicitation, and relates to the occasional and significant flood event resulting in a large number of deaths.

For inland flooding, flood deaths would be anticipated to occur more often, but without the potential for the substantial loss of life experienced with coastal flooding, and as indicated historically. Recent inland flood events indicate an average documented mortality rate of about three per year, although as stated in section 4.4.3, this is likely to be an underestimate due to smaller less reported flood events, as well as deaths not directly attributed to a flood. An estimate of 5-10 deaths per year for the current day has therefore been assumed, with a best estimate of 8, again based on expert elicitation. However, this figure will have significantly less scatter than for coastal flood related deaths.

The response function used to determine the change in risk of death due to inland flooding is based on the change in risk for flooding of properties presented in the floods and coastal erosion sector report (Ramsbottom *et al.*, 2012). Change in risk due to pluvial flooding cannot currently be determined. Although this response function has been determined based on fluvial flooding only (for England and Wales), the current day baseline is based on both fluvial and pluvial flooding. The inclusion of pluvial flooding in this response function would be expected to change the function derived. The factoring of this response function for flooding in Scotland and Northern Ireland would not be anticipated to make a noticeable effect. However, these effects cannot currently be established, and also whether these are likely to lead to an over or under estimate. Estimates for the change in risk to flooding of properties due to both pluvial as well as fluvial flooding (including Scotland and Northern Ireland) should improve the estimates given for flood related deaths in future CCRAAs. Future occupancy rates were also assumed to remain constant, and future CCRAAs should consider changes in these rates. However, these effects are not considered significant considering the potential effect of the response function for inland flooding discussed.

Deaths due to coastal wave activity during storms are related to the change in risk relative to the current day estimate. However, this metric requires an accurate estimate of the current baseline mortality figure, as well as the definition of how risk changes with time. Baseline mortality figures are based on a limited data set, less than two years (although other cited events over a slightly longer period give a similar estimate), and some uncertainty would be anticipated. The change in risk is based on the change in periods of time that significant storm activity near the coastline would be expected. This is difficult to estimate, as there is no methodology to describe significant storm activity at a site. This is compounded by the fact that each location is different, and conditions that could result in a large increase in wave activity at one location, could have little or a much changed effect elsewhere. Investigation of past flood deaths due to coastal wave activity indicates a strong relationship with high sea levels, with all deaths occurring near high water, when the predicted high water was around MHWS. As significant nearshore wave activity typically can only occur during periods of high sea levels, and a strong correlation between storm activity and high storm surges, a presumption was made that the period of time that sea levels exceed a certain sea level is proportional to the level of risk at a site. Based on recorded fatalities and expert elicitation, this “certain sea level” was taken as MHWS. As this relationship varies around the UK, with a lower future risk in high tidal areas such as the Bristol Channel, and a higher future risk in low tidal areas such as in the lee of the Isle of Wight, a mean UK average was taken. It is difficult to assess the robustness of this methodology given the lack of relevant published evidence, and no confidence can be given on these estimates.

Projections of future changes in storm conditions are uncertain, and it is difficult to establish a baseline number of deaths due to storms (excluding those due to coastal wave activity outlined above). However, “changes” in the number of deaths due to storm activity, apart from those linked to wave activity outlined above are anticipated to be small, and have been assumed to be negligible relative to changes in the number of flood related deaths.

Future planned adaptation, such as greater levels of flood proofing, improved flood warning schemes etc could reduce the baseline mortality estimates given above. However it is difficult to assess quantitatively the effect of planned adaptation on future mortality related to floods and storms.

7.4 HE4 – Summer air pollution (ozone)

The complex nature of ozone and its interaction with future atmospheric emissions means that premature deaths and additional (or brought forward) respiratory hospital admissions associated with population exposure to future levels of tropospheric ozone are difficult to assess in relation to a single climate variable. The current ozone levels and associated mortality and respiratory hospital admissions estimates are consistent with results published by Stedman and Kent (2008), although there was a noticeable difference of the region of 40% for respiratory hospital admissions. This has been attributed to the larger baseline morbidity rates used in this study, as well as the fact that regional baseline rates have been used as opposed to the national averages considered by Stedman and Kent (2008).

The future ozone estimates used in this study are based on modelling work by Athanassiadou *et al.*, (2010), which assume no changes in ozone precursor emission levels. However, tighter controls on future emissions may lead to a reduction in ozone levels in the UK and in associated deaths and respiratory hospital admissions in the future. The application of a non-threshold exposure-response relationship also gives an upper bound on mortality and respiratory morbidity estimates. A threshold of $100\mu\text{g}/\text{m}^3$, which is commonly quoted (see section 4.5.3), would result in significantly lower estimates of ozone related deaths and respiratory hospital admissions than those given in this report. As a result of the complex nature of ozone projections outlined above, results are only presented for the 2080s for which published estimates of ozone concentrations in the UK, as affected only by climate change, are available, Section 4.5.6.

7.5 HE9 – Sunlight / UV exposure

Sunlight and UV exposure is an extremely complex metric that as noted in section 4.6.3 is mainly linked to changes in cloud cover, the stratospheric ozone layer recovery, periods of time spent outdoors, and other behaviour factors (e.g. use of sunbeds, sun screens, protective clothing, etc). The complex nature of this metric, and its interaction with other non climate drivers means that similar to ozone covered above, estimates of projected increases in melanoma skin cancer (MSC) and non-melanoma skin cancer (NMSC) incidence and mortality attributable to climate change are highly uncertain. This metric is further complicated by various socio-economic factors that were outlined in section 4.6.5. However, there are also some beneficial effects, the main one of which is linked to increased exposure to vitamin D levels. The climate variable for this metric is UVB radiation. This falls between the short and long wave radiation flux that has been assessed within UKCP09. This leads to further uncertainty in future UVB levels for the UK and as a result, estimates of associated skin cancer mortality as a result of climate change have not been made. Similarly, the potentially beneficial effect of increased sunlight exposure on physical (e.g. improved vitamin D levels) and mental health has not been quantitatively assessed due to the lack of relevant quantitative evidence.

7.6 HE10 – Effect of floods / storms on mental health

Mental health effects due to floods and storms have been assessed based on the number of people who go from a Global Health Questionnaire (GHQ-12) score of below 4 to 4 or above as a direct result of flooding. Storms were not considered as part of

UKCP09, as projections are less certain, and any effects are likely to be small when compared against effects due to flooding.

The GHQ-12 has been commonly used in flood studies to assess the mental health effects as a result of flooding, and is now a well-validated method for assessment as a result of severe weather events. It is considered the most appropriate way to assess mental health effects even though it can only be used to detect unspecified psychiatric distress. Other methods such as the PTSS have been used in a limited number of studies.

The number of people who go from a GHQ-12 score of below 4 to 4 or above as a result of a flood has been mainly based on two papers, both of which give very similar estimates. However, these estimates were based on the more extreme flood events, and it is likely that the estimate of 30-40% of flood victims who go from a GHQ-12 score of below 4 to 4 or above as a result of a flood is conservative. The response functions (as noted in section 7.3 above) were also based on figures determined for England and Wales only and for fluvial flooding only. Estimates based on the methodology given in this report have therefore probably been under-estimated by in the region of 10-15%.

7.7 HE7 – Extreme weather event (flooding and storms) injuries

As outlined in section 4.8, the number of injuries as a result of extreme events flooding and storms is difficult to quantify as often in flood events they are not reported, or difficult to associate with a particular extreme event. The definition of an injury is also often not specified, or different definitions are or may be used for different flood events. For the basis of this report, an injury was defined as an injury sustained during an event that requires medical attention from a hospital admission.

From an assessment of previous flood events, there is an indication of a simple linear relationship between flood related deaths and injuries, and the estimate outlined in section 4.8 has been used in this report. This same estimate has been used for flood related injuries as a result of coastal wave activity for which no information is available.

As the response function for this metric is a direct response to number of fatalities identified for metric HE3, confidence on these projections is lower. However, evidence presented in section 4.8 does indicate a fairly consistent relationship from several flood events of approximately 15-20 injuries to every one fatality.

This ratio of 20 injuries for every one fatality outlined in this report can therefore be considered an upper estimate. However, this requires consistency of the definition of an injury, and it is not known how these have been defined within different reports. However, overall the “robustness” of this metric is dependant on the robustness of metric HE3 which is outlined in section 7.3.

7.8 Gaps in evidence

Although a large amount of research has been carried out into the health effects of climate change for the UK, there are certain gaps pertinent to most risks and these are highlighted below:

- Most of the research outlined in this report has been carried out for England and Wales. Where applicable, the research should be extended to include Scotland and Northern Ireland.
- Most risks in the health sector are strongly correlated to social demographics. The elderly for example are typically more vulnerable to most health impacts, and a projected ageing population is likely to increase these risks. Further social demographic specific research, in particular related to age should therefore be considered for many of the impacts identified in this sector.
- A number of health impacts are very uncertain as they are to a greater or lesser degree driven by human behaviour or actions. Where applicable, the effect of human actions such as links between periods spent outside and levels of UV exposure should be explored, and how these are likely to change in the future.
- In many cases it is difficult to break health impacts down to a regional basis. However, this mainly relates to a general lack of research in these areas rather than any lack of region specific research. Where possible, health impacts should be looked at regionally.

Specific areas of research where further work could increase understanding of the effects of climate change, help remove uncertainties regarding their scale and nature, and aid climate change adaptation in relation to the impacts identified in the health sector are given below.

7.8.1 Temperature mortality (heat and cold)

- Limited information is available on thresholds and exposure response functions for cold-related mortality. In addition, many winter deaths are as a result of infectious diseases such as influenza and pneumonia⁸¹ which means that it is difficult to attribute individual deaths to a cold related disease. Based on current published evidence, this means that any estimate of cold related deaths would be unreliable, although still significant. Additional analysis of existing data sets should enable this to be done for the next CCRA.
- There are no known published temperature-mortality relationships for Scotland or Northern Ireland. As a result, the results presented are likely to be under-estimated for heat (although not significantly), yet over-estimated for cold related mortality. Although these relationships would be relatively easy to establish, the data sets required for the analysis cannot be released without ethical clearance, which typically takes six months.
- The additional impact of heatwaves on mortality (and morbidity) requires estimates of the intensity, frequency and duration of heatwaves in the future which is currently uncertain. Additional analysis of existing data sets should enable this to be done for the next CCRA.
- It is likely that a future population would be more acclimatised to heat, and less acclimatised to cold. Limited research has been carried out in this area, and this was not considered in this assessment.

⁸¹ The exposure response models used in this report considered influenza, but not pneumonia

7.8.2 Temperature morbidity (heat and cold)

- Although there is certain evidence that very high and very cold temperatures have an impact on a range of morbidity outcomes, with an increase in patient-days per year due to heat and cold related illnesses, the rate of change is highly uncertain. In addition, as for cold mortality noted above, winter hospitalisations are confounded by infectious diseases more common in the winter which means that it is difficult to attribute individual hospitalisations to a cold related disease. Existing NHS data sets should enable this to be assessed in more detail for the next CCRA, although ethical clearance, as noted above, would probably be required before these data sets could be released.

7.8.3 Air pollution

- The research for ozone presented in this report is based on a linear non-threshold effect on human health. The effect of different threshold models for ozone needs to be considered, and further research should enable this to be done for the next CCRA.
- Projections of future ground-level ozone concentrations depend on emission scenarios, atmospheric transport, chemical reactions and removal processes which are currently not fully understood. Further modelling of these processes is therefore required.
- There is lack of concrete evidence of the health impacts of potentially prolonged exposure to allergens such as pollen, and future exposure levels in the UK are uncertain.
- Modelling is required to investigate the effect of climate change on winter air pollution (nitrogen dioxide and PM₁₀).
- Levels of the different types of air pollution will show noticeable variations across the UK, which will need to be investigated, and will disproportionately affect certain population groups. There is a large amount of research therefore required to better understand these impacts and how they are likely to change.

7.8.4 Extreme weather event (flooding and storms) mortality and morbidity

- Very little research has been carried out into the relationship between extreme weather events and their impacts, and the consequent increased deaths and injuries as a result of these events. This is particularly the case for countries such as the UK that are not exposed to weather events such as hurricanes, and/or the large scale deep flood events experienced in recent decades in places such as the USA, India and Bangladesh.
- Baseline data sets are poor, with no central record of deaths or injuries related to individual floods or storms kept. There is also no clear accepted definition of what is a flood or storm related injury. With relatively few deaths and injuries due to extreme weather event flooding and storms, as well as the highly clustered nature of these events, it is currently difficult to establish baseline estimates. A national surveillance system set in place to

officially record all flood related deaths and injuries would remove this gap, although limited data would be in place in time for the next CCRA.

- As with all flood related risk metrics, research in Scotland and Northern Ireland lags behind England and Wales. It is likely that flood related risk metrics in the health sector may therefore not be assessed with the same level of confidence in these countries unless these research areas are coordinated across the UK.

7.8.5 Solar / UV exposure

- The relationship between UV exposure and melanoma incidence and mortality is unclear. Little if any evidence exists linking UV exposure and non melanoma incidence, particularly for the more aggressive forms, squamous and merkel cell carcinoma.
- Although there would be expected to be public health benefits of increased UV exposure, such as increased vitamin D levels and improved physical and mental health due to people spending more time outdoors, these levels are not currently fully documented.

7.8.6 Effects of floods/storms on mental health

- Although significant progress has been made in recent years researching the mental health effects due to extreme weather events, little is known about the effects long term. The methodology commonly used in flood studies uses the GHQ-12 to assess mental health effects. Although this methodology indicates that a mental health effect has occurred, it is unspecified and gives no indication of the nature or severity of the effect.
- Current estimates do not cover Scotland and Northern Ireland. Research into the change in flood risk in these countries would enable these estimates to be updated for the next CCRA.

7.8.7 Food borne diseases

- More research is required linking changes in temperatures to changes in cases of food borne diseases, and the effect on hospital admissions.

7.8.8 Vector borne diseases

- Monitoring of malaria transmission and other risks related to climate sensitive vector borne diseases is required so as to consider it for assessment in the next CCRA.

7.8.9 Water quality and water borne diseases

- There is limited evidence linking pathogen survival to projected temperature increases, and whether this is the driving factor.

- As this metric is likely to affect those on a private water supply, and is also regionally dependant, regional projections are required on how the public to private water supply balance is likely to change over the rest of this century.

7.8.10 Agricultural contaminants

- The link between climate change and agricultural contaminants and the consequent human health impacts is inconclusive.

7.8.11 Emergency medicine

- Emergency medicine is very likely to experience a significant change in demand for its services over and above current annual levels as a result of climate change. This is likely to result in an increase in levels and variety of demand during extreme weather events, such as floods and heatwaves.

7.8.12 Medicine efficacy

- Manufactured drugs are in general licensed for storage at temperatures up to 25°C, and these medicines can be exposed to temperatures greater than this either on the storage premises (e.g. GP surgeries), or in bags during home visits. Additional research is therefore required (on a regional basis) to investigate the efficacy of different medicines both on site and during home visits during future heatwaves.

7.8.13 Algal/fungal growth in buildings and respiratory diseases

- Research undertaken since the mid 1990s has limited evidence and data available to analyse the impact of improved housing standards on damp and mould occurrences, and thus the impact on respiratory conditions. There seems to be limited data on the link between damp homes and respiratory conditions which needs to be investigated.

7.8.14 Hospitals at risk from flooding

- The current and future risk to hospitals due to flooding in Scotland and Northern Ireland is currently unknown. Future and ongoing research into flood risk for Scotland and Northern Ireland should start to address this issue, and this should be considered in time for the next CCRA.

7.8.15 Transport and communications network failure

- There is little known research into the human health effects due to disruption of transport systems and communications network failure.

7.8.16 Traffic accidents

- A future changing climate is likely to have an effect on the number of traffic accidents. The different climate factors and exposure-response relationships need to be investigated, as well as how these are likely to change under a different climate.

7.8.17 Social disruption

- Although some research has been carried out into how social behaviour changes under different climate effects, further research is required in this area.

8 Conclusions

8.1 HE1 – Temperature mortality (heat) and HE5 temperature mortality (cold)

8.1.1 Results temperature mortality (heat)

For the available population projections, it is estimated that there could be in the region of 130 to 1670 additional premature deaths per year as a result of increasing temperatures by the 2020s, increasing to between 580 to 5,900 by the 2050s and 1,040 to 14,400 by the 2080s.

The highest levels of excess mortality are typically observed in the southern regions, with the South-East and London accounting for approximately one third of the total UK estimates given. The most northern regions give the lowest levels of excess mortality. The north east for example accounts for about half the number of heat-related mortalities per year relative to the size of its population and the rest of the UK. The estimates given for Scotland and Northern Ireland are considered to be more uncertain due to the lack of published heat-related mortality exposure-response slopes for these regions, as outlined in section 4.2.5.

For the future socio-demographic scenarios, these rates typically increase by between 4-18% for the 2020s, 5-50% for the 2050s and 8-85% for the 2080s, with the lower figure corresponding to the low population projection, and the higher figure corresponding to the high population projection.

8.1.2 Results temperature mortality (cold)

For the available population projections, it is estimated that in the region of 1,260 to 12,000 premature deaths due to cold could be avoided per year as a result of increasing temperatures by the 2020s. The deaths averted per year as temperatures increase are about 3,850 to 23,900 by the 2050s and 5,750 to 35,550 by the 2080s.

Relative to population, there are large variations in the numbers of cold-related premature deaths avoided per year. The rates for South-West and Wales for example are noted to be approximately double those of the national average. Rates for the North-East and South are approximately half the national average. Again the estimates given for Scotland and Northern Ireland are considered to be uncertain due to the lack of published cold-related mortality exposure-response slopes for this region, as outlined in section 4.2.5.

For the different social economic scenarios, the rate of premature cold-related deaths avoided decreases in the latter half of the current century. By the 2080s, cold-related deaths averted are estimated to increase to about 8,200 to 30,700, 11,100 to 41,800 and 14,500 to 54,800 respectively for the medium emissions scenario under the low, principle and high population projections.

8.2 HE2 – Temperature morbidity (heat and cold)

Heat and cold related morbidity outcomes have been tentatively estimated as approximately 100 times greater than heat and cold related mortality estimates outlined above.

8.3 HE3 – Extreme weather event (flooding and storms) mortality

The overall number of deaths due to extreme event flooding and storms in the UK currently are noted to be small. Although a significant and “newsworthy” event, the primary effects of flooding on people are disruption, displacement, mental stress, etc. Based on the analysis carried out in this report, 4-17, 6-34 and 13-69 additional deaths are estimated to occur on an annual basis by the 2020s, 2050s and 2080s respectively due to floods and storms potentially associated with climate change based on the current population. These rates rise to 5-21, 8-49 and 14-98 when the various population growth estimates are taken into account. These deaths are likely to be clustered to a small number of events for coastal flooding, perhaps 2 or 3 large events every 100-1,000 years.

8.4 HE4 – Summer air pollution (ozone)

From an assessment of the results, the number of premature deaths on an annual basis is projected to increase on a UK basis by between 650-2,900 by the 2080s. For additional (or brought forward) respiratory hospital admissions, these are anticipated to increase by between 2,300-10,000 by the 2080s.

For the low, principal and high population growths, these figures are anticipated to increase by approximately 2%, 40% and 84% respectively.

On a regional basis, these ratios relative to the populations are approximately 30-40% lower in the North East and Wales regions and approximately 60% larger in the South East.

8.5 HE9 – Sunlight/UV exposure

No estimates were given for this metric in this report.

8.6 HE10 – Effect of floods /storms on mental health

Assessing the number of people who go from a GHQ-12 score of below 4 to 4 or above, in the region of 3,000 to 4,000 additional people per year are anticipated to be affected by psychological distress due to flooding in the 2020s. This may rise to between 4,000 to 7,000 by the 2050s and 5,000 to 8,000 by the 2080s.

These figures, which have been given for England and Wales only, are anticipated to increase in direct proportion to the number of properties flooded under the different socio-economic futures considered. Maintaining house occupancy rates at current levels, this indicates that these figures are likely to increase by approximately 10-20% for the low population growth for all time periods considered. For the high population

growth, these figures are likely to increase noticeably by the 2050s and 2080s. Approximately 8,000 to 13,000 additional people may be affected by psychological distress due to flooding in the 2050s, and 13,000 to 20,000 in the 2080s.

Accounting for Scotland and Northern Ireland, for which results could not be quantified, these estimates would be anticipated to increase by approximately 10-15%.

8.7 HE7 – Extreme weather event (flooding and storms) injuries

Based on the analysis carried out in this report, it is estimated that approximately 80-340, 120-680 and 270-1,380 additional injuries may occur due to flooding on an annual basis by the 2020s, 2050s and 2080s respectively. These rates rise to approximately 100-420, 160-980 and 290-1,960 when the various population growth estimates are taken into account. Similar to flood related mortality, injuries from coastal flooding are also likely to be clustered to a small number of events as outlined in section 4.8.

References

CCRA Sector Reports (excluding the Health Sector)

Baglee A., Haworth A. and Anastasi S. 2012. CCRA Risk Assessment for the Business, Industry and Services Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Brown I., Ridder B., Alumbaugh P., Barnett C., Brooks A., Duffy L., Webbon C., Nash E., Townend I., Black H. and Hough R. 2012. CCRA Risk Assessment for the Biodiversity and Ecosystem Services Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Capon R. and Oakley G. 2012. CCRA Risk Assessment for the Built Environment Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Knox J.W., Hurford A., Hargreaves L. and Wall E. 2012. CCRA Risk Assessment for the Agriculture Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

McColl L. and Angelini T. 2012. CCRA Risk Assessment for the Energy Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Moffat A.J., Morison J.I.L., Nicoll B. and Bain V. 2012. CCRA Risk Assessment for the Forestry Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Pinnegar J., Watt T. and Kennedy K. 2012. CCRA Risk Assessment for the Marine and Fisheries Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Ramsbottom D., Sayers P. and Panzeri M. (2012. CCRA Risk Assessment for the Floods and Coastal Erosion Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

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.

Thornes J., Rennie M., Marsden H. and Chapman L. (2012. CCRA Risk Assessment for the Transport Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

Other CCRA Reports

CCRA. 2011. Systematic Mapping Report. UK 2012 Climate Change Risk Assessment, Defra, London.

Defra. 2010a. Method for Undertaking the CCRA, UK 2012 Climate Change Risk Assessment, Defra, London.

Defra. 2010b. Method for Undertaking the CCRA Part II - Detailed Method for Stage 3: Assess Risk, UK 2012 Climate Change Risk Assessment, Defra, London.

CCRA. 2012. CCRA Evidence Report. UK 2012 Climate Change Risk Assessment, Defra, London.

Other References

- Admiralty Tide Tables. 2010. Volume 1. United Kingdom and Ireland (Including European Channel Ports). Hydrographer of the Navy.
- Ahern M., Kovats R.S., Wilkinson P., Few R. and Matthies F. 2005. Global Health Impacts of Floods: Epidemiologic Evidence. *Epidemiologic Reviews*. Volume 27(1). pp 36-46.
- Anderson C.A. 1987. Temperature and Aggression: Effects on Quarterly, Yearly, and City Rates of Violent and Nonviolent Crime. *Journal of Personality and Social Psychology*. Volume 52. pp 1161-73.
- Anderson H.R., Derwent D., Stedman J. and Hayman G. 2008. The Health Impact of Climate Change due to Changes in Air Pollution. In: *Health Effects of Climate Change in the UK*. Editor Kovats S.
- Anderson R.R. and Parrish J.A. 1981. The Optics of the Human Skin. *Journal of Investigative Dermatology*, Volume 77. pp 13-19.
- AQEG. 2009. Ozone in the United Kingdom. Air Quality Expert Group. London.
- Arnell B. P. and Darch G.J.C. 2006. Impact of Climate Change on London's Transport Network. *Proceedings of the Institution of Civil Engineers: Municipal Engineer*. Volume 159. Issue 4. pp 231-237.
- Arnell B., Darch G. and McEntee P. (eds.). 2007. Preparing for a Changing Climate in Northern Ireland. Report for SNIFFER.
- Armstrong B. 2006. Models for the Relationship between Ambient Temperature and Daily Mortality. *Epidemiology*. Volume 17. Number 6. November 2006. pp 624-631.
- Armstrong B., Chalabi Z., Fenn B., Hajat S., Kovats S., Milojevic A. and Wilkinson P. 2010. Association of Mortality with High Temperatures in a Temperate Climate: England and Wales. *Journal of Epidemiology and Community Health*.
- Ascherio A., Chen H., Weisskopf M.G. O'Reilly E., McCullough M.L., Calle E.E., Schwarzschild M.A. and Thun M.J. 2006. Pesticide Exposure and Risk of Parkinson Disease. *Annals of Neurology*. Volume 60. Issue 2. pp 197-203.
- Athanassiadou M., Baker J., Carruthers D., Collins W., Girmay S., Hassell D., Hort M., Johnson C., Johnson K., Jones R., Thomson D., Trought N. and Witham C., 2010. An Assessment of the Impact of Climate Change on Air Quality at Two UK Sites. *Atmospheric Environment*. Volume 44, pp 1877-1886.
- Autier P., Dore J.F., Lejeune F., Koelmel K.F., Geffeler O., Hille P., Cesarini J.P., Lienard D., Liabeuf A., Joarlette M., Chemaly P., Hakim K., Koeln A. and Kleeberg U.R. 1994. Recreational Exposure to Sunlight and Lack of Information as Risk Factors for Cutaneous Malignant Melanoma. Results of an European Organisation for Research and Treatment of Cancer (EORTC) Case Control Study in Belgium, France and Germany. *Melanoma Research*. Volume 4. pp 79-85.
- Baker-Austin C., Stockley L., Rangdale R. and Martinez-Urtaza J. 2009. Environmental Occurrence and Clinical Impact of *Vibrio Vulnificus* and *Vibrio Parahaemolyticus*: a European Perspective. *Environmental Microbiology Reports*. pp 1758-2229.
- Ballard, D. 2009. Working Paper on Adaptive Capacity. Working paper 1 for the UK's Climate Change Risk Assessment 2012. Alexander Ballard Ltd for HR Wallingford Ltd.
- Ballereau F., Prazuck T., Schrive I., Lafleur M.T., Rozec D., Fisch A. and Lafaix C. 1997. Stability of Essential Drugs in the Field: Results of a Study Conducted over a

- Two-Year Period in Burkina Faso. *American Journal of Tropical Medicine and Hygiene*. Volume 57. pp 31-36.
- Bashir K., Blizzard R., Jenkins R. and Mann A. 1996. A Validation of the 12-Item General Health Questionnaire in British Practice. *Primary Care Psychiatry*. Volume 2. pp 245-248.
- Baxter P. 2005. The East Coast Great Flood, 31 January - 1 February 1953: A Summary of the Human Disaster. *Philosophical Transactions of the Royal Society. Series A*.
- Beck R.J. and Franke D.I. 1996. Rehabilitation of Victims of Natural Disasters. *Journal of Rehabilitation*. Volume 62. Number 4. pp 28-32.
- Bentham G. 2008a. Climate Change, Ground Level Ultraviolet Radiation (UVR) and Health. In: *Health Effects of Climate Change in the UK*. Editor Kovats S.
- Bentham G. 2008b. Foodborne Disease and Climate Change. In: *Health Effects of Climate Change in the UK*. Editor Kovats S.
- Bentham G. and Langford I. H. 2001. Environmental Temperatures and the Incidence of Food Poisoning in England and Wales. *International Journal of Biometeorology*. Volume 45. pp 22-26.
- Besaratinia A., Kim S., Pfeifer G.P. 2008. Rapid Repair of UVA-Induced Oxidized Purines and Persistence of UVB-Induced Dipyrimidine Lesions Determine the Mutagenicity of Sunlight in Mouse Cells. *Journal of the Federation of the American Societies for Experimental Biology*. Volume 22. pp 2379-2392.
- Bloom E., Grimsley L.F., Pehrson C., Lewis J. and Larsson L. 2009. Molds and Mycotoxins in Dust from Water-Damaged Homes in New Orleans after Hurricane Katrina. *Indoor Air*. Volume 19. Issue 2. pp 153-158.
- Bloomfield J.P., Williams R.J., Goody D.C., Cape J.N. and Guha P. 2006. Impacts of Climate Change on the Fate and Behaviour of Pesticides in Surface and Groundwater – a UK Perspective. *Science of the Total Environment*. Volume 369. pp 163-177.
- Bokszczanin A. 2000: Psychological Consequences of Floods in Children and Youth. *Psychol Wychowawcza*. Volume 43. pp 172-181.
- Bokszczanin A. 2002: Long-Term Negative Psychological Effects of a Flood on Adolescents. *Polish Psychological Bulletin*. Volume 33. pp 55-61.
- Bologna J.L., Jorizzo J.L. and Rapini R.P. 2008. *Dermatology*. Elsevier. Volume 2.
- Bower P., Byford S., Sibbald B., Ward E., King M., Lloyd M. and Gabbay M. 2000. Randomised Controlled Trial of Non-Directive Counselling, Cognitive Behaviour Therapy, and Usual General Practitioner Care for Patients with Depression. II: Cost Effectiveness. *British Medical Journal*. Volume 321. pp1389-1393.
- Boxall A. B. A., Hardy A., Beulke S., Boucard T., Burgin L., Falloon P.D., Haygarth P.M., Hutchinson T., Kovats R.S., Leonardi G., Levy L.S., Nichols G., Parsons S.A., Potts L., Stone D., Topp E., Turley D.B., Walsh K., Wellington E.M.H. and Williams R.J. 2009. Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture. *Environmental Health Perspectives*. Volume 117(4). pp 508-514.
- Braga A.L., Zanobetti A. and Schwartz J. 2001. The Time Course of Weather-Related Deaths. *Epidemiology*. Volume 12. pp 662-667.

Breslau N., Davis C.G., Peterson E.L. and Schultz I. 1997. Psychiatric Sequelae of Posttraumatic Stress Disorder in Women. *Archives of General Psychiatry*. Volume 54. pp 81-87.

Breslau N. and Peterson E.L. 2010. Assaultive Violence and the Risk of Posttraumatic Stress Disorder Following a Subsequent Trauma. *Behaviour Research and Therapy*. October 2010. Volume 48. Issue 10. pp 1063-1066.

Bruls W.A.G., Slaper H., Van Der Leun J.C. and Beurrens L. 1984. Transmission of Human Epidermis and Stratum Corneum as a Function of Thickness in the Ultraviolet and Visible Wavelengths. *Photochemistry and Photobiology*. Volume 40. pp 485-495.

Burge H.A. 2002. An Update on Pollen and Fungal Spore Aerobiology. *Journal of Allergy and Clinical Immunology*. Volume 110. Issue 4. pp 544-552.

Cabinet Office. 2008. National Risk Register of Civil Emergencies. 2010 Edition.

Cancer Research UK. 2009. Statistical Information Team.

Cancer Research UK. 2010. www.cancerresearchuk.org. Accessed 21st October 2010.

Cape J. N. 2008. Surface Ozone Concentrations and Ecosystem Health: Past Trends and a Guide to Future Projections. *Science of the Total Environment*. Volume . Issues 1-3. pp 257-269.

Carroll B., Morbey H., Balogh R. and Araoz G. 2009. Flooded Homes, Broken Bonds, the Meaning of Home, Psychological Processes and their Impact on Psychological Health in a Disaster. *Health and Place*. Volume 15(2). pp 540-547.

Casteel M.J., Sobsey M.D. and Mueller J.P. 2006. Fecal Contamination of Agricultural Soils Before and After Hurricane Associated Flooding in North Carolina. *Journal of Environmental Science and Health. Part A: Toxic/Hazardous Substances and Environmental Engineering*. Volume 41. Number 2. pp 173-184.

Cazenave A. and Llovel W. 2010. Contemporary Sea Level Rise. *Annual Review of Marine Science*. Volume 2. pp 145-173.

Chapman L., Thornes J.E., Huang Y., Cai X., Sanderson V.L. and White S.P. 2008. Modelling of Rail Surface Temperatures: A Preliminary Study. *Theoretical and Applied Climatology*. Volume 92. pp 121-131.

Chen D., Wangberg S.A., Wulff A. and Borne K. 2004. Attenuation of Biologically Effective UV Doses Under Overcast Skies: A Case Study from the Eastern Atlantic Sector of the Southern Ocean. *Deep Sea Research Part II: Tropical Studies in Oceanography*. Volume 51. Number 22-24. pp 2673-2682.

Chief Medical Officer. 2001. Getting Ahead of the Curve. A Strategy for Combating Infectious Diseases (Including Other Aspects of Health Protection). London. Department of Health.

Clark C.G., Price L., Ahmed R., Woodward D.L., Melito P.L., Rodgers F.G., Jamieson F., Ciebin B., Li A. and Ellis A. 2003. Characterisation of Waterborne Outbreak-Associated *Campylobacter jejuni*, Walkerton, Ontario. *Emerging Infectious Diseases*. Volume 9. Number 10. pp 1232-1241.

Comiso J.C., Parkinson C.L., Gersten R. and Stock L. 2008. Accelerated Decline in the Arctic Sea Ice Cover. *Geophysical Research Letters*. Volume 35.

Communities and Local Government. 2009. Household Projections to 2031, England. Housing Statistical Release. 11/03/09. Available at: <http://www.communities.gov.uk/documents/statistics/pdf/1172133.pdf>.

Confalonieri U., Menne B., Akhtar R., Ebi K., Hauengue M., Kovats R.S., Revich B. and Woodward A. 2007. Human Health. In *Climate Change 2007 : Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (ed. Parry M., Canziani O., Palutikof J., Van der Linden P. and Hanson C.). pp. 391–431. Cambridge University Press, Cambridge.

Costello A., Abbas M., Allen A., Ball S., Bell S., Bellamy R., Friel S., Groce N., Johnson A., Kett M., Lee M., Levy C., Maslin M., McCoy D., McGuire B., Montgomery H., Napier D., Pagel C., Patel J., de Oliveira J.A., Redclift N., Rees H., Rogger D., Scott J., Stephenson J., Twigg J., Wolff J. and Patterson C. 2009. *Managing the Health Effects of Climate Change: Lancet and University College London Institute for Global Health Commission*. Lancet. Volume 373. pp 1693–1733.

Coyle M., Smith R.I., Stedman J.R., Weston K.J. and Fowler, D. 2002. Quantifying the Spatial Distribution of Surface Ozone Concentration in the UK. *Atmospheric Environment*. Volume 36. pp 1013–1024.

Crichton B. 2004. Keep in a Cool Place: Exposure of Medicines to High Temperatures in General Practice During a British Heatwave. *Journal of the Royal Society of Medicine*. Volume 97. pp 328-329.

Curriero F.C., Heiner K.S., Samet J.M., Zeger S.L., Strug L. and Patz J.A. 2002. Temperature and Mortality in 11 Cities of the Eastern United States. *American Journal of Epidemiology*. Volume 155. Number 1.

Daley W.R., Shireley L. and Gilmore R. 2001. A Flood Related Outbreak of Carbon Monoxide Poisoning – Grand Forks, North Dakota. *The Journal of Emergency Medicine*. Volume 21. Issue 3. pp 249-253. October 2001.

Defra. 2000. *Guidelines for Environmental Risk Assessment and Management*.

Defra. 2004. *Flood and Coastal Defence Project Appraisal Guidance. FCDPAG3 Economic Appraisal. Supplementary Note to Operating Authorities*. July 2004.

Defra. Interdepartmental Group on Costs and Benefits (IGCB). 2007. *An Economic Analysis to Inform the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits*. Available at: <http://archive.defra.gov.uk/environment/quality/air/airquality/publications/stratreview-analysis/exec-summary-icgb.pdf>

Defra. 2011. *Climate Resilient Infrastructure: Preparing for a Changing Climate*. Available at: <http://www.defra.gov.uk/publications/files/climate-resilient-infrastructure-full.pdf>

Defra / Environment Agency. 2003. *Flood and Coastal Defence R&D Programme. Flood Risks to People Phase 1. R&D Technical Report FD2317/TR*. July 2003.

Defra / Environment Agency. 2006. *Flood and Coastal Defence R&D Programme. Flood Risks to People Phase 2. R&D Technical Report FD2321/TR2*. March 2006.

Department of Health, 1998. *Committee on the Medical Effects of Air Pollutants. Quantification of the Health Effects of Air Pollutants in the UK*. HMSO, London.

Department of Health. 1999. *Economic Appraisal of the Health Effects of Air Pollution. Ad-Hoc Group on the Economic Appraisal of the Health Effects of Air Pollution*. London. The Stationery Office.

Department of Health. 2002. *Health Effects of Climate Change in the UK*. London.

Department of Health. 2008. *Health Effects of Climate Change in the UK*. London.

Department of Health. 2010a. Climate Change Plan.

Department of Health. 2010b. The Operating Framework for the NHS in England 2011/12.

Department of Health. 2010c. New Horizons. Confident Communities, Brighter Futures: A Framework for Developing Well-Being. Published 26/03/10. 98 pp.

Department of Health. 2011. Healthy Lives, Healthy People: Update and Way Forward.

Derwent R.G., Simmonds P.G., O'Doherty S. Stevenson D.S., Collins W.J., Sanderson M.G., Johnson C.E., Dentener F., Cofala J., Mechler R. and Amann M. 2005. External Influences on Europe's Air Quality: Baseline Methane, Carbon Monoxide and Ozone from 1999 to 2030 at Mace Head, Ireland. *Atmospheric Environment*. Volume 40. pp 844–855.

Dickie M. and Gerking S. 1996. Formation of Risk Beliefs, Joint Production and Willingness to Pay to Avoid Skin Cancer. *The Review of Economics and Statistics*. Volume 78. Number 3. pp. 451-463.

Dickie M., Gerking S. and Agee M. 1991. Health Benefits of PMP Control: The Case of Stratospheric Ozone Depletion and Skin Damage Risks. Chapter 7 in *Persistent Pollutants* (editors Opschoor J. B. and Pearce D. W.). Boston. Kluwer Academic.

Diffey B. 2004. Climate Change, Ozone Depletion and the Impact on Ultraviolet Exposure of Human Skin. *Physics in Medicine and Biology*. Volume 49. R1-R11.

Diffey B.L. and Langtry J.A. 2005. Skin Cancer Incidence and the Ageing Population. *British Journal of Dermatology*. Volume 153. pp 679-680.

Donaldson G., Kovats R.S., Keatinge W.R. and McMichael A.J. 2002. Heat and Cold Related Mortality and Morbidity and Climate Change. In: *Health Effects of Climate Change in the UK*. Department of Health. London. pp 70-80.

Dousset B., Gourmelon F., Laaidi K., Zeghnoun A., Giraudet E., Bretin P., Mauri E. and Vandentorren S. 2011. Satellite Monitoring of Summer Heat Waves in the Paris Metropolitan Area. *International Journal of Climatology*. Volume 31. Issue 2. pp 313-323.

Drabeck T.E. 1991. Anticipating Organisational Evacuations: Disaster Planning by Managers of Tourist-Oriented Private Firms. *International Journal of Mass Emergencies and Disasters*. Volume 8. Number 2. pp 219-245.

Duffy Chartered Engineers. 2010. Dundalk Retail Park Phase 2 B: Flood Risk Assessment. Duffy Chartered Engineers Report 3258.

Durkin M.S., Khan N., Davidson L.L., Zaman S.S. and Stein Z.A. 1993. The Effects of a Natural Disaster on Child Behaviour: Evidence for Posttraumatic Stress. *American Journal of Public Health*. Volume 83. pp 1549-1553.

Eccles R. 1996. Reply in *New Scientist* dated 9th March 1996 by Professor Ron Eccles, Director of the Common Cold Centre, Cardiff School of Biosciences, University of Cardiff to the question "Why do people catch colds and flu more often in the winter?".

Elwood J.M. and Jopson J. 1997. Melanoma and Sun Exposure: An Overview of Published Studies. *International Journal of Cancer*. Volume 73. pp 198-203.

Employers Organisation. 2004. Demographics and the Workforce in England and Wales: Trends and Projections. November 2004.

- Enarson E. and Hearn-Morrow E. 1998. *The Gendered Terrain of Disaster: Through Women's Eyes*. Praeger. London.
- Environment Agency 2009. *Flooding in England: A National Assessment of Flood Risk*. Environment Agency, Bristol, 2009.
- Environmental Protection Agency (EPA). 2010. www.epa.gov.uk/sunwose/uvandhealth.html. Accessed 23rd October 2010.
- European Commission Health & Consumer Protection Directorate-General. 2001. *Opinion of the Scientific Committee on Veterinary Measures Relating to Public Health on Vibrio Vulnificus and Vibrio Parahaemolyticus*. Geneva, Switzerland: European Commission.
- European Environment Agency. 2000. *Stratospheric Ozone Destruction in Environmental Signals 2000*. Environmental Assessment Report No 6. European Environment Agency.
- European Environment Agency. 2005. *Climate Change and River Flooding in Europe*. EEA Briefing. Number 1. 4 pages.
- Fears T.R., Bird C.C., Guerry D., Sagebiel R.W., Gail M.H., Elder D.E., Halpern A., Holly E.A., Hartge P. and Tucker M.A. 2002. *Average Midrange Ultraviolet Radiation Flux and Time Outdoors Predict Melanoma Risk*. *Cancer Research*. Volume 62. July 2002. pp 3992-3996.
- Ferraro F.R. 2003. *Psychological Resilience in Older Adults Following the 1997 Flood*. *Clinical Gerontologist*. Volume 26. pp 139-43.
- Fleisher J.M., Kay D., Salmon R.L., Jones F., Wyer M.D. and Godfree A.F. 1996. *Marine Waters Contaminated with Domestic Sewage: Nonenteric Illnesses Associated with Bather Exposure in the United Kingdom*. *American Journal of Public Health*. Volume 86. pp 1228–1234.
- Floyd P., George C., Tunstall S., Tapsell S., Green C., Jones-Lee M., and Metcalfe H. 2003. *The Appraisal of Human-Related Intangible Impacts of Flooding*. Defra. London.
- Food and Agriculture Organization (FAO). 2006. *Climate Change: Implications for Food Safety*.
- Fordham M.H. 1998. *Making Women Visible in Disasters: Problematizing the Private Domain*. *Disasters*. Volume 22. Number 2. pp 126-143.
- Fordham M. and Ketteridge A.M. 1995. *Flood Disasters – Dividing the Community* (presentation]. International Emergency Planning Conference. Lancaster. UK.
- Foresight. 2011. *International Dimensions of Climate Change*. Foresight Horizon Scanning Centre. Government Office for Science.
- French J., Ing R., Von Allmen S. and Wood R. 1983. *Mortality from Flash Floods: A Review of National Weather Services Reports, 1969-81*. *Public Health Rep*. Volume 98. Number 6. pp 584-588.
- Friedlingstein P., Houghten R.A., Marland G., Hacklar J., Boden T.A., Conway T.J., Canadell J.G., Raupach M.R., Ciais P. and Le Quéré C. 2010. *Update on CO₂ emissions*. *Nature Geosciences*. Volume 3. pp 811-812.
- Frieser B. I., Vrijling J. K. and Jonkman S. N. 2005. *Probabilistic Evacuation Decision Model for River Floods in the Netherlands*. 9th International Symposium on Stochastic Hydraulics. Nijmegen, The Netherlands. IAHR.

Frumkin H. and McMichael A.J. 2008. Climate Change and Public Health. Thinking, Communicating, Acting. American Journal of Preventative Medicine. Volume 35. pp 403–410.

Fullilove M.D. 1996. Psychiatric Implications of Displacement: Contributions from the Psychology of Place. American Journal of Psychiatry. Volume 153. pp 1516-23.

Galea S., Nandi A. and Vlahov D. 2005: The Epidemiology of Post-Traumatic Stress Disorders after Disasters. Epidemiologic Reviews. Volume 27. pp 78-91.

Geroldinger-Simic M., Zelniker T., Aberer W., Ebner C., Egger C., Greiderer A., Prem N., Lidholm J., Ballmer-Weber B.K., Vieths S. and Bohle B. 2011 Birch Pollen-Related Food Allergy: Clinical Aspects and the Role of Allergen-Specific IgE and IgG₄ Antibodies. The Journal of Allergy Clinical Immunology. Volume 127. Issue 3. pp 616-622.

Ginexi E.M., Weihs K., Simmens S.J. and Hoyt D.R. 2000. Natural Disaster and Depression: a Prospective Investigation of Reactions to the 1993 Midwest Floods. American Journal of Community Psychology. Volume 28. pp 495-518.

Goh S., Reacher M., Casemore D.P., Verlander N.Q., Charlett A., Chalmers R.M., Knowles M., Pennington A., Williams J., Osborn K. and Richards S. 2005. Sporadic Cryptosporidiosis Decline after Membrane Filtration of Public Water Supplies, England, 1996-2002. Emerging Infectious Diseases. Volume 11. Number 12. pp 251-259.

Goldberg D. and Williams P. 1998. A User's Guide to the General Health Questionnaire. NFER-Nelson. Windsor.

Gosling S., Lowe J., McGregor G.R., Pelling M. and Malamud B.D. 2009. Associations Between Elevated Atmospheric Temperature and Human Mortality: A Critical Review of the Literature. Climatic Change. Volume 92. Issue 3. pp 299-341.

Green B.L., Wilson J. and Lindy J. 1985. Conceptualizing Posttraumatic Stress Disorder: a Psychosocial Framework. In: Figley C (ed). Trauma and Its Wake. New York, NY. Bruner/Mazel.

Hader D.P., Helbling E.W., Williamson C.E. and Worrest R.C. (11. Effects of UV Radiation on Aquatic Ecosystems and Interactions with Climate Change. Photochemical and Photobiological Sciences. Volume 10. Issue 2. pp 242-260.

Haines A., McMichael A.J., Smith K.R., Roberts I., Woodcock J., Markandya A., Armstrong B.G., Campbell-Lendrum D., Dangour A.D., Davies M., Bruce N., Tonne C., Barrett M. and Wilkinson P. 2009. Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Overview and Implications for Policy Makers. Lancet. Volume 374. pp 2104-2114.

Hajat S., Ebi K.L., Kovats S., Menne B., Edwards S. and Haines A. 2003. The Human Health Consequences of Flooding in Europe and the Implications for Public Health: A Review of the Evidence. Applied Environmental Science and Public Health. Volume 1. Number 1. pp 13-21.

Hajat, S. Ebi, K.L., Kovats, R.S. Menne, B., Edwards, S. and Haines, A. 2005. The Human Health Consequences of Flooding in Europe: a Review. Extreme Weather Events and Public Health Responses. 185-196.

Hajat S., Kovats R.S. and Lachowycz K. 2007. Heat-Related and Cold-Related Deaths in England and Wales: Who is at Risk? Occupational and Environmental Medicine. Volume 64. pp 93-100.

- Hajat S., O'Connor M. and Koratsky T. 2010a. Health Effects of Hot Weather: From Awareness of Risk Factors to Effective Health Protection. The Lancet. Volume 375(9717). pp 856-863.
- Hajat S., Sheridan S.C., Allen M.J., Pascal M., Laaidi K., Yagouti A., Bickis U., Tobias A., Bourque D., Armstrong B.G. and Kosatsky T. 2010b. Heat-Health Warning Systems: A Comparison of the Predictive Capacity of Different Approaches to Identifying Dangerously Hot Days. American Journal of Public Health. Volume 100(6). pp 1137-1144.
- Hames D., Reeve D., Marriott M. and Chadwick A. 2004. Effect of Data Quality on the Analysis of Water Levels along the Cumbrian Coastline. International Conference on Flood Risk Assessment. Institute of Mathematics and its Applications. University of Bath. April 2004.
- Hassi J., Rytönen M., Kotaniemi J. and Rintamäki. 2005. Impacts of Cold Climate on Human Heat Balance, Performance and Health in Circumpolar Areas. Climate Change and Human Health. International Journal of Circumpolar Health. Volume 64. Number 5. pp 459-467.
- Hayes J., Mason J., Brown F. and Mather R. 2009. Floods in 2007 and Older Adult Services: Lessons Learnt. Psychiatric Bulletin. Volume 33. pp 332-336.
- Health Protection Agency. 2010. Flood – Advice to Healthcare Professionals. Available at: www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1214291249452.
- Hegglin M.I. and Shepard T.G. 2009. Large Climate Induced Changes in Ultraviolet Index and Stratosphere to Troposphere Ozone Flux. Nature Geoscience.
- Hess J. J., Heilpern K.L., Davis T.E. and Frumkin H. 2009. Climate Change and Emergency Medicine: Impacts and Opportunities. Academic Emergency Medicine. Volume 16. Issue 8. pp 782-794.
- HM Treasury. 2003. The Treasury Green Book – Appraisal and Evaluation in Central Government. London.
- HM Treasury. 2007. The Green Book. Appraisal and Evaluation in Central Government Treasury Guidance. Her Majesty's Treasury. London:TSO.
- Hoek M. R., Oliver I., Barlow M., Heard L., Chalmers R. and Paynter S. 2008. Outbreak of *Cryptosporidium Parvum* among Children after a School Excursion to an Adventure Farm, South West England. Journal of Water and Health. Volume 6(3). pp 333-338.
- Holick M.F. 2001. A Perspective on the Beneficial Effects of Moderate Exposure to Sunlight: Bone Health, Cancer Prevention, Mental Health and Well Being. Chapter 2. Comprehensive Series in Photosciences. Volume 3. pp 11-37.
- Holick, M. F. 2004. Sunlight and Vitamin D for Bone Health and Prevention of Autoimmune Diseases, Cancers, and Cardiovascular Disease. American Journal of Clinical Nutrition. Volume 80. pp 1678S-1688S.
- Holme S.A., Malinowsky K. and Roberts D.L. 2000. Changing Trends in Non-Melanoma Skin Cancer in South Wales, 1988-98. British Journal of Dermatology. Volume 143. Number 6. pp 1224-1229.
- Horton B. 2004. An Interdisciplinary Model of Risk from Ultraviolet Radiation Exposure. PhD Thesis. University of East Anglia, Norwich.
- HR Wallingford. 2010. Framework for Modelling People's Behaviour in Flood Emergencies: Life Safety Model Improvement to Agent's Behaviour. September 2010.

- Hunter P.R. 2003. Climate Change and Waterborne and Vector-Borne Disease. *Journal of Applied Microbiology*. Volume 94. pp 37S-46S.
- IPCC. 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds). Cambridge: Cambridge University Press.
- IPCC. 2007b. 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, 996 pp.
- ISCCC. 2009. International Scientific Congress Climate Change: Global Risks, Challenges & Decisions – Synthesis Report. ISCCC, Copenhagen.
- ISD Online. 2010. Cancer Incidence and Mortality Data. Available at: www.isdscotland.org/. Accessed 21st October 2010.
- Jenkins G.J., Murphy J.M., Sexton D.M.H., Lowe J.A., Jones P., Kilsby C.G. 2009. UK Climate Projections: Briefing report. Met Office Hadley Centre, Exeter, UK.
- Jeremy Benn Associates Ltd. 1998. Extreme Sea levels for Section 105 Surveys – Final report for Environment Agency North West Region. July 1998.
- Johnson H., Kovats S., McGregor G., Stedman J., Gibbs M., Walton H., Cook L. and Black E. 2004. The Impact of the 2003 Heat Wave on Mortality and Hospital Admissions in England. *Epidemiology*. Volume 15. Number 4. pp 6-11.
- Jones L., Asare J., El Masri M., Mohanraj A., Sherief H. and Van Ommeren M. 2009. Severe Mental Disorders in Complex Emergencies. *Lancet*. Volume 374. pp 654-661.
- Jones G. S., Stott P.A. and Christidis N. 2008. Human Contribution to Rapidly Increasing Frequency of Very Warm Northern Hemisphere Summers. *Journal of Geophysical Research D: Atmospheres*. Volume 113. Issue 2.
- Keane E.P. 1998. Phenomenological Study of the North Dakota Flood Experience and its Impact on Survivor's Health. *International Journal of Trauma Nursing*. Volume 4. pp 79-84.
- Keatinge W. R.Donaldson G.C., Bucher K., Jendritsky G., Cordioli E., Martinelli M., Dardanoni L., Katsouyanni K., Kunst A.E., Mackenbach J.P., McDonald C., Nayha S. and Vuori I. 1997. Cold Exposure and Winter Mortality from Ischaemic Heart Disease, Cerebrovascular Disease, Respiratory Disease, and All Causes in Warm and Cold Regions of Europe. *The Lancet*. Volume 349. Issue 9062. pp 1341-1346. 10 May 1997.
- Keatinge W. R.Donaldson G.C., Cordioli E., Martinelli M., Kunst A.E., Mackenbach J.P., Nayha S. and Vuori I. 2000. Heat Related Mortality in Warm and Cold Regions of Europe: Observational Study. *British Medical Journal*. Volume 321(7262). pp 670-673.
- Kemper N. 2008. Veterinary Antibiotics in the Aquatic and Terrestrial Environment. *Ecological Indicators*. Volume 8. Number 1. pp 1-13.
- Kessler R.C., Sonnega A., Bromet E., Hughes M., Nelson C.B. and Breslau N.N. 1999. Epidemiological Risk Factors for Trauma and PTSD. In: Yehuda R (ed). *Risk Factors for PTSD*. Washington, DC: American Psychiatric Press.

- Kessler R., Galea S., Gruber M., Sampson N., Ursano R. and Wessely S. 2008. Trends in Mental Illness and Suicidality after Hurricane Katrina. *Molecular Psychiatry*. Volume 13. pp 374–384.
- Klein D.F. and Wender P.H. 1993. *Understanding Depression*. Oxford University Press. New York.
- Knowlton K., Lynn B., Goldberg R.A., Rosenzweig C., Hogrefe C., Rosenthal J.K. and Kinney P.L. 2007. Projecting Heat-Related Mortality Impacts under a Changing Climate in the New York City Region. *American Journal of Public Health*. Volume 97. Number 11. November 2007.
- Knowlton K., Rotkin-Ellman M., King G., Margolis H.G., Smith D., Solomon G., Trent R. and English P. 2009. The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits. *Environmental Health Perspectives*. Volume 117. Number 1. pp 61-67.
- Koren D., Arnon I. and Klein E. 1999. Acute Stress Response and Posttraumatic Stress Disorder in Traffic Accident Victims: a One- Year Prospective, Follow-up Study. *American Journal of Psychiatry*. Volume 156. pp 367-373.
- Kovats S., Armstrong B. and Hunt A. 2006. Climate Change Impacts and Adaptation: Cross Regional Research Programme - Quantify the Costs of Impacts and Adaptation - GA01075. In *Metroeconomica* (2006) Defra. London, UK.
- Kovats R. S., Edwards S.J., Hajat S., Armstrong B.G., Ebi K.L. and Menne B. 2004a. The Effect of Temperature on Food Poisoning: A Time-Series Analysis of Salmonellosis in Ten European Countries. *Epidemiology Infection*. Volume 132. Number 3. pp 443-453.
- Kovats R. S. and Hajat S. 2008. Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*. Volume 29. pp 41-55.
- Kovats R. S., Hajat S. and Wilkinson P. 2004b. Contrasting Patterns of Mortality and Hospital Admissions During Hot Weather and Heat Waves in Greater London, UK. *Occupational and Environmental Medicine*. Volume 61. Number 11. pp 893-898.
- Kuhn K.G., Campell-Lendrum D.H., Armstrong B. and Davies C.R. 2003. Malaria in Britain: Past, Present, and Future. *Proceedings of the National Academy of Sciences of the United States of America*. Volume 100. pp 9997-10001.
- Lake I.R., Gillespie I.A., Bentham G., Nicols G.L., Lane C., Adak G.K. and Threlfall E.J. 2009. A Re-evaluation of the Impact of Temperature and Climate Change on Foodborne Illness. *Epidemiology and Infection*. Volume 137(11). pp 1538-1547.
- Lee K. 2000. For debate. The Impact of Globalization on Public Health: Implications for the UK Faculty of Public Health Medicine. *Journal of Public Health*. Volume 22. pp 253-262.
- Lee Y., Kim J., Lee B. and Cho H. 2004. Effects of Ozone, Cloud and Snow on Surface UV Irradiance. *Ocean and Polar Research*. Volume 26. Issue 3. September 2004. pp 439-451.
- Le Quéré C., Raupach M.R., Canadell J.G., Marland G., Bopp L., Ciais P., Conway T.J., Doney S.C., Feely R.A., Foster P., Friedlingstein P., Gurney K., Houghton R.A., House J.I., Huntingford C., Levy P.E., Lomas M.R., Majkut J., Metzl N., Ometto J.P., Peters G.P., Prentice I.C., Randerson J.T., Running S.W., Sarmiento J.L., Schuster U., Sitch S., Takahashi T., Viovy N., van der Werf G.R. and Woodward F.I. 2009. Trends in the Sources and Sinks of Carbon Dioxide. *Nature Geoscience*. Volume 2. pp 831-836.

- Licence K., Oates K.R., Synge B.A. and Reid T.M. 2002. An Outbreak of *E. Coli* O157 Infection with Evidence of Spread from Animals to Man through Contamination of a Private Water Supply. *Epidemiology and Infection*. Volume 126. pp 135-138.
- Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolstrom, M., Lexer, M. J. and Marchetti, M. 2010. Climate change impacts, adaptive capacity and vulnerability of European forest ecosystems. *Forest Ecology and Management*, 259, 698 – 709.
- Loosemore M., Carthey J., Chandra V. and Chand A.M. 2011. Climate Change Risks and Opportunities in Hospital Adaptation. *International Journal of Disaster Resilience in the Built Environment*. Volume 2. Issue 3. pp.210-221.
- MacKenzie W.R., Hoxie N.J., Proctor M.E., Gradus M.S., Blair K.A., Peterson D.E., Kazmierczak J.J., Addiss D.G., Fox K.R., Rose J.B. and Davis P. 1994. A Massive Outbreak in Milwaukee of Cryptosporidium Infection Transmitted through the Public Water Supply. *The New England Journal of Medicine*. Volume 331. pp 161-167.
- Malilay J. 1997. Floods. In “The Public Health Consequences of Disasters”. Ed. Noji E.K. pp 287-301. Oxford. Oxford University Press.
- Marmot Review. 2010. “Fair Society, Healthy Lives”.
- Marshall G., Schell T., Elliott M., Rayburn N. and Jaycox L. 2007. Psychiatric Disorders Among Adults Seeking Emergency Disaster Assistance after a Wildland-Urban Interface Fire. *Psychiatric Services*. Volume 58. pp 509–514.
- Martinez-Urtaza J., Bowers J. C., Trinaes J. and DePaola A. 2010. Climate Anomalies and the Increasing Risk of *Vibrio Parahaemolyticus* and *Vibrio Vulnificus* Illnesses. *Food Research International*. Volumen 43. pp 1780-1790.
- Marzuk P.M., Tardiff K., Leon A.C., Hirsch C.S., Portera L., Iqbal M.I., Nock M.K. and Hartwell N. 1998. Ambient Temperature and Mortality from Unintentional Cocaine Overdose. *Journal of the American Medical Association*. Volume 279. pp 1795–800.
- McGeehin M. A. and Mirabelli M. 2001. The Potential Impacts of Climate Variability and Change on Temperature-Related Morbidity and Mortality in the United States. *Environmental Health Perspectives*. Volume 109. pp 185-189.
- McGuigan C.C., Steven K. and Pollock K.G.J. 2010. Cryptosporidiosis Associated with Wildlife Center, Scotland. *Emerging Infectious Diseases*. Volume 16. pp 895-896.
- McMichael T., Campbell-Lendrum D., Kovats S *et al.*, 2002. Comparative Risk Assessment: Climate Change. London: Centre on Global Change and Health. London School of Hygiene and Tropical Medicine.
- McMillen C., North C., Mosley M. and Smith E. 2002. Untangling the Psychiatric Comorbidity of Posttraumatic Stress Disorder in a Sample of Flood Survivors. *Comprehensive Psychiatry*. Volume 43. Issue 6. pp 478-485.
- Medlock J.M., Snow K.R. and Leach S. 2005. Potential Transmission of West Nile Virus in the British Isles: An Ecological Review of Candidate Mosquito Bridge Vectors. *Medical and Veterinary Entomology*. Volume 19. pp 2-21.
- Meleux F., Solmon F. and Giorgi F. 2007. Increase in Summer European Ozone Amounts due to Climate Change. *Atmospheric Environment*. Volume 41. Issue 35. pp 7577-7587.
- Miettinen I.T., Zacheus O., Von Bonsdorff C.H. and Vartiainen T. 2001. Waterborne Epidemics in Finland in 1998-1999. *Water Science and Technology*. Volume 43. pp 67-71.

- Molokhia A.M. 1984 Effect of Storage on the Bioavailability of Cephalexin from its Capsules. *Research Communications in Chemical Pathology and Pharmacology*. Volume 45. pp 219-224.
- Morabito M., Cecchi L., Crisci A., Modesti P.A. and Orlandini S. 2006. Relationship Between Work-Related Accidents and Hot Weather Conditions in Tuscany (Central Italy). *Industrial Health*. Volume 44. Number 3. pp 458-464.
- Morrow B.H. 1999. Identifying the Mapping Community Vulnerability. *Disasters*. Volume 23. Number 1. pp 1-18.
- Mukherjee A. 2002. Outbreak of Cryptosporidiosis in Grampian NHS Board Area (January-March 2002). <http://www.nhsgrampian.org/grampianfoi/files/CryptoAberdFRep2002.pdf> [Accessed 22/08/2011]
- Murphy J.M., Sexton D.M.H., Jenkins G.J., Boorman P.M., Booth B.B.B., Brown C.C., Clark R.T., Collins M., Harris G.R., Kendon E.J., Betts R.A., Brown S.J., Howard T.P., Humphrey K.A., McCarthy M.P., McDonald R.E., Stephens A., Wallace C., Warren R., Wilby R., Wood, R.A., 2009. UK Climate Projections Science Report: Climate Change Projections. Met Office Hadley Centre, Exeter.
- National Audit Office. 2011. Transforming NHS ambulance services, 10 June 2011.
- National Health Service (NHS). 2011a. Developing the NHS Commissioning Board.
- National Health Service (NHS). 2011b. Food Poisoning Overview. Available at: <http://www.nhs.uk/Conditions/Food-poisoning/Pages/Introduction.aspx>, Accessed 30/06/11.
- National Health Service for Scotland (NHS), Greater Glasgow Outbreak Control Team. 2001. Report of an Outbreak of Cryptosporidiosis in the Area Supplied by Milngavie Treatment Works–Loch Katrine Water. Glasgow. Department of Public Health, Greater Glasgow Health Board.
- National Radiological Protection Board. 2002. Health Effects from Ultraviolet Radiation. Documents of the NRPB. Volume 13. Number 1.
- NEGTA. 2001. Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK. Prepared by the National Expert Group on Transboundary Air Pollution (NEGTA) on behalf of the Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland.
- NHS Wales. 2005. Designed for Life: Creating World Class Health and Social Care for Wales in the 21st Century. Available at: <http://www.wales.nhs.uk/documents/Designed-for-life-e.pdf>
- Nichols G. and Kovats S. 2008. Water and Disease and Climate Change. In: *Health Effects of Climate Change in the UK*. Editor Kovats S.
- Nichols G., Lane C., Asqari N., Verlander N.Q. and Charlett A. 2009. Rainfall and Outbreaks of Drinking Water Related Disease and in England and Wales. *Journal of Water and Health*. Volume 7. pp 1-8.
- Norris F., Friedman M., Watson P., Byrne C., Diaz E. and Kaniasty K. 2002. 60,000 Disaster Victims Speak: Part I. An Empirical Review of the Empirical Literature, 1981–2001. *Psychiatry*. Volume 65. pp 207–239.
- North C.S., Nixon S.J., Shariat S., Mallonee S., McMillen J.C., Spitznagel E.L. and Smith E.M. 1994a. Psychiatric Disorders Among Survivors of the Oklahoma City

Bombing. Journal of the American Medical Association. Volume 282. Number 8. pp 755-762.

North C.S., Ringwalt C.L., Downs D., Derzon J. and Galvin D. 2010. Postdisaster Course of Alcohol Use Disorders in Systematically Studied Survivors of 10 Disasters. Archives of General Psychiatry. October 2010.

North C.S., Smith E.M. and Spitznagel E.L. 1994b. Posttraumatic Stress Disorder in Survivors of a Mass Shooting. American Journal of Psychiatry. Volume 15. pp 82-88.

Office for National Statistics (ONS). 2004. Urban and Rural Classifications. Available at <http://www.ons.gov.uk/about-statistics/geography/products/area-classifications/rural-urban-definition-and-la-classification/index.html>.

Office for National Statistics. 2009. National Population Projections, 2008-based. Available at <http://www.statistics.gov.uk/pdfdir/pproj1009.pdf>. October 2009.

Office for National Statistics. 2011. Annual Mid-Year Population Estimates, 2010. Statistical Bulletin.

Ogden L.D., Fenlon D.R., Vinten A.J. and Lewis D. 2001. The Fate of *Escherichia coli* O157 in Soil and its Potential to Contaminate Drinking Water. International Journal of Food Microbiology. Volume 66. Issues 1-2. pp 111-117.

Ohl C.A. and Tapsell S.M. 2000. Flooding and Human Health: The Dangers Posed are not Always Obvious. British Medical Journal. Volume 321. pp 1167-1168.

Oliver J.D., 2005. Wound Infections Caused by *Vibrio Vulnificus* and Other Marine Bacteria. Epidemiology and Infection. Volume 133. pp 383-391.

Olsen S.J., Miller G., Breuer T., Kennedy M., Higgins C., Walford J., McKee G., Bibb W. and Mead P. 2002. A Waterborne Outbreak of *Escherichia coli* O157:H7 Infections and Hemolytic Uremic Syndrome: Implications for Rural Water Systems. Emerging Infectious Diseases. Volume 8. Number 4. pp 370-375.

Ostro B., Rauch S., Green R., Malig B. and Basu R. 2010. The Effects of Temperature and Use of Air Conditioning on Hospitalizations. American Journal of Epidemiology. Volume 172. Issue 9. pp 1053-1061.

Page L. A., Hajat S., Kovats R.S. 2007. Relationship Between Daily Suicide Counts and Temperature in England and Wales. British Journal of Psychiatry. Volume 191. pp 106-112.

Page L.A. and Howard L.M. 2010. The Impact of Climate Change on Mental Health (but will Mental Health be Discussed at Copenhagen?). Psychological Medicine. Volume 40. pp 177-180.

Pattenden S., Armstrong B., Milojevic A., Heal M.R., Chalabi Z., Doherty R., Barratt B., Kovats R.S. and Wilkinson P. 2010. Ozone, Heat and Mortality: Acute Effects in Fifteen British Conurbations. Occupational Environmental Medicine. Volume 67. Number 10. October 2010. pp 699-707.

Patterson D.T. 1995. Weeds in a Changing Climate. Weed Science. Volume 43. Number 4. pp 685-701.

Patz J. A., Campbell-Lendrum D. Holloway T. and Foley J.A. 2005. Impact of Regional Climate Change on Human Health. Nature. Volume 438. pp 310-317.

Penning-Rowsell E., Floyd P., Ramsbottom D. and Surendran S. 2005. Estimating Injury and Loss of Life in Floods: A Deterministic Framework. Natural Hazards. Volume 36. pp 43-64.

Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis (PESETA). 2009. Climate Change Impacts in Europe. Final Report of the PESETA Research Project.

Phifer J.F., Kaniasty K.Z. and Norris F.H. 1988. The Impact of Natural Disaster on the Health of Older Adults: A Multiwave Prospective Study. *Journal of Health Social Behaviour*. Volume 29. pp 65-78.

Photochemical Oxidants Review Group (PORG). 1997. Ozone in the United Kingdom. Fourth Report Prepared by the Photochemical Oxidants Review Group for the (DETR) Department of the Environment, Transport and the Regions.

Pitt Review. 2008. Lessons Learnt from the 2007 Floods. 43 pages.

Poon T.S. 2005. Sunlight-Induced Immunosuppression in Humans is Initially Because of UVB, then UVA, Followed by Interactive Effects. *Journal of Investigative Dermatology*. Volume 125. Number 4. October 2005. pp 840-846.

Power M.J. 1988. The "Worst Ever" Version of the General Health Questionnaire. Extended Version. *Journal of Clinical Psychology*. Volume 44. Issue 2. March 1988. pp 215-216.

Quinn M., Babb P., Brock A., Kirby L. and Jones J. 2001. Cancer Trends in England and Wales 1950-1999. *Studies on Medical and Population Statistics No. 66*. National Statistics. The Stationary Office.

Randolph S. E., 2004. Evidence that Climate Change has Caused 'Emergence' of Tick-Borne Diseases in Europe? *International Journal of Medical Microbiology*. Volume 293. pp 5-15.

Randolph S. E., 2010. To What Extent has Climate Change Contributed to the Recent Epidemiology of Tick-Borne Diseases? *Vet Parasitol*. Volume 167. pp 92-4.

Ratard R. 2006. Health Concerns Associated with Mold in Water-Damaged Homes After Hurricanes Katrina and Rita --- New Orleans Area, Louisiana, October 2005. *Morbidity and Mortality Weekly Report (MMWR)*. Volume 55. Number 2. pp 41-44.

Reacher M., McKenzie K., Lane C., Nicols T., Kedge I., Iverson A., Hepple P., Walter T., Laxton C. and Simpson J. 2004. Health Impact of Flooding in Lewes: a Comparison of Reported Gastrointestinal and Other Illness and Mental Health in Flooded and Non-Flooded Households. *Communicable Disease and Public Health*. Volume 7. Number 1. March 2004.

Reid S. and Wessley A. 2001. Somatisation and Depression. In: Dawson A. and Tylee A. (ed). *Depression: Social and Economic Timebomb*. London. BMJ Books. pp 55-61.

Risha P.G., Vervaet C., Vergote G., Bortel L.V. and Remon J.P. 2003. Drug Formulations Intended for the Global Market Should be Tested for Stability Under Tropical Climatic Conditions. *European Journal of Clinical Pharmacology*. Volume 59. pp 135-141.

Rogers D., Randolph S., Lindsay S. and Willis S.G. 2008. Vector-Borne Diseases and Climate Change,. In: *Health Effects of Climate Change in the UK*. Editor Kovats S.

Royal Academy of Engineering. 2011. Infrastructure, Engineering and Climate Change Adaptation – Ensuring Services in an Uncertain Future. London. Royal Academy of Engineering. 106p.

Royal Society. 2008. Ground-Level Ozone in the 21st Century: Future Trends, Impacts and Policy Implications. Science Report. Royal Society.

Ruckerl R., Greven S., Ljungman P., Aalto P., Antoniadou C., Bellander T., Berglund N., Chrysohoou C., Forastiere F., Jacquemin B., Von Klot S., Koenig W., Kuchenhoff H., Lanki T., Pekkanen J., Perucci C.A., Schneider A., Sunyer J. and Peters A. 2007. Air Pollution and Inflammation (Interleukin-6, C-reactive Protein, Fibrinogen) in Myocardial Infarction Survivors. *Environmental Health Perspectives*. Volume 115(7). pp 1072-1080.

Schmier J. K. and Ebi K. L. 2009. The Impact of Climate Change and Aeroallergens on Children's Health. *Allergy and Asthma Proceedings*. Volume 30. pp 229-237.

Schwartz J., Samet J.M. and Patz J.A. 2004. Hospital Admissions for Heart Disease: The Effects of Temperature and Humidity. *Epidemiology*. Volume 15. Number 6.

Scott W. and Dua J. 1999. The Development of a Scale to Assess Posttraumatic Stress Disorder. *International Journal of Stress Management*. Volume 6. Number 3. pp 149-165.

Scottish Government. 2007. Household Survey in Exploring the Social Impacts of Flood Risk and Flooding in Scotland. Chapter 4.

Scottish Government. 2009. Scotland's Climate Change Adaptation Framework. Available at: <http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/adaptation/AdaptationFramework>.

Semenza J.C., Rubin C.H., Falter K.H., Selanikio J.D., Flanders W.D., Howe H.L. and Wilhelm J.L. 1996. Heat Related Deaths During the July 1995 Heat Wave in Chicago. *The New England Journal of Medicine*. Volume 335. pp 84-90.

Serup-Hansen N., Gudum A. and Sørensen M.M. 2004. Valuation of Chemical Related Health Impacts. Environmental Project Number 929. Danish Environmental Protection Agency.

Sexton D.M.H., Murphy J. 2010. UKCP09: Probabilistic Projections of Wind Speed.

SGHD. 2009. Private Water Supplies: Understanding Engagement of Owners and Users. <http://www.scotland.gov.uk/Publications/2009/11/06133634/15> [Accessed 26/08/2011].

Sharma U., Patwardhan A. and Parthasarathy D. 2009. Assessing Adaptive Capacity to Tropical Cyclones in the East Coast of India: A Pilot Study of Public Response to Cyclone Warning Information. *Climatic Change*. Volume 94. pp 189-209.

Shennan I. and Horton B. 2002. Holocene Land and Sea Level Changes in Great Britain. *Journal of Quaternary Science*. Volume 17. pp 511–526.

Smith C., Tomassini C., Smallwood S. and Hawkins M. 2005. Focus on People and Migration. Chapter 4 "The Changing Age Structure of the UK". Office for National Statistics Publication.

Smith E.S., North C.S., McCool R.E. and Shea J.M. 1990. Acute Postdisaster Psychiatric Disorders: Identification of Persons at Risk. *American Journal of Psychiatry*. Volume 147. pp 202-206.

Smith H.V., Robertson L.J. and Ongerth J.E. 1995. Cryptosporidiosis and Giardiasis: the Impact of Waterborne Transmission. *Journal of Water Supply: Research and Technology – Aqua*. Volume 44. pp 258-274.

Solomon Z., Mikulincer M. and Avitzur E. 1988. Coping, Locus of Control, Social Support and Combat-Related Posttraumatic Stress Disorder: a Prospective Study. *Journal of Personality and Social Psychology*. Volume 55. Issue 2. August 1988. pp 279- 285.

- Sommer J., Plaschke P. and Poulsen L.K. 2009. Allergic Disease-Pollen Allergy and Climate Change. *Ugeskr Laeger*. Volume 171. pp 3184-7.
- Sorensen J. 1991. "When Shall we Leave: Factors Affecting the Timing of Evacuation Departures." *International Journal of Mass Emergencies and Disasters*. Volume 9. pp 153-165.
- Stafford-Smith M., Horrocks L., Harvey A. and Hamilton C. Rethinking Adaptation for a 4^o World. *Philosophical Transactions of the Royal Society. Series A. Mathematical Physical and Engineering Sciences*. Volume 369. Number 1934. Pp 196-216.
- Stanwell-Smith R. 2008. Climate Change and its Health Implications. A summary report for environmental health practitioners on the health implications of climate change. Chartered Institute of Environmental Health. Issue 1: Version 2. November 2008.
- Stedman J. R., 2004. The Predicted Number of Air Pollution Related Deaths in the UK During the August 2003 Heatwave. *Atmospheric Environment*. Volume 38. pp 1087-1090.
- Stedman J.R. and Kent A.J. 2008. An Analysis of the Spatial Patterns of Human Health Related Surface Ozone Metrics Across the UK in 1995, 2003 and 2005. *Atmospheric Environment*. Volume 42. Issue 8. pp 1702-1716.
- Stillerman K.P., Mattison D.R., Giudice L.C. and Woodruff T.J. 2008. Environmental Exposure and Adverse Pregnancy Outcomes: A Review of the Science. *Reproductive Sciences*. Volume 15. Number 7. pp 631-650.
- Stoellberger C., Lutz W., Finsterer J. 2009. Heat-Related Side-Effects of Neurological and Non-Neurological Medication may Increase Heatwave Fatalities. *European Journal of Neurology*. Volume 16. Number 7. pp 879-882.
- Stott P. A., Stone D.A. and Allen M.R. 2004. Human Contribution to the European Heatwave of 2003. *Nature*. Volume 432. pp 610-614.
- Tam C.C., Rodrigues L.C., Vivani L., Dodds J.P., Evans M.R., Hunter P.R., Gray J.J., Letley L.H., Rait G., Tompkins D.S. and O'Brien A.J. 2011. Longitudinal Study of Infectious Intestinal Disease in the UK (IID2 study): Incidence in the Community and Presenting to General Practice. *British Medical Journal*. Published online 27 June 2011. Available at: <http://gut.bmj.com/content/early/2011/06/26/gut.2011.238386.full.pdf>
- Tapsell S.M. and Tunstall S.M. 2001. The Health and Social Effects of the June 2000 Flooding in the North East Region. Report to the Environment Agency. Flood Hazard Research Centre. Middlesex University. Enfield.
- Tapsell S.M., Tunstall S.M. and Wilson T. 2003. Banbury and Kidlington Four Years After the Flood: An Examination of the Long-Term Effects of Flooding. Report to the Environment Agency, Thames Region. Flood Hazard Research Centre. Middlesex University. Enfield.
- Taylor J., Lai K.M., Davies M., Clifton D., Ridley I., Biddulph, P. 2011. Flood Management: Prediction of Microbial Contamination in Large-Scale Floods in Urban Environments. *Environment International*. Volume 37. Issue 5. pp 1019-1029.
- Tomlinson C.J., Chapman C., Thornes J.E. and Baker C.J. 2011. Including the Urban Heat Island in Spatial Heat Health Risk Assessment Strategies. *International Journal of Health Geographics*. Volume 10. Issue 42.
- Toms J.R. 2004. CancerStats Monograph. London. Cancer Research UK.

- Townend I.H. 1994. Variation in Design Conditions in Response to Sea Level Rise. *Proceedings of the Institution of Civil Engineers - Water, Maritime and Energy*. Volume 106. September 1994. pp 205-213.
- Tunstall S. 2007. Vulnerability and Flooding: A Re-analysis of FHRC Data. Country Report for England and Wales. Floodsite.
- Tunstall S., Tapsell S., Green C., Floyd P and George C. 2006. The Health Effects of Flooding: Social Research Results from England and Wales. *Journal of Water and Health*. Volume 4. Number 3. pp 365-380.
- UKCIP. 2003. Climate Adaptation: Risk, Uncertainty and Decision-Making. Willows R. and Connell R. UK Climate Impacts Programme, Oxford, UK.
- UKCP09. 2009. Climate Change Projections. June 2009.
- United Nations Environment Programme (UNEP). 2010. Scientific Assessment of Ozone Depletion: 2006 Assessment.
- Ursano R.J., Fullerton C.S., Epstein R.S., Crowley B., Kao T.C., Vance K., Craig J., Dougall A.L. and Baum A. 1999. Acute and Chronic Posttraumatic Stress Disorder in Motor Vehicle Accident Victims. *American Journal of Psychiatry*. Volume 156. pp 589-595.
- US Environmental Protection Agency (EPA). 1985. Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis. USA.
- US Pharmacopeia. 2000. Volume 26. Rockville, MD: USP.
- Van den Berg B., Grievink L., Yzermans J., and Lebret E. 2005. Medically Unexplained Physical Symptoms in the Aftermath of Disasters. *Epidemiologic Reviews*. Volume 27. pp 92–106.
- Vardoulakis S. 2010. The First UK Climate Change Risk Assessment. Health Sector, Scoping Study. Department of Public Health and Policy, London School of Hygiene and Tropical Medicine. April 2010.
- Vassallo M., Gera K.N., and Allen S. 1995. Factors Associated with High Risk of Marginal Hyperthermia in Elderly Patients Living in an Institution. *Postgraduate Medical Journal*. Volume 71. Number 834. pp 213-216.
- Verger P., Rotily M., Hunault C., Brenot J., Baruffol E., Bard D. 2003. Assessment of Exposure to a Flood Disaster in a Mental Health Study. *Journal of Exposure Analysis and Environmental Epidemiology*. Volume 13. pp 436-442.
- Vieths S., Scheurer S. and Ballmer-Weber B. 2002. Current Understanding of Cross-Reactivity of Food Allergens and Pollen. *Annals of the New York Academy of Sciences*. Volume 964. pp 47-68.
- Vingarzan R. 2004. A Review of Surface Ozone Background Levels and Trends. *Atmospheric Environment*. Volume 38. Issue 21. pp 3431-3442.
- Viscusi W.K. and Aldy J.E. 2003. The Value of a Statistical Life. A Critical Review of Market Estimates Throughout the World. *Journal of Risk and Uncertainty*. Volume 27. Number 1. pp 5-76.
- Wade T.J., Sandhu S.K., Levy D., Lee S., LeChevallier M.W., Katz L. and Colford J.M. 2004. Did a Severe Flood in the Midwest Cause an Increase in the Incidence of Gastrointestinal Symptoms? *American Journal of Epidemiology*. Volume 159. pp 398-405.

- Watkins P., Byrne D. and McDevitt M. 2001. Winter Excess Morbidity: Is it a Summer Phenomenon? *Journal of Public Health Medicine*. Volume 23. Number 3. pp 237-241.
- Watkiss P. and Hunt A. (forthcoming). Projection of Economic Impacts of Climate Change in Sectors of Europe based on Bottom up Analysis: Human Health. *Climatic Change*.
- Watkiss P., Hunt A. and Horrocks L. 2009. Literature Review: Scoping Study for a National Climate Change Risk Assessment and Cost-Benefit Analysis. *Metroeconomica*, AEA group, and Paul Watkiss Associates.
- Weisler R., Barbee J. and Townsend M. 2006. Mental Health and Recovery in the Gulf Coast after Hurricanes Katrina and Rita. *Journal of the American Medical Association*. Volume 296. pp 585–588.
- West C.C. and Gawith M.J. (eds.). 2005. *Measuring Progress: Preparing for Climate Change through the UK Climate Impacts Programme*. UKCIP. Oxford.
- Wheeler J.G., Sethi D., Cowden J.M., Wall P.G., Rodrigues L.C., Tompkins D.S., Hudson M.J. and Roderick P.J. 1999. Study of Infectious Intestinal Disease in England: Rates in the Community, Presenting to General Practice, and Reported to National Surveillance. The Infectious Intestinal Disease Study Executive. *British Medical Journal*. Volume 318. pp 1046-1050.
- Whiteman D.C., Whiteman C.A. and Green A. 2001. Childhood Sun Exposure as a Risk Factor for Melanoma: A Systematic Review of Epidemiologic Studies. *Cancer Causes and Control*. Volume 12. pp 69-82.
- Wilkinson P., Pattenden S., Armstrong B., Fletcher A., Kovats R.S., Mangtani P. and McMichael A.J. 2004. Vulnerability to Winter Mortality in Elderly People in Britain: Population Based Study. *British Medical Journal*. Volume 329(7467). pp 647-651.
- Wolf J., Adger W.N., Lorenzoni I., Abrahamson V. and Raine R. 2010. Social Capital, Individual Responses to Heat Waves and Climate Change Adaptation: An Empirical Study of Two UK cities. *Global Environmental Change*. Volume 20. pp 44-52.
- Wolff S.P. 1995. Cataract and UV radiation. *Documenta Ophthalmologica*. Volume 88. Number 3-4. pp 201-204. Cancer Research UK, accessed online 20/10/2010. <http://info.cancerresearchuk.org/cancerstats/types/skin/incidence/#source7>.
- World Health Organisation (WHO), 2004. Meta-analysis of Time-Series Studies and Panel Studies of Particulate Matter (PM) and Ozone (O₃). Report of a WHO Task Group. World Health Organisation, Copenhagen. Available at: <http://www.euro.who.int/document/E82792.pdfS>.
- World Health Organisation (WHO), 2010. International Classification of Diseases. See <http://www.who.int/classifications/icd/en/>.
- World Meteorological Organization. 2011. Press Release No. 906. Available at: www.wmo.int/pages/mediacentre/press_releases/pr_906_en.html.
- Young C. 2009. Solar Ultraviolet Radiation and Skin Cancer. *Occupational Medicine*. Volume 59. pp 82-88.
- Zmirou D., Pena L., Ledrans M. and Letertre A. 2003. Risks Associated with the Microbiological Quality of Bodies of Fresh and Marine Water Used for Recreational Purposes: Summary Estimates Based on Published Epidemiological Studies. *Archives of Environmental Health*. Volume 58. pp 703-711.

Data sets

Population and Mortality Data

<http://www.statistics.gov.uk/>

<http://www.gro-scotland.gov.uk/>

<http://www.nisra.gov.uk/>

Hospital Admission Data

<http://www.hesonline.nhs.uk/>

<http://www.infoandstats.wales.nhs.uk/>

<http://www.isdscotland.org/>

<http://www.dhsspsni.gov.uk/>

Appendices

Appendix 1 Extent of consultation/review

Sector Scoping Report, comments received by:

Professor Ben Armstrong (London School of Hygiene and Tropical Medicine)

Dr Zaid Chalabi (London School of Hygiene and Tropical Medicine)

Dr Kate Charlesworth (NHS Sustainable Development Unit)

Agatha Ferrao (Department of Health)

Professor Ian Gilmore (Royal College of Physicians)

Dr Shakoor Hajat (London School of Hygiene and Tropical Medicine)

Dr Clare Heaviside (Health Protection Agency)

Dr Sari Kovats (London School of Hygiene and Tropical Medicine)

Dr Giovanni Leonardi (Health Protection Agency)

Professor Robert Maynard (Health Protection Agency)

Professor Virginia Murray (Health Protection Agency)

Dr Jo Nurse (Department of Health)

Francisco Pozo-Martin (London School of Hygiene and Tropical Medicine)

Health Sector Workshop, Reading 26th May 2010

This following people attending the Health sector workshop in Reading on 26th May 2010 (titles not given):

Louise Newport (Department of Health)

Chris Holme (Department of Health)

Clare Heaviside (Health Protection Agency)

Delphine Grynszpan (Health Protection Agency)

Lynn Gibbons (Sustainability South West)

Chris West (UKCIP)

Kimberley Cann (Public Health Wales CDSC)

Nigel McMahon (Department of Health, Social Services and Public Safety Northern Ireland)

Seamus Camplisson (Department of Health, Social Services and Public Safety Northern Ireland)

George Roycroft (British Medical Association)

Dave Stone (Natural England)

Joyce Whitock (Scottish Government)

Elsbeth Lee (Department of Health, Regional Public Health Group- London)

Bob Mayho (Chartered Institute of Environment and Health)

Vicky Beechey (Hampshire County Council)

Damien Basher (Department of Health)

Dan Shears (GNB)

Sotiris Vardoulakis (London School of Hygiene and Tropical Medicine / Health Protection Agency, Sector Champion)

Appendix 2 'Tier 1' List of Impacts

This appendix outlines the Tier 1 list of impacts that were identified for this study. In considering this list, the following points need to be considered:

- In addition to the impacts identified in the sector report, impacts were extracted from the CCRA scoping study (Watkiss *et al.*, 2009) as well as PESETA (2009), West and Gawith, (2005), Arkell *et al.*, (2007) and Scottish Government (2009). Impacts were also identified from additional grey and research literature.
- Where the same or similar impacts have been identified, attempts have been made to remove duplicates. However, where there are subtle differences between impacts, similar impacts have been retained as separate impacts in the spreadsheet. Additional and sometimes novel impacts raised at the CCRA Forum event (21st January 2010) have also been recorded.
- There are many potentially adverse impacts but a number of opportunities have also been identified. A preliminary assessment has been made of threats (adverse impacts) and opportunities in the tables using the following colour code:
- T= threat (red), O = opportunity (green); N = neutral impact (amber).
- However it is recognised that there may be both positive and negative aspects of the same impact.
- A pedigree scoring system was applied to the collective evidence available to support each impact identified as follows:
 - 0 Non-expert opinion, unsubstantiated workshop discussion with no supporting evidence
 - 1 Expert view based on limited information, e.g. anecdotal evidence
 - 2 Estimation of potential impacts, using accepted methods and with some agreement across the sector
 - 3 Reliable analysis and methods, subject to peer review and accepted within a sector as 'fit for purpose'
 - 4 Comprehensive evidence using the best practice and published in the peer reviewed literature; accepted as an ideal approach.

At this early stage the highest scores are generally '3' for impacts in each sector, although '4' has been used in relation to some impacts (although none in the health sector) linked to sea level rise where there are good observations and comprehensive impacts assessments in the research literature. Pedigree scores may improve as further evidence is gathered or change either way through a peer review process.

The confidence terminology from IPCC WG1⁸² was used to provide some guidance, although at this preliminary stage only high, medium and low confidence classes were generally used. 'Very high' was used for a small number of impacts.

⁸² http://www.ipcc.ch/publications_and_data/ar4/wg1/en/tssts-2.html

Confidence Terminology Degree of confidence in being correct

Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Evidence is linked to Sector Scoping Report or the other main sources. Users are directed to the bibliography in the Sectors Summary Report, Vardoulakis (2010) and the full list of references in Sector Scoping Report, Watkiss *et al.*, (2009) for further details.

The 'hash' symbol # within the spreadsheets indicates comments or characterisation of impacts by the HR Wallingford team rather than the sector champion.

Climate effects	Impacts	Threat / opportunity / neutral	Consequences	# Pedigree	# Level of confidence
# Temperature / rainfall variations	Cases of malaria may become more common (this is unlikely to become a serious public health concern in the UK)		# Impact on health	2	# M
# Temperature / rainfall variations	New disease (or disease boundaries)		This will influence the training and requirements of the health workforce, the physical infrastructure of hospitals, care homes and other facilities, and emergency transportation of patients and equipment	1	# L
Heatwaves	Increased summer mortality		Increased demands on health and adult care services	3	# H
Increased average temperature	Reduced winter mortality			3	# M
Hot summers / # heatwaves; increase in average temperatures	Exposure of medicines (or other medical and laboratory materials) to high temperatures during storage and transit (most licences specify storage below 25°C)		Reduction in medicine efficacy	2	# M
Increase in average summer temperature (see also cloud cover/sunny days)	People encouraged to spend more time in the sun		Increased sunlight exposure enhancing vitamin D levels and related health benefits	2	# M
Increase in average summer temperature; heatwaves	Multiplication of pathogenic micro-organisms		Increase in cases of food poisoning during the summer	2	# M
Increase in average temperature (linked to warm weather)	Increase in water-borne diseases (Cryptosporidiosis) in people using surface waters (inland and coastal) for recreational purposes		# Impact on health	2	# M
Increase in average temperature	Longer pollen season and more days with high pollen concentrations		Impact on health - more people with hay fever and pollen asthma; increased severity of symptoms. This then leads to higher costs and demands on NHS for diagnosis and treatment of more complex allergies (budgetary impact on health care sector - Schmier and Ebi, 2009)	2	# M
Increase in average temperature	Increase in vector reproduction, parasite development and bite frequency		Increase in prevalence of certain vector borne diseases (mainly ticks and lyme disease)	2	# M
Increased average temperature	Increased summer morbidity		Increased demands on health and adult care services	2	# L
Increased average temperature (linked to warm weather)	Exacerbation of food borne disease (no acclimatisation) (food poisoning, campylobacteriosis, salmonellosis, <i>salmonella typhimurium</i> infections and <i>salmonella enteritidis</i> infections)		Increased demands on health and adult care services (however the impact of climate change on this aspect of UK public health is likely to be relatively small compared to other factors such as food hygiene)	2	# M

Climate effects	Impacts	Threat / opportunity / neutral	Consequences	# Pedigree	# Level of confidence
Increased average temperature, heatwaves, UV, wind-speeds etc	Changes in air quality and increase in frequency and intensity of air pollution episodes during warm seasons (mainly high ground-level ozone concentrations)		Increase in intensity and frequency of associated mortality and morbidity e.g. increase in respiratory disease and associated hospital admissions (this is predicted to cause an increase of 15-53% in attributable deaths and respiratory hospital admissions (HPA, 2008)). Budgetary impact on health care sector	2	# M
Increased frequency of high or extreme temperature episodes (heatwaves)	Additional effects from extremes (heat-waves) - morbidity impacts		Impacts on workforce; increased care / hospital intake for vulnerable people; dehydration; heat cramps; heat stress/exhaustion and sun stroke; mental health	2	# M
# Increase in average winter temperature	Decline in frequency and intensity of winter air pollution episodes		Proportional decrease in associated mortality and morbidity	1	# L
# Milder, wetter winters	Increased algal or fungal growth in existing buildings		Impact on respiratory conditions	1	# M
Frequent heatwaves	Disruption to building maintenance work		# Impact on services	1	# M
Heatwaves	IT server overheating in PCTs and hospitals		Disruption to email communication in PCTs and hospitals	1	# M
Increase in average temperature	Other (food, diet, water, etc)		Increase in healthy eating if sustainable farming and food policy are adapted	1	# L
Increased average temperature	Reduced winter morbidity			1	# M
Increased average temperature	Increase in outdoor activities/ recreation leading to exercise and lifestyle benefits		Better health and wellbeing; contributions to the economy	1	# L
Milder winters	Fewer traffic accidents		Smaller burden on emergency services during winter	1	# L
# Sea level rise, storm surge, increase in rainfall	Flooding of property		Loss of medication	3	# H
Sea level rise, storm surge, # increase in rainfall	Flood risk – fatality/injury		Increased demands on health and adult care services	3	# H
Sea level rise, storm surge, # increase in rainfall	Flood risk – psychological well-being and mental stress		Common mental disorders, including anxiety and depression which may last for months and possibly even years after the flood event. Mental health, psychological support and counselling services may experience a rise in demand	3	# H
Sea level rise, storm surge, # increase in rainfall	Flood risk – other e.g. spread of communicable diseases		Increase in self-reported illnesses, particularly relating to skin, respiratory and gastro-intestinal conditions	3	# M
# Sea level rise, storm surge, increase in rainfall	Flooding leading to physical damage of NHS infrastructure and buildings, and disruptions in transportation of patients, medical staff and supplies		Disruptions in hospital, clinics, general practice offices and care homes. Failure to deliver healthcare. Certain services may need to be relocated	2	# M
Increase in frequency of heavy rainfall events	Deterioration in the quality of surface waters		Could adversely affect the health of those engaged in recreational water contact	3	# M

Climate effects	Impacts	Threat / opportunity / neutral	Consequences	# Pedigree	# Level of confidence
Increased frequency of heavy rainfall events	Flooding leading to negative impact on raw water quality		Private water and surface water supplies without filtration may be affected. Increased incidence of water borne diseases	3	# M
Climate change	Increase in indirect human exposure to agricultural contaminants including certain pesticides, fertilizers, bacteria and viruses (magnitude of the increases highly dependent on contaminant type)		Health risks associated with many pathogens, particulate and particle-associated contaminants could increase significantly	2	# M
Extreme weather events (such as droughts and hurricanes)	Social disruption, injuries, deaths, disability, migration, homelessness and food shortages		Exacerbate inequalities in communities; increasing tension e.g. between those who live in areas more likely to flood and those who do not or can afford to protect their properties affecting community cohesion	2	# L
Higher occurrence of extreme weather events such as heatwaves and floods	A significant rise in demand for emergency medicine (including ambulatory emergency care)		Overwhelming public services	2	# M
Extreme weather events	Health care staff performance compromised			1	# L
Extreme weather events	Patient recovery in hospitals may be compromised			1	# L
Extreme weather events	Extreme weather risk to elderly (over 75), especially those who are socially isolated or living on their own			1	# L
Extreme weather events	More traffic accidents		Greater burden on emergency services	1	# L
Extreme weather events e.g. heatwaves and floods	Buildings and other NHS infrastructure may not be resilient to these events		May require certain wards to temporarily close down as patients could not be treated in a safe environment; demand for cooling increases	1	# M
Increased volatility and severe weather	Increased strain on mobile care and support services			1	# L
Reduction in cloud cover; increase in sunny days; increase in average summer temperature	People encouraged to spend more time in the sun		Increase in UV radiation exposure and sunburn and skin cancer incidence	2	# L
Increase in sunny days	Increase in cataracts			1	# L
Climate change	Delay in the rate of recovery of the stratospheric ozone layer		UV radiation exposure affected	2	# M

Appendix 3 Selection of Tier 2 consequences

The health impacts were scored according to the guidelines above using the following formula:

$$100 * \left(\frac{\text{Social} + \text{Environmental} + \text{Economic}}{9} \right) \left(\frac{\text{Likelihood}}{3} \right) \left(\frac{\text{Urgency}}{3} \right) \quad (\text{A3.1})$$

where each criteria were scored as 1, 2 or 3 dependent on their relative importance for that impact. Different scoring methods were considered but application of more complex approaches would indicate an overly high level of precision in the evidence and in most cases would lead to bias in the selection of impacts towards particular criteria. For example a logarithmic scale (1,10,100) could be used for the magnitude of impacts but this would lead to only high magnitude impacts being selected and make urgency and likelihood scores irrelevant. More details on the scoring methodology are given in Defra (2010b).

The scoring process was initially carried out by the sector champion for health in discussion with the sector analyst. These were then reviewed based on a meeting at the Department of Health on 27/07/10, with consistency checked against other sectors.

HEALTH SECTOR SCORING

Name of 'rationalised' consequences (incl. individual impact reference numbers from sectors summary report) <i>Note 5</i>	Magnitude <i>Note 1</i>			<i>Note 7</i>	<i>Note 2</i>	<i>Note 3</i>	<i>Note 4</i>		<i>For info.</i>		
	Economic Score	Environ. Score	Social Score	Vuln. Groups Y/N	Likelihood Score	Urgency Score	Total Score	Ranking	Average Pedigree	Tier 2 impact?	Comments on selection <i>Note 6</i>
Temperature (incl. heatwave) Mortality (Summer) (1)	3	2	3	Y (elderly, people with compromised health, etc.)	3	3	89	1	3	Yes	Score >30
Extreme Weather Event (flooding and storms) Mortality (30,34)	3	2	3	Y (elderly, people with mobility/cognitive constraints, etc.)	3	3	89	2	2	Yes	Score >30
Summer Air Pollution (ozone) (10)	3	2	3	Y (asthmatics, people with compromised health, etc.)	3	3	89	3	2	Yes	Score >30
Temperature (incl. heatwave) Morbidity (Summer) (11,13)	3	2	2	Y (elderly, people with compromised health, etc.)	3	3	78	4	3	Yes	Score >30
Extreme Weather Event (flooding and storms) Injuries (30,34)	2	2	2	Y (elderly, people with mobility/cognitive constraints, etc.)	3	3	67	5	2	Possible	Score >30. Link with Floods sector. Difficult to assess.
Pollen and allergens (7)	2	2	2	Y (asthmatics, people with compromised health, etc.)	3	3	67	6	2	Possible	Score >30. Difficult to assess.
Sunlight / UV Exposure (4,38,39,41)	2	1	3	N	3	3	67	7	2	Yes	Score >30
Mental Health (35)	2	1	3	Y (elderly, socially isolated people, etc.)	3	3	67	8	2	Yes	Score >30
Temperature Mortality (Winter) (2)	3	1	3	Y (elderly, people with compromised health, etc.)	3	2	52	9	3	Yes - opportunity	Score >30
Winter Air Pollution (18)	2	2	3	Y (elderly, people with compromised health, etc.)	3	2	52	10	2	Possible - opportunity	Score >30. Difficult to assess.
Temperature Morbidity (Winter) (17)	3	1	2	Y (elderly, people with compromised health, etc.)	3	2	44	11	3	Yes - opportunity	Score >30
Demand for Emergency Medicine (25)	2	1	2	N	3	2	37	12	1	Possible	Score >30. Difficult to assess.
Algal/Fungal Growth in Buildings (14)	2	1	2	Y (people living in flood risk areas)	2	3	37	13	1		Score >30. Not included. No robust evidence identified in the Built Environment sector.
Infrastructure Failure (16,27,37)	2	1	2	N	2	3	37	14	2		Score >30. Some of this is covered in the Floods sector
NHS Property Damage (33,37)	2	1	2	N	2	3	37	15	2	Possible	Score >30. Covered in the Floods sector
Vector-Borne Diseases (8,12,22)	2	1	2	N	2	3	37	16	2	Possible	Score >30
Water Quality and Water-Borne Diseases (6, 23, 24, 36)	2	2	3	N	2	2	35	17	2	Possible	Score >30
Social Disruption (26)	3	1	3	Y (elderly, homeless, impoverished, etc.)	2	2	35	18	1		Score >30. Highly uncertain and difficult to assess.
Food-Borne Diseases (5,9)	2	1	3	N	2	2	30	19	2	Possible	Score 30
Transport Network Failure (37)	2	1	2	N	2	2	25	20	2		Possible assessment in the Floods sector
Agricultural Contaminants (40)	1	2	2	N	2	2	25	21	2		
Medicine Efficacy (3)	2	1	2	Y (elderly, people with compromised health, etc.)	2	2	25	22	2	Possible	Included following expert review.
Traffic Accidents (21,31)	2	1	3	N	1	3	22	23	1		
NHS Staff Performance (28)	1	1	2	N	2	2	20	24	1		
Patient Recovery Rates (29)	1	1	2	Y (people with compromised health)	2	2	20	25	1		
Building Maintenance (15)	2	1	1	N	2	2	20	26	1		
Healthy Eating (19)	1	1	2	N	2	2	20	27	1		
Increased Outdoor Activities (20)	2	1	2	N	2	1	12	28	1		
Mobile Care and Support Services (32)	1	1	2	Y (elderly, people with compromised health, etc.)	1	1	5	29	1		

Note 1

Note 2

Note 3

Note 4

Note 5

Note 6

Note 7

Score

High

Medium

Low

Magnitude - Reference should be provided here regarding what general assumptions have been made, whether it has been based on any data/information, who has been consulted, etc.

Likelihood - Reference should be provided here regarding what general assumptions have been made, whether it has been based on any data/information, who has been consulted, etc.

Urgency - Reference should be provided here regarding what general assumptions have been made, whether it has been based on any data/information, who has been consulted, etc.

Threshold will be based on results from all sectors, with the top 100 consequences being selected.

Details of which 'rationalised' consequences (previously referred to as clusters) have been used should be provided here.

Individual comments on assumptions, etc. should go here

Y/N should be used as an indication of whether vulnerable groups have been identified (via the social vulnerability checklist) as being particularly affected and the selection of associated risk metrics should reflect this. (Check - If Y, this should have resulted in a High social score).

Magnitude, confidence and presentation of results

The table below defines the magnitude classes used in the assessment. These were used for scoring impacts in the Tier 2 selection process as well as for scoring risk levels for the scorecards presented for each metric in Chapter 4. For the scorecard, the risk/opportunity level relates to the most relevant of the economic/environmental/social criteria.

Guidance on classification of relative magnitude: qualitative descriptions of high, medium and low classes

Class	Economic	Environmental	Social
High	<ul style="list-style-type: none"> Major and recurrent damage to property and infrastructure Major consequence on regional and national economy Major cross-sector consequences Major disruption or loss of national or international transport links Major loss/gain of employment opportunities <p><i>~ £100 million for a single event or per year</i></p>	<ul style="list-style-type: none"> Major loss or decline in long-term quality of valued species/habitat/landscape Major or long-term decline in status/condition of sites of international/national significance Widespread Failure of ecosystem function or services Widespread decline in land/water/air quality Major cross-sector consequences <p><i>~ 5000 ha lost/gained</i> <i>~ 10000 km river water quality affected</i></p>	<ul style="list-style-type: none"> Potential for many fatalities or serious harm Loss or major disruption to utilities (water/gas/electricity) Major consequences on vulnerable groups Increase in national health burden Large reduction in community services Major damage or loss of cultural assets/high symbolic value Major role for emergency services Major impacts on personal security e.g. increased crime <p><i>~million affected</i> <i>~1000's harmed</i> <i>~100 fatalities</i></p>
Medium	<ul style="list-style-type: none"> Widespread damage to property and infrastructure Influence on regional economy Consequences on operations & service provision initiating contingency plans Minor disruption of national transport links Moderate cross-sector consequences Moderate loss/gain of employment opportunities <p><i>~ £10 million per event or year</i></p>	<ul style="list-style-type: none"> Important/medium-term consequences on species/habitat/landscape Medium-term or moderate loss of quality/status of sites of national importance Regional decline in land/water/air quality Medium-term or Regional loss/decline in ecosystem services Moderate cross-sector consequences <p><i>~ 500 ha lost/gained</i> <i>~ 1000 km river water quality affected</i></p>	<ul style="list-style-type: none"> Significant numbers affected Minor disruption to utilities (water/gas/electricity) Increased inequality, e.g. through rising costs of service provision Consequence on health burden Moderate reduction in community services Moderate increased role for emergency services Minor impacts on personal security <p><i>~tens of thousands affected, ~100s harmed, ~10 fatalities</i></p>
Low	<ul style="list-style-type: none"> Minor or very local consequences No consequence on national or regional economy Localised disruption of transport <p><i>~ £1 million per event or year</i></p>	<ul style="list-style-type: none"> Short-term/reversible effects on species/habitat/landscape or ecosystem services Localised decline in land/water/air quality Short-term loss/minor decline in quality/status of designated sites <p><i>~ 50 ha of valued habitats damaged/improved</i> <i>~ 100 km river quality affected</i></p>	<ul style="list-style-type: none"> Small numbers affected Small reduction in community services Within 'coping range' <p><i>~1000's affected</i></p>

The levels of confidence used by the CCRA can be broadly summarised as follows:

Low - Expert view based on limited information, e.g. anecdotal evidence.

Medium - Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector.

High - Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'.

The lower, central and upper estimates provided in the scorecards relate to the range of the estimated risk or opportunity level. For risk metrics that have been quantified with UKCP09 and response functions, this range relates to the results that are given for the low emissions, 10% probability level (lower); medium emissions, 50% probability level (central); and high emissions, 90% probability level (upper). For the risk metrics that have been estimated with a more qualitative approach, these estimates cover the range of potential outcomes given the evidence provided.

The CCRA analysis uses three discrete time periods to estimate future risks up to the year 2100: the 2020s (2010 to 2039), 2050s (2040 to 2069) and the 2080s (2070 to 2099). This is consistent with the UKCP09 projections.

Appendix 4 Systematic mapping

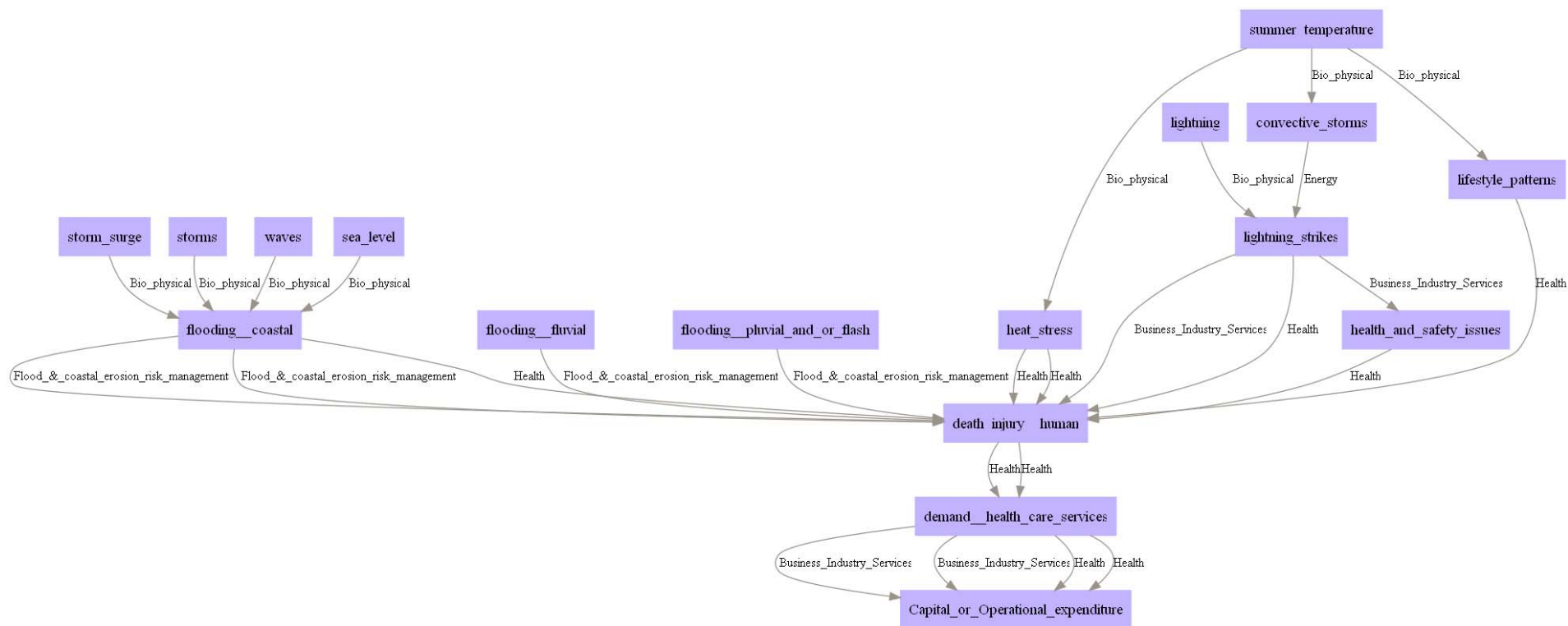
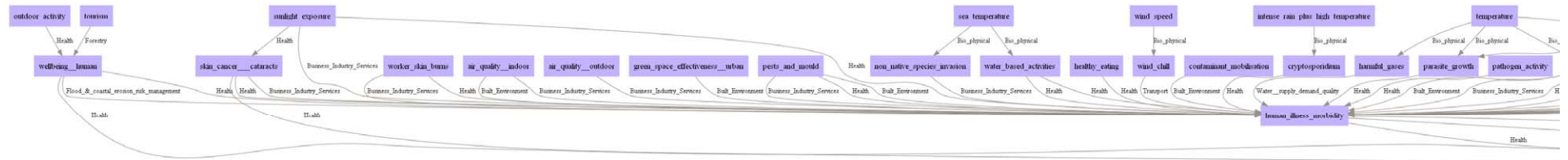


Figure A4.3 Systematic map for “Death/injury (human)”

Left Hand Side of Graph



Right Hand Side of Graph

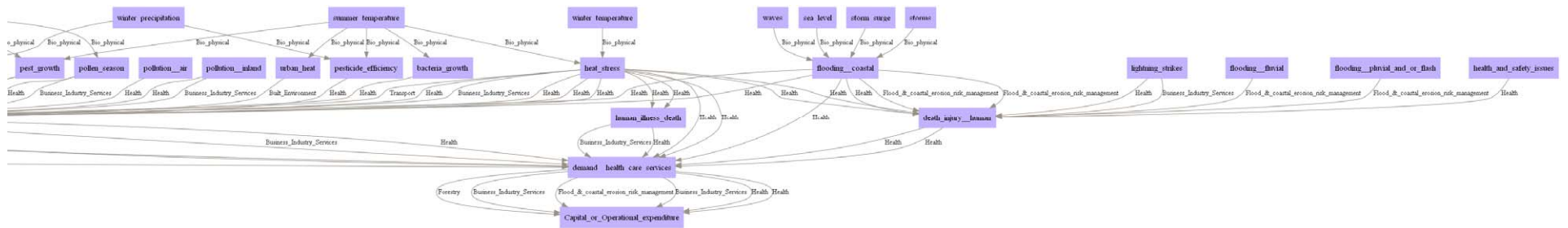


Figure A4.4 Systematic map for “Demand (Health Care Services)”

Appendix 5 Social Vulnerability Checklist

Certain groups of people or organisations are less able to withstand adverse impacts from one or a number of stressors to which they are exposed. A social vulnerability checklist was therefore drawn up based on the clustered health sector impacts to highlight any social equity issues related to the impacts and consequences within this sector. This identifies people or societies who are less able to withstand adverse affects from one or more stressors to which they are exposed, as well as their ability to prepare and recover from a stressful event.

The socially deprived are likely to be more prone to climate change related health issues. Those with pre-existing respiratory illnesses are more vulnerable during hot summer temperatures and high summer ozone episodes. The elderly are also more at risk during hot summer temperatures, although conversely their risk will reduce more as winter temperatures increase. Lack of awareness will also become an issue due to (for example) potential increased levels of UV exposure and associated preventative measures and changed levels of risk in flood prone areas, particularly near the coastline due to a lack of understanding of fast-moving coastal processes. Morbidity and mental health issues would also be anticipated to be greater in certain groups (the poor, those living alone etc) who may be less able to respond and subsequently recover from climatic driven events such as floods.

The full social vulnerability checklist for the health sector is included below. This considers the effects of social vulnerability in health under the three themes given in Section 2 under the four categories given below. These findings highlight the need to consider social capital and potential inequality within the metrics chosen.

Categories of Social Vulnerability Factors:

1. Place
 - a. Which locations are effected by these impacts? Are they evenly spread across regions or not?
2. Social Deprivation
 - a. How will people with poor health (physical or mental) be affected by these impacts?
 - b. How will people with fewer financial resources be affected?
 - c. How will people living or working in poor quality homes or workplaces be affected?
 - d. How will people who have limited access to public and private transport be affected?
3. Disempowerment
 - a. How will people with a lack of awareness of the risks be affected?
 - b. How will people without social networks be affected?
 - c. How will people with little access to systems and support services (e.g. health care) be affected?
4. Other
 - a. Are there any other social vulnerability issues relevant?

Health sector social vulnerability checklist

Sector	Health			
Cluster/Theme	Health Care Services Facilities and Infrastructure			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	Which locations are affected by these impacts? Is it spread evenly across regions or not?	Expected to be evenly spread across regions, however, reduced access to lower density areas (e.g. Scottish Isles) where services will be sparser. Increased risk for facilities near flood risk areas and differing variations between north and south, but otherwise evenly spread.	Balbus and Malina (2009). Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational and Environmental Medicine. 51, 33-37.	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	Increased risk for extreme weather events (e.g. flooding, storms and heatwaves) and reduction in medicine efficacy as those with poor health are more vulnerable and less able to react. Those with poor health will also be the most affected by any direct effects of climate change on health and social services, such as flooding of a hospital.	Head <i>et al.</i> , (2010). Overview of sources of information on health and social effects of flooding. Chemical Hazards and Poisons Report. Health Protection Agency, 2010, pp. 40-43.	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
	How will people with fewer financial resources be affected?	Expected to effect all roughly equally as Health Services are in the main utilised free across all social groups.		
	How will people living or working in poor quality homes or workplaces be affected?	Slight increased risk for those living in poor quality care homes, hospitals etc who by		

Sector	Health			
Cluster/Theme	Health Care Services Facilities and Infrastructure			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		definition are already vulnerable.		
	How will people who have limited access to public and private transport be affected?	Access to medical care will be delayed if access to car or public transport is limited.	Sector Report (Vardoulakis, 2010)	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
Disempowerment	How will people with lack of awareness of the risks be affected?	Limited effect.		
	How will people without social networks be affected?	Limited access to Health care services (e.g. NHS Direct).	Sector Report (Vardoulakis, 2010)	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
	How will people with little access to systems and support services (e.g. health care) be affected?	Same as above.	Sector Report (Vardoulakis, 2010)	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)

Sector	Health			
Cluster/Theme	Health Care Services Facilities and Infrastructure			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Other	Are any other social vulnerability issues relevant?	Emergency services more prone to disruption during severe weather events.	Sector Report (Vardoulakis, 2010)	

Sector	Health			
Cluster/Theme	Population Health and well being			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	Which locations are affected by these impacts? Is it spread evenly across regions or not?	Variations between the north and south particularly for high temperatures in urban areas (urban heat island effect, summer air pollution) and regions in flood prone areas where deprived groups are more likely to live.	Patz <i>et al.</i> , (2005). Impact of regional climate change on human health. <i>Nature</i> . 438, 310-317. Balbus and Malina, (2009). Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. <i>Journal of Occupational and Environmental Medicine</i> . 51, 33-37.	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	More vulnerable to effects of heatwaves (e.g. increased incidence of UV radiation exposure and sunburn) and extreme weather events (e.g. flooding, storms) and increases in air pollution (e.g. increase severity of symptoms for people with asthma, hay fever	Page <i>et al.</i> , (2007). Relationship between daily suicide counts and temperature in England and Wales. <i>British Journal of Psychiatry</i> . 191, 106-112. Hajat <i>et al.</i> , (2005).	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index

Sector	Health			
Cluster/Theme	Population Health and well being			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		etc). However, increased winter temperatures will mean that they are likely to be less vulnerable to cold in the winter. Those with poor health will be more susceptible to food poisoning and water born diseases that are likely to increase.	The human health consequences of flooding in Europe: a review. Extreme Weather Events and Public Health Responses. 185-196.	(www.communities.gov.uk)
	How will people with fewer financial resources be affected?	Less capacity for planned adaptation. However, less of a requirement to adapt to low extreme winter temperatures. Less able to recovery from flooding.	Sector Report (Vardoulakis, 2010)	
	How will people living or working in poor quality homes or workplaces be affected?	Same as two above.	Kovats and Hajat, (2008). Heat stress and public health: A critical review. Annual Review of Public Health. 29, 41-55. Morabito <i>et al.</i> , (2006). Relationship between work-related accidents and hot weather conditions in Tuscany (central Italy). Industrial Health. 44, 458-464. Sector Report (Vardoulakis, 2010)	
	How will people who have limited access to public and private transport be affected?	Limited effect.		

Sector	Health			
Cluster/Theme	Population Health and well being			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Disempowerment	How will people with lack of awareness of the risks be affected?	Lack of awareness will make them more prone to risks (e.g. sunlight exposure, hay fever, food poisoning etc).	Bentham and Langford, (2001). Environmental temperatures and the incidence of food poisoning in England and Wales. International Journal of Biometeorology. 45, 22-26. Lake <i>et al.</i> , (2009). A re-evaluation of the impact of temperature and climate change on foodborne illness. Epidemiology and Infection. 137, 1538-1547. Kovats (2004). Will climate change really affect our health? Results from a European assessment. J Br Menopause Soc. 10, 139-44.	
	How will people without social networks be affected?	A relatively low number of heat related deaths in the Latino population in 1995 Chicago heatwave was thought to be due to the tight social networks in that community. However, a recent paper by Wolf indicates evidence on the effect of social networks is not clear, and that they could in fact perpetuate	Sector Report (Vardoulakis, 2010) Klineberg, (2002). A social autopsy of disaster in Chicago. London: University of Chicago press Wolf <i>et al.</i> , (2010). Social capital,	

Sector	Health			
Cluster/Theme	Population Health and well being			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		rather than reduce the effects of heatwaves.	individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. Global Environmental Change. 20. pp 44-52.	
	How will people with little access to systems and support services (e.g. health care) be affected?	Level of risk is likely to be exacerbated as a consequence of delayed access.	Sector Report (Vardoulakis, 2010)	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
Other	Are any other social vulnerability issues relevant?	Frequent extreme weather events leads to a fear (psychological stress and anxiety) over future potential risks and associated injury, loss of life, property damage and displacement. Impoverished and homeless individuals are at greater risk due to potential greater exposure during heatwaves.	Hajat <i>et al.</i> , (2005). The human health consequences of flooding in Europe: a review. Extreme Weather Events and Public Health Responses. 185-196. Sector Report (Vardoulakis, 2010)	

Sector	Health			
Cluster/Theme	Environmental Health			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	Which locations are affected by these impacts? Is it spread evenly across regions or not?	Variations between the north and south particularly for high temperatures in urban areas (urban heat island effect, summer air pollution).	Balbus and Malina, (2009). Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational and Environmental Medicine. 51, 33-37.	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	More vulnerable to heatwaves and extreme weather events and air pollution. However, relatively less vulnerable to increased winter temperatures.	Page <i>et al.</i> , (2007). Relationship between daily suicide counts and temperature in England and Wales. British Journal of Psychiatry. 191, 106-112.	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
	How will people with fewer financial resources be affected?	None.		
	How will people living or working in poor quality homes or workplaces be affected?	More prone to mould growth and consequent effects, respiratory illnesses etc. People living in densely populated areas or areas next to major roads might already be more vulnerable to respiratory illnesses.	Kovats and Hajat (2008). Heat stress and public health: A critical review. Annual Review of Public Health. 29, 41-55. Morabito <i>et al.</i> , (2006). Relationship between work-related accidents and hot weather conditions in Tuscany (central Italy). Industrial	

Sector	Health			
Cluster/Theme	Environmental Health			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			Health. 44, 458-464. Sector Report (Vardoulakis, 2010)	
	How will people who have limited access to public and private transport be affected?	No effect.		
Disempowerment	How will people with lack of awareness of the risks be affected?	Lack of awareness is likely to make them more prone to risks (e.g. air pollution, water contamination, food poisoning etc).	Bentham and Langford, (2001). Environmental temperatures and the incidence of food poisoning in England and Wales. International Journal of Biometeorology. 45, 22-26. Lake <i>et al.</i> , (2009). A re-evaluation of the impact of temperature and climate change on foodborne illness. Epidemiology and Infection. 137, 1538-1547. Kovats, (2004). Will climate change really affect our health? Results from a European assessment. J Br Menopause Soc. 10, 139-44. Hunter (2003). Climate change and waterborne and vector-borne disease. Journal of Applied	Lack of awareness is likely to make them more prone to risks (e.g. sunlight exposure, hay fever, food poisoning etc).

Sector	Health			
Cluster/Theme	Environmental Health			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			Microbiology. 94, 37S-46S.	
	How will people without social networks be affected?	Same as above.	Sector Report (Vardoulakis, 2010)	Same as above.
	How will people with little access to systems and support services (e.g. health care) be affected?	Similar to above, but also lack of access to (e.g.) pollen alerts etc.	Sector Report (Vardoulakis, 2010)	Health Statistics (www.dh.gov.uk , www.statistics.gov.uk , www.airquality.co.uk) Population Statistics (census data) Deprivation Index (www.communities.gov.uk)
	Are any other social vulnerability issues relevant?	Higher levels of ozone/pollen in rural areas.	Hajat <i>et al.</i> , (2005). The human health consequences of flooding in Europe: a review. Extreme Weather Events and Public Health Responses. 185-196. Sector Report (Vardoulakis, 2010)	

See following page for notes on usage.

NOTES ON USING THE SOCIAL VULNERABILITY CHECKLIST

- 1.1 When defining/scoring the magnitude of consequences, the impact on vulnerable groups needs to be considered as part of the **assessment of magnitude of social consequences**. This checklist can be used as a means of capturing the answers to the key questions regarding social vulnerability.
- 1.2 The **cluster/theme** refers to the broad categories of impacts/consequences identified for the sector. For the water sector these were water availability; water quality and ecology; water company assets; and water use and recreation. It would be impractical to complete an assessment using the above table for every impact (or rationalised group of impacts). However, a Y/N check box is provided in the 'selection_of_tier_2_impacts_template' to indicate whether the assessment has identified vulnerable groups as being particularly affected by each impact/rationalised group of impacts. It is important to capture this, so that suitable risk metrics are identified.
- 1.3 In filling in the checklist, information can be drawn from the sector scoping reports, current research and expert opinion. 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.
- 1.4 The **extent column** is where information on how many people might be affected could be indicated. Initially, this will help with identifying suitable risk metrics. Later on, when the selection of Tier 2 impacts is being revisited as part of the DA/Regional assessments, these data might be available from the sector-based Tier 2 assessment based on baseline socio-economic data, the use of Government projections (for the near term) and scenarios (for the longer term).
- 1.5 The final row will capture any **other social vulnerabilities** not explicitly included in the checklist.
- 1.6 The information from this assessment is designed to feed into the selection of Tier 2 impacts, but it could also be updated during other stages of the project. Further thought needs to be put into this yet.

Appendix 6 Response functions

HE1 and HE2 – Temperature Mortality (Summer) and HE5 Temperature Mortality (Winter)

Table A6.1 Broad cause of death groupings

Cause	ICD9 code (pre 2001)	ICD10 code (2001 to date)
Cardiovascular disease	390.0 to 459.9	I
Respiratory disease	460.0 to 519.9	J
External causes	800.0 to 999.9	S, T, V, W, X, Y, Z
All other causes	All excluding above	All excluding above
ICD9 – International Classification of Diseases (9 th edition)		
ICD10 – International Classification of Diseases (10 th edition)		

Table A6.2 Heat thresholds and slopes coefficients for England and Wales

Region	Slope (1/°C)	Threshold (°C)
South West	0.023	18.1
South East	0.028	18.9
London	0.047	20.5
East	0.035	19.1
West Midlands	0.029	18.3
East Midlands	0.026	18.5
North West	0.020	17.9
North East	0.017	17.3
Yorkshire/Humberside	0.021	18.2
Wales	0.016	17.6
Scotland	0.017	15.6
Northern Ireland	0.020	16.7

Table A6.3 Cold thresholds and slopes coefficients for England and Wales

Region	Slope (/ $^{\circ}\text{C}$)			Threshold ($^{\circ}\text{C}$)		
	5%	60%	90%	5%	60%	90%
South West	0.049	0.022	0.021	4.0	12.3	16.8
South East	0.053	0.015	0.014	3.6	12.5	17.4
London	0.063	0.017	0.017	4.2	13.3	18.7
East	0.095	0.016	0.017	3.2	12.3	17.4
West Midlands	0.049	0.016	0.016	2.9	11.8	16.8
East Midlands	0.055	0.016	0.015	2.9	11.7	16.8
North West	0.056	0.013	0.013	3.4	11.9	16.4
North East	0.040	0.012	0.013	3.0	10.9	15.6
Yorkshire/Humberside	0.053	0.014	0.013	3.0	11.5	16.5
Wales	0.060	0.020	0.018	3.8	12.0	16.3
Scotland	0.040	0.012	0.013	1.8	9.6	14.1
Northern Ireland	0.056	0.013	0.013	3.6	11.0	15.2

Table A6.4 Unadjusted baseline mortality and morbidity rates

Region	Baseline mortality rate	Baseline morbidity rate
South West	984	1448
South East	880	1225
London	641	1248
East of England	889	1261
West Midlands	931	1402
East Midlands	916	1431
North West	986	1540
North East	1019	1628
Yorkshire/Humberside	937	1467
Wales	1029	1420
Scotland	1034	1432
Northern Ireland	806	1735
Notes:		
1	Rates are per 100,000 people	
2	Population levels are based on The Office for National Statistics estimated mid-years populations for the regions for the years 2006 to 2008. The General Register Office for Scotland has also been used to estimate a mid-year population for 2009 for Scotland.	
2	Numbers and causes of deaths are based on published data from the Office for National Statistics, The General Register Office for Scotland and Northern Ireland Statistics and Research Agency. The baseline rates are all cause excluding external causes as defined by ICD10.	
3	Mortality rates for the English regions and Wales exclude those whose usual residence is outside of England or Wales.	
4	Mortality rates for Scotland have been determined based on the assumption that the ratio of external causes of mortality to all causes of mortality determined from 2009 figures are the same for the years 2006-2008.	
5	Mortality rates for Northern Ireland have been proportioned for exclusion of external causes based on average values for England and Wales.	
6	Morbidity rates are defined as Emergency Respiratory Hospital Admissions, ICD10 J00 to J99.	
7	Hospital admissions only take account of those admitted who reside in a known Strategic Health Authority. These figures are therefore likely to be underestimated by approximately 3-5%.	
8	Hospital admission data for Wales obtained from http://www.infoandstats.wales.nhs.uk/	
9	Hospital admission data for Scotland has been equated to Hospital Discharges obtained from http://www.isdscotland.org/	
10	Hospital admission data for Northern Ireland obtained from http://www.dhsspsni.gov.uk/index/stats_research/stats-activity_stats-2/hospital_inpatients-3.htm	

Table A6.5a Mean changes in temperatures for low emission scenario

	2020s			2050s			2080s		
Admin Region	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				0.8	1.6	2.7	1.2	2.2	3.6
South East				0.8	1.7	2.8	1.2	2.3	3.7
London				0.8	1.7	2.8	1.2	2.3	3.6
East of England				0.8	1.6	2.7	1.2	2.2	3.5
West Midlands				0.7	1.6	2.7	1.1	2.2	3.5
East Midlands				0.7	1.6	2.6	1.1	2.2	3.4
North West				0.7	1.5	2.5	1.1	2.1	3.3
North East				0.7	1.5	2.5	1.1	2.1	3.4
Yorkshire and Humber				0.7	1.5	2.5	1.1	2.1	3.3
Wales				0.7	1.5	2.5	1.1	2.1	3.4
Scotland				0.5	1.3	2.2	0.8	1.8	2.9
Northern Ireland				0.6	1.3	2.1	0.9	1.8	2.9

Table A6.5b Mean changes in temperatures for medium emission scenario

	2020s			2050s			2080s		
Admin Region	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	0.3	0.9	1.6	1.0	2.0	3.1	1.7	2.9	4.6
South East	0.3	0.9	1.7	1.1	2.0	3.2	1.7	3.0	4.6
London	0.3	0.9	1.6	1.1	2.0	3.2	1.7	3.0	4.6
East of England	0.3	0.9	1.6	1.0	1.9	3.0	1.7	2.9	4.4
West Midlands	0.2	0.9	1.6	1.0	1.9	3.1	1.6	2.9	4.6
East Midlands	0.2	0.9	1.5	1.0	1.9	3.0	1.6	2.8	4.3
North West	0.2	0.8	1.5	0.9	1.8	2.8	1.4	2.7	4.1
North East	0.2	0.8	1.5	0.9	1.8	2.8	1.5	2.7	4.1
Yorkshire and Humber	0.2	0.8	1.5	0.9	1.8	2.9	1.6	2.7	4.2
Wales	0.2	0.8	1.5	0.9	1.8	3.0	1.6	2.8	4.4
Scotland	0.1	0.7	1.3	0.6	1.5	2.5	1.1	2.2	3.6
Northern Ireland	0.2	0.7	1.3	0.8	1.6	2.5	1.4	2.4	3.7

Table A6.5c Mean changes in temperatures for high emission scenario

	2020s			2050s			2080s		
Admin Region	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				1.2	2.2	3.5	2.3	3.8	5.8
South East				1.3	2.3	3.6	2.4	3.9	5.8
London				1.3	2.3	3.6	2.4	3.9	5.8
East of England				1.2	2.2	3.4	2.3	3.7	5.6
West Midlands				1.2	2.2	3.5	2.2	3.8	5.7
East Midlands				1.2	2.2	3.3	2.2	3.7	5.5
North West				1.1	2.0	3.2	2.0	3.4	5.2
North East				1.1	2.0	3.2	2.0	3.4	5.2
Yorkshire and Humber				1.2	2.1	3.2	2.1	3.6	5.3
Wales				1.1	2.1	3.3	2.1	3.6	5.5
Scotland				0.8	1.7	2.8	1.6	2.8	4.4
Northern Ireland				1.0	1.8	2.8	1.9	3.1	4.6

Table A6.6 Baseline and projected populations for regions

UKCP09 region	Projection	Population in thousands								
		Low population			Principal projection			High population		
	2008 baseline population	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
East Midlands	4,429	4,823	4,976	4,795	5,065	5,922	6,700	5,312	6,925	8,863
East of England	5,717	6,326	6,563	6,284	6,700	8,026	9,229	7,083	9,577	12,575
London	7,668	8,344	8,607	8,297	8,759	10,231	11,566	9,184	11,952	15,280
North East	2,571	2,685	2,729	2,677	2,755	3,003	3,228	2,826	3,293	3,854
North West	6,874	7,138	7,241	7,120	7,300	7,875	8,397	7,466	8,547	9,847
South East	8,369	9,090	9,370	9,039	9,532	11,101	12,525	9,985	12,936	16,483
South West	5,210	5,685	5,870	5,652	5,976	7,010	7,947	6,275	8,218	10,555
West Midlands	5,408	5,714	5,832	5,692	5,901	6,566	7,170	6,093	7,344	8,848
Yorkshire and The Humber	5,218	5,687	5,870	5,654	5,975	6,996	7,923	6,270	8,190	10,499
Wales	2,990	3,093	2,918	2,562	3,249	3,511	3,710	3,411	4,149	5,040
Eastern Scotland	2,368	2,381	1,844	1,122	2,612	2,692	2,650	2,851	3,588	4,441
Northern Scotland	287	289	225	139	316	325	320	344	432	533
Western Scotland	2,513	2,515	2,451	2,365	2,542	2,552	2,547	2,571	2,658	2,760
Northern Ireland	1,775	1,828	1,592	1,143	1,963	2,076	2,044	2,101	2,596	3,107

Table A6.7 Media reported fatalities due to nearshore wave action over the period March 2003 to November 2005 (courtesy William Allsop, Technical Director, HR Wallingford).

Location	Date	Weather conditions / comments	Fatalities	Source
Lulworth Cove, Dorset	03/11/2005	Heavy rain and strong winds combined to produce one of the worst storms in living memory. The accidents occurred around the time of predicted high tide which records indicate was around the MHWS level.	2	http://news.bbc.co.uk/1/hi/england/dorset/4413716.stm
Scarborough	13/03/2005	Swept out to sea by what was reported as a "freak wave". Incident occurred near predicted high water, which was above MHWS.	3	http://news.bbc.co.uk/1/hi/england/north_yorkshire/4346361.stm
Teesside	23/01/2005	Swept into sea by what was reported as "massive waves". Incident appears to have occurred around high water, for a predicted high tide that was around mean high water (MHW).	1	http://news.bbc.co.uk/1/hi/england/tees/4201095.stm
Benbecula	12/01/2005	Swept out to sea due to stormy weather probably around high tide. The predicted tide was around MHWS.	5	http://news.bbc.co.uk/1/hi/scotland/4166901.stm http://news.bbc.co.uk/1/hi/scotland/4172981.stm
Lossiemouth	25/10/2004	Conditions were described as "rough". The incident occurred around high water, for which the predicted tide was around MHWS.	1	http://news.bbc.co.uk/1/hi/scotland/3953879.stm
Cornwall Cliff Path	09/08/2004	Accident caused by a large wave who fell and was knocked unconscious on the rocks below. This incident was probably an accident, and not as a result of storm conditions.	1	http://news.bbc.co.uk/1/hi/england/cornwall/3576432.stm
Harrington Cumbria	18/03/2004	Accident caused by a large wave in heavy wave action. Incident occurred near high water during a spring tidal cycle, when the predicted high water was lower than MHWS.	1	http://news.bbc.co.uk/1/hi/england/cumbria/3549933.stm

Appendix 7 Application of climate change projections



Figure A7.1 UKCP09 administrative regions

Source: UKCP09

Table A7.1 Additional premature deaths (heat) for the low emissions scenario, current population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				56	165	371	98	273	614
South East				93	288	641	171	474	1,035
London				96	284	619	170	463	996
East of England				76	221	475	135	355	765
West Midlands				58	177	398	107	293	659
East Midlands				39	118	254	72	189	408
North West				58	155	351	95	251	570
North East				16	48	106	28	76	172
Yorkshire and Humber				35	109	235	64	175	379
Wales				20	63	146	37	107	245
Scotland				24	85	198	46	137	318
Northern Ireland				9	25	50	16	39	82
United Kingdom				579	1,738	3,842	1,040	2,834	6,242

Table A7.2 Additional premature deaths (heat) for the medium emissions scenario, current population projection

Administrative Region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	13	68	163	82	217	487	166	435	971
South East	22	113	271	139	375	803	295	745	1,583
London	23	117	265	141	365	775	288	719	1,519
East of England	17	91	207	111	282	595	224	552	1,166
West Midlands	13	72	176	89	233	519	182	465	1,044
East Midlands	8	48	111	59	151	315	121	293	621
North West	13	70	153	75	193	424	144	383	836
North East	4	20	47	22	59	129	45	116	252
Yorkshire and Humber	7	44	102	53	139	294	109	272	579
Wales	4	25	63	30	85	193	65	172	391
Scotland	3	35	87	31	101	234	70	199	456
Northern Ireland	2	12	25	13	32	64	27	62	125
United Kingdom	129	715	1,671	847	2,231	4,831	1,736	4,412	9,544

Table A7.3 Additional premature deaths (heat) for the high emissions scenario, current population projection

Administrative Region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				103	273	593	279	690	1,465
South East				188	472	989	488	1,167	2,400
London				187	458	951	472	1,129	2,302
East of England				147	353	726	364	862	1,764
West Midlands				111	293	634	299	736	1,574
East Midlands				78	188	389	194	457	941
North West				97	239	524	239	582	1,262
North East				29	73	160	74	177	382
Yorkshire and Humber				71	173	361	179	426	877
Wales				39	107	235	109	274	589
Scotland				44	124	285	112	294	663
Northern Ireland				17	38	77	44	95	188
United Kingdom				1,110	2,788	5,924	2,854	6,889	14,405

Table A7.4 Additional premature deaths avoided (cold) for the low emissions scenario, current population projection

Administrative Region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				529	1068	1641	777	1409	2060
				765	1571	2468	1132	2099	3164
South East				523	1061	1617	775	1391	2019
				776	1597	2478	1157	2115	3145
London				419	845	1287	613	1110	1607
				642	1313	2038	945	1743	2588
East of England				372	756	1157	551	995	1453
				630	1295	2013	938	1720	2561
West Midlands				376	772	1201	565	1028	1518
				592	1232	1951	895	1657	2508
East Midlands				288	596	916	432	786	1147
				425	890	1391	641	1185	1766
North West				380	783	1223	559	1031	1537
				575	1197	1894	849	1586	2410
North East				141	289	446	206	377	558
				223	466	734	329	615	937
Yorkshire and Humber				284	602	925	431	794	1160
				426	912	1426	649	1215	1814
Wales				271	567	879	407	753	1112
				368	778	1229	555	1044	1581
Scotland				207	498	800	331	659	1008
				329	801	1303	529	1066	1662
Northern Ireland				62	135	210	100	184	271
				91	202	318	148	277	417
United Kingdom				3854	7972	12302	5747	10516	15450
				5844	12254	19244	8766	16322	24552

Table A7.5 Additional premature deaths avoided (cold) for the medium emissions scenario, current population projection

Administrative Region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	176	607	1063	691	1249	1862	1075	1767	2469
	253	879	1563	1004	1849	2830	1582	2673	3897
South East	184	596	1024	682	1228	1800	1076	1738	2408
	271	886	1539	1015	1858	2777	1619	2676	3826
London	149	479	809	543	976	1433	851	1384	1918
	226	735	1256	835	1524	2286	1323	2202	3154
East of England	125	422	725	484	873	1293	763	1247	1740
	210	716	1242	823	1503	2261	1308	2177	3118
West Midlands	123	435	771	498	906	1363	784	1294	1835
	193	686	1231	787	1454	2234	1252	2113	3099
East Midlands	93	331	575	379	691	1019	605	983	1371
	136	489	858	560	1036	1556	905	1498	2146
North West	124	443	777	466	893	1342	749	1277	1808
	187	671	1187	706	1369	2087	1144	1981	2871
North East	46	164	286	174	327	489	276	466	651
	73	260	460	277	530	811	445	770	1118
Yorkshire and Humber	90	332	580	380	698	1031	604	994	1386
	134	498	879	571	1063	1600	915	1538	2207
Wales	85	316	563	360	665	1001	574	950	1343
	114	429	774	490	918	1411	789	1334	1950
Scotland	42	274	506	254	552	871	441	802	1184
	66	437	813	405	889	1424	707	1307	1975
Northern Ireland	18	76	137	85	161	240	143	236	329
	26	113	204	126	242	365	214	359	513
United Kingdom	1256	4476	7816	4996	9219	13744	7942	13138	18441
	1889	6800	12005	7600	14234	21643	12202	20629	29873

Table A7.6 Additional premature deaths avoided (cold) for the high emissions scenario, current population projection

Administrative Region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				802	1409	2031	1424	2163	2825
				1169	2099	3114	2123	3342	4615
South East				822	1387	1979	1412	2126	2797
				1228	2108	3076	2148	3328	4565
London				651	1103	1574	1121	1697	2232
				1004	1733	2532	1763	2749	3776
East of England				584	991	1419	1008	1532	2034
				995	1712	2497	1744	2712	3725
West Midlands				577	1026	1492	1038	1593	2120
				915	1655	2462	1675	2644	3678
East Midlands				455	783	1123	796	1207	1599
				676	1180	1726	1201	1865	2562
North West				569	1005	1481	1006	1551	2105
				864	1545	2316	1546	2433	3408
North East				211	368	540	370	564	753
				337	599	904	602	948	1334
Yorkshire and Humber				459	788	1134	803	1221	1610
				691	1205	1771	1230	1918	2628
Wales				422	751	1093	761	1167	1544
				576	1042	1550	1056	1666	2303
Scotland				320	621	957	587	973	1375
				511	1004	1573	947	1600	2331
Northern Ireland				102	179	263	196	291	386
				152	270	403	295	450	616
United Kingdom				5973	10411	15086	10523	16084	21381
				9117	16151	23925	16329	25655	35542

Table A7.7 Baseline estimates of the health impacts of mapped ozone

Region	Premature deaths			Respiratory hospital admissions		
	1995	2003	2005	1995	2003	2005
South West	938	990	946	3195	3374	3223
South East	1341	1404	1309	4319	4524	4219
London	686	772	705	3095	3481	3180
East of England	891	933	908	2926	3064	2981
West Midlands	828	913	866	2884	3181	3017
East Midlands	667	734	666	2413	2655	2409
North West	1097	1200	1104	3965	4339	3990
North East	440	456	456	1627	1687	1686
Yorkshire and Humberside	790	831	795	2861	3011	2882
Wales	583	597	596	1863	1907	1903
Scotland	882	1039	926	2826	3330	2966
Northern Ireland	226	237	225	1128	1180	1119
United Kingdom	9368	10107	9501	33098	35727	33571

Table A7.8 Effect of future levels of ozone for the 2080s on premature deaths and additional (or brought forward) respiratory hospital admissions based on scenarios outlined in Section 7.5.4. These scenarios are based on a repeat of emissions for 1995, 2003 and 2005.

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	1	82	87	83	282	297	284
	2	233	247	236	796	840	804
	3	383	405	387	1307	1380	1320
South East	1	119	125	117	386	404	377
	2	341	358	335	1102	1154	1077
	3	566	593	554	1823	1910	1784
London	1	63	71	65	282	317	290
	2	183	205	187	820	923	843
	3	306	343	314	1376	1548	1414
East of England	1	79	83	81	259	271	264
	2	224	234	228	733	768	748
	3	368	386	375	1206	1265	1230
West Midlands	1	74	82	78	259	286	271
	2	213	235	223	743	820	778
	3	354	391	371	1233	1362	1292
East Midlands	1	59	65	59	214	236	215
	2	168	185	168	608	670	609
	3	277	305	277	1002	1105	1003
North West	1	99	108	99	358	391	360
	2	284	312	286	1029	1127	1037
	3	474	520	477	1714	1878	1727
North East	1	40	41	41	146	151	151
	2	113	117	117	417	432	432
	3	187	194	194	692	717	717
Yorkshire and Humberside	1	70	75	72	256	270	258
	2	202	214	205	733	773	739
	3	335	354	339	1216	1282	1226
Wales	1	52	53	52	164	168	167
	2	145	149	148	463	474	473
	3	238	244	243	760	778	777
Scotland	1	78	92	82	250	294	263
	2	221	261	232	708	835	745
	3	364	429	382	1165	1374	1226
Northern Ireland	1	21	21	20	102	106	101
	2	59	61	58	292	305	290
	3	98	102	96	486	507	482
United Kingdom	1	837	902	849	2958	3196	3002
	2	2386	2575	2422	8446	9122	8575
	3	3948	4263	4010	13978	15107	14196

Region	Scenario	Premature Deaths			Respiratory Hospital Admissions		
		1995	2003	2005	1995	2003	2005
South West	4	67	71	68	229	241	230
	5	177	188	179	605	638	609
	6	277	293	279	944	996	951
South East	4	92	97	91	299	313	291
	5	244	256	239	789	826	769
	6	381	399	372	1229	1286	1197
London	4	45	50	46	201	226	207
	5	118	132	121	529	596	544
	6	183	205	188	822	925	845
East of England	4	63	67	65	207	217	212
	5	167	175	171	549	574	560
	6	261	273	266	856	896	873
West Midlands	4	56	62	59	197	216	206
	5	149	164	155	520	571	542
	6	232	255	242	809	889	843
East Midlands	4	47	51	47	170	187	170
	5	124	136	124	450	494	448
	6	194	212	193	701	770	698
North West	4	74	81	74	267	292	268
	5	194	213	195	704	769	706
	6	303	331	304	1095	1196	1099
North East	4	30	32	31	112	116	115
	5	80	83	82	296	305	305
	6	124	129	128	460	476	475
Yorkshire and Humberside	4	54	57	55	196	207	197
	5	143	151	144	518	545	521
	6	222	234	224	807	848	811
Wales	4	42	43	42	134	137	136
	5	111	114	113	354	363	361
	6	173	177	176	553	566	563
Scotland	4	63	74	66	201	236	211
	5	166	195	173	531	624	556
	6	259	304	270	828	973	867
Northern Ireland	4	16	16	15	77	79	76
	5	41	42	40	202	210	200
	6	63	65	62	313	327	311
United Kingdom	4	650	699	658	2291	2470	2320
	5	1715	1846	1735	6047	6519	6121
	6	2671	2876	2704	9419	10147	9535

Appendix 8 Socio-economic influence

Table A8.1 Additional premature deaths for the low emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				63	185	418	107	296	666
South East				104	323	717	184	512	1118
London				108	319	695	184	501	1077
East of England				87	254	545	149	391	841
West Midlands				63	191	429	113	309	693
East Midlands				44	133	285	78	205	441
North West				61	163	369	98	260	590
North East				17	51	113	30	80	180
Yorkshire and Humber				39	122	264	70	190	411
Wales				19	62	143	31	92	210
Scotland				21	75	173	32	96	223
Northern Ireland				8	22	45	11	25	53
United Kingdom				633	1899	4196	1086	2956	6503

Table A8.2 Additional premature deaths (heat) for the low emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				75	222	500	107	296	666
South East				117	362	803	256	710	1549
London				121	358	780	257	698	1502
East of England				100	291	626	218	574	1235
West Midlands				68	206	463	142	389	873
East Midlands				50	149	320	109	286	617
North West				64	172	389	116	306	696
North East				18	54	120	36	96	216
Yorkshire and Humber				44	137	297	98	266	576
Wales				19	60	139	46	133	304
Scotland				18	65	151	49	146	339
Northern Ireland				7	20	40	19	45	95
United Kingdom				700	2095	4627	1451	3946	8667

Table A8.3 Additional premature deaths (heat) for the low emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				88	260	586	199	554	1243
South East				144	446	990	336	934	2039
London				150	443	965	339	922	1984
East of England				127	370	795	297	782	1682
West Midlands				79	240	540	176	480	1077
East Midlands				62	185	397	144	379	816
North West				72	192	436	136	359	817
North East				21	62	136	43	115	258
Yorkshire and Humber				54	170	368	130	353	763
Wales				28	88	203	62	180	412
Scotland				30	110	255	68	205	475
Northern Ireland				13	36	73	29	69	144
United Kingdom				866	2602	5744	1959	5332	11711

Table A8.4 Additional premature deaths (heat) for the medium emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	P ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	14	74	178	93	245	549	181	471	1053
South East	24	123	294	156	420	899	319	805	1710
London	25	127	288	159	410	869	311	778	1644
East of England	19	101	229	128	323	683	247	607	1282
West Midlands	13	76	186	95	251	560	191	489	1099
East Midlands	9	53	121	66	169	354	131	317	672
North West	13	73	159	79	203	447	149	396	866
North East	4	21	49	23	63	137	47	121	262
Yorkshire and Humber	8	47	112	60	157	330	118	294	628
Wales	4	26	65	30	83	188	55	148	335
Scotland	3	35	87	27	88	205	49	139	320
Northern Ireland	2	12	26	12	29	57	17	40	81
United Kingdom	139	768	1795	929	2440	5278	1816	4606	9952

Table A8.5 Additional premature deaths (heat) for the medium emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	P ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	14	78	187	111	292	655	254	663	1481
South East	25	129	309	185	498	1065	442	1115	2369
London	26	134	302	189	487	1033	434	1085	2291
East of England	20	107	242	156	395	835	362	891	1882
West Midlands	14	79	193	107	283	630	241	616	1385
East Midlands	10	55	127	79	201	422	183	443	939
North West	14	75	162	86	221	486	176	467	1022
North East	4	22	51	26	69	150	56	146	316
Yorkshire and Humber	8	50	117	71	187	394	166	412	880
Wales	5	27	68	36	99	226	80	214	485
Scotland	3	37	92	34	109	252	75	212	487
Northern Ireland	2	13	28	15	37	75	31	71	144
United Kingdom	145	804	1878	1095	2878	6224	2500	6336	13682

Table A8.6 Additional premature deaths (heat) for the medium emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	P ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	15	82	197	130	343	768	337	880	1967
South East	26	135	323	216	580	1241	582	1467	3118
London	27	140	317	220	569	1207	574	1433	3027
East of England	21	113	256	187	472	996	493	1215	2565
West Midlands	14	81	199	120	316	705	297	760	1709
East Midlands	10	58	134	92	235	493	242	586	1243
North West	14	76	166	93	240	528	207	548	1198
North East	4	22	52	28	76	165	67	174	378
Yorkshire and Humber	9	52	123	84	219	461	220	547	1166
Wales	5	28	71	42	117	268	109	290	659
Scotland	4	39	97	40	130	302	105	297	682
Northern Ireland	2	14	30	19	47	94	47	109	219
United Kingdom	152	841	1965	1272	3343	7227	3279	8306	17930

Table A8.7 Additional premature deaths (heat) for the high emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	P ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				116	308	669	303	748	1589
South East				210	528	1107	527	1260	2592
London				209	514	1068	511	1222	2490
East of England				169	405	834	400	947	1939
West Midlands				120	316	683	315	775	1656
East Midlands				87	211	437	210	495	1019
North West				102	252	552	248	602	1307
North East				31	77	170	77	184	398
Yorkshire and Humber				80	194	406	194	462	950
Wales				38	104	229	94	235	504
Scotland				38	108	249	78	207	465
Northern Ireland				15	34	69	28	61	121
United Kingdom				1217	3051	6473	2985	7198	15031

Table A8.8 Additional premature deaths (heat) for the high emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	P ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				139	368	798	303	748	1589
South East				235	591	1240	731	1746	3592
London				235	577	1199	712	1703	3472
East of England				194	465	957	588	1391	2847
West Midlands				129	340	737	397	976	2086
East Midlands				98	237	491	293	692	1424
North West				108	265	582	292	710	1541
North East				33	82	180	93	222	480
Yorkshire and Humber				90	219	456	272	647	1332
Wales				37	101	224	136	340	730
Scotland				33	94	218	119	314	707
Northern Ireland				14	30	62	50	110	216
United Kingdom				1345	3370	7144	3985	9600	20017

Table A8.9 Additional premature deaths (heat) for the high emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				163	431	936	565	1397	2968
South East				290	729	1529	962	2298	4727
London				291	713	1483	941	2250	4587
East of England				247	591	1216	801	1896	3880
West Midlands				151	397	860	489	1204	2575
East Midlands				121	294	608	388	915	1883
North West				121	297	652	343	833	1807
North East				38	93	205	110	265	573
Yorkshire and Humber				111	271	566	360	858	1765
Wales				54	148	326	184	462	992
Scotland				56	160	368	167	440	992
Northern Ireland				25	55	113	77	167	329
United Kingdom				1668	4180	8862	5388	12986	27076

Table A8.10 Additional premature deaths avoided (cold) for the low emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				596	1203	1849	843	1529	2235
				862	1770	2780	1228	2277	3432
South East				586	1188	1811	837	1503	2181
				869	1787	2774	1250	2284	3396
London				471	948	1444	663	1201	1738
				720	1473	2288	1022	1887	2801
East of England				427	868	1329	606	1094	1597
				724	1487	2311	1031	1890	2815
West Midlands				406	832	1295	594	1082	1597
				639	1329	2104	942	1744	2640
East Midlands				324	670	1030	468	851	1242
				478	1000	1562	694	1283	1912
North West				401	825	1289	579	1068	1592
				606	1260	1996	879	1643	2496
North East				149	307	473	214	392	581
				237	494	780	342	640	976
Yorkshire and Humber				320	677	1041	467	860	1257
				479	1026	1604	703	1317	1966
Wales				265	553	858	349	645	953
				359	759	1199	476	895	1354
Scotland				181	436	700	232	462	707
				288	701	1140	371	748	1166
Northern Ireland				55	121	188	64	118	175
				82	181	285	95	178	268
United Kingdom				4181	8628	13305	5917	10805	15855
				6342	13270	20823	9033	16786	25222

Table A8.11 Additional premature deaths avoided (cold) for the low emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				712	1437	2208	1185	2149	3142
				1030	2114	3320	1726	3202	4826
South East				694	1407	2145	1160	2082	3022
				1029	2118	3287	1732	3165	4706
London				559	1127	1717	925	1674	2423
				856	1751	2719	1425	2630	3904
East of England				523	1061	1625	890	1606	2345
				885	1818	2826	1515	2776	4134
West Midlands				457	937	1458	749	1362	2012
				719	1496	2369	1187	2197	3325
East Midlands				385	797	1225	653	1189	1736
				568	1190	1859	969	1792	2671
North West				436	897	1401	683	1259	1878
				659	1371	2170	1037	1937	2944
North East				164	337	521	258	473	700
				261	544	858	413	772	1177
Yorkshire and Humber				381	807	1240	655	1206	1761
				571	1223	1911	986	1845	2755
Wales				319	665	1032	506	934	1380
				432	914	1443	689	1295	1961
Scotland				223	537	862	353	703	1076
				355	863	1405	564	1138	1774
Northern Ireland				72	158	245	115	212	312
				107	236	372	170	319	480
United Kingdom				4925	10169	15680	8131	14850	21788
				7472	15639	24540	12412	23069	34658

Table A8.12 Additional premature deaths avoided (cold) for the low emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				835	1685	2588	1573	2855	4174
				1207	2478	3893	2293	4252	6410
South East				808	1640	2500	1526	2740	3977
				1199	2468	3830	2279	4165	6193
London				653	1317	2006	1222	2212	3201
				1000	2046	3177	1882	3474	5158
East of England				623	1266	1939	1212	2189	3195
				1056	2170	3372	2064	3783	5633
West Midlands				511	1048	1630	924	1681	2483
				804	1673	2650	1465	2712	4104
East Midlands				451	932	1433	864	1573	2296
				665	1392	2174	1282	2371	3534
North West				473	974	1521	800	1477	2202
				715	1488	2356	1216	2272	3452
North East				180	370	571	308	565	836
				286	597	941	493	921	1405
Yorkshire and Humber				446	944	1452	868	1598	2334
				668	1432	2238	1306	2445	3651
Wales				377	786	1220	687	1269	1875
				511	1080	1705	936	1760	2664
Scotland				268	644	1034	495	986	1508
				426	1035	1684	791	1596	2486
Northern Ireland				90	198	307	175	322	475
				133	296	465	259	484	730
United Kingdom				5716	11804	18200	10656	19465	28556
				8671	18154	28484	16265	30236	45419

Table A8.13 Additional premature deaths avoided (cold) for the medium emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	193	662	1160	778	1407	2098	1166	1917	2679
	276	960	1706	1131	2083	3188	1716	2900	4227
South East	200	648	1112	763	1375	2015	1162	1877	2601
	295	962	1671	1137	2080	3109	1749	2890	4132
London	162	522	881	610	1095	1608	921	1497	2075
	245	800	1367	937	1711	2566	1431	2383	3413
East of England	138	467	803	556	1003	1484	839	1371	1913
	233	792	1374	944	1725	2596	1437	2393	3428
West Midlands	130	459	815	537	977	1470	825	1362	1931
	204	725	1301	849	1567	2409	1318	2224	3261
East Midlands	101	361	626	425	776	1145	656	1064	1485
	149	533	934	630	1164	1748	980	1621	2324
North West	129	460	807	491	941	1414	776	1323	1872
	194	697	1233	744	1442	2199	1185	2052	2974
North East	48	171	298	185	347	519	288	485	678
	76	272	481	294	562	861	463	801	1164
Yorkshire and Humber	99	362	632	428	785	1160	654	1077	1501
	147	543	958	643	1196	1799	992	1666	2391
Wales	88	327	583	352	649	977	492	814	1151
	118	444	800	478	896	1377	676	1143	1671
Scotland	42	275	507	222	483	762	309	563	831
	67	438	816	354	778	1246	496	917	1385
Northern Ireland	18	79	141	76	145	215	92	152	212
	27	117	210	113	217	328	138	231	330
United Kingdom	1348	4792	8364	5423	9983	14867	8180	13502	18928
	2028	7282	12850	8254	15421	23426	12581	21223	30700

Table A8.14 Additional premature deaths avoided (cold) for the medium emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	202	696	1219	930	1680	2505	1640	2696	3766
	290	1009	1793	1351	2487	3807	2413	4078	5944
South East	210	679	1166	904	1629	2387	1610	2601	3604
	309	1009	1752	1347	2464	3684	2424	4004	5725
London	170	548	925	725	1302	1912	1284	2087	2892
	258	840	1435	1114	2033	3051	1995	3322	4758
East of England	146	495	850	680	1226	1815	1231	2013	2809
	246	839	1455	1155	2110	3175	2111	3515	5034
West Midlands	134	474	841	604	1100	1655	1039	1716	2433
	210	748	1343	956	1765	2712	1660	2802	4108
East Midlands	106	379	657	506	924	1363	916	1487	2074
	156	560	981	749	1385	2080	1369	2265	3247
North West	132	470	825	534	1023	1537	915	1560	2208
	198	712	1261	809	1568	2391	1397	2420	3507
North East	49	175	306	203	382	571	347	585	818
	78	279	493	324	619	948	559	966	1403
Yorkshire and Humber	104	381	665	510	936	1383	917	1509	2104
	154	571	1006	766	1425	2145	1390	2335	3350
Wales	92	343	612	423	781	1175	713	1179	1666
	124	466	841	576	1079	1656	979	1656	2420
Scotland	44	290	535	274	595	938	470	856	1264
	70	462	860	436	958	1535	754	1395	2108
Northern Ireland	20	85	151	99	189	280	165	272	378
	29	125	226	147	283	427	247	414	591
United Kingdom	1411	5015	8753	6392	11767	17523	11247	18561	26017
	2122	7620	13447	9729	18177	27611	17297	29172	42196

Table A8.15 Additional premature deaths avoided (cold) for the medium emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West	213	730	1280	1090	1970	2937	2178	3580	5002
	305	1059	1883	1584	2916	4463	3205	5416	7894
South East	220	711	1221	1054	1899	2782	2119	3423	4743
	324	1057	1836	1569	2872	4293	3190	5270	7535
London	178	574	969	847	1521	2233	1696	2757	3821
	270	881	1504	1301	2375	3564	2635	4388	6286
East of England	155	523	899	811	1463	2165	1678	2743	3828
	261	887	1539	1378	2518	3788	2876	4790	6859
West Midlands	139	490	869	676	1230	1851	1283	2117	3002
	217	773	1387	1069	1974	3033	2049	3457	5069
East Midlands	112	397	689	592	1080	1594	1212	1967	2744
	164	587	1029	876	1620	2433	1811	2997	4295
North West	135	481	844	580	1110	1669	1073	1829	2589
	203	729	1289	878	1702	2595	1638	2838	4113
North East	51	180	314	223	419	626	414	698	976
	80	286	506	355	678	1039	667	1154	1675
Yorkshire and Humber	109	399	697	597	1096	1619	1215	2000	2788
	162	599	1056	897	1669	2511	1842	3095	4440
Wales	97	360	643	500	923	1389	968	1602	2264
	130	489	882	680	1274	1957	1330	2249	3287
Scotland	47	306	564	328	713	1125	659	1200	1772
	74	487	907	523	1149	1841	1057	1956	2955
Northern Ireland	21	91	162	124	236	351	251	413	575
	31	134	242	184	354	534	375	629	898
United Kingdom	1475	5243	9151	7421	13660	20341	14746	24331	34104
	2219	7968	14059	11294	21101	32052	22675	38238	55307

Table A8.16 Additional premature deaths avoided (cold) for the high emissions scenario, low population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				903	1588	2288	1545	2346	3065
				1317	2365	3508	2303	3625	5007
South East				920	1553	2215	1525	2296	3021
				1375	2360	3444	2320	3594	4931
London				730	1239	1767	1213	1836	2415
				1127	1945	2842	1907	2975	4086
East of England				670	1137	1629	1108	1684	2235
				1142	1966	2867	1917	2981	4094
West Midlands				623	1106	1609	1093	1676	2232
				987	1784	2655	1763	2783	3871
East Midlands				511	880	1262	862	1307	1732
				759	1325	1939	1300	2019	2774
North West				599	1058	1560	1042	1607	2180
				910	1627	2439	1602	2520	3530
North East				224	390	573	385	587	784
				358	635	960	627	987	1389
Yorkshire and Humber				516	886	1276	870	1323	1745
				777	1356	1992	1333	2079	2848
Wales				412	733	1066	652	1000	1323
				562	1017	1513	905	1428	1974
Scotland				280	543	837	412	682	965
				447	878	1376	664	1123	1636
Northern Ireland				92	161	236	126	187	248
				136	242	362	190	289	396
United Kingdom				6480	11275	16319	10833	16532	21946
				9897	17501	25897	16830	26403	36536

Table A8.17 Additional premature deaths avoided (cold) for the high emissions scenario, principal population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				1079	1896	2733	2172	3299	4309
				1573	2824	4190	3238	5097	7040
South East				1090	1840	2625	2113	3182	4187
				1629	2797	4081	3215	4980	6833
London				868	1472	2101	1691	2560	3367
				1339	2312	3378	2659	4147	5696
East of England				819	1391	1992	1628	2473	3283
				1396	2404	3506	2815	4378	6013
West Midlands				701	1246	1812	1376	2111	2811
				1111	2009	2990	2221	3505	4876
East Midlands				608	1047	1502	1205	1826	2420
				903	1577	2307	1816	2821	3876
North West				652	1151	1696	1228	1895	2571
				990	1770	2653	1889	2972	4163
North East				246	429	631	464	708	946
				394	699	1056	756	1190	1675
Yorkshire and Humber				615	1056	1521	1220	1854	2445
				927	1616	2374	1867	2913	3990
Wales				496	882	1283	945	1448	1916
				677	1223	1820	1311	2067	2858
Scotland				345	670	1031	627	1038	1468
				551	1082	1695	1011	1708	2489
Northern Ireland				119	210	308	225	335	444
				177	316	472	340	518	709
United Kingdom				7638	13289	19233	14894	22729	30166
				11667	20629	30522	23137	36298	50218

Table A8.18 Additional premature deaths avoided (cold) for the high emissions scenario, high population projection

Administrative region	2020s			2050s			2080s		
	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀	p ₁₀	p ₅₀	p ₉₀
South West				1264	2223	3203	2885	4382	5723
				1844	3311	4912	4300	6770	9350
South East				1270	2144	3059	2781	4187	5510
				1898	3259	4755	4230	6554	8992
London				1014	1720	2454	2235	3382	4448
				1565	2701	3946	3512	5479	7524
East of England				978	1660	2377	2218	3370	4473
				1666	2868	4183	3835	5965	8193
West Midlands				784	1393	2026	1698	2605	3469
				1243	2247	3344	2741	4326	6017
East Midlands				712	1224	1756	1594	2415	3201
				1056	1844	2698	2403	3732	5128
North West				707	1249	1841	1441	2222	3015
				1074	1921	2879	2215	3485	4882
North East				270	471	692	554	845	1129
				432	767	1158	903	1421	1999
Yorkshire and Humber				720	1237	1780	1616	2457	3240
				1085	1892	2779	2474	3860	5288
Wales				586	1042	1516	1283	1967	2603
				800	1446	2151	1781	2808	3883
Scotland				414	803	1237	878	1456	2058
				660	1297	2033	1417	2395	3489
Northern Ireland				149	262	385	342	510	675
				222	395	590	517	787	1078
United Kingdom				8868	15428	22326	19525	29797	39544
				13545	23947	35429	30328	47582	65823

Table A8.19 Effect of future levels of ozone for the 2080s on premature deaths and additional (or brought forward) respiratory hospital admissions based on scenarios outlined in Section 7.5.4 for the low population projection. These scenarios are based on a repeat of emissions for 1995, 2003 and 2005.

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	1	89	94	90	306	322	308
	2	253	268	256	864	911	872
	3	415	439	420	1418	1497	1432
South East	1	129	135	126	417	436	407
	2	368	387	362	1190	1246	1163
	3	611	640	598	1969	2063	1927
London	1	68	77	70	305	343	314
	2	198	222	202	887	999	912
	3	331	371	340	1489	1675	1530
East of England	1	87	91	89	285	298	290
	2	246	257	251	806	844	822
	3	404	424	412	1326	1390	1352
West Midlands	1	78	86	82	273	301	285
	2	224	247	235	782	863	819
	3	373	412	390	1298	1434	1360
East Midlands	1	64	70	64	232	256	233
	2	182	200	182	658	725	659
	3	300	330	300	1085	1196	1086
North West	1	103	112	103	371	405	373
	2	294	323	296	1066	1167	1074
	3	491	539	494	1775	1945	1789
North East	1	42	43	43	152	157	157
	2	118	122	122	434	450	450
	3	195	202	202	721	747	747
Yorkshire and Humberside	1	76	81	78	277	293	280
	2	219	232	222	794	838	801
	3	363	384	367	1318	1389	1328
Wales	1	45	45	45	141	144	143
	2	124	128	127	397	406	405
	3	204	209	208	651	667	666
Scotland	1	55	65	58	175	206	185
	2	155	183	163	497	586	523
	3	255	301	268	817	964	860
Northern Ireland	1	14	14	13	66	68	65
	2	38	39	37	188	196	187
	3	63	66	62	313	326	310
United Kingdom	1	853	919	865	3013	3256	3058
	2	2430	2623	2467	8603	9292	8735
	3	4022	4342	4085	14238	15388	14461

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	4	73	77	74	248	261	250
	5	192	204	194	656	692	661
	6	300	318	303	1024	1080	1032
South East	4	99	105	98	323	338	314
	5	264	276	258	852	892	831
	6	412	431	402	1327	1389	1293
London	4	49	54	50	217	245	224
	5	128	143	131	572	645	589
	6	198	222	203	889	1001	914
East of England	4	69	74	71	228	239	233
	5	184	192	188	603	631	616
	6	287	300	292	941	985	960
West Midlands	4	59	65	62	207	227	217
	5	157	173	163	547	601	570
	6	244	268	255	851	936	887
East Midlands	4	51	55	51	184	202	184
	5	134	147	134	487	535	485
	6	210	230	209	759	834	756
North West	4	77	84	77	277	302	278
	5	201	221	202	729	797	731
	6	314	343	315	1134	1239	1138
North East	4	31	33	32	117	121	120
	5	83	86	85	308	318	318
	6	129	134	133	479	496	495
Yorkshire and Humberside	4	59	62	60	212	224	213
	5	155	164	156	561	591	565
	6	241	254	243	874	919	879
Wales	4	36	37	36	115	117	117
	5	95	98	97	303	311	309
	6	148	152	151	474	485	482
Scotland	4	44	52	46	141	166	148
	5	116	137	121	373	438	390
	6	182	213	189	581	683	608
Northern Ireland	4	10	10	10	50	51	49
	5	26	27	26	130	135	129
	6	41	42	40	202	211	200
United Kingdom	4	662	712	670	2334	2516	2363
	5	1747	1880	1767	6160	6640	6235
	6	2721	2930	2754	9595	10336	9713

Table A8.20 Effect of future levels of ozone for the 2080s on premature deaths and additional (or brought forward) respiratory hospital admissions based on scenarios outlined in Section 7.5.4 for the principal population projection. These scenarios are based on a repeat of emissions for 1995, 2003 and 2005.

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	1	125	133	127	430	453	433
	2	355	377	360	1214	1281	1226
	3	584	618	590	1994	2105	2013
South East	1	178	187	175	578	605	564
	2	510	536	501	1649	1727	1612
	3	847	887	829	2728	2858	2670
London	1	95	107	98	425	478	437
	2	276	309	282	1237	1392	1272
	3	462	517	474	2075	2335	2133
East of England	1	128	134	131	418	437	426
	2	362	378	368	1183	1240	1208
	3	594	623	605	1947	2042	1986
West Midlands	1	98	109	103	343	379	359
	2	282	312	296	985	1087	1031
	3	469	518	492	1635	1806	1713
East Midlands	1	89	98	89	324	357	325
	2	254	280	254	920	1014	921
	3	419	461	419	1516	1672	1517
North West	1	121	132	121	437	478	440
	2	347	381	349	1257	1377	1267
	3	579	635	583	2094	2294	2110
North East	1	50	51	51	183	190	190
	2	142	147	147	524	542	542
	3	235	244	244	869	900	900
Yorkshire and Humberside	1	106	114	109	389	410	392
	2	307	325	311	1113	1174	1122
	3	509	538	515	1846	1947	1862
Wales	1	65	66	65	203	208	207
	2	180	185	184	574	588	587
	3	295	303	302	943	965	964
Scotland	1	83	98	88	267	314	281
	2	236	279	248	756	891	795
	3	389	458	408	1244	1467	1309
Northern Ireland	1	24	24	23	117	122	116
	2	68	70	67	336	351	334
	3	113	117	111	560	584	555
United Kingdom	1	1172	1263	1189	4141	4474	4203
	2	3340	3605	3391	11824	12771	12005
	3	5527	5968	5614	19569	21150	19874

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	4	102	108	104	349	368	351
	5	270	287	273	923	973	929
	6	423	447	426	1440	1519	1451
South East	4	138	145	136	447	468	436
	5	365	383	358	1181	1236	1151
	6	570	597	557	1839	1925	1791
London	4	68	75	69	303	341	312
	5	178	199	183	798	899	821
	6	276	309	284	1240	1395	1275
East of England	4	102	108	105	334	350	342
	5	270	283	276	886	927	904
	6	421	441	429	1382	1446	1409
West Midlands	4	74	82	78	261	286	273
	5	198	217	206	689	757	719
	6	308	338	321	1073	1179	1118
East Midlands	4	71	77	71	257	283	257
	5	188	206	188	681	747	678
	6	293	321	292	1060	1165	1056
North West	4	90	99	90	326	357	327
	5	237	260	238	860	939	862
	6	370	404	371	1338	1461	1342
North East	4	38	40	39	141	146	144
	5	100	104	103	372	383	383
	6	156	162	161	578	598	596
Yorkshire and Humberside	4	82	87	84	298	314	299
	5	217	229	219	787	828	791
	6	337	355	340	1225	1288	1231
Wales	4	52	53	52	166	170	169
	5	138	141	140	439	450	448
	6	215	220	218	686	702	699
Scotland	4	67	79	70	215	252	225
	5	177	208	185	567	666	594
	6	276	325	288	884	1039	926
Northern Ireland	4	18	18	17	89	91	88
	5	47	48	46	233	242	230
	6	73	75	71	360	377	358
United Kingdom	4	910	979	921	3207	3458	3248
	5	2401	2584	2429	8466	9127	8569
	6	3739	4026	3786	13187	14206	13349

Table A8.21 Effect of future levels of ozone for the 2080s on premature deaths and additional (or brought forward) respiratory hospital admissions based on scenarios outlined in Section 7.5.4 for the high population projection. These scenarios are based on a repeat of emissions for 1995, 2003 and 2005.

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	1	166	176	168	571	602	575
	2	472	500	478	1613	1702	1629
	3	776	820	784	2648	2796	2674
South East	1	234	246	230	760	796	743
	2	672	705	660	2170	2273	2121
	3	1115	1168	1091	3590	3762	3514
London	1	126	141	130	562	632	578
	2	365	409	373	1634	1839	1680
	3	610	683	626	2742	3085	2818
East of England	1	174	183	178	570	596	581
	2	493	515	502	1612	1689	1645
	3	809	849	825	2653	2782	2705
West Midlands	1	121	134	128	424	468	443
	2	348	384	365	1216	1342	1273
	3	579	640	607	2017	2228	2114
East Midlands	1	118	130	118	428	472	430
	2	336	370	336	1217	1341	1219
	3	554	610	554	2005	2211	2007
North West	1	142	155	142	513	560	516
	2	407	447	410	1474	1614	1486
	3	679	745	683	2455	2690	2474
North East	1	60	61	61	219	226	226
	2	169	175	175	625	648	648
	3	280	291	291	1037	1075	1075
Yorkshire and Humberside	1	141	151	145	515	543	519
	2	406	431	412	1475	1555	1487
	3	674	712	682	2447	2579	2467
Wales	1	88	89	88	276	283	281
	2	244	251	249	780	799	797
	3	401	411	410	1281	1311	1310
Scotland	1	117	138	123	374	440	394
	2	331	391	347	1060	1250	1115
	3	545	642	572	1743	2056	1835
Northern Ireland	1	37	37	35	179	186	177
	2	103	107	102	511	534	508
	3	172	179	168	851	887	844
United Kingdom	1	1536	1655	1558	5429	5866	5510
	2	4379	4726	4445	15501	16742	15738
	3	7246	7824	7360	25655	27727	26055

Region	Scenario	Premature deaths			Respiratory hospital admissions		
		1995	2003	2005	1995	2003	2005
South West	4	136	144	138	464	488	466
	5	359	381	363	1226	1293	1234
	6	561	594	565	1912	2018	1927
South East	4	181	191	179	589	616	573
	5	481	504	471	1554	1627	1515
	6	750	786	733	2421	2533	2358
London	4	90	100	92	401	450	412
	5	235	263	241	1054	1188	1084
	6	365	409	375	1638	1843	1684
East of England	4	139	147	143	455	477	466
	5	367	385	376	1208	1263	1232
	6	574	600	585	1883	1971	1920
West Midlands	4	92	101	97	322	353	337
	5	244	268	254	851	934	887
	6	380	417	396	1324	1454	1379
East Midlands	4	94	102	94	340	374	340
	5	248	272	248	901	989	897
	6	388	424	386	1403	1541	1397
North West	4	106	116	106	382	418	384
	5	278	305	279	1008	1102	1011
	6	434	474	435	1569	1713	1574
North East	4	45	48	46	168	174	172
	5	120	124	123	444	457	457
	6	186	193	192	690	714	712
Yorkshire and Humberside	4	109	115	111	394	416	396
	5	288	304	290	1042	1097	1048
	6	447	471	451	1624	1706	1632
Wales	4	71	72	71	226	231	229
	5	187	192	190	597	612	609
	6	292	298	297	932	954	949
Scotland	4	94	111	99	301	353	316
	5	248	292	259	795	934	832
	6	388	455	404	1239	1456	1297
Northern Ireland	4	28	28	26	135	138	133
	5	72	74	70	354	368	350
	6	110	114	109	548	572	544
United Kingdom	4	1193	1283	1208	4205	4533	4258
	5	3148	3388	3184	11098	11965	11234
	6	4902	5278	4963	17287	18623	17500