Chapter 5:
People and the built environment

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Lead contributors: Sari Kovats, LSHTM, Dan Osborn, UCL

Contributing authors: Jon Ayres, University of Birmingham; Paul Bates, University of Bristol; Matthew Baylis, University of Liverpool; Sarah Bell, UCL; Andrew Church, University of Brighton; Sarah Curtis, University of Durham; Mike Davies, UCL; Mike Depledge, University of Exeter; Sotiris Vardoulakis, PHE/LSHTM; Nick Reynard, CEH; Jeremy Watson, UCL/BRE

Additional contributors: Anna Mavrogianni, UCL; Clive Shrubsole, UCL; Jonathon Taylor, UCL; Geoff Whitman, LSHTM

ASC contributors: Kathryn Humphrey, Dave Thompson, Daniel Johns

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Implications of the vote to leave the European Union

This chapter was written before the results of the EU Referendum were known. Leaving the European Union is unlikely to change the overall scale of current and future risks from climate change, but in some areas it may affect policies and programmes important to address climate-related vulnerabilities.

If such policies and programmes are changed, it will be necessary for UK measures to achieve the same or improved outcomes to avoid an increase in risk. The Adaptation Sub-Committee will consider the impact of the EU Referendum and the Government's response in its next statutory progress report on the UK National Adaptation Programme, to be published in June 2017.

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Key messages

Key risks and opportunities

Increasing temperatures, rising sea levels and modified rainfall patterns will change the climate-related risks involving people and the built environment in the UK, and create new challenges for those working in planning, community development, the health and social care system, flood and water management, and emergency preparedness. Flooding and extreme hot weather pose the highest magnitude risks and the greatest need for action in the next five years. There are some potential benefits from reduced cold and opportunities from warmer weather.

Table 5.1 summarises the urgency scores for this chapter. The table outlines the Adaptation Sub-Committee's view, based on the evidence presented by the authors of this chapter, on the need for different types of action over the next five years, against each of the risks and opportunities shown. Further detail is provided in the accompanying appendix to the CCRA Synthesis Report on urgency scores.

The table reflects current and future climate risks. Thus, climate risks that may decrease with climate change but still require policy action are included (e.g. cold effects on health).

Also included are some environmental hazards, such as outdoor air pollution, that require policy action, but for which climate change plays a relatively small role as a determinant of risk in the future compared to other determinants (in the case of air pollution, the main cause is emissions of pollutants or pollutant precursors). Outdoor air quality is currently one of the top health protection priorities for the UK Government and the Devolved Administrations.

Table 5.1. Urgency scores for people and the built environment

Risk/opportunity (relevant section(s) of chapter)	More action needed	Research Priority	Sustain current action	Watching Brief	Rationale for score
PB1: Risks to health and wellbeing from high temperatures (5.2.2, 5.3.2, 5.5.3)	England	Northern Ireland, Scotland, Wales			There are approximately 2,000 heat-related deaths per year across the UK. The risk to health is likely to increase in the future as temperatures rise. Around 20% of homes in England overheat even in the current climate. There is some evidence that the risks of overheating in hospitals, care homes, schools and offices will increase in the future. There is more evidence for England than for the devolved administrations. Policies do not exist at present to adapt homes or other buildings to higher temperatures.
PB2: Risks to passengers from high temperatures on public transport (5.3.9)		Wales	England	Northern Ireland and Scotland	The action underway in London to assess and manage risks of overheating on public transport should continue, together with similar action as needed elsewhere in the UK.

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PB3: Opportunities for increased outdoor activities from higher temperatures (5.2.3)				UK	Leisure and other activities are likely to be taken up autonomously by people as the climate warms.
PB4: Potential benefits to health and wellbeing from reduced cold (5.3.3, 5.5.4)	UK				Currently there are between 35,800 and 49,700 cold-related deaths per year across the UK. Climate change alone is projected to reduce the health risks from cold, but the number of cold-related deaths is projected to decline only slightly due to the effects of an ageing population increasing the number of vulnerable people at risk. Further measures need to be taken in the next 5 years to tackle large numbers of cold homes and reduce cold effects on health, even with climate warming.
PB5: Risks to people, communities and buildings from flooding (5.2.5, 5.3.4, 5.5.1)	England	Northern Ireland, Scotland, Wales			Under the most optimistic flood defence investment scenario for England, the level of risk declines but remains high by mid-century, and future spending plans for the devolved administrations are unclear. Increases in flood risk cannot be avoided under a 4°C climate scenario even if the most ambitious adaptation pathway considered in this report were in place.
PB6: Risks to the viability of coastal communities from sea level rise (5.2.6, 5.2.7)		UK			Research is needed to better characterise the impacts from sea level rise on coastal communities, thresholds for viability, and what steps should be taken to engage and support affected communities.
PB7: Risks to building fabric from moisture, wind and driving rain (5.3.4, 5.3.6, 5.3.7)		UK			More research is needed to better determine the future level of risk and what further steps in adaptation might be appropriate.
PB8: Risks to culturally valued structures and the wider historic environment (5.3.8)		UK			Climate-related hazards damage historic structures and sites now, but there is lack of information on the scale of current and future risk, including for historic urban green spaces and gardens as well as structures.

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PB9: Risks to health and social care delivery from extreme weather (5.4)	England	Northern Ireland, Scotland, Wales			There is some evidence of inconsistent planning for extreme weather across the UK. Surveys indicate that many Clinical Commissioning Groups, NHS providers, GPs and Local Authorities may not have appropriate plans in place.
PB10: Risks to health from changes in air quality (5.2.2, 5.3.5, 5.5.5)		UK			More research is needed to understand the influence of climate change on ground level ozone and other outdoor air pollutants (especially particulates), and how climate and other factors (behaviour) affect indoor air quality.
PB11: Risks to health from vector-borne pathogens (5.5.2)		UK			Further research is needed to improve the monitoring and surveillance of vector species and related infectious disease, and to assess the extent to which current efforts are focussed on those infections that pose the biggest long-term risks.
PB12: Risk of food borne disease cases/outbreaks (5.5.6)				UK	Regulations in place to monitor and control food-related hazards should be kept under review.
PB13: Risks to health from poor water quality (5.5.6)			UK		Current policies and mechanisms to assess and manage risks to water quality in the public water supply should continue to be implemented.
PB14: Risk of household water supply interruptions (5.2.4)			UK		Policies are in place to safeguard the continuity of public water supplies during droughts and from burst pipes in cold weather. These risks should be kept under review to make sure long-term risks continue to be managed appropriately.

Summary of key findings

Flood impacts on people (health, social, economic) and buildings

Flooding is one of the most important risks from climate change for people, communities, buildings, and historic structures in the UK. As well as risks to life and property, flooding causes long-term damage to health, wellbeing, livelihoods and social cohesion. There is little data and considerable uncertainty regarding the total (i.e. direct and indirect) social and economic cost of flooding currently occurring in the UK.

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According to research conducted to support this CCRA, approximately 1.8 million people in the UK currently live in areas at greater than a 1 in 75 (1.3%) annual chance of river, surface water or coastal flooding. The population living in areas at or greater than a 1 in 75 risk of flooding is projected to rise to 2.6 million by the 2050s under a 2°C scenario or 3.3 million under a 4°C scenario, assuming low rates of population growth and a continuation of current levels of adaptation. The future population exposed to flooding will also depend on the rate of new development in the UK floodplain. The modelling for this report indicates that additional investment will be needed to avoid increases in flood risk from climate change and population growth. Modelling that assumes enhanced levels of adaptation (including investment in flood defences but also property-level protection and other measures) suggest that the risk across the UK can largely be managed in a 2°C climate scenario but not a 4°C scenario. At present, there is a low uptake of 'low-regret' actions to reduce the impacts of flooding, such as propertly level protection and sustainable urban drainage systems (SuDS). In England, the rate of development in the floodplain declined slightly in 2008 – 2014 compared to 2001 - 2007, and similar data does not exist for the devolved administrations. There is a lack of evidence regarding the effectiveness of emergency responses and measures to increase community resilience.

Climate change risks to the UK landscape including loss of communities from sea-level rise

Analysis conducted for the CCRA suggests that 0.5 – 1.0m of sea-level rise could make some 200km of coastal flood defences in England (~4% of the total length of the English coastline at 5500km, and 20% of the length with coastal flood defences) highly vulnerable to failure in storm conditions in the future, which could lead to difficulty in maintaining defences in their current alignment. This analysis does not include the effects of coastal erosion and only covers England. Significant additional investment is likely to be required to sustain these defences or to retreat defence lines to a more sustainable location, and it is not known how much of the coast it will be economically viable to protect in the future.

Some communities could become at risk of economic blight in the absence of plans to manage long-term coastal change. There is a need for improved understanding of the long-term risks to coastal communities in England and in the devolved administrations, and for decision-makers to engage with local communities and businesses on realignment even though such discussions can be complex and emotive. The rate of coastal managed realignment needs to increase five-fold to reach the aspirations contained in shoreline management plans in England.

Effects of higher temperatures on health, wellbeing, and thermal comfort

Higher summer temperatures are likely to have a range of impacts on the UK population. Some of these could be beneficial, but as specific thresholds are exceeded, the adverse effects of hot weather will increasingly be felt.

Heat-related deaths are likely to increase in the future. According to one study, the current burden of heat (approximately 2,000 heat-related deaths per year in the UK) may increase by 257% by the 2050s (median estimate) due to the combination of both climate change, population growth and ageing and with no adaptation. The rate at which populations wil adapt to higher temperatures remains uncertain.

All types of buildings are at risk of overheating including homes, hospitals, care homes, offices, schools and prisons. Although around 20% of homes in England are thought to overheat even in the current climate, there are no policies in place to adapt homes or other buildings to higher temperatures. Overheating on public transport is also likely to increase although some research and management is already in place in London. Outdoor activities may become more attractive in higher temperatures, with perhaps an increase in active travel and other aspects of physical activity, which benefit health and wellbeing. Very little quantitative evidence exists that considers these benefits.

Key messages

Reduced cold-related mortality and morbidity

Cold is currently a significant public health problem, with between 35,800 and 49,700 cold-related deaths per year across the UK. Cold will remain an important climate risk, even with milder average winter temperatures, due to the poor thermal performance of the UK housing stock, and population ageing. The latest estimates at UK-level suggest a reduction in cold-related mortality of 2% by the 2050s (medium emissions and including population growth and ageing). Interventions to reduce the burden of cold through household energy efficiency measures can also reduce greenhouse gas emissions, but carry a risk of increasing the propensity of buildings to overheat.

Disruption of health services and social care from extreme weather events

Extreme weather (including heatwaves, flooding, and snow storms) disrupts health and social care service delivery, and can damage health care infrastructure. Health services are vulnerable to an increase in the frequency and intensity of extreme weather events and the capacity of the system to cope with shocks could decrease given increasing pressures on the health service and local government. Modern built facilities are designed to support contemporary care models and to be thermally efficient in cold weather, but this has led to problems with thermal comfort during heatwaves, for patients and staff in hospitals and care homes. Floods and storms cause significant disruption to health and social care systems. Across England and Wales, the number of hospitals, GP surgeries, emergency service stations or care homes located in areas at or greater than a 1 in 75 annual chance of flooding (on average) are projected to increase by between 3 and 24% in the 2050s under a 2°C scenario, and between 27 and 110% under a 4°C scenario (assuming a continuation of current levels of adaptation), while the risks are somewhat lower for Scotland and Northern Ireland.

Infectious diseases and pests

Globally, human infectious disease risks are affected by the movement of people, animals and goods. Climate change may increase the capacity of existing UK mosquito species to transmit certain arboviruses that are harmful to human health. Higher temperatures may facilitate the expansion of the range of a vector of West Nile virus that has recently invaded south-east England. Higher temperatures in the future will also increase the suitability of the UK's climate for invasive mosquito species. The risk of introduction of dengue and Chikungunya viruses is contingent on the risk of invasion by non-native mosquito vectors. This risk remains low in the near term, but may increase under a 4ºC scenario. The risk of introduction of malaria leading to local transmission between people remains low.

Key messages

Box 5.1. Comparison between key findings in this chapter with CCRA1

- This second climate change risk assessment takes account of the potential effects of adaptation on impacts from climate change.
- Risks from flooding set out in this chapter are of a similar magnitude to CCRA1 but now cover all four types of flooding (river, coastal, surface water and groundwater), rather than just river and coastal flooding. The chapter presents consistent projections for the whole of the UK for the first time, whereas in CCRA1 only England and Wales could be covered as suitable data was not available for Northern Ireland and Scotland.
- This chapter also contains more information than was available for the CCRA1 on the health, social and economic impacts from flooding, and flood risks to communities.
- CCRA1 did not consider the risks to coastal communities for rises in sea level beyond 1 metre.
- CCRA1 projected a large benefit arising from a reduction in cold-related mortality. A more comprehensive assessment published in 2014 makes this large benefit less certain due to the compounding effects of population ageing.
- Unlike the first CCRA, this chapter reviews the evidence regarding the capacity of the health and social care system to cope with climate risks.
- New risks and opportunities assessed here that were missing from CCRA1 include the risks to historic buildings, structures, and gardens, risks to passengers on public transport and opportunities for health and wellbeing from warmer weather.

5.1 Context

5.1.1 Scope of the chapter

This chapter summarises the available evidence regarding the key risks and opportunities of climate change for the UK population, with a particular focus on health and wellbeing, and on the built environment – where we live, work and study. This chapter covers all UK populations, both urban and rural, and addresses how climate change risks are likely to vary by type of settlement as well by geographic region within the UK.

The chapter is divided into four sections that focus on the main policy areas for managing climate risks: communities; buildings; the health and social care system; and population health and health protection (Figure 5.1). The chapter is structured in this way in order to provide a more useful review of the evidence for decision-makers, and also to consider interacting risks and trade-offs. The structure of the chapter also mirrors the lead responsibilities of different government departments – for example the Department of Health and Defra lead on health protection while DCLG and Defra lead on communities and settlements at the UK Government level.

There are complex connections between these topic areas. For example, the built environment (urban planning, housing quality) is an important determinant of health and wellbeing. It is also important to note that many of the wider (environmental and social) determinants of health are governed by 'non-health' government departments – such as, at the UK level, housing (DCLG), urban planning (DCLG), transport (Department for Transport) and social protection measures (Department for Work and Pensions). Defra also has a role in regulating hazards in the environment that are very important for human health (flood risk management and regulation of chemical and microbiological hazards in the air, water and soil).

Many climate hazards, such as flooding and heat waves, have implications across all four sections of this chapter. Figure 5.1 shows how some of the key risks discussed cut across the different sections. The chapter conclusions, Adaptation Sub-Committee's urgency scoring and CCRA Synthesis Report bring these risks back together and discuss the wider picture.

Figure 5.1. Chapter structure and content

	Communities and settlements	Buildings	Health and social care system	Population health
Heatwaves	Heatwaves, urban heat island, air pollution	Overheating	Overheating risks to patients, social care, occupational risks, energy use	Heatwave risks to population, mortality, injury etc.
Floods	Flooded communities, resilience, relocation, blight/ economic effects	Flood damage, damp, mould	Flood risks to NHS assets, service disruption	Flood impact on mental health, deaths and injuries
Drought	Risk to water supply, drought	Subsidence	Service disruption	Water supply failure, risks to public health
Cold	Risks from extreme weather	Damp homes, cold homes	Service disruption	Cold risks to mortality and morbidity

Notes: Grey boxes denote the sections in chapter 5. Blue boxes denote chapter sub-sections. Text on the far left with red boxes denotes climate hazards. This figure focuses on extreme weather events in order to give a flavour of the cross-cutting nature of climate hazards, and does not describe all the climate risks in the chapter (e.g. on infectious disease).

5.1.2 Current adaptation policy related to people and the built environment

The effects of climate change on people (including health, social and economic impacts) and the built environment cover a very wide and complex range of policies, strategies and measures that also vary by country and region within the UK. This section provides an overview of high-level adaptation policies related to this chapter. Each chapter section also summarises the major policies that affect the risks and opportunities considered.

England

The National Adaptation Programme (NAP) covers the UK for reserved matters and England for devolved matters (House of Commons, 2010; Defra, 2013b). It includes dedicated themes on Healthy and Resilient Communities (Chapter 4) and the Built Environment (Chapter 2). It notes that climate change poses risks to population health and to the effective delivery of public health, clinical (National Health Service, NHS) and social care services. Climate change is also acknowledged as having implications for the emergency services. The NAP highlights the impacts on the built environment of extreme weather including flooding, overheating and drought. Some impacts affect the direct fabric of the building with implications for function and costs. Many of the climate risks that directly affect people – particularly flooding and high temperatures – are mediated through the built environment.

Northern Ireland

Adaptation policy is described in the Northern Ireland Climate Change Adaptation Programme (Northern Ireland Government, 2014). It does not have a specific section on health, but the health effects of climate change are referenced throughout, mainly in relation to those outlined in the CCRA for Northern Ireland. The Preparing for a Changing Climate in Northern Ireland report (SNIFFER, 2007) stated that consideration should be given to including Northern Ireland in any future UK-wide heatwave plan.

Scotland

The Climate Change (Scotland) 2009 Act requires the Scottish Government to produce a Scottish adaptation programme that addresses the key risks and opportunities for Scotland set out in each CCRA. The first Scottish Climate Change Adaptation Programme (SCCAP) was published in 2014. It contains themes on the built environment and society, which include risks to health and wellbeing. The SCCAP aims to increase resilience in health systems and emergency responders. NHS Boards in Scotland are also required to undertake adaptation planning.

Wales

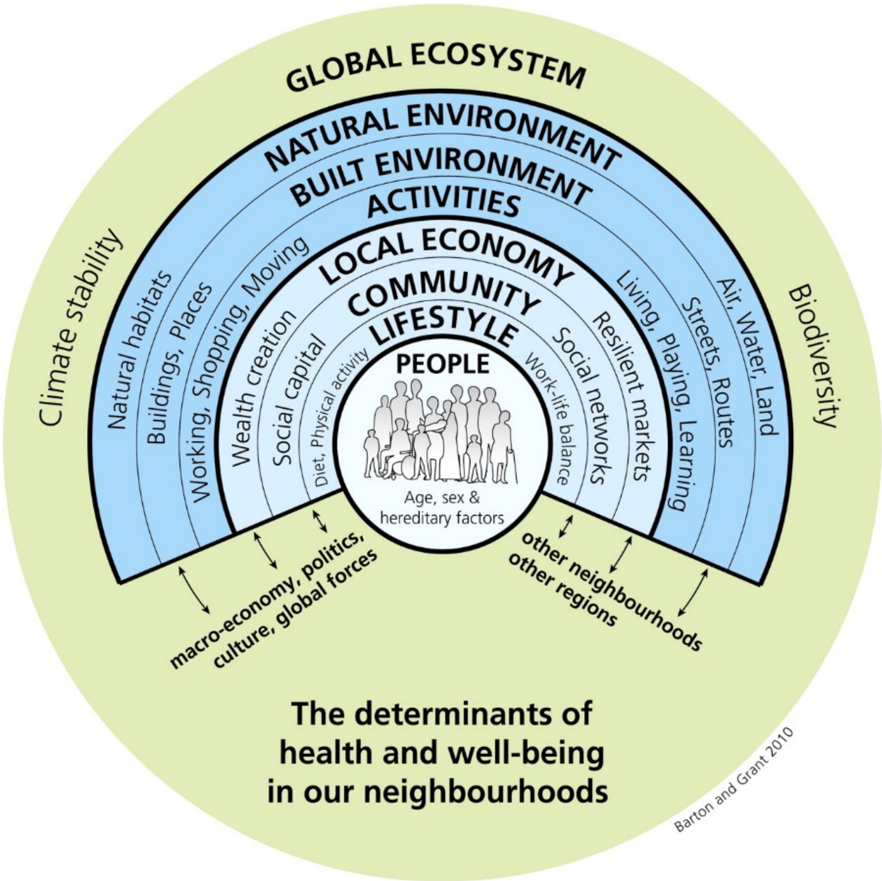
Wales has a number of key policy documents that link climate change adaptation with public health and the built environment. The health impacts associated with climate change were recognised in both the Climate Change Strategy for Wales (CCSW) (Welsh Assembly Government, 2010a) and the Climate Change Strategy for Wales Adaptation Delivery Plan (CCSWDP) (Welsh Assembly Government, 2010b). The CCSWDP aims to mainstream adaptation within health policy in Wales through the Sectoral Adaptation Plan for Health (Welsh Government, 2009). The impacts of climate change on public health are also reported in the Climate Change Delivery Plan for Wales Annual Progress Report (Welsh Government, 2012a). The relationship between health and climate change adaptation is also recognised in the Environment (Wales) Bill (National Assembly for Wales, 2015a), Planning (Wales) Bill (National Assembly for Wales, 2014) and the Wellbeing of Future Generations (Wales) Act (National Assembly for Wales, 2015b).

5.1.3 Assessment approach

This chapter is an evidence review; we aim to identify and assess the quality of the scientific and other evidence in relation to the current and future risks from climate, and the evidence regarding the capacity to adapt to these climate risks, including the effectiveness of policies, strategies and measures. This type of evidence relies heavily on observational studies, including the impacts of recent weather events such as heatwaves, floods and cold winters in the UK. Many key risks are likely to occur when systems face climate impacts beyond their usual experience, and therefore other types of evidence are required. The level of quantification of future risks to health, populations and buildings is still limited (see conclusions), and models generally do not capture well the complexity of these systems (see chapter 8).

The public health framework in the UK acknowledges the wider determinants of human health (Figure 5.2); these include social determinants (poverty, employment), the physical (built) environment (including housing), and the natural environment, as well as environmental pollution (including outdoor air quality). Future trends in these wider determinants are important for the future health status of the UK population, and this is acknowledged throughout the chapter.

Figure 5.2. The wider determinants of health



Source: Barton et al. (2010).

In addition to health (or illness), this chapter considers people's quality of life and wellbeing which are now seen as an important measure of national progress alongside the traditional economic measures such as gross domestic product (GDP). Quality of life and wellbeing are affected by a wide range of factors and have economic, social and psychological elements including measures linked to community cohesion and connectedness (OECD, 2015; O'Donnell and Oswald, 2015; Ryff et al., 2015).

There is good evidence that local neighbourhood factors are an important determinant of health and quality of life (Curtis, 2010; Mitchell et al., 2015). These neighbourhood factors include both physical characteristics (e.g. built and natural environment) and how safe and secure people feel in that place. Scotland's strategy of "Good Places, Better Health" was based on this growing recognition of the need to shape places which are nurturing of positive health, wellbeing and resilience (Scottish Government, 2008). Such neighbourhood factors are also recognised in The National Planning Policy Framework (DCLG, 2012a).

In examining the evidence of climate change impacts on people and the built environment, we have also considered the benefits of the natural environment for the economy, human health and wellbeing, based on the frameworks from the Natural Capital Committee and earlier UK work on the UK National Ecosystem Assessment (2011) and its Follow On (2014). Proper management of natural assets should help make better decisions on adaptation and in this chapter we consider the opportunities and challenges that may be involved in adapting. Thus, climate impacts on the natural environment (described in Chapter 3) will have implications for policy areas such as development planning, as well as for the economy, human health and wellbeing. Natural capital and the built environment interact to create cultural and heritage assets that are also at risk from climate change.

Methods

This chapter relies upon a very broad range of scientific evidence. The focus on current climate risks and effectiveness of current policies, strategies and measures requires robust observational studies. The evidence base regarding the health, wellbeing, social and economic burdens of climate risks is increasing, but is still limited.

This chapter also reviews the evidence, where this exists, regarding the effectiveness of specific adaptation policies, strategies and measures. Several policies have been established for a sufficient period such that the evaluations can be undertaken. Where systematic reviews have been undertaken on specific response (adaptation) options, these are also included.

There is increasing recognition of the social aspects of climate change in the peer-reviewed literature (WHO, 2011; Fresque-Baxter and Armitage, 2012). In addition, there has been an increase in qualitative evidence on factors that increase and decrease resilience in communities since the first CCRA was published in 2012.

Quantitative risk assessment has been undertaken for a very limited range of outcomes – principally heat- and cold-related mortality, flooding and air pollution-related health effects. Quantitative estimates have been included in this chapter as far as possible. Quantitative risk assessment for environmental hazards is typically done for the near-term (not over the century, as needed for climate change) and for expected ranges of exposures. However, there is also a need to consider possible high impact, low probability events that may occur due to climate change – such as risks considered by the National Risk Register.

5.1.4 Summary of risks and opportunities to people and the built environment in CCRA1

Health chapter

Quantification of future risks was undertaken for flooding (mortality, mental health), heat-related mortality and ozone-related mortality (Hames and Vardoulakis, 2012). Flooding was identified as one of the most important risks to health from climate change in the first CCRA.

The assessment also concluded that there was a risk that current NHS infrastructure, including hospitals, was not resilient to climate change and extreme weather events. Floods in particular could cause substantial disruption to NHS services. Heatwaves may also cause disruption to the healthcare sector if indoor temperatures in hospitals and care homes were not appropriately controlled.

Built environment chapter

The following key risks in the built environment were identified:

- The risk of overheating of buildings requires urgent action. Energy demand to cool buildings was projected to increase, possibly exceeding £1 billion by 2050.
- Flood risk was projected to increase, with damages rising from £1.3 billion now, to £2.1 – £12 billion by the 2080s.
- The urban heat island effect will mean that increases in temperature are exacerbated in urban areas.
- Between 27 and 52 million people could live in areas with water supply problems by 2050.
- Sewers were projected to fill and spill more frequently.

5.1.5 Current and future socioeconomic trends that affect risks and adaptation

Many important socio-economic non-climate trends are relevent to the impacts of climate change discussed in this chapter. The trends are described here and summarised in Table 5.2, for completeness, before being picked up in individual sections.

Demographic change

The UK population is growing and also growing older. The fastest population increases will be in those aged 85 and over. Of the four UK constituent countries, Wales currently has the greatest proportion of elderly population and Northern Ireland the smallest (ONS 2014). The UK's population is projected to increase from 64 million in 2012 to 73 million by 2035 and 86 million by 2085 according to the ONS principal population projection. The UK population aged over 75 is projected to increase from 8% in 2015 to 18% by 2085; figure 5.3 shows these projections broken down by country and age class.

There were 25.5 million households in Great Britain in 2011, an increase of 9.2 million since 1961 and 1.6 million since 2001 (ONS, 2014). The average household size in Great Britain has decreased from 3.1 persons in 1961 to 2.4 persons in 2011, and 29% of all households consist of one person. A smaller proportion of households in Great Britain had children living in them in 2011 than in 1961, and those households with children have fewer children living in them. These trends are anticipated to continue in the next few decades.

In addition to population growth and ageing, population distribution within the UK is an important part of demographic change. Trends for people to move to the coast (increasing coast populations), to move to the South of England, and to urban areas (see below) would all have implication for the populations exposed to climate risks.

Figure 5.3. Ageing projections by country

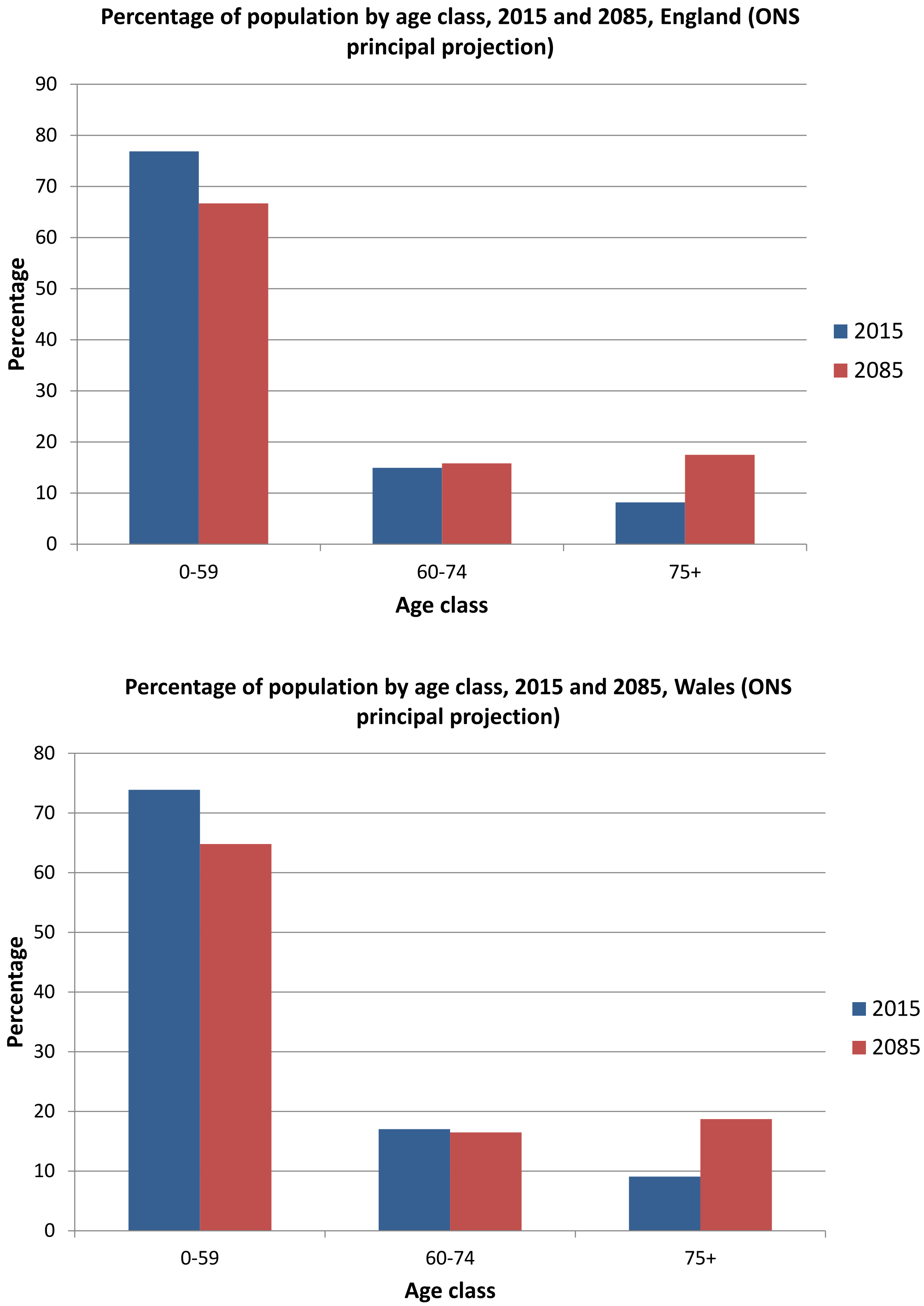
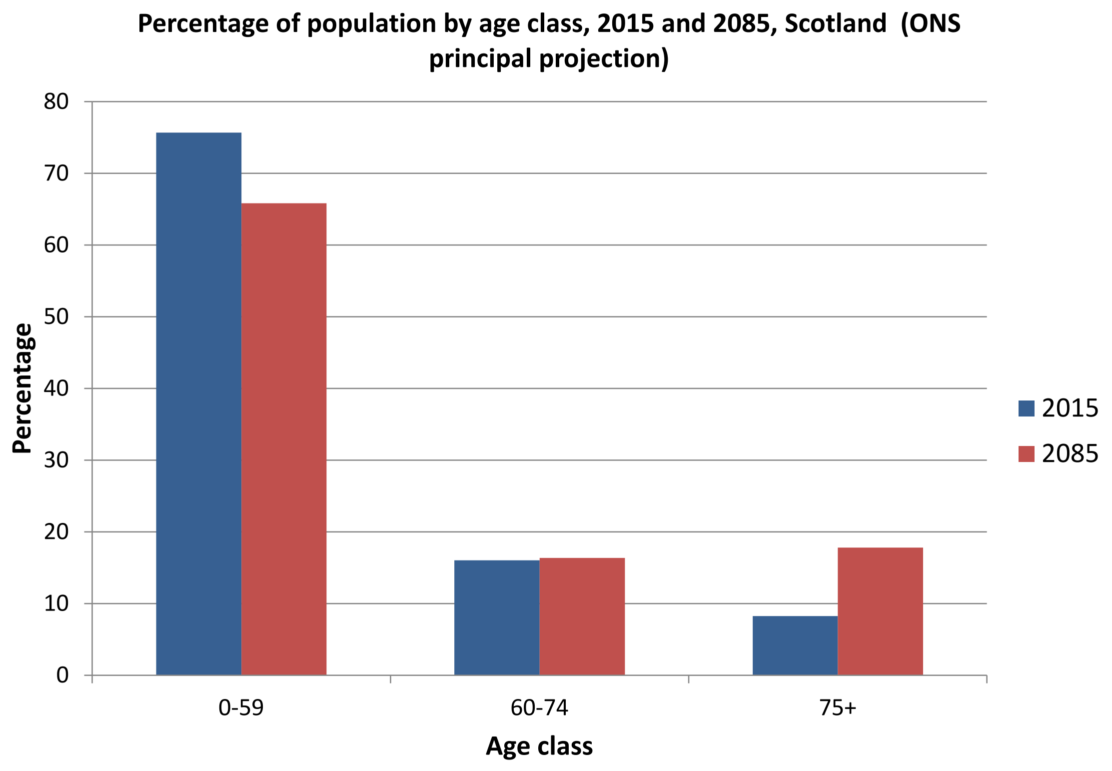


Figure 5.3. Ageing projections by country



Source: Office for National Statistics 2014.

Urbanisation and housing

Future trends or scenarios in the built environment – housing need, housing type and urbanisation – are not as well characterised as other socio-economic trends for the UK.

In the UK, urban areas account for less than 12% of land cover (House of Commons, 2010). Around 80% of dwellings in England and Scotland, 65% in Wales and 60% in Northern Ireland are located in urban areas. There is very limited information regarding future trends in urbanisation in the UK (either development of new towns or expansion of current cities). Some assumptions about land-use change were included in the scenarios of the National Ecosystem Assessment (UK NEA, 2014). Movement in and out of cities and peri-urbanisation is probably the major factor affecting urbanisation in the UK, similar to other countries in Europe. There are limited plans for new cities (three Garden Cities were announced in 2014). The expansion of urban areas is restricted by the policy to avoid building on greenfield sites. Within urban areas, however, the area of urban green space in England decreased by 7% (from 1,028,000ha to 954,000ha) between 2001 and 2013, two-thirds of which was caused by paving over household gardens (ASC, 2014).

Housing need is thought to have increased because of demographic and economic pressures, inadequate supply and recent credit rationing (DCLG, 2012b). Housing need is forecast to remain at high levels for the current decade, with the prospect of only gradual improvement over time. Increasing social housing supply has a larger and earlier impact on need than private supply (DCLG, 2012b). Social housing allocation policies appear to have quite a significant impact on need trajectories (DCLG, 2012b).

Housing quality is also an issue of concern in the UK. Based on data from 2014 – 2015 for example, 4.6 million dwellings in England (20%) failed to meet the decent homes standard (DCLG, 2016). The private rented sector continues to have the highest proportion of poor quality housing at 33%. Over 3% of properties are overcrowded in England, yet over half of owner-occupied properties are under-occupied.

In terms of energy efficiency the average Standard Assessment Procedure (SAP) rating of English dwellings in 2013 was 60 points (up from 45 points in 1996); 91% of dwellings had central heating. In 2012, 34% of dwellings had 200mm of loft insulation, 40% had cavity wall insulation and 79% double glazing. Over 4% of properties in England had damp problems (DCLG, 2015). The Scottish House Condition Survey (2014) states that around 67,000 (2.8%) homes suffer from penetrating damp and 226,000 (9.3%) from condensation. Only 3% of the UK population has air conditioning in their homes at present (Khare et al., 2016; BRE, 2013) but this is projected to increase. Using the newest official definition for fuel poverty, there were an estimated 2.35 million (10.4% of all households) fuel poor households in England in 2013 (communication from DECC). In Scotland there were estimated to be 940,000 fuel-poor households in 2013, equivalent to 39% of all households (Scottish Parliament Information Centre, 2015). In 2011, in Wales the figure was 26% of households (National Assembly for Wales, 2011) and in 2011 in Northern Ireland 42% of households were classed as fuel poor, the highest in the UK.[1]

Population health and social inequalities

The health of the UK population is improving. In addition, life expectancy is increasing. Some affluent areas of the country may reach life expectancy of 90 years by 2030 (Bennett et al., 2015).

[1] www.consumercouncil.org.uk/energy/fuel-poverty/

There are important regional differences in longevity and other measures of population health. Life expectancy in the affluent London borough of Kensington and Chelsea would be five to six years higher than in the low income area of Tower Hamlets, assuming no change in the ratio of health inequalities between the two areas (Marmot and Bell, 2012). Reducing health inequalities is a stated aim of the UK Government and devolved administrations and an important goal for UK public health policy (ibid.).

Health system futures

Healthy life expectancy has not risen as fast as life expectancy and this has caused an increase in the number of people with long term health needs. The greater burden from chronic and multiple conditions (co-morbiditiies) are increasing pressure on the health and social care system (Care Quality Commission, 2015; House of Commons, 2010).

Health systems are also undergoing organisational change. For example, the health system in England underwent a major reorganisation in the 2014 that increased the number of health providers and commissioning agencies, as well as moving the responsibility of public health into local government.

Future trends of health systems are unclear and are generally not evidence-based. The NHS Five Year Forward review (NHS England, 2015) highlighted the shift from hospital-focused systems in the future to community-based care. GP care is likely to continue to be important as well as community-based speciality care facilities. The NHS may rely increasingly on the voluntary sector and with a public and private network of providers to deliver health care. A workshop at the Academy of Medical Sciences concluded that changes in the UK health system would be significant for the health of the population in 2040 (AMS, 2014). The interface between clinical medicine and population health may become increasingly important, as the need for long-term prevention and management of co-morbidities to achieve improved healthy life expectancy increases.

Table 5.2 shows how these social and economic pressures may affect the capacity to adapt in the UK in the future.

Table 5.2. Summary of UK future pressures likely to affect capacity to adapt

Factor	Communities	Buildings	Health systems	Health protection
Population growth	Population growth increases population at risk of flooding by increasing demand for housing.			
Population ageing	Increases in older age groups who are most vulnerable to extreme weather		Increases in population vulnerable to extreme weather	Increases in population vulnerable to extreme weather

Table 5.2. Summary of UK future pressures likely to affect capacity to adapt

Factor	Communities	Buildings	Health systems	Health protection
Urban development (urban expansion)	Population growth increases population at risk of flooding	Population growth increases the number of buildings at risk of flooding and water damage		
Loss of green space	Increases surface water flood risk Increased outdoor temperatures	Increases surface water flood risk		Increased outdoor temperatures
Housing need	Population growth increases population at risk of flooding as houses more likely to be built in flood risk areas			
Energy efficiency		Reduced ventilation increases overheating risks		
Fragmentation of health and social care (public services)			Organisational barriers to implement coherent strategies	Organisational barriers to implement coherent strategies
Reductions in public health spending (health protection meaures (austerity)				Local authorities unable to implement public health policies, strategies and measures
Reductions in social protection measures (austerity)			Local authorities unable to implement social care measures	

Notes: Empty cells indicate lack of significant effect – positive or negative.

Climate futures

The future climate of the UK is described in more detail in Chapter 1. A summary of specific projections and trends that are relevant to this chapter is given below.

Future hot summers and heatwaves

UK mean summer temperatures have increased by about 0.28°C per decade since 1960 (Met Office, 2014). The number of hot[2] days per year across England has increased from about 10 in 1960 to 20 in 2010 (HR Wallingford, 2014). The extreme values of maximum and minimum daily temperatures in the UK have risen by just over 1°C since the 1950s (Brown et al., 2008).

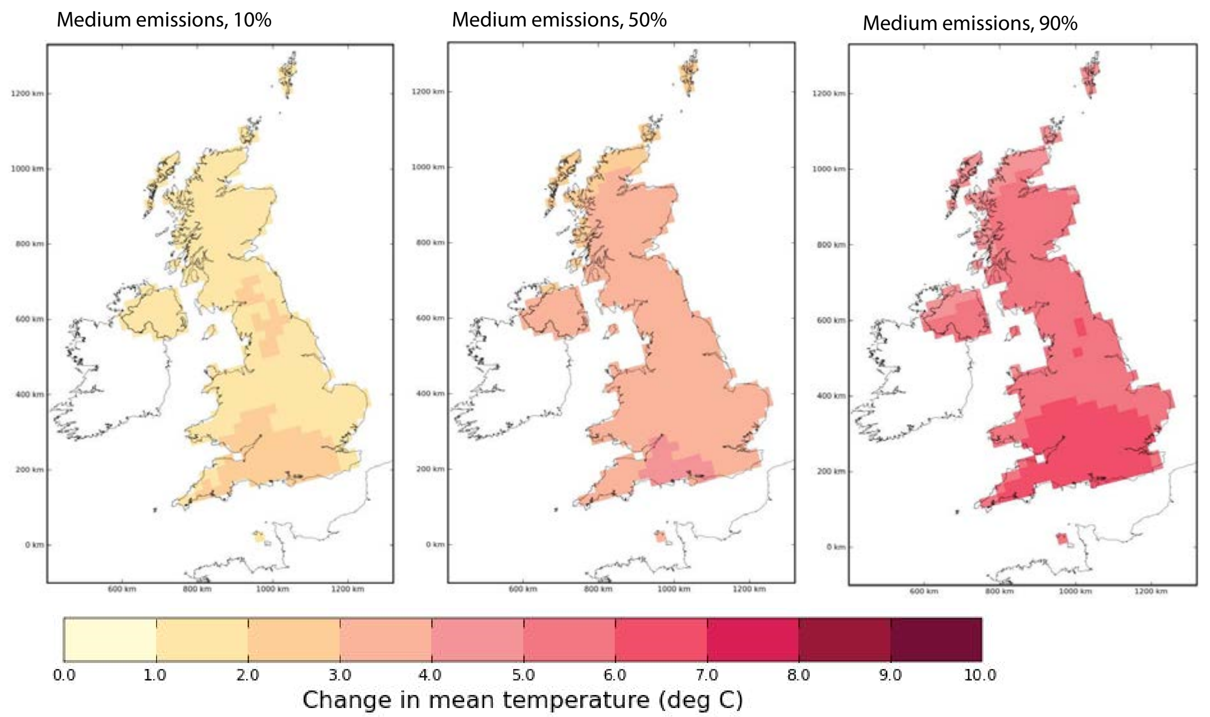
The summer of 2003 was the hottest for 500 years in Western Europe (Met Office, 2014); Stott et al. (2004) estimates that human influence had at least doubled the risk of this event. The intensity of heatwaves across Europe could be increased by positive feedbacks associated with vegetation and drying of the soil (Clark et al., 2010).

The UK recorded its highest ever temperature of 38.5°C in Faversham, Kent in August 2003. 2014 is currently the warmest year on record for the UK, England, Wales and Scotland (in a series from 1910, and for central England in a series from 1659 (Kendon et al., 2015). 2015 is the hottest year on record globally but not for the UK. King et al. (2015) estimated with 90% confidence that human influence increased the likelihood of the record Central England Temperature of 2014 by at least 13-fold.

In the future, annual average and seasonal temperatures in the UK are expected to increase (see chapter 1). The central estimate from the UKCP09 projections suggests that, under a medium emissions scenario (A1B), regional summer mean temperatures around the UK may increase by up to 2.8°C (with a range of 0.9 – 4.6°C) by the 2050s compared with the 1961-1990 average climate (see Figure 5.4 for projections of summer temperatures).

[2] A ‘hot’ day is defined here as one where the daily maximum temperature exceeds the 93rd percentile of the 1993 – 2006 daily maximum temperature for individual weather stations. The thresholds vary from about 16 C in Shetland to 28 C in south east England.

Figure 5.4. Future summer temperature projections for the UK for the 2050s



Source: UK climate projections 2009 (http://ukclimateprojections.metoffice.gov.uk/21708)
Notes: Maps show the range of projections in summer mean temperature for the period 2040-2069, medium emissions, from the 10% to 90% probability level.

Future cold and extreme winters

Average wintertime temperature across the UK has increased by 0.23°C per decade since 1960 (Met Office, 2014) and the number of days classed as cold[3] has declined in England (HR Wallingford, 2014).

Future cold winters and cold days in the UK are likely to be less severe, occur less frequently and last for a shorter period of time than present day events (Murphy et al., 2010; Sexton and Harris, 2015). Under a medium emissions scenario, the 30-year mean daily minimum temperature increases on average in winter by about 2.1°C (0.6 to 3.7°C) to 3.5°C (1.5 to 5.9°C) depending on location by the 2080s.

The frequency of extreme winters has also declined, although December 2010 was the coldest December for at least 100 years (Met Office, 2014). Some studies have linked the cold winters such as in 2010/2011 to declining Arctic sea ice (Stocker et al., 2013), which could encourage the North Atlantic Oscillation (NAO) to enter or remain in its negative phase associated with colder and drier winters over the UK (Francis and Vavrus, 2012). However, there is only weak evidence of an impact on the NAO (and Arctic sea ice cover) in winter in climate model simulations relative to that of other sources of natural variability (Screen et al., 2013) although the ability of climate models to deal with Arctic ice may be limited (Stroeve et al., 2012). The influence of

[3] Defined as the number of days per year when the daily minimum temperature is below the 10th percentile of the 1993–2006 two-day average minimum temperature.

Arctic sea ice on the atmospheric circulation, and thus potentially dry periods and storms in the UK, is a topic of active debate (Gramling, 2015). Development of a consensus will require improved understanding of impacts on the Atlantic jet stream (Wallace et al., 2014) amongst other factors, including better quantification of the ice extent and mass (Laxon et al., 2013) (see also Chapter 1).

Future storms and high winds

Understanding windstorm climate risks for the UK is complex (Yan et al., 2002). Climate models, which in general do not represent storms well, indicate only a small change in storm frequency over the UK in winter, despite a projected southward shift in the North Atlantic storm track. Future storm and wind intensity and direction will be strongly tied to the future position of storm tracks over the UK, which are influenced by the behaviour of the NAO over decadal time periods.

There is considerable uncertainty about the way climate change might affect the strength, track and temporal or spatial clustering of windstorms. A number of recent studies (Ludwig et al., 2014) imply that climate change may change the nature of storm-generating systems, storm severity, track and clustering. However, decadal variations in the datasets make trend detection difficult.

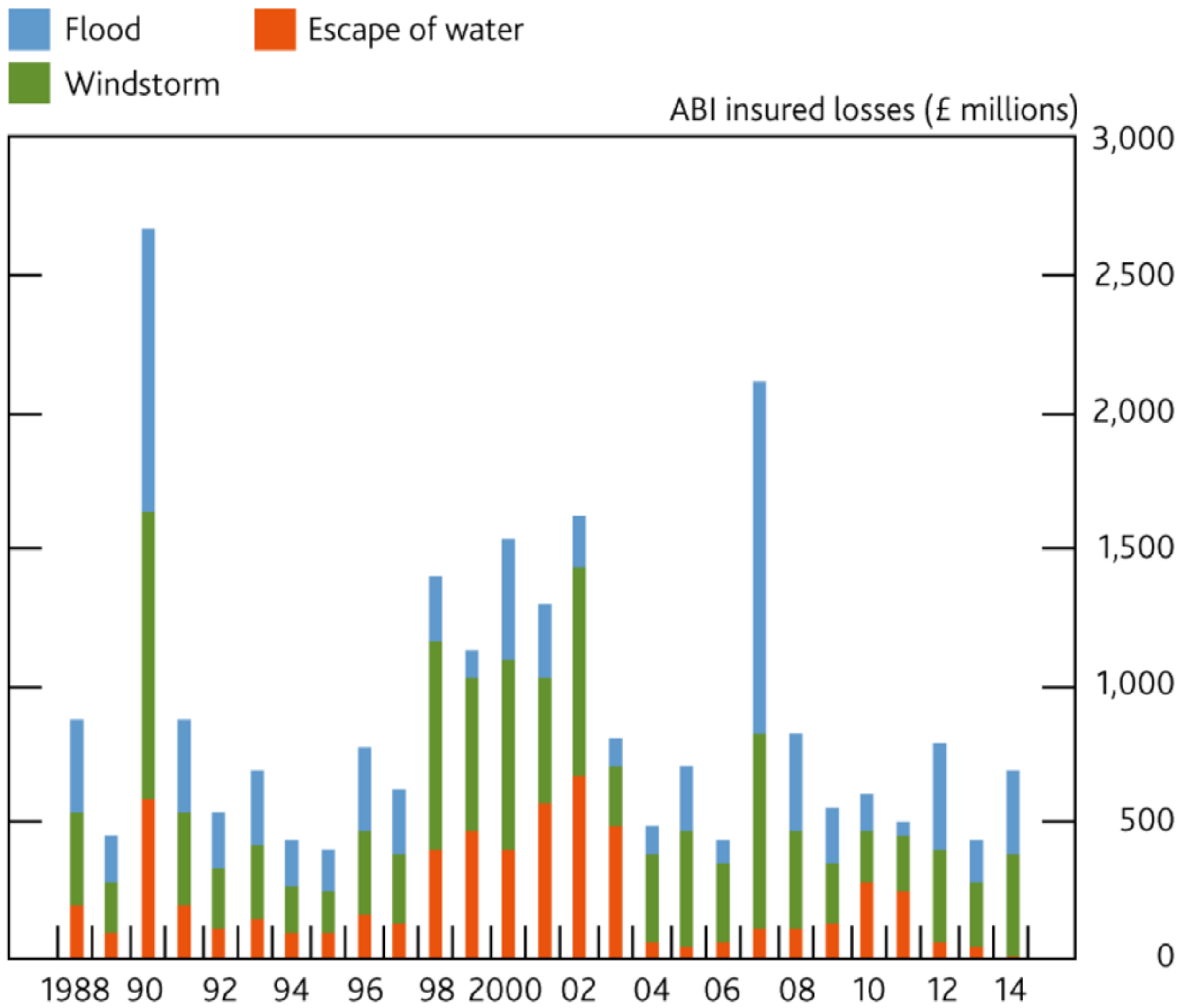
Insurance damages are one indicator of wind damage. Figure 5.5 shows losses over the period 1988 to 2014 from different climate hazards. The figures include situations where particular weather events dominate, for example, in 2007. The figure illustrates the large annual variation in damage from windstorms.

Tornadoes occur quite often in the UK both on land and off-shore as water spouts (Mulder and Schultz, 2015). They are usually too small to do significant damage; however, one tornado in Birmingham in the 1980s caused considerable damage (~£40 million and 19 injuries), more than any other. The impact of climate change on tornadoes in the UK is uncertain.

Windstorms are often, but not always, accompanied by heavy and persistent rainfall. Flood projections are discussed in detail in Section 5.2.5. The effect of climate change on future rainfall and river flows is described in Chapter 1. Monthly updates are also available in the Hydrological Summaries issued by the Centre for Ecology & Hydrology (CEH). CEH, with the British Geological Survey, have recently produced a range of river flow and groundwater projections and CEH now provide a Flood Estimation Handbook point estimation service to help water resource managers, developers and the planning system become more aware of the annual and decadal variability that affects UK weather patterns.

Attribution of flooding events to anthropogenic climate change is an evolving area of research (see Box 5.2).

Figure 5.5. Insured UK losses from windstorms and other drivers according to the ABI (1988 – 2014)



Source: Prudential Regulation Authority (2015) based on data from Association of British Insurers available at https://www.abi.org.uk/Insurance-and-savings/Industry-data/Industry-data-downloads.
Notes: Spikes in losses correspond to wind storms in 1990 and flooding in 2007.

Box 5.2. Evidence on attribution of observed changing flood risk to climate change

At present, the evidence for a link between human-induced climate change and specific flood events or even in long-term trends in flooding (as detailed by Hannaford and Marsh, 2008) is difficult to establish. The difficulty in detecting trends from observations is not surprising as large UK floods can depend on relatively infrequent atmospheric events depositing large volumes of water in river catchments (Lavers et al., 2011). Decadal variation also makes it difficult to detect the climate signal from natural variability in the data. Further, whether a flood occurs in a particular catchment depends on a range of geophysical and hydrological factors in addition to climatic and meteorological ones.

Attribution studies have begun to link some flood events, such as those in the UK in autumn/winter 2000, to climate change driven by human activity (Kay et al., 2011; Pall et al., 2011). Pall et al. (2011) concluded that anthropogenic forcing had very likely increased by at least 20% the risk of the floods that occurred in England and Wales in autumn 2000. Chapter 1 includes more detail on trends and projections for climate extremes including heavy rainfall.

Understanding the effects of climate on current and future flooding will need to take account of a range of physical, social and economic factors. The modelling challenge is becoming more tractable (Huntingford et al., 2014). Recent events are put in their observational and earth system context by Slingo et al. (2014).

5.2 Communities and settlements

Key risks and opportunities – communities and settlements

PB5: Risks to communities, people, health and buildings from flooding

- Climate change is likely to increase flood risk in the UK from the four main types of flooding (fluvial, coastal, surface water and groundwater). According to research conducted to support the CCRA, at present approximately 1.8 million people across the UK are estimated to be living in areas at or greater than a 1 in 75 (1.3%) annual chance of river, surface water or coastal flooding. The population living in areas at or greater than a 1 in 75 risk of flooding is projected to rise to 2.6 million by the 2050s under a 2°C scenario and 3.3 million under a 4°C scenario assuming low population growth and a continuation of current levels of adaptation. As well as risks to life and property, flooding causes long-term damage to health, wellbeing, livelihoods and social cohesion. There is uncertainty regarding the total social and economic cost of flooding in the UK. Significant central government investment is already underway, and further action will be required to maintain current flood risk levels in a future with climate change and population growth. Currently, the uptake of property-level flood protection and sustainable urban drainage systems to reduce the impact of flooding is low. The rate of development in the floodplain in England declined slightly in 2008 – 2014 compared to 2001 – 2007. Similar data are not available for the devolved administrations.

PB8: Risks to culturally valued structures, sites and landscape

- Climate change may lead to the loss and damage of culturally important sites and structures that would have cultural and community significance. This may be particularly acute in coastal areas. These risks are not well assessed.

PB6: Risks to the viability of coastal communities from sea-level rise

- Sea-level rise will increase the risks of coastal flooding and potentially the viability of some coastal communities in the future. Due to the long time frames required for investment, the social and economic impacts of sea-level rise are already apparent in some locations. Communities are at risk of economic blight in the absence of plans to manage coastal change, including the effects of coastal flooding and coastal erosion.

PB1/ PB10: Risks to health and wellbeing from high outdoor temperatures and from poor air quality.

- Climate change is likely to add to the urban heat island effect in increasing outdoor temperatures in high density urban areas. The effects of climate change on local air quality are complex and uncertain, as they are likely to depend on topography, atmospheric chemistry and emissions from transport systems.

PB3: Opportunities for increased outdoor activities

- There may also be opportunities associated with higher temperatures. For example, outdoor activities may become more attractive, with perhaps an increase in active travel and other types of physical activity, which would also benefit health and wellbeing. However, there is very little evidence that considers these potential opportunities.

PB14: Risk of household water supply interruptions

- Climate change may create conditions that favour the development of droughts. Temporary use bans may become more common. There are large uncertainties related to the future incidence of droughts and the capacity of water companies to address them.

This section describes the current impact on communities from extreme weather events and other climate hazards, and how these climate risks may change in the future. This section focuses on issues that are within the remit of decision makers responsible for planning and development.

5.2.1 Policy framework: land-use planning and emergency preparedness

Land-use planning

As the primary policy mechanism for shaping the location and composition of settlements in both the near and long term, land-use planning has a key role to play in enabling communities to adapt to climate change. Planning policy across the UK is devolved and 'localised'; it has the potential to support adaptation through reducing flood risk, managing coastal change and improving urban environments.

England

Development Plans in England are at the core of the land use planning system and include the Local Plan, neighbourhood plans and, in London, the London Plan. Local Plans contain a vision for the sustainable growth of local communities and identify the areas where new development is either encouraged or not allowed. Local Plans should be consistent with national planning policy, which is principally set out in the National Planning Policy Framework. Under the Localism Act 2011, local authorities also have a duty to co-operate with neighbouring authorities in the delivery of their land-use planning functions.

All Local Plans go through consultation and are examined by an independent inspector at public inquiry. Only once the Plan has been through this examination and found to conform to the NPPF, can it be formally adopted. Individual planning applications must be determined in accordance with the development plan, unless material considerations indicate otherwise.

Paragraph 94 of the NPPF requires that local planning authorities adopt proactive strategies to adapt to climate change, taking full account of flood risk, coastal change and water supply and demand considerations in their Local Plans. This is supported by planning practice guidance, including guidance on climate change which also considers risks from rising temperatures.[4] Local Plans should therefore aim to ensure that new development is planned to avoid increased vulnerability to the impacts of climate change. The Environment Agency produces guidance on climate change for planners.

The NPPF also outlines how Local Plans can promote healthy communities, include access to open spaces, and avoid development on existing open space (commonly known as greenfield sites).

The Localism Act (2011) made changes to the planning system on three levels:

- Strategic: The regional tier of planning was abolished and replaced with a new 'duty to co-operate' between neighbouring authorities in relation to the sustainable development of land. London has a London Plan that includes consideration of adaptation.
- Local: Contents of Local Plans are shaped by the NPPF.

4 planningguidance.communities.gov.uk/

- Neighbourhood: The Act introduced a voluntary neighbourhood planning process, including Neighbourhood Development Plans (NDPs) and Neighbourhood Development Orders (NDOs).

Thus, planning policy varies significantly at the local level. Further, there has been limited time for evaluation of Local Plans in relation to either local or national adaptation objectives (ASC, 2015). A review of Local Plans, commissioned by the ASC (LUC and JBA Consulting, 2015) found that most did include strategic policies that identify climate adaptation measures, however, these were mostly in relation to flooding. A review of planning applications found that flooding was the only climate risk taken into account in recommendations by local planning officers (LUC and JBA Consulting, 2015).

Northern Ireland

Regional Development Strategy 2035 (RDS) (Department for Regional Development, 2012) has a statutory basis and sets out the framework for the spatial development of Northern Ireland up to 2035. The RDS is cross-cutting with linkages to other key government policies and statutory legislation.

The Strategic Planning Policy Statement for Northern Ireland (SPPS) provides a strategic planning policy framework for the reformed two-tier planning system which became operational on 1 April 2015. It applies to the whole of Northern Ireland and its provisions must be taken into account by Councils in the preparation of Local Development Plans and is material to all decisions on individual planning applications and appeals. The aim of the SPPS in relation to flood risk is to prevent future development that may be at risk from flooding or that may increase the risk of flooding elsewhere. The SPPS is in general conformity with the RDS 2035.

The Northern Ireland Executive's commitment to sustainable development and healthy communities is represented by the SPPS's policy for 'Open Space, Sport and Outdoor Recreation', which provides for the protection of open space, the provision of new areas of open space in association with residential development and the use of land for sport and outdoor recreation.

Scotland

The Scottish Planning Policy (SPP) (Scottish Government, 2014c) addresses nationally important land-use planning matters. It is non-statutory, although Section 3D of the Town and Country Planning (Scotland) 1997 Act requires that functions relating to the preparation of the National Planning Framework (NPF) by Scottish Ministers and development plans by planning authorities need to contribute to sustainable development. Scotland has a statutory National Planning Framework 3 (NPF3) (Scottish Government, 2014b) which is a spatial strategy for Scotland's long-term development strategy including the Government Economic Strategy (Scottish Government, 2015). Local authorities are also required to consider the NPF3 as they work with community planning partners to take forward their Single Outcome Agreement. The Scottish Government considers that the NPF3 and the SPP (Scottish Government, 2014c) should be applied together at the national, strategic and local levels to deliver the Government's vision of a planning system for Scotland.

Wales

The Wales Spatial Plan “People, Places, Futures” (Welsh Government, 2004) was updated in 2008. The 20-year plan that aims to ensure that future developments adhere to the principles of sustainable development. The Planning (Wales) Bill (National Assembly for Wales, 2014) aims to introduce a new legal framework for the Welsh Ministers to prepare a national land-use plan, the National Development Framework for Wales. The framework will set out national land-use priorities and infrastructure requirements for Wales. It will also make provision for the production of Strategic Development Plans, to tackle cross-boundary issues, such as housing supply and areas for economic growth and regeneration. There is also a Planning Policy Wales (PPW) (Welsh Government, 2014b) that sets out the land-use planning policies of the Welsh Government. It is supplemented by a series of 23 Technical Advice Notes.

Emergency planning and response

The Civil Contingencies Act (2004) created the UK’s first mandatory emergency planning system (Figure 5.6). At the national level, individual departments or agencies within each of the four UK countries have responsibility for advising on and preparing for weather-related emergencies. For example, in England, Defra leads on flooding and drought, and the Met Office on heatwaves and cold snaps.

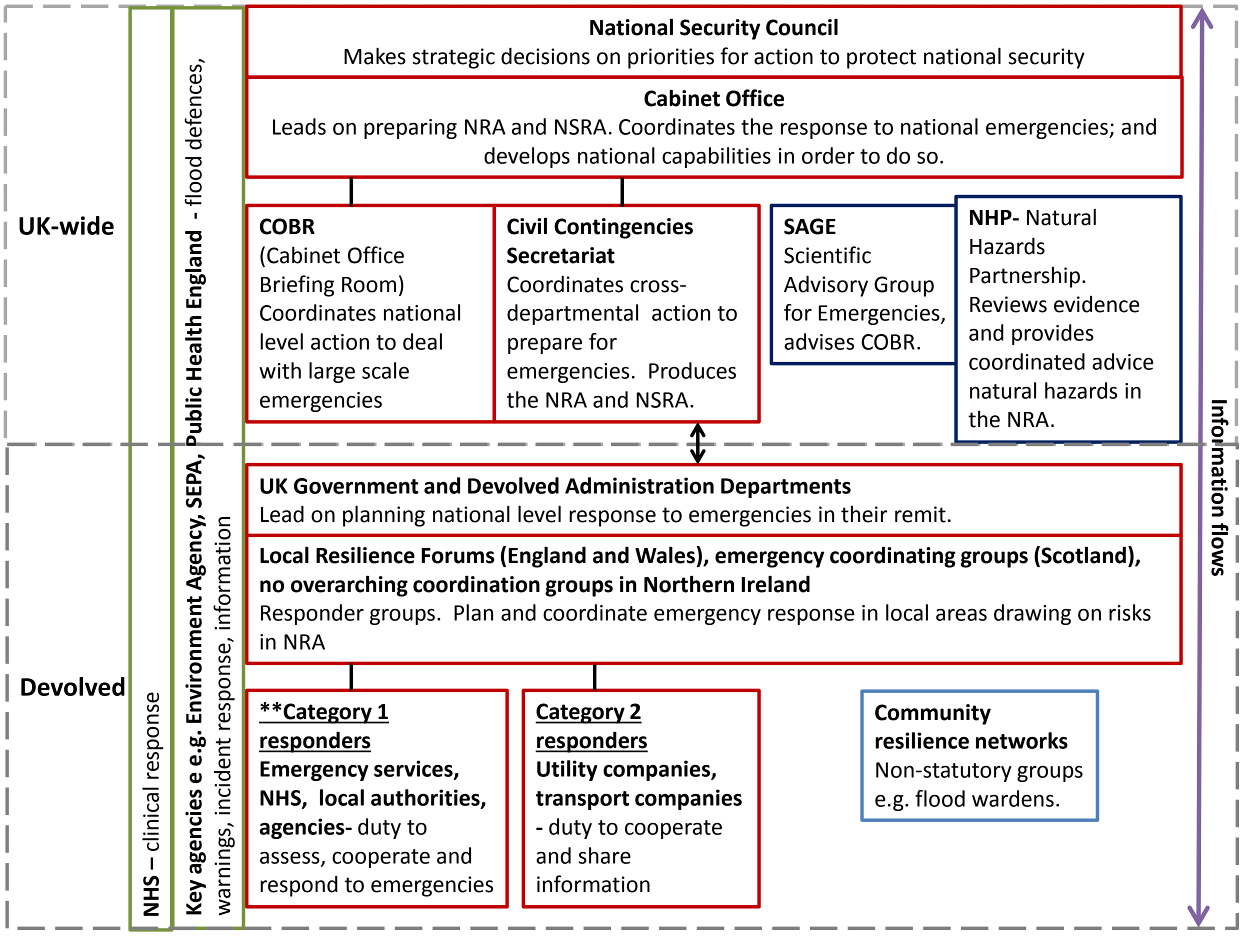
National-level risks that inform prioritisation and planning are set out in the National Risk Assessment (NRA), which is co-ordinated and published by the Cabinet Office on a bi-annual basis (Cabinet Office, 2015a). The NRA has a five-year appraisal period, and therefore risks considered do not include future changes in occurrence or intensity due to the effects of climate change.

The National Security Risk Assessment (NSRA) covers risks to UK interests, both domestically and internationally, over a 20-year appraisal period. The NSRA includes consideration of how climate change affects and may exacerbate existing risks (Cabinet Office, 2015b).

Short-term risk is communicated to the UK public primarily via: centrally organised initiatives such as the Heatwave Plan for England (PHE); the publishing of the public-facing National Risk Register by Cabinet Office; and the publishing of community risk registers at the local level by Local Resilience Forums (or devolved equivalents).

At the local level, emergency response is delivered differently in the four UK countries. In England and Wales, the response is led by category 1 and category 2 responders that are designated in the Act, and that together form Local Resilience Forums (LRFs). At the local level in Scotland, three Regional Resilience Partnerships based on current police force areas promote effective planning for all types of incidents in their area. In Northern Ireland, incidents are handled at a local level by the individual emergency services, district councils, health and social care bodies and other locally based organisations, without an overarching co-ordination group. The four UK countries have a number of accompanying local strategies and guidance documents that consider emergency planning and response.

Figure 5.6. UK emergency planning system



5.2.2 Urban heat islands and urban air quality

The design of urban environments has a large influence on the scale of air pollution and temperature gradients within urban areas. These factors all have implications for health and wellbeing and are likely to be affected by climate change. There has been a decline in urban green space in the UK (see section 5.1.5).

Policy framework

England

The National Planning Policy Framework for England does not specifically mention the urban heat island, but outlines more generally how planners should take account of the need to improve environmental quality and to promote healthy communities. This includes maintaining urban green space which is known to reduce urban heat islands. The NPPF directs planners to avoid development on greenfield sites. Local communities can also designate certain areas as Local Green Space, which precludes new development in those areas except in 'very special circumstances'. A review of Local Plans (LUC and JBA Consulting, 2015) did not find much evidence of strategies to reduce urban heat islands.

Northern Ireland

The Regional Development Strategy 2035 highlights the need to provide adequate provision for green and blue infrastructure in cities, towns and neighbourhoods, and new developments. The SPPS's strategic planning policy for 'Open Space, Sport and Outdoor Recreation', also provides for the protection of open space, the provision of new areas of open space in association with residential development and the use of land for sport and outdoor recreation.

Scotland

The Scottish Planning Policy (SPP) states that town centre strategies should identify how green infrastructure can enhance air quality, open space, landscape and settings, and reduce urban heat island effects. Its Third National Planning Framework (NPF3) highlights the importance of green space for people as well as the natural environment and prioritises the Central Scotland Green Network for further attention in the coming years.

Wales

The PPW allows local authorities to include policies for managing urban form by means of green belts and wedges. There should be a presumption against inappropriate development that would affect green belts and wedges. The PPW specifies that development proposals should include features that provide effective adaptation, including incorporating green space to provide shading and prevent overheating and to avoid the need for artificial cooling of buildings.

Urban heat islands

Current climate risks and adaptation

Urban heat islands (UHI) are a factor in many urban settlements and refer to the difference in temperatures measured inside and outside the urbanised area. High outdoor temperatures have impacts on thermal comfort, productivity (Chapter 6), energy use (see Chapters 4 and 6) and human health (see Section 5.5.3). Several studies have quantified the role of the built environment in increasing outdoor temperatures (Jankovic, 2013). The UHI intensity is typically higher at night than during the day and shows seasonal variation for most cities in the UK. The temperature increment at the centre of a large city can be as large as 5 – 10°C compared with the surrounding countryside (Stewart and Oke, 2012). The UHI effect may be considered as beneficial in winter, since it reduces somewhat the impacts on health from cold weather and heating demand. However, in summer, and especially during heatwaves, it may exacerbate building overheating since it prevents buildings from cooling down, particularly at night (Heaviside et al., 2015).

In the UK, urban heat islands have been modelled in London (McCarthy et al., 2010; Bohnenstengel et al., 2011; Taylor et al., 2015b; Barlow et al., 2014), Birmingham (Heaviside et al., 2015), Manchester (Levermore and Parkinson, 2015) and Glasgow (Emmanuel and Krueger, 2012). The measurement of the heat island depends on the urban heat island metrics chosen (e.g. peak UHI intensity) and the urban–rural reference points. The London UHI is generally found to be greater than those of other UK cities. There has been no increase in UHI intensity with the observed increase in mean temperature over the past 30 years (ASC, 2014), and this may be because rural temperatures are rising faster than urban temperatures (ASC, 2014). Wilby (2008) also found no detectable trend in UHI intensity in London since the late 1950s.

Urban heat islands may lead to assessments overestimating the space heating demand of core urban dwellings by up to 45% (Mavrogianni et al., 2009). Similarly, the heating and cooling load of a typical air-conditioned office located within the London UHI, may be up to 22% lower and 25% higher, respectively, compared with a rural location (Watkins et al., 2002; Kolokotroni et al., 2007). Variations due to site microclimatic factors also need to be taken into account (Kolokotroni et al., 2010). For example, overshadowing by adjacent buildings has the potential to decrease the cooling load by up to 14% more than at a rural site (Watkins et al., 2002, 2007).

Strategies to reduce urban heat islands include both building design (white roofs, green roofs) and urban design measures (planting trees, increasing green and blue space). For example, planting deciduous trees offers protection from solar heat gains in the summer, however, the selection of vegetation species in urban areas should be based on a range of considerations, including emission of pollen and biogenic volatile organic compounds, and energy demand for maintenance (Salmond et al., 2016). The benefits and effectiveness of green infrastructure is discussed in more detail in section 5.6 and Table 5.11.

Future climate risks and adaptation

Climate change will increase summer temperatures, adding to the urban heat island effect in urban areas. Table 5.3 reviews published studies on the interaction between climate change and urban heat islands for UK cities.

Urban heat islands may be beneficial during the winter, as temperatures are increased, because heating costs may be lower and, in theory, there may be reductions in cold-related mortality compared with a situation with a reduced UHI effect. Reducing the heat island intensity would therefore be advisable as long as it takes place alongside building energy retrofit that protects the occupants from low indoor temperatures.

Currently, none of the UK strategies outlined in Section 5.2.1 above makes more specific recommendations for reducing the urban heat island effect through planning beyond the provision of urban green space. This is despite the growing evidence regarding urban design and greening interventions to reduce heat islands. There are several potential win–win measures, i.e. measures that have benefits additional to temperature control (see Table 5.11).

Table 5.3. Studies on climate change and urban heat islands

City, Reference	Methods	Climate scenario	Results	Comments
London (Wilby, 2008)	Statistical Downscaling Model	Projections of both indices are derived from atmospheric variables supplied by four general circulation models, driven by a medium-high (A2) emissions scenario for the 2050s.	Intensification of nocturnal heat island and higher ozone concentrations, more pronounced in summer.	Implications for planning in London from the 2050s onwards.
Glasgow (Emmanuel and Loconsole, 2015)	Scenario-based assessment of urban model	UKCP09: six scenarios: (1). 2012 climate + current development. (2) 2050 climate, (3) 2050 climate with 'loss' of green infrastructure, (4–6). 2050 climate with 3 levels of green cover (+10%, +20%, +100% relative to baseline)	20% increase in green cover over present could eliminate third to half of the expected extra urban heat island effect in 2050, local reductions in surface temperature by up to 2°C.	Green infrastructure could play a role in mitigating the urban heat island
Birmingham (Heaviside et al., 2015)	High-resolution, regional meteorological Weather Research and Forecasting model, with urban canopy and Building Energy Parameterization scheme.	Year 2003 used as proxy for future warming.	During 2003: Birmingham centre UHI: heatwave 3.2°C with maximum 5.6°C. Wolverhampton: max UHI was 6.8°C.	High density areas enhance the effect of heatwaves, horizontal advection means areas downwind experience warming.
London, Birmingham, Glasgow Portsmouth (Kershaw et al. 2010)	Method to calculate UHI from gridded temp data; added to climate model projections	Climate scenario not stated	Approx linear association between temperature and urban fraction, especially in larger cities.	

Urban air quality

Outdoor air quality depends on the intensity of emission sources, primarily associated with road transport in urban areas, and on the atmospheric dispersion, deposition and chemical transformation of pollutants. The dispersion of air pollution depends on local weather conditions and the stability of the atmosphere. Increases in ground-level ozone concentrations in urban areas often occur during periods of hot and calm weather. In urban situations there are complex chemical reactions occurring between ozone and nitrogen oxides from vehicle traffic that may further increase or decrease either component (McMurry et al., 2004). High pollution episodes are caused by reduced atmospheric dispersion in high pressure episodes (associated with urban heat islands), static atmospheric conditions and temperature inversions (McGranahan and Murray, 2004). Section 5.5.5 discusses the impact of climate change on risks to health from urban air pollution in more detail.

5.2.3 Opportunities from warmer weather

There are opportunities associated with higher temperatures in communities and settlements. Climate change is increasingly recognised as a factor that may influence the recreational use of the outdoor and natural environment.

Very few studies exist to try to quantify this effect. One study suggests that the number of people taking part in outdoor recreational activities such as boating, golfing and beach recreation is estimated, under medium emissions scenarios, to increase by 14 to 36%, based on data from North America (Shaw and Loomis, 2008). A study in Switzerland estimated significant increases in the use of outdoor swimming pools (increase in annual number of visitors ranges from 9 to 19%, increases of more than 30% are expected for August and September) (Finger and Lehmann, 2012).

Observational studies have shown that active transport (walking) in children increases with higher temperatures and less rain (Oxford and Pollock, 2015). Cyclist volume is affected by weather factors (Sabir et al., 2008; Ahmed et al., 2010; Thomas et al., 2012). Strong winds and heavy rain are associated with decreased bicycle use but this effect is smaller in more experienced cyclists. Higher temperatures also increase the time spent out walking and cycling in older adults (Prins and van Lenthe, 2015). No studies were found that attempt to project future patterns of active transport as the climate changes due to warmer weather. Overall, walking and cycling could increase with warmer summers and active travel (walking and cycling) has significant benefits for health and wellbeing, as well as mitigation of climate change through reductions in car use (Woodcock et al., 2009).

Chapter 6 (6.6.2) describes commercial opportunities in the UK from warmer weather, particularly from increased tourism. In Scotland, Harrison et al. (2015) suggest that the improved summer climate in the highlands and a sunnier east coast could lead to greater consumer confidence conducive to outdoor activities and touring. In winter, the ski resorts could well continue to receive a reasonable supply of snow, while access roads may be less prone to blockage by snow and ice (ibid.).

At very high rates of warming, high temperatures could prevent some activities. For example, some sporting activities could be restricted on very hot days (see Section 5.5.3). There are also some potential disbenefits from increased outdoor exposure, such as increased contact with ticks (vectors of Lyme disease) and increased exposure to UV radiation. Moderate sun exposure is beneficial to health (via the production of vitamin D), however, too much sun exposure can lead to sunburn and an increased risk of skin cancer (Williamson et al., 2014).

5.2.4 Risks to community water supplies

Policy framework

Water supply in the UK is managed under the Water Acts of 2003 and 2014 (England and Wales), Water Resources (Scotland) Act 2013 and Water and Sewerage Services Order 2006 (Northern Ireland). UK water utilities are required to work with regulators (e.g. OFWAT, Environment Agency and their equivalents in Wales, Scotland and Northern Ireland) to provide long-term plans for public water supply that should account for increased demand, drought and climate change. Each company has to provide a set Level of Service, and the means to achieve this are set out in each company's Water Resource Management Plan (WRMP) which looks 25 years ahead. Through the WRMP, water companies address value for money of investments and the need to meet environmental requirements such as those set out in the EU Water Framework Directive. Both technical issues (leakage and storage capacity) and social issues (water consumption behaviours) are addressed.

Water companies are mandated to account for drought in their WRMPs. When droughts occur, emergency powers can be used to restrict water supplies and advice is issued to reduce consumption (e.g. temporary use bans, requests from water companies to re-use water for watering gardens). In England, security of supply has been increasing over time (ASC, 2011) but there is a lack of coverage of drought in Local Resilience Forum community risk registers (ASC, 2014). Similar data is not available for the devolved administrations.

Private water supplies are covered by separate legislation, with local authorities responsible for their regulation. The various Drinking Water Inspectorates in each UK country provide advice and guidance to local authorities. Local authorities do not have a duty to provide an alternative water supply should it become insufficient (e.g. during a drought), unless there is deemed to be a risk to health or life.

Current climate risks and adaptation

The UK has experienced repeated periods of low precipitation over time, with implications for public water supply (see Chapter 4). Some of these have lasted longer than anything experienced recently (e.g. mid-1880s to early 1900s). The most severe and widespread drought conditions in the UK in relatively recent times were those peaking in 1976 when nationally rainfall was 59% of the 1981 – 2010 average (Met Office, 2015). There was also a period of low rainfall beginning in 1995 which put public water supplies at risk in some areas. Rainfall patterns in the UK can be very variable; periods of low rainfall can be followed by periods of high rainfall as was experienced in 2011 – 2012 when a drought was followed by some of the wettest weather of recent decades (Marsh and Parry, 2012). There is no clear evidence that climate change has thus far increased the severity, duration or extent of drought conditions in the UK (see Chapter 1). It is also not necessarily the case that those regions of the country that are most prone to supply– demand deficits (see Chapter 4) are also those that might be affected most in a drought. For example, in 2012 a large number of areas around the country were declared in drought including Devon and Cornwall, the Humber, Staffordshire and South Yorkshire as well as London, Kent and Norfolk.

The most obvious community-level manifestations of drought are periodic temporary use bans (e.g. hose-pipe bans in southern and eastern England). Less frequently there are restrictions on the industrial and agricultural use of water that temporarily affect employment. Even more rarely there are restrictions on domestic supplies that can affect health and wellbeing, but standpipes have not been used in response to a drought since 1976. A range of health issues arise when tankers, standpipes and/or bowsers are used (PHE, 2014). Plans to avoid health and wellbeing impacts ensure that vulnerable individuals who need access to plentiful water are not adversely affected (e.g. dialysis patients or those with high laundry requirements). However, a community's ability to cope with severe droughts when standpipes need to be used is not well-researched in the UK as it is such a rare event.

Water supply interruptions can also be caused by flooding, problems with water quality (see Section 5.5.6) and cold weather. For example, Mythe water treatment works was unusable for 17 days as a result of flooding in July 2007, leaving around 140,000 residents without a household supply (EA, 2007). In winter 2010/11, 450,000 customers in Northern Ireland experienced supply problems due to pipe bursts (UREGNI, 2011).[5] Consequently, Northern Ireland Water took various steps to improve security of the supply as well as communication with residents.

Future climate risks and adaptation

Droughts are difficult to model because the science of estimating prolonged and extensive low rainfall patterns – for which multi-annual projections are required – is insufficiently advanced. Higher temperatures in the future will dry the ground (partly through increased evapotranspiration) and create conditions in which droughts become more likely (Chapter 1).

If droughts were to become more common, then the current approach to managing drought in the UK may need to change because it is based broadly on treating droughts as a – fairly rare – civil emergency. An integration of groundwater and surface water science (Boorman et al., 2012) suggests particular attention may be needed to water resources in south-eastern, eastern and midland England to avoid periodic use restrictions. Conversely, HR Wallingford et al. for the ASC (2015) found no clear picture of extreme dry events in the future across the UK. Changes in groundwater levels were projected to be minimal at the national level, although increases and decreases are found in different locations. For river flows, the projections suggest an increasing frequency of extreme dry events, though not for all locations and with a wide uncertainty range.

Alternative approaches for assessing and dealing with droughts have been examined in the EU context (Kampragou et al., 2011) and a high-level meeting of international bodies (WMO, 2013) concluded that a more rounded approach incorporating social as well as technical measures was required to deal with the risks from drought. These ideas and similar ones were elaborated by Wilhite et al. (2014) and, for Europe, by Rossi and Cancelliere (2013). These approaches explore how ideas on managing drought risks in ways other than as crises or emergencies might be more effective than simply building more storage capacity (e.g. Fisher et al., 1995). Such approaches might include consideration of different ways that science and evidence can interact with local governance arrangements when dealing with adaptation issues, including drought (e.g. Nelson et al., 2008).

Adaptation options in terms of designing the water supply system to maintain security of supplies are discussed in Chapter 4, section 4.5.

It is also not clear how water in public spaces could be managed in periods of drought (including the water bodies for recreation and sports which also help reduce outdoor temperatures). More research is needed to ascertain the degree of risk and potential for adaptation.

[5] www.northernireland.gov.uk/consolidated_report_-_freezethaw_2010-11_incident.pdf

Approximately 525,000 people in England,[6] 80,000 in Wales,[7] and 150,000 in Scotland[8] live or work in premises with a private water supply (the number for Northern Ireland is not known). Local authorities may step in to provide alternative supplies in times of drought for households with private supplies. However, this may not be practicable for large supplies and the responsibility remains with the owner of the supply to plan for interruptions.

There is also a lack of evidence on how supply interruptions may change in the future due to cold weather or flooding, though it would be expected that, over the long term, risks from cold weather would decline as winters warm, and risks from flooding would increase (see section 5.2.5). The risks to water treatment and supply infrastructure from flooding, cold and heat are covered in Chapter 4. Some water companies report to the UK Government on risks from climate change under the Adaptation Reporting Power, which will feed into the upcoming National Adaptation Plan.

5.2.5 Flood risk to communities

Flooding can cause loss of life, injury and ill health, damage to buildings and structures, and disruption to critical infrastructure. Flooding can have severe impacts on households and communities. Catastrophic flooding is a serious risk for the UK, and as such is one of the largest risks identified in the UK Government's National Risk Register. Flooding was identified as one of the most important risks from climate change in the first CCRA and it is also the climate risk most associated with climate change in public perception (Capstick et al., 2015). This section considers four types of flooding that affect the UK:

- **River:** flooding from a watercourse when water from an established river or drainage channel spills onto the floodplain (also referred to as fluvial flooding).
- **Coastal:** flooding from the sea when tidal surge, wave action or a combination of tidal surge and waves overtop or overflow the shoreline boundary – also covered in Section 5.2.6.
- **Surface water**: flooding directly from a rainfall event before the generated runoff reaches an established river or drainage channel (also called pluvial flooding).
- **Groundwater**: flooding from the ground caused by high groundwater levels.

More than one type of flooding can affect an area at any one time. Climate change is likely to affect both the likelihood and severity of all sources of flooding. The risk of flooding from sewers and reservoirs is considered further in Chapter 4.

This section discusses the potential impact of climate change on future flood risk and flood impacts on communities. Flood risks to the fabric of buildings are covered in Section 5.3.4, and the health and wellbeing risks to people are covered in Section 5.5.1. This chapter does not cover the cross-cutting risks from flooding when considered across many sectors, which are addressed in Chapter 8. Changing risks to infrastructure assets, including to flood and coastal defence assets themselves, are addressed in Chapter 4. Flood risk management policy for agricultural land and the natural environment is described in Chapter 3.

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6 https://www.salford.gov.uk/d/private-england.pdf
7 dwi.defra.gov.uk/about/annual-report/2014/pws-wales.pdf
8 www.gov.scot/Topics/Environment/Water/17670/pws

Policy framework

In the UK there is no legal duty or requirement for the government to provide protection from flood risk. However, since the 1930s legislation has provided extensive permissive powers to allow authorities to alleviate flood and coastal erosion risk because of the social and economic consequences (most notably the Land Drainage Acts, Coast Protection Act, and the Flood and Water Management Act/Flood Risk Management (Scotland) Act).

In 2007, a European Union Directive on flooding came into effect.[9] This put in place a consistent framework across Member States for the assessment and management of flood risk from all sources (i.e. rivers, the sea, surface water, groundwater and reservoirs). Under the Directive, Member States are required to undertake preliminary flood risk assessments for each river basin district to inform the preparation of flood hazard and risk maps and subsequent flood risk management plans. The Floods Directive has been transposed into legislation in each of the four countries: Flood Risk Regulations 2009 and the Flood and Water Management Act 2010 in England and Wales; the Flood Risk Management (Scotland) Act 2009; and the Water Environment (Floods Directive) Regulations (Northern Ireland) 2009.

The Water Act 2014 put in place arrangements for household flood insurance through the setting up of a re-insurance pool for high-risk households, known as Flood Re. This legislation applies at the UK level.

England

The Coast Protection Act 1949, Land Drainage Act 1991, Flood Risk Regulations 2009 and the Flood and Water Management Act 2010 provide the primary legal framework for flood and coastal erosion risk management in England (as well as Wales).

The Flood and Water Management Act gives the Environment Agency a strategic overview of the management of flood and coastal erosion risk in England. The Agency is required to develop a national strategy for flood and coastal erosion risk management, to review and update it and monitor its application. The Act specifies that the strategy must account for the current and predicted impacts of climate change on flood and coastal erosion risk management. The National Flood and Coastal Erosion Risk Management Strategy for England was laid before Parliament in 2011 (Defra and EA, 2011). It describes the roles of all organisations involved in flood and coastal erosion risk management. These include local authorities, internal drainage boards, water and sewerage companies, highways authorities and the Environment Agency. The 2010 Act also requires the Agency to prepare regular reports to ministers on the application of the national strategy (known as 'section 18 reports'). These have been produced every year since 2011/2012. A more comprehensive report to Parliament on progress under the national strategy is due from the Environment Agency in 2016.

The Act gave Lead Local Flood Authorities (LLFAs) responsibility for putting in place strategies for managing flood risk from groundwater, surface water and ordinary watercourses in their areas. The Act also included provisions to enable the widespread uptake of sustainable drainage systems (SuDS) in new development. In 2015 the planning system was changed to make the use of SuDS a 'material consideration' by planning authorities in deciding whether to approve or reject a development application, where the development is for ten homes or more. Local

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9 Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

authorities are free to adopt their own approach to implementing SuDS. For example, the Greater London Authority has consulted on a draft SuDS plan. LLFAs are now statutory consultees on planning applications in relation to surface water drainage.

The Act also provided for the creation of Regional Flood and Coastal Committees (RFCCs). RFCCs provide a degree of local democratic accountability for the delivery of flood and coastal erosion risk management within their areas. RFCCs consist of members appointed by LLFA and the Environment Agency, with a chair appointed by the Secretary of State. The consent of RFCCs is required before the Environment Agency's regional programme for their area can be implemented and the RFCCs can make decisions on the raising and spending of levies from their constituent local authorities.

The 2009 Regulations required the Environment Agency and LLFAs to prepare detailed assessments of the areas of highest flood risk by 2013 and flood risk management plans by the end of 2015. The plans must be reviewed in 2021, which should include an assessment of the likely impact of climate change on flood occurrence.

Central Government, through national taxation, is the primary funder of flood risk management activity in England. The majority of funding is provided by Defra to the Environment Agency as Flood & Coastal Erosion Risk Management Grant-in-Aid. The benefits and costs of managing risks across the country are appraised using guidelines based on the HM Treasury Green Book. Since 2012, the Government has been encouraging a partnership funding approach to flood defence (Defra, 2011b). Long-Term Investment Scenarios, published by the Environment Agency in 2014, provide an economic assessment of the costs and benefits of a range of different investment levels in flood and coastal erosion risk management for England in the future, taking into account population growth and climate change.

Flood warnings in England, and Wales, are provided through the joint Met Office/Environment Agency Flood Forecasting Centre.

Northern Ireland

The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009 transposes the EU Flood Directive. Flood risk management and drainage functions are delivered by the Rivers Agency, a Division of DARD (Department of Agriculture and Rural Development).

The timeline for implementation of the Regulations is the same as set out in the Directive, and therefore consistent with the rest of the UK. A preliminary flood risk assessment for the North Eastern river basin district and those parts of the three international river basin districts shared with the Republic of Ireland was completed by 2011. These have identified Significant Flood Risk Areas that will form the basis for further mapping and planning.

Northern Ireland's Strategic Planning Policy Statement was published in September 2015, and contains requirements on climate change adaptation and mitigation. The main adaptation provisions include avoiding development in flood risk areas, retaining and restoring natural floodplains and promoting integrated flood risk management.

Flood warning and informing activities in Northern Ireland as yet do not extend to the provision of a flood forecasting centre or flood guidance statements. However DARD (now DfI) Rivers Agency provides key expertise to fellow drainage agencies and other responders on the potential flood impacts associated with heavy rainfall weather conditions. In relation to coastal flooding, the Agency liaises with the UK Coastal Monitoring and Forecasting Service regarding the likelihood of tidal surges and will inform fellow responders should there be potential tidal conditions which could lead to serious coastal flooding.

Scotland

The Flood Risk Management (Scotland) Act 2009 transposed the EU Floods Directive. Part 3 of the Act put in place a framework for the Scottish Environment Protection Agency (SEPA) to prepare a National Flood Risk Assessment (NFRA, first published in 2011) flood hazard and risk maps (first published in 2013) and flood risk management plans. The review of flood risk management plans in 2021 must account for the likely impacts of climate change. In 2015, SEPA published 14 new flood risk management strategies for each Local Plan district. These will be transposed into delivery plans called local flood risk management plans in 2016.[10]

The Act also gives local authorities a 'general power' to take forward a full range of flood risk management measures.

The Act provides SEPA with new statutory framework for delivering its flood risk management functions. Under the Water Environment (Controlled Activities) (Scotland) Regulations 2011, it is a general requirement for SuDS to be installed where new developments have surface water that drains into the water environment in order to protect water quality. Where legally required, SuDS should manage surface water drainage up to a1 in 30 year rainfall event and protect water quality. Not all SuDS are required to manage surface water flooding (up to the 1 in 200 year rainfall event in Scotland). Surface water drainage in Scotland falls under water company and road authority responsibility for sewers and roads respectively, while surface water flooding falls under the responsibility of flood authorities (see chapter 4 for discussion on surface water drainage).

Flood warnings in Scotland are provided by SEPA through the Scottish Flood Forecasting Service.

Wales

As noted above, the Flood Risk Regulations 2009 and Flood and Flood and Water Management Act 2010 apply to both England and Wales. The Regulations were amended in 2011 in relation to Wales. Under the Act, Welsh Ministers are responsible for preparing a national strategy. This was set out in the National Strategy for Flood and Coastal Erosion Risk Management in Wales published in April 2012.

In April 2013 Natural Resources Wales took over the functions of Environment Agency Wales. Since then the remit of key organisations mentioned elsewhere, particularly the Environment Agency and Defra, do not include Wales. However guidance issued by the latter for project appraisal is still used to assess options, determine cost-benefit ratios and justify a preferred option.

The Welsh Government did not adopt the English position on partnership funding. Prioritisation is currently based on the level of flood risk determined from flood risk mapping and recorded in the Communities at Risk register. The Welsh Government has recently consulted on a new approach to prioritising projects within a national Flood and Coast Investment Programme (FaCIP), based on generating a flood risk index for each community (Welsh Government, 2014a).

[10] https://www.sepa.org.uk/media/162585/frm_work_together_leaflet.pdf

The majority of funding for flood and coastal erosion risk management in Wales is via Welsh Government grant-in-aid to Natural Resources Wales and Lead Local Flood Authorities. National planning policy also seeks to direct new development away from areas of high flood risk and states that proposals for highly vulnerable or emergency services development in such areas should not be permitted. There is also a requirement for all new development to consider the impacts of climate change on flood risk over the lifetime of the development. Consideration of a range of extreme flood events is required, including those with a 0.1% (1:1,000 year) probability of occurrence (correspondence from Natural Resources Wales). Other Welsh Government administered sources include the Wales Infrastructure Investment Plan (WIIP) and the European Regional Development Fund (ERDF). In addition Dwr Cymru (Welsh Water) invests a proportion of its asset management programme to reduce the risk of sewer flooding to properties.

The Welsh Government plans to publish interim national standards on an advisory basis until such time as it determines the most effective way of embedding SuDS principles in new developments in the longer term.

Current risks and adaptation

The UK experiences recurrent flooding. During the major flood events of 2007, approximately 55,000 properties were flooded, around 7,000 people were rescued by the emergency services and 13 people died. For this event, insurers handled 180,000 claims and paid out over £3 billion, with 17,000 people having to be found temporary accommodation (Pitt, 2008). Flood damage to the Mythe water treatment works cut off supply to 140,000 people for up to 17 days (see above). Some 42,000 households also lost power. Regional-scale but less widespread flooding events have occurred in 1998, 2000, 2012 and the winters of 2013/14, 2014/15 and 2015/16. Localised but destructive flood events have occurred at Boscastle in 2004, Carlisle in 2005, Morpeth in 2008, Cumbria in 2009, Cornwall in 2010 and Newcastle in 2012. Very often in the UK, one flood event has several causes. For example, events in 2007 had a mixed river and surface water component and those of 2013/14 happened included river, surface water, groundwater and coastal flooding.

Methods of estimating flood risks.

Estimating changes in flood risk resulting from climate change is technically challenging, not least because there are gaps in the science of flood risk estimation.

Methods to estimate and manage current flood risk and to maintain management through suitable levels of investment (e.g. as expressed in the EA Long Term Investment Scenarios or LTIS; EA, 2014) cannot readily be extended far enough into the future for the purposes of this Climate Change Risk Assessment. They also cannot address the key policy question as to whether, at some point in the future, no amount of adaptation can remove the increased risk from climate change. This question is important as it affects the approach the UK and the Devolved Administrations will need to take to flooding as the climate changes.

Thus, to meet the needs of this Climate Change Risk Assessment, the ASC commissioned Sayers and Partners to use the Future Flood Explorer (FFE), a proprietary emulator of flood risk, to address policy questions about the role adaptation was likely to play in moderating flood risk for the whole of the UK. The report of this work is available as Sayers et al. for the ASC (2015) and can be accessed via: https://www.theccc.org.uk/publication/sayers-for-the-asc-projections-of-future-flood-risk-in-the-uk/.

It is important to recognise that for England, although both the FFE and LTIS use similar datasets as starting points the datasets are treated differently and thus the two very different approaches will have different results and draw different kinds of conclusions (see annex 5.A). Direct comparisons between Sayers and LTIS should not be made. The point of LTIS is to help plan investment. The point of the FFE work is to determine how future flood risk is likely to change and the scope for reducing the risk through a range of adaptation pathways. Relative comparisons between Sayers and LTIS can be made, say, to inform dialogue and debate about changes in risk over time and on the degree to which investment in various kinds of adaptation might be effective.

Estimating current flood risks

Accurate estimates for numbers of properties at risk are difficult to generate due to the lack of detailed mapping data and limited modelling studies. Flood risk also fluctuates based on both changes to flood defences and the populations exposed.

Sayers et al. for the ASC (2015) estimate that around 2.7 million properties in the UK are exposed to any degree of river, coastal or surface water flood risk, of which 860,000 are located in areas defined as being at or greater than a 1 in 75 chance in any given year.

Estimates for residential properties at risk in England vary between Sayers et al. (2015) and statistics used by the Environment Agency (EA, 2015) (Table 5.4) but are consistent for fluvial and tidal flooding (Sayers: 1.9 million; Environment Agency: 1.85 million). Environment Agency figures for properties at risk of surface water flooding are larger. Due to the fragmented and dispersed nature of surface water flood risk the threshold used to differentiate between properties at risk and those that are not has a large influence on the property counts at risk. Sayers also suggests there could be a larger overlap between those properties at risk of river and/or coastal flooding and surface water flooding. In Scotland, SEPA have also collated values for current levels of risk from across the Flood Risk Management Strategies, and their values are also provided in table 5.4 alongside the Sayers results.[11]

The majority of people living in areas at or greater than a 1 in 75 flood risk in the UK are in England; in many areas tens or hundreds of thousands of people are exposed. Parts of central Scotland, South Wales and the east coast of Northern Ireland also have significant populations living in high-risk flood areas (see also chapter 8).

There is uncertainty around these estimates both in relation to the absolute numbers of people and properties involved and the damage costs (see Box 5.4 for discussion of the sources of these uncertainties). However, the estimates remain the only ones available to use for a national risk assessment. More locally specific and/or high resolution information is available (such as LTIS and Scotland's Flood Risk Management Strategies) but these studies are not consistent at the UK level in terms of approach or outputs and so cannot be used to create a UK-wide estimate of risk. A summary of the different assumption in the estimates by Sayers et al. 2015 and LTIS (EA, 2015) are summarised in Table 5.A.

[11] SEPA figures are as follows: total no of residential properties at risk (all sources excluding groundwater) 1 in 10 = 21,000, 1 in 50 = 47,000, 1 in 100 = 66,000, 1 in 200 = 79,000, 1 in 1000 = 134,000. Figures taken from http://apps.sepa.org.uk/FRMStrategies/

Table 5.4. Estimates of the number of residential properties and people located in areas at risk of flooding (2014)

	England	Wales	Scotland	Northern Ireland
Total number of residential properties	20.2 million	1.2 million	2.5 million	1.5 million
Number of residential properties located in areas at any degree of risk	Sayers et al., 2015: 2.3 million (11%) Environment Agency, 2015: 1.85 million (9%) for fluvial and tidal, 2.4 million (12%) for surface water[12]	160,000 (13%)	180,000 (7%) SEPA figures: 134,000 (5%)	56,000 (4%)
Residential properties in areas at a greater than 1:75 annual chance of flooding	690,000 (3%)	51,000 (4%)	97,000 (4%)	23,000 (2%)
Number of people living in areas at a greater than 1:75 annual chance of flooding	1.4 million	95,000	200,000	56,000

Source: Sayers et al. (2015), table H-1. Numbers for residential properties in brackets for England are a comparison with Sayers et al. taken from Environment Agency (2015) Managing flood and coastal erosion risks in England.[13] Total number of properties is taken from Sayers et al. (2015), tables 6-3 to 6-6. Numbers in brackets are % of properties at risk compared with total number of properties.
Notes: Table shows the number of people and residential properties located in areas at risk from flooding by rivers, the sea and surface water for the present day. Groundwater flood risk is excluded.

Factors affecting estimates of flood risk

A large number of factors affect the way in which flood risk estimates can currently be used to manage the exposure of people and property to floods. Evidence about these is set out in the following sub-sections. These factors will also be relevant to how future flood risks are managed.

12 Note that some properties are at risk from both categories of flooding and so the two totals cannot be added together to estimate 'total risk from flooding'

13 https://www.gov.uk/government/publications/managing-flood-and-coastal-erosion-risk-april-2014-to-march-2015

Social and economic costs of flooding

Flooding has a wide range of impacts on communities. Social impacts of flooding include displacement from home, loss of work days, loss of school days and impacts on household income. The Pitt Review estimated the impacts on days of work lost and days of schooling lost (Pitt, 2008). The health implications of flooding are discussed in the health protection section 5.5.1 below.

Damage to critical infrastructure from flooding can have long lasting impacts on affected communities. Chapter 4 describes current and future risks to transport, solid waste, energy and water infrastructure from flooding.

Displacement following flooding can be long term and represents a significant burden on affected households. A study in Hull found that a very high proportion (59%) of flooded households were displaced (Milojevic et al., 2014). Twelve per cent of displaced households remained out of their homes for longer than a year, a further 5% for more than 2 years. A review of the 2007 floods in England estimated that 25% of flooded households were displaced (approximately 17,500 of 65,000), with 3% (1,953 households) still displaced 12 months after the flood (Chatterton et al., 2010).

Research shows that the impacts of flooding can be felt months and years after the event. Further, it is not a simple linear recovery through gradual improvement in wellbeing. Individuals affected by flooding may experience a 'recovery gap' – the period when the legally defined arrangements provided by the local authority diminish and before the less well-defined services provided by the private sector (e.g. insurance and builders) emerge (Whittle et al., 2010). People's experiences of recovery is also linked to the ways in which they are treated by the different companies and organisations involved in the recovery process (Whittle et al., 2010).

The costs of flooding to households is, to some extent, covered by insurance. The private insurance market has in recent decades provided cover for flood insurance, with prices for high-risk households kept affordable by uncertain flood risk models, reputational concerns among insurers and the added transaction costs of identifying high-risk households (Defra, 2013c). At present there are no plans to incentivise high-risk households to implement flood protection measures through Flood Re (ASC, 2015).

Flooding effects on low income households

Flood risk, flood exposure and response following flooding all vary by socio-economic group but the findings are complex. In England, analysis using EA data (1995 – 2006) to identify actual flooded areas has shown no significant difference in who gets flooded by household income groups (across England as a whole) (Milojevic et al., 2011).

Studies where flood risk (but not actual flooding) is mapped indicate that there are regions that may be particularly disadvantaged by flooding. For example, in England, poorer communities are often at higher risk of coastal flooding (but not riverine flooding) (Walker et al., 2003; Walker et al., 2006). In Scotland, low income regions are particularly vulnerable to flooding (Kazmierczak and Cavan, 2011). Chapter 8 contains more details on the distributional impacts of flooding.

A review of inequalities associated with environmental risks in Europe found very little quantitative research on the distribution of flood exposures or flood impacts on health and wellbeing (Braubach and Fairburn, 2010).

Flooding and community resilience

The Pitt Review concluded that there were serious failings in the management and response to flood risks and identified specific measures to improve the response to flooding and the resilience of communities (Pitt, 2008). As a result, the concept of resilience was picked up in the Strategic National Framework on Community Resilience (Cabinet Office, 2011).

Several qualitative studies have been undertaken on the resilience of flooded communities in the UK and other countries (Werrity et al., 2007; Walker et al., 2011). Research on resilience at the community level has focused on networks and relationships between people, essentially providing resources and processes that enable groups of people to be resilient rather than individuals (Twigger-Ross et al., 2014). Work in Australia shows the importance of social capital within flooded towns and the strength of community networks in building resilience (Keogh et al., 2011). Case studies in England find that flooding can have both positive and negative effects on social cohesion, even within the same communities (Butler et al., 2016). It is also clear that flood impacts have effects beyond the impact of individual households, for example, box 5.3 describes how damage to transport infrastructure can disrupt communities for an extended period.

While some studies have shown that prior experience of flooding leads to increased uptake of protective actions (Tunstall et al., 2006; Fielding et al., 2007; Twigger-Ross et al., 2014), anxiety about future flooding has also been shown to be a barrier to householders undertaking flood protection (Harries, 2008; Harries, 2012; Walker et al., 2011). A review of academic literature on resilience found that "only a very small proportion of flood victims are prepared for a future event. The causes of low preparedness range from an understandable wish to move on and reduce anxiety, to feeling that one cannot do anything about flooding" (Fernandez-Bilbao and Twigger-Ross, 2009). Further, it has been argued that flooding can cause a change in the long term outlook of individuals (Butler et al., 2016).

Comprehensive evidence on community impacts is lodged in local and national media reports, as well as qualitative research and small scale surveys, and has not been systematically collected or reviewed. Many areas across the UK have their own community flood groups and forums that aim to increase community resilience. In general they are advised by national bodies such as the National Flood Forum and Scottish Flood Forum.

Box 5.3. Flood impacts from bridge and road collapse on communities

In the storms of winter 2015 - 2016 in the north of the UK, at least 22 bridges were closed temporarily, collapsed, or were severely damaged (see more details in Chapter 4). As a consequence, communities were divided, or even cut off with severe implications for the local population, including difficulties in accessing employment, health services, and education. Communities were affected by collapsed or badly-damaged bridges in Pooley, Tadcaster (Grade II listed), Elland (Grade II listed), damage to the New Invercauld Bridge (Grade B Listed); the collapse of Copley Bridge (Grade II Listed) and a bridge between Collingham and Linton (Grade II listed)[14]. The impacts of flooding on historic structures is discussed in more detail in Section 5.3.8.

Damage or collapse of roads have similar impacts for communities (for example, the A591 and A592 in northern England and the A93 in Scotland). Footbridges can have similar although less severe impacts on communities, although tourism might be adversely affected. Footbridges destroyed or damaged in this period include: the Cambus O'May footbridge over the River Dee; Fitz Footbridge in Keswick; the suspended footbridge at Allen Banks in Tyne and Wear; and former railway bridges on the old Cockermouth Keswick and Penrith Railway.

Recovery can take months. Damaged bridges are often in town centres and so can be difficult to repair quickly because of nearby buildings. In Cumbria, 13 road bridges and 7 footbridges remained in the lost or closed category and 15 road closures (some of a kilometre and more) were still in place in February 2016 following the winter floods[15].

Evidence on current adaptation

This section discusses the evidence in relation to the main strategies to reduce the impacts of floods on people and the built environment:

- flood defence spending on river and coastal structures;
- avoiding new development in flood risk areas;
- surface water management;
- natural flood management;
- property-level protection (PLP);
- emergency planning and response, and strategies to increase community resilience

Various studies, covering a range of circumstances, typically show that flood prevention measures are cost effective – both hard defences (Poussin et al., 2012; Aerts et al., 2014; Bouwer et al., 2014) and early warning (Pappenberger et al., 2015).

Flood defence spending

In England, around £2.55 billion was allocated by Central Government to flood and coastal erosion risk management over the last spending period (2011/12 to 2014/15). This provided new or refurbished defences to over 180,000 homes (3.5% of those at risk) as well as defence maintenance, and support for flood warnings and development control.

14 www.bbc.co.uk/news/uk-england-leeds-35217446 ; happypontist.blogspot.co.uk/2016_01_01_archive.html
15 www.cumbria.gov.uk/floods2015/roadclosures.asp

Recent flood events have led to increases in both capital and revenue funding that are consistent with the long-term assessment of optimal expenditure levels for England (EA, 2014). However, even if investment grows in line with the most cost-beneficial level set out in the Environment Agency's long-term investment scenarios, 40,000 more homes and other existing properties are expected to become at a high risk of flooding (1 in 30 annual chance or greater) from rivers and the sea by the 2060s as a result of climate change and ageing defences (EA, 2014). This would increase the number of properties in high flood risk areas in England from 240,000 to around 280,000. Longer-term projections for the latter half of the century within the 2014 LTIS suggest (with less confidence) that the number of properties in areas of high flood risk may begin to fall, if optimal investment continues and the impact of new development on flood risk is assumed to be zero.

In Northern Ireland, spending on capital works by DARD (now DfI) Rivers Agency to provide new or improved river flood defences is approximately £8 million per year. Northern Ireland Water is also spending around £3 million per year in upgrading its sewerage systems to alleviate out-of-sewer flooding (correspondence from DARD). It is not known what effects this investment has had on the number of properties in areas at high risk of flooding.

In Wales, around £165 million was invested between 2011 and 2014 in flood and coastal erosion risk management. A significant proportion of the funding was Welsh Government grant aid provided to Lead Local Flood Authorities and grant-in-aid to Natural Resources Wales to deliver capital projects. This programme of works included the construction of new flood and coastal defences, significant maintenance works, modelling improvements, environmental mitigation/enhancement works and developing shoreline management plans (correspondence from Welsh Government). It is not known what effects this investment has had on the number of properties in areas at high risk of flooding.

Information on current investment plans and the impact on the number of properties at risk has not been provided for Scotland.

Avoiding development in flood risk areas

In England, around 250,000 new homes were built on the floodplain between 2001 and 2014 (ASC, 2015).[16] The majority (183,000) of these homes were in lower risk area (where annual chance of flooding is less than 1 in 200 once current flood defences are taken into account) and in towns and cities on rivers (e.g. London, York, Reading and Oxford) and on the coast (e.g. Hull, Southampton, Portsmouth and Bristol). Approximately 68,000 new homes (3% of all new homes in England) were built in areas with a 1 in 100 or greater annual chance of flooding. Of these, 23,000 were built in areas of high flood risk (a 1 in 30 or greater annual chance of flooding even accounting for flood defences if they are in place). Communities with a relatively high

[16] The ASC's 2012 progress report included original spatial analysis of the number of addressable properties in England built in areas at risk of (a) river or coastal flooding, (b) coastal erosion and (c) surface water flooding between 2001 and 2011. This analysis was updated for the purposes of the ASC's 2015 progress report. For river and coastal flooding, the Environment Agency's 2014 National Flood Risk Assessment (NaFRA) flood hazard data was used. This defines four categories for the annual chance of the onset of flooding from rivers or the sea, after accounting for the presence of flood defences: high (greater than 1-in-30 annual chance), medium (1-in-30 to 1-in-100 annual chance), low (1-in-100 to 1-in-1,000 annual chance) or very low (less than 1-in-1,000 annual chance). For the purposes of this chapter, the term 'floodplain' refers to the combined area at high to low likelihood (i.e. excludes the 'very low' category. For further details of the technical method taken see HR Wallingford (2015) for the ASC. www.theccc.org.uk/publications/

proportion of new development in high flood risk zones since 2008 include Lancaster (5%), Warrington (7%), Doncaster (11%), Great Yarmouth (15%), Boston (23%), Lincoln (8%), Shepway (5%) and South Bucks (11%) (HR Wallingford 2015).

Across England as a whole, there has been a slight reduction in the proportion of new development on the floodplain since 2008 but much local variation. Counties with an increase in floodplain development include: Cumbria, Cheshire, Worcestershire, Gloucestershire and Kent (HR Wallingford, 2015). The EA estimates that 280,000 new properties will be built in high risk areas by the 2060s (EA, 2014). The ASC estimates a higher figure of approximately 350,000 (ASC, 2015).

The actual risk of flooding inside a property depends on the characteristics of the site and the building design. National planning policy is clear that new developments in flood risk areas should be made safe for their lifetime, without increasing flood risk elsewhere, and appropriately flood resilient and resistant. Developers are responsible for commissioning detailed flood risk assessments for sites in areas at risk and proposing mitigation measures in terms of enhanced drainage and safe entry and egress routes. There are many anecdotal examples of development in flood risk areas that have incorporated appropriate design measures. However, developers, decision-makers and other authorities currently bear no long-term liability (at least in England and Wales) if flood risk assessments are incorrect or understate the true nature of the risk, and flooding subsequently occurs. Some Flood Risk Assessments are poor quality or missing from planning applications (ASC, 2014).

The Environment Agency has a statutory role to scrutinise planning applications in flood risk areas. Where the Environment Agency provides advice and is informed of the outcome, it is almost always followed, with only 4% of planning applications proceeding against a sustained objection by EA (HM Government, 2015). Similar figures on current and future development on the floodplain, and the quality and outcomes of planning applications are not currently available for the devolved administrations.

The Environment Agency is not able to respond to every individual planning application with bespoke advice. Thus, small-scale applications or changes of use are more likely to proceed with inadequate flood risk assessment (ASC, 2014). There are currently no routine data on developments that meet (or fail to meet) flood risk requirements. Continued development in flood risk areas also commits future generations to increasing investment in flood protection.

Similar figures on current and future development on the floodplain, and the quality and outcomes of planning applications are not currently available for the devolved administrations.

Surface water management

The key drivers affecting the severity of surface water flooding include the ongoing loss of permeable urban green space (see Section 5.1.5 above) and an ageing sewer network that is at or near capacity in many areas. Sustainable urban drainage systems (SuDS) include green roofs, rain gardens, tree planting, detention ponds, swales, permeable paving and rainwater harvesting. They increase local storage and infiltration of surface water, reducing the risk of localised flooding and reducing flows to conventional drains. As well as mitigating surface water flooding, SuDS can have benefits for biodiversity, air quality, ecosystem functioning, water resources and health and wellbeing (see Table 5.11, (Charlesworth, 2010).

In England, the uptake of sustainable drainage systems in new development is currently low (15% of development, AMEC (2014) for ASC) even though the planning system has prioritised the use of SuDS since 2007. The barriers to the widespread uptake of SuDS identified by the Pitt Review in 2008 (the automatic right developers have to connect new development to sewers, uncertainty over adoption of SuDS once built and who pays for their ongoing maintenance) have not been addressed.

In England, 71% of the respondents to the public consultation on the new approach to SuDS, subsequently introduced in April 2015, expressed doubt that the new approach would be effective in increasing SuDS uptake. LLFAs have made slow progress with developing local flood risk management strategies, a statutory requirement introduced by the Flood and Water Management Act in 2010. The ASC found that five years after the Act was passed, less than half of LLFAs had finalised a local flood risk management strategy (ASC, 2015). However, Defra reports that as at 31 March 2015, 102 out of 152 LLFAs in England had a strategy in the public domain; that is, where the consultation was in progress, has been completed or a final strategy has been published. There is some investment by water companies in retrofitting SuDS to alleviate the risk of sewer flooding, but this is not widespread (ASC, 2015).

In Scotland, flood risk management legislation promotes the implementation of a more sustainable and integrated approach to managing surface water (drainage and flooding), which includes a significant change away from more traditional hard engineering (e.g. underground storage) to manging water on the surface and reducing water in sewers using 'green and blue' infrastructure (including sustainable urban drainage systems). According to SEPA, coordination between the drainage and flooding authorities is happening in localised areas but needs to be improved.

There is a lack of information available on how surface water flooding is being managed in Northern Ireland and Wales.

"Natural" Flood Management

"Natural" flood management (NFM) practices are now widely promoted but actual uptake is low (see Chapter 3). A lack of evidence of their benefits for flooding is a recognised barrier to implementation (see wider discussion in Section 5.6.1). There has been a recent investment in research on the benefits of NFM for flooding and other environmental goals (e.g. biodiversity) as well as health and wellbeing. For example, a series of area trials are under way in Wales.[17]

In Scotland, the framework for delivering a more sustainable approach to flood risk management has been established in legislation under the Flood Risk Management (Scotland) Act 2009 (FRM Act). Under this Act, SEPA is required to work with local authorities and other responsible authorities to identify the most sustainable actions to manage flood risk, including natural flood management[18]. Delivery of actions, including more detailed assessments of the potential for natural flood management to help reduce flood risk, will be the responsibility of local authorities.

[17] https://naturalresources.wales/about-us/how-we-work/natural-resource-management-trials/?lang=en
[18] See http://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

Property-level protection (PLP)

Uptake of property-level protection (PLP) in England has been low (3,174 properties undertook PLP up to 2015, with 3,074 either planned or in the works for 2016 – 2021) (correspondence from Defra). Information on privately-funded PLP is not available.

In Wales, investment in individual property protection measures began in 2010/11, and since then over 600 properties have benefitted, including Dolybont, Lechryd and Cardigan in Ceredigion, with over £850,000 invested by Natural Resources Wales. They vary from permanent fixtures to demountable devices, such as flood gates, air brick guards and drain covers (correspondence from Natural Resources Wales). Analysis has not yet been done to consider what the cost-effective uptake of PLP in Wales would look like.

Uptake of PLP is also deemed to be low in Scotland, although actual uptake figures are not available (JBA consulting, 2014). The same report estimated that 43,000 properties located in areas at 1 in 25 to 1 in 30 flood risk could benefit from PLP and that uptake would be cost-effective. Some local authorities in Scotland provide subsidy/discount schemes for PLP (for example, Scottish Borders Council) and the potential for PLP has also been identified in the FRM Strategies.

The current uptake of PLP in Northern Ireland is thought to be low. There are no firm data available on this but it is known that a small number of homeowners at risk have arranged their own installations.

There are currently no financial incentives for individuals to implement PLP, for example through reduced insurance premiums. Defra's six-year flood defence investment plan (2014 – 2021) expects to support a further 1,800 homes with grant funding. However, the ASC estimates that PLP measures are likely to be cost-effective in 120,000 households (ASC, 2012). Flood Re, the forthcoming subsidised flood insurance scheme, will largely remove the financial incentive for high-risk households to take up PLP (ASC, 2015). Thus, Flood Re has been criticised by the ASC as counter-productive to the long-term management of flood risk (ASC, 2014).

Research on barriers to implementing household measures has shown that individuals may not want to accept that their home is at risk of flooding (Harries, 2012; Tunstall et al., 2006) (see also above).

Community resilience and emergency planning and response

Improving community networks and social capital is an important part of increasing resilience to flooding. Recent research has explored the role that individuals and communities can play in flood risk management. Some of this work involves consideration of the role of local decision-makers and other studies incorporate the use of cloud technologies as part of the engagement process while still others consider the factors that might need to be accounted for when communicating climate change risks. Such studies include those covering: concepts (Viglionea et al., 2014); uncertainties (Lawrence et al., 2013); rural areas bordering Scotland and England (Rouillard et al., 2014); individual households (Botzen et al., 2013); risk perceptions and behaviours (Bubeck et al., 2012); flood action groups in England and Wales (Geaves and Penning-Rowsell, 2015); and modern technologies to promote engagement of decision-makers and communities (Mackay et al., 2015). All these techniques, and others, may have a role to play in helping communities adapt to climate change risks.

It is important to understand how local authority strategic planning is translating into flood risk adaptation on the ground in communities. In England, Local Planning Authority Level Strategic Flood Risk Assessments and the Local Flood Risk Groups play a major role and rely on advice from the National Flood Forum. Some communities, such as Pickering in Yorkshire have acted to help design flood protection measures across a catchment (see Table 5.11 on use of green infrastructure). However, there is very little published evidence of the effectiveness of current response measures in specific communities.

At the regional level, Health and Well-being Boards (HWBs) and documents such as the Joint Strategic Needs Assessments (JSNAs) consider how hazards such as flooding may affect public health. However, Button and Coote (2016) found that flood risks were rarely addressed in JSNAs, although flooding can affect health and wellbeing and the delivery of health and social care services (see Sections 5.4.3 and 5.5.1).

Emergency response measures are not often formally evaluated, although local resilience fora will review and report on issues after a specific incident. There is a very limited evidence base regarding the current or required capacity for emergency response to flooding (ASC, 2014).

Future risks and adaptation

Projections of future flood risk

As this century proceeds, climate change is likely to increase the risk of several types of flooding. Projections of UK-wide future flood risk are presented in Sayers et al. for the ASC (2015). The approach used in the research to inform this report is based on an emulator called a Future Flood Explorer (FFE) to look at what future flood risk might be under a range of climate and population growth scenarios over three 30-year time periods centred on the 2020s, 2050s and the 2080s. It includes low and high population growth projections in which UK populations towards the end of the century are around 70 million or 90 million, respectively. Population growth is clearly a major determinant of increased flood risk (Figure 5.7), particularly if rates of population growth are higher in flood risk areas, such as areas of the coast. Future flood risk is also estimated for five future adaptation scenarios (AS1 to AS5).

Figure 5.7 shows projections of the number of people in each UK country at or greater than a 1 in 75 annual risk of flooding, under the full range of adaptation assumptions included in the model. Given the uncertainties in flood modelling, there is more confidence in the approximate percentage and sign of change, rather than in the absolute numbers (see Box 5.4 for a discussion on the uncertainties in flood projections).

Figure 5.7. Future populations at risk of flooding in the UK from Sayers et al. for the ASC (2015)

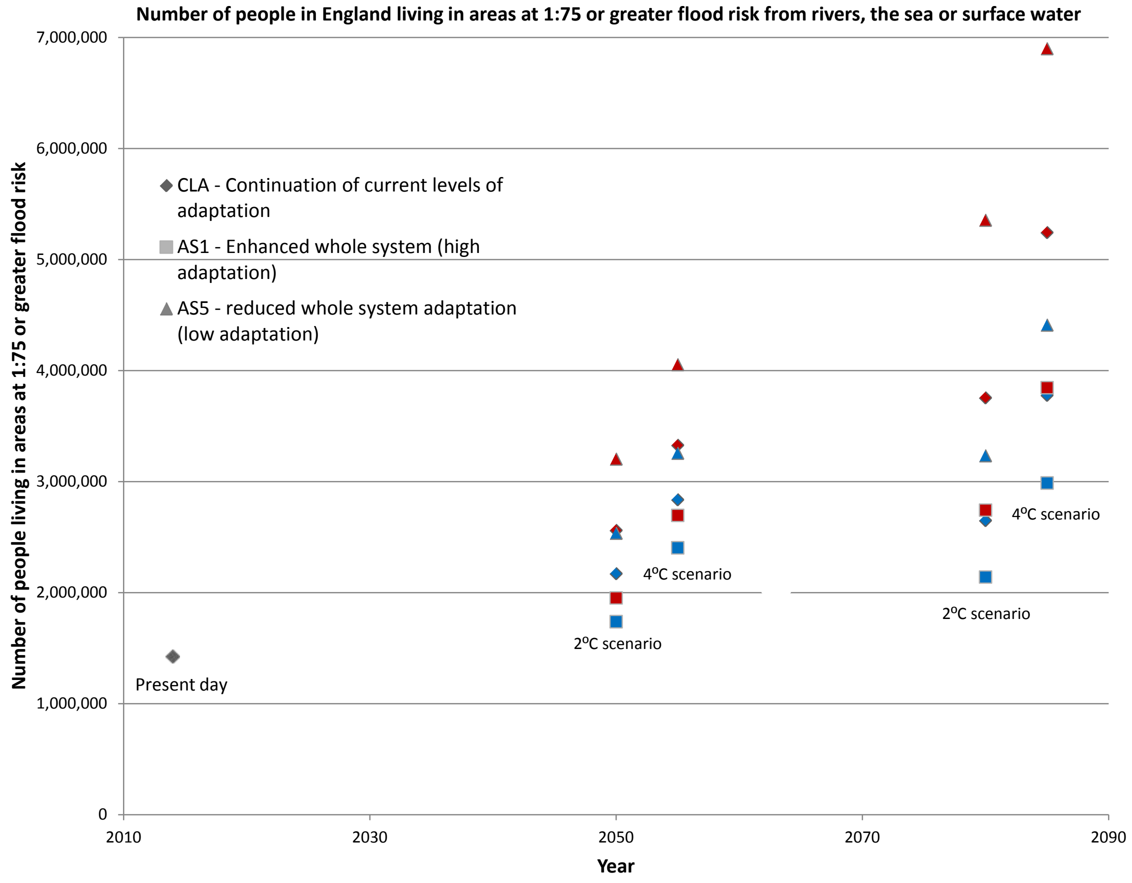


Figure 5.7. Future populations at risk of flooding in the UK from Sayers et al. for the ASC (2015)

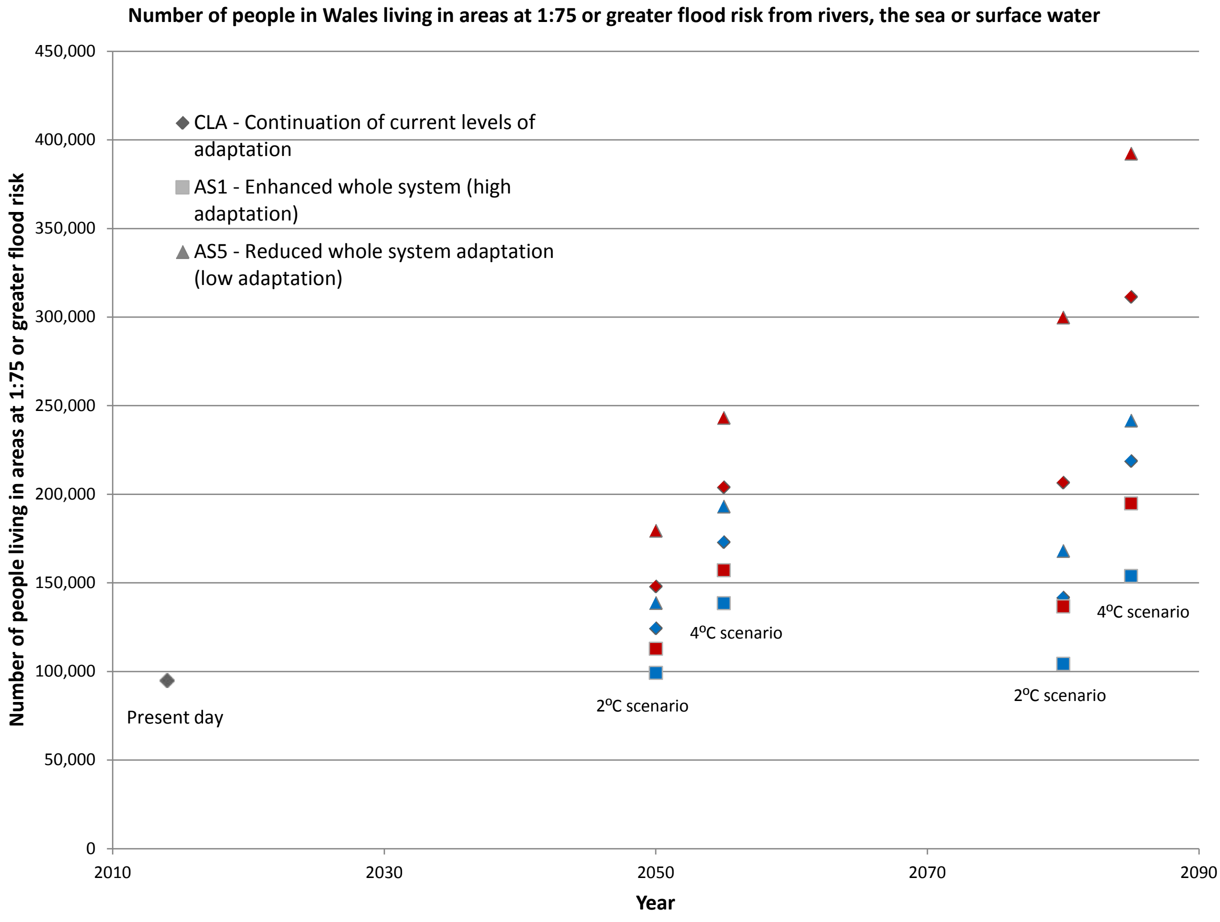


Figure 5.7. Future populations at risk of flooding in the UK from Sayers et al. for the ASC (2015)

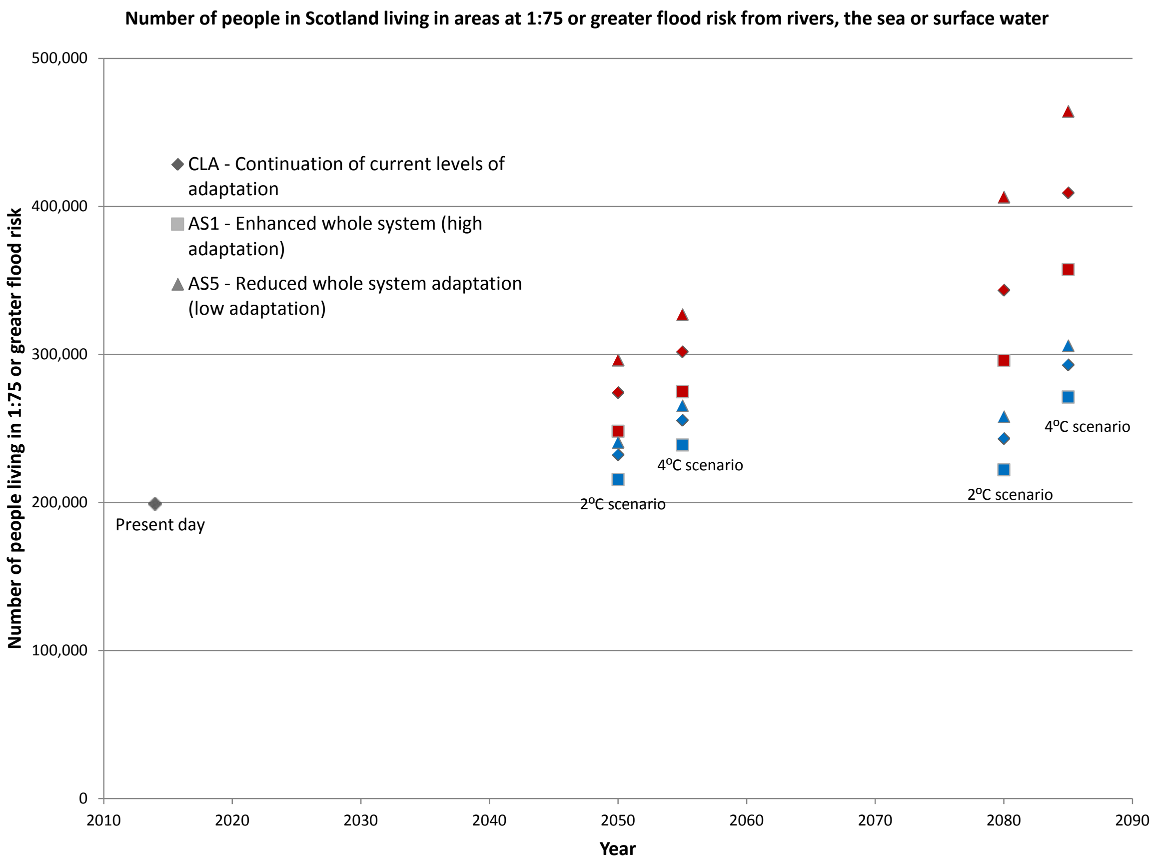
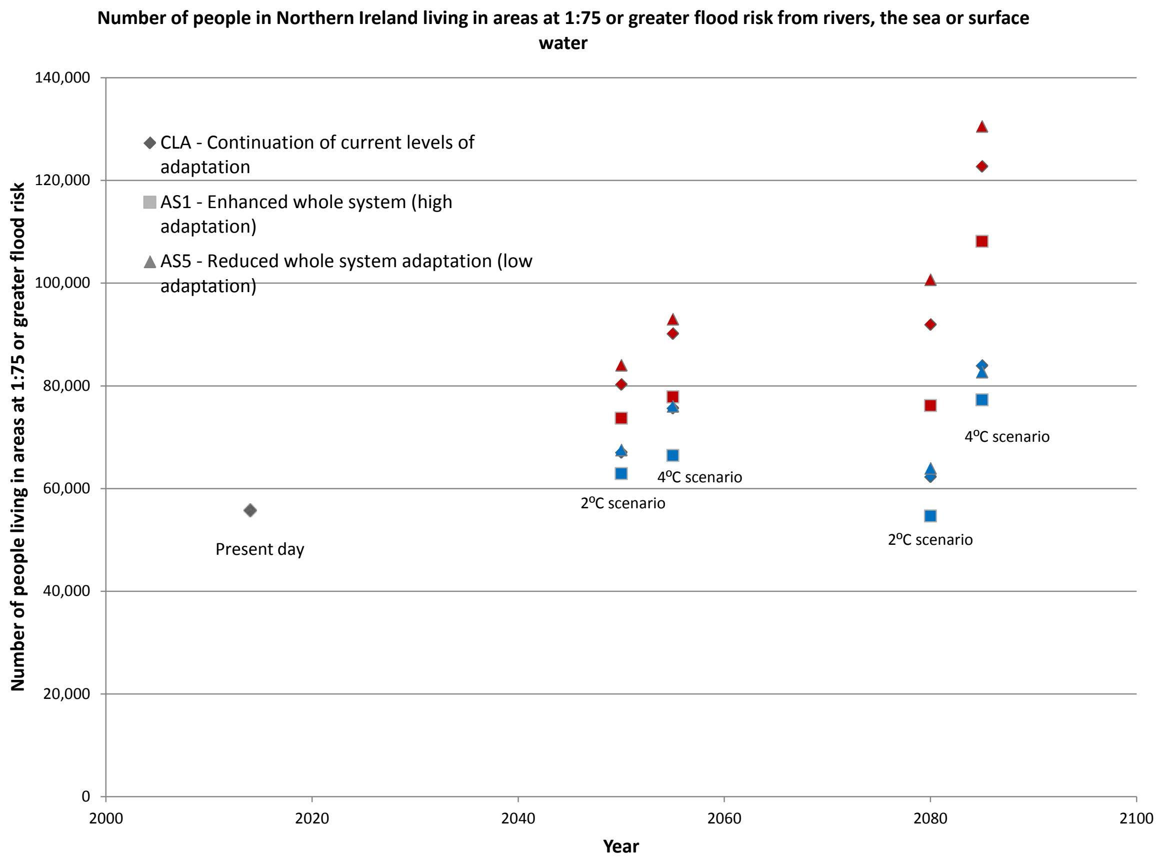


Figure 5.7. Future populations at risk of flooding in the UK from Sayers et al. for the ASC (2015)



Source: Sayers et al. (2015) for the ASC.
Notes: Each symbol represents a projection of future flood risk (river, coastal and surface water combined) for different combinations of climate, population and adaptation scenarios, for each of the four UK countries for the present day, 2050s and 2080s. Blue symbols denote projections with low population growth, red symbols with high population growth. Adaptation and climate scenarios are shown in the legend and on the chart. Scenarios for 2 degrees and 4 degrees are not conducted for different time periods but are offset slightly in the chart for clarity.

Projections of flooding up to 2050 can be based on evidence from several sources and there is also more confidence in assessing the potential for adaptation to reduce flood risks over this time period. Projections for this time period from the Enhanced Whole System scenario in Sayers et al. (2015) are broadly consistent for England with the 'baseline scenario' within the Environment Agency's Long-term Investment Scenarios (EA, 2014). The two studies both estimate future flood risk but contain different assumptions (described in annex 5.A) and answer different questions.

The aim of LTIS is to identify the most cost-effective level and regional spread of investment in flood defences in the future, whereas Sayers et al. estimates future flood risk under a range of different national-level adaptation scenarios. LTIS estimates that if investment of the order of £750 – 900 million per year (in 2014 prices) is undertaken between now and the 2060s, future flood damages will decrease by 12% (although as mentioned above more properties are expected to fall into the highest flood risk category). This scenario assumes there are no long-costs arising from continuing development in the floodplain (see above), and a medium emissions scenario. In both studies, the aggregate national result hides significant regional and local variation in long-term flood risk.

The analysis by Sayers et al. (2015) reaches a similar conclusion, with expected annual damages (EAD) potentially being reduced by 11% under the 2°C scenario if 'Enhanced Whole System' adaptation is pursued between now and mid-century. Note that Enhanced Whole System Adaptation includes measures such as householders taking action on property level protection as well as local action to build community resilience, perhaps led by local authority bodies, forums and networks (see discussion above about the effectiveness of these activities). Figure 5.7 focuses on the number of people at risk rather than expected annual damages, and in the enhanced whole system scenario for the 2050s the number of people living in areas at risk increases slightly across the UK. In the enhanced whole system scenario, the beneficial effect on expected annual damages comes from adaptations such as take up of receptor level protection, forecasting and warning, and these measures do not influence the numbers of people affected. Therefore, although the number of people at risk increases, expacted annual damages decrease in this scenario.

Figure 5.7 illustrates that under a scenario of lower levels of adaptation than currently used (Reduced Whole System Adaptation [AS5]) there would be a dramatic increase in the numbers of people exposed to flood risk around mid-century. This is a representation of a plausible retreat from major intervention by the state to counter flood risk even at current levels, and it is presented as a "worst case scenario" with which to compare policy alternatives.

The impacts of climate change on flood risks beyond 2050 are more difficult to assess. Only one set of up to date UK published projections for all types of flooding are available (Sayers et al., 2015). This analysis estimates that, under a 4°C rise, enhancing current levels of adaptation (scenario AS1) does not offset the effect of climate change and population growth. The risk, in terms of numbers of people exposed to risk and expected annual damage, increases despite the effectiveness of investments and adaptations in holding back the increases to levels well below those that might be expected under Reduced Whole System Adaptation and some other scenarios (see Sayers et al. for the ASC (2015)) for fuller details, for example on the annual damages that might occur under the different adaptation scenarios).

Box 5.4. Uncertainties in flood risk and flood damage estimates

The Future Flood Explorer (FFE) used in Sayers et al. (2015) to inform the CCRA is based upon the same flood risk datasets that are widely in use by the UK national governments. In England and Wales this includes the National Flood Risk Assessment (NaFRA, as available in October 2014) and equivalents in Scotland and Northern Ireland. The data and methods used each country vary. In all cases the data contain uncertainty. A National Audit Office review of the data for England (NAO, 2011) recognised this and called for greater effort to be directed towards understanding and communicating the confidence in NaFRA analysis and validating the outputs. Similar statements are likely applicable to the approaches used in Northern Ireland, Scotland and Wales. Despite these uncertainties, the information available from the Environment Agency, SEPA, Rivers Agency NI and Natural Resources Wales are the only data available to populate the FFE.

A main source of uncertainty relates to modelling of flood extent (Sayers and Marti, 2006; L'homme et al., 2009). This relies on detailed information on return period flows and local topography. Only limited work has been undertaken to validate NaFRA and its equivalents for England using observed flood data, which makes it difficult to understand the range of uncertainty. It is also difficult to determine whether future flood risk will change differently in the different countries of the UK, partly because of the scales at which climate projection models are normally run. Attempts are now being made to address these issues (Kay et al., 2014). We have more confidence in the rough percentage and sign of change rather than the absolute numbers.

There is also considerable uncertainty regarding the quantification of the impacts of flooding (annualised damage costs) which are primarily estimated from insured losses. Evidence from peer-reviewed studies demonstrates that these uncertainties may be significant. Actual reported annual flood damages in England for the period 1998 to 2010 have been shown to be lower than the £1 billion figure predicted by NaFRA (Penning-Rowsell, 2015). Current methodologies focus on the number of flooded properties in order to gauge immediate financial cost arising from damage. The wider economic and social costs are not included. The impacts on health (direct and indirect health costs) are also not included.

Risks from different types of flooding

Fluvial flood risk is currently the most significant source of flooding in terms of its contribution to populations at risk and expected annual damages. This remains the case under most future climate and population growth scenarios outlined in Sayers et al. 2015 (see full report for more details). In addition, more frequent, intense rainfall events are highly likely to result in more frequent surface water flooding, particularly in urban areas. The Foresight Future Flooding study (2004) used a scenario of a 20% increase in the intensity of storms of less than 6 hours duration by 2100. The current 1:100 year storm would then have a return period of 1:63 years, and the current 1:30 year storm would increase in frequency to 1:17. A more recent study based on a single but very high resolution climate model for southern England found extreme rainfall totals in summer to be five times as likely by the 2080s in a high emissions scenario (Kendon et al., 2014). Changes around the UK coastal from sea-level rise are dealt with in the following section.

5.2.6 Places we like, need or live in

Much of peoples' wellbeing, quality of life and economic prosperity are linked to the places they value. These include places in which they live, that they like (aesthetic and amenity values; see UK National Ecosystem Assessment, 2011 and its Follow On, 2014) and need (to support livelihoods). Ryff (2015) describes links between wellbeing, psychological, place-related and health factors. Some of the value systems involved with wellbeing or cultural factors are sometimes difficult to account for in policy and decisions even though, for example, many aspects of the National Planning Policy Framework advise planning authorities to work to achieve sustainable developments that encourage healthy lifestyles and well-functioning vibrant communities. A summary of how the value of landscapes is recognised in policy terms is provided in Chapter 3.

Climate change will alter the nature of these valued places in ways that are difficult to determine becausethe evidence base for the impact of climate on valued places is limited for developed economies, even internationally, although there is a good deal of evidence – much of it from Australia and the United States on how a sense of place interacts with health or well-being (e.g. Frumkin, 2003; Wolfab et al., 2015 and Jennings et al., 2016). There is limited evidence regarding the effect of current weather events on places of cultural importance such as archaeological sites (see Chapter 3), with the exception of storm surge impacts on coastal communities.

Recently, new evidence relevant to climate change has begun to emerge (e.g. Adams, 2016) which is already being integrated with international research (e.g. Adams et al., 2015) although more social and economic work may be needed to explore issues such as governance (Gasper et al., 2011). These developments are being paralled by the recent publication of a range of high level analyses (Pretty et al., 2016; Pejchar et al., 2015) and some more focused tools and approaches linked to specific places such as urban areas (Nottingham; Tratalosa et al., 2016) and a section of England's coastline (Norfolk; Day et al., 2015).

These tools and approaches should enable community values (such as cultural ones) and adaptive capacity to be better accounted for in policy and decisions although there is first a need for integration with climate focused studies. If such integration were achieved a more robust evidence base on the places people value and relevant adaptation to climate change would develop. Before then, no more than broad points can be made except in the case of coastal communities vulnerable to sea-level rise where some evidence and experience already exists (see section 5.2.7).

From the international and UK evidence base it appears the implications of climate change for landscapes, seascapes and places people value are likely to include:

- Changing characteristics of culturally important locations, landscapes and seascapes: for example, coasts, woodland, moorland, green and blue space, and cultural heritage sites (see section 5.3.8 below on heritage buildings and facilities and Chapter 3). Markham et al. (2016) identifies some World Heritage Sites at risk from climate change. The list includes Stonehenge and Avebury (and associated sites) in England and the Heart of Neolithic Orkney in Scotland.
- Challenging forms of objection and debate over climate change and to proposed adaptation responses: for example coastal community engagement on plans for realignment and the risk of blight (e.g. Box 5.6).
- Loss or relocation of communities due to coastal inundation from sea-level rise and/or coastal erosion (section 5.2.7).

Drawing on evidence presented in this report, Box 5.5 summarises how different types of places might be affected by climate change.

Box 5.5. Summary of broad implications of climate change for different kinds of communities in the UK

Different types of communities will be affected by climate change differently, in the context of both current and future challenges. This summary has been derived from other sections of this chapter as well as the literature.

High density urban communities. Although high density urban areas offer some advantages, such as the shading buildings can provide one another, these areas are more likely to have higher outdoor temperatures associated with urban heat islands. High density urban areas, if flooded, also entail a high exposure to flooding. Many of the issues relevant to suburban communities apply also to these areas (see below). These communities are also likely to encounter air pollution issues as presently designed. Such communities, and suburban ones could benefit from the use of green infrastructure (see section 5.6).

Suburban communities. The Suburban Neighbourhood Adaptation for a Changing Climate project (Williams and Hopkins 2010, Williams et al., 2013) identified the following challenges for suburban communities in adapting to climate change: difficulties retrofitting existing housing stock, the fragmented ownership and management of land and housing, and the slow pace of change in suburban areas. In terms of mobilising social change to effect adaptation, there were problems of co-ordinating multi-actor partnerships, developing political will, generating public acceptance and encouraging behaviour change.

Rural communities are more vulnerable to flood impacts on transport links (see Box 5.3), and also have more difficulty accessing health and social care services when there has been an extreme weather event.

Remote rural communities that rely on communications and road connectivity to access vital services may be particularly vulnerable to climate risks that affect transport (see also Chapter 4).

Coastal communities. Many settlements in the UK are coastal and thus may be affected by sea-level rise (36% of the UK population lives within 5km of the coast and 63% lives within 15km).[19] Living on the coast has benefits for health and wellbeing (Wheeler et al., 2012). However, coastal communities may increasingly bear the brunt of climate change-driven storm surges, sea-level rise and coastal erosion. The viability of some coastal communities may also be threatened by climate change (see section 5.2.6). An international humanitarian perspective on large coastal cities has recently been provided in Christian Aid (2016).

In the following section we focus on coastal communities as an illustration of the issues and risks that likely need accounting for when valued places are affected by climate change. Some of the evidence base is very strong and in other areas there are large and significant knowledge gaps in relation to both risks and the effective responses.

5.2.7 Risks to coastal communities from sea level rise

Current policy

The Coast Protection Act 1949, Land Drainage Act 1991, Flood Risk Regulations 2009 and the Flood and Water Management Act 2010 provide the primary legal framework for flood and coastal erosion risk management in England and Wales. Local plans may also include some consideration of climate change (see above). In Scotland, the Flood Risk Management (Scotland)

[19] ec.europa.eu/eurostat/statistics-explained/index.php/Coastal_regions_-_population_statistics

Act 2009 and the Coast Protection Act (1949) provide the primary legal framework for flood and coastal erosion risk management.

Shoreline Management Plans (SMPs) are non-statutory documents that indicate how local authorities and other bodies can plan and implement coastal management such as “hold the line”, “no active intervention” and “managed realignment” strategies. SMPs exist for coastal areas in England and Wales. Where appropriate (e.g. in Ayshire) similar arrangements exist in Scotland, and Northern Ireland does not currently implement SMPs. SMPs consider several epochs between now and the end of this century and cover coastal communities and coastal economic and natural assets. Other organisations such as the National Trust have done similar pieces of work for their own assets ; Esteves, 2013). It is important to note that the favoured approaches to managing the coastline identified within SMPs are not based on a detailed assessment of the costs, benefits and affordability of the options involved. Questions thus remain about the ways in which much of the coastline will be managed in future.

Current climate risks and adaptation

Across the world, the coastal zone is one of the most vulnerable to current and future climate change, while at the same time being one of the most valuable to people for economic, social, cultural and even health reasons (e.g. UK National Ecosystem Assessment, 2011; UK National Ecosystem Assessment Follow-On, 2014). Although coastal erosion and flooding have been reshaping the UK coastline since the last ice age (and before), there has been a steady increase in sea levels over the past 100 years. Hay et al. (2015) have re-evaluated observations and suggest global average sea-level rise is now happening at a rate of about 3mm per year and may be accelerating. However, monitoring and understanding sea-level rise at the local level is difficult as the actual level of sea-level rise at any one place depends on a wide range of factors including gravitational variation across the Earth and oceanographic factors (see chapter 1). At present, there is a paucity of evidence suggesting that sea level rise alone would create risks for the viability of UK coastal communities in the near-term, although coastal erosion already poses risks for some communities.

Future climate risks and adaptation

Many of the UK’s trading partners (China, India, the United States) appear more vulnerable to coastal losses than the UK (McGranahan et al., 2007). Within Europe overall, the UK may be vulnerable to loss of coastal places as the climate changes. For example, Ciscar et al. (2011) examined a set of issues related to national welfare (such as agriculture) at a national scale and, allowing for conservative increases in sea level, pointed to how sensitive the losses in UK national welfare appear to be with respect to higher levels of sea-level rise. The study suggests that less than 1m of sea-level rise is likely to be a major contributor to welfare losses.

Sayers et al. for the ASC (2015) analysed how the size of the coastal floodplain might change in the future in England. The results are a ‘what if’ analysis that looks at impacts for different extents of sea-level rise. The analysis considered (i) the vulnerability of the existing defence line; and (ii) the potential extent of the coastal floodplain (and number of properties impacted) should the existing flood defences be lost. This analysis applies to England only because it relies on detailed defence toe levels that are readily available only in England through the Continuous Defence Line dataset (completed in 2015), but not available for Northern Ireland, Scotland or Wales.

The results show that for sea-level rise of 0.5 - 1m, there may be 200km or more of coastal flood defences that are particularly vulnerable to failure in storm conditions, and may not be cost-effective to maintain in the future. This equates to around 4% of the total length of the English coastline and 20% of the length of coastline with coastal flood defences. This analysis did not include the effects of climate change on coastal erosion more widely. Some individual communities are already undertaking work to assess the feasibility of a variety of adaptation options to sea-level rise, such as Fairbourne in Wales (see Box 5.6).

The EA Coastal Handbook (EA, 2010) uses extreme high water figures of 2 metres and annual rates of sea-level rise of 3 mm/year to inform work with coastal local authorities. In discussing the impact on East Anglia in England it points out the seriousness of the issue of climate change risks for coastal communities; with a 70cm sea-level rise (in the middle of the expected range for this century) return periods for extreme high water levels reduce from 1:100 years to 1:8 or even 1:2 depending on local conditions. Similarly, at Fairbourne, Wales, 1:100 years becomes 1:2.[20] This means a greatly increased risk of inundation for such coastal communities.

Climate change may also lead to the loss of important coastal sites in many parts of the UK such as at Cuckmere Haven in Sussex, part of the Giant's Causeway in Northern Ireland, sections of the National Trust Coastal Path, some of the Machair in the Western Isles and some Welsh beaches (National Trust, 2008; National Trust, 2015). The loss of these sites would have cultural, wellbeing and community impacts that are not well assessed (see Chapter 3). Coasts in particular were identified in the UK National Ecosystem Assessment as the broad habitat most valued by people (other highly valued habitats were woods and domestic gardens in urban areas) (UK NEA, 2014).

At the national level, as mentioned above, Shoreline Management Plans[21] indicate how local authorities and other bodies can plan and implement management of coastal defences in terms of holding the line, managed realignment and no active intervention. If implemented as set out, SMPs for England indicate thatabout 10% of the coast will be subject to some form of realignment by around 2030 and almost 15% by around 2060. To meet this goal, the rate of realignment would need to increase fivefold from the current 6km each year to 30km each year (ASC, 2014). One strength of the SMPs is that they have the potential to provide a focus for agencies to work together. This is because delivering an SMP needs multi-agency co-operation and engagement with the local community if it is to work. However, there are multiple and competing pressures facing local authorities, home and land owners that make SMP implementation particularly challenging (see Figure 5.9).

Scotland is currently undertaking a National Coastal Change Assessment, the findings of which are due in 2016/17. Similar information on national coastal management is not currently available for Northern Ireland and Wales.

There is a growing body of evidence that has examined how smaller coastal communities might also be able to address their vulnerability to climate risks and how such communities can be engaged by their local authorities and regional bodies in planning and making decisions for the future. Many reports and web resources exist on a growing number of UK regions and communities in England, Scotland and Wales.[22] In the main these studies deal with low-lying communities.

[20] fairbourne.info/wp-content/uploads/2014/08/Royal-Haskoning-Presentation-220116.pdf
[21] https://www.gov.uk/government/publications/shoreline-management-plans-smps
[22] www.dynamiccoast.com/about_project.html

A number of pathfinder projects have been done to explore how coastal communities placed at increased risk might adapt. These have been evaluated independently and by Defra and almost all point to the benefits of community engagement and a large number of co-benefits that can be delivered through adaptation, but none has as yet delivered enduring solutions to those affected communities that might not be sustainable in the longer term (Defra, 2011; Defra, 2012). The evidence base generated by the pathfinders and similar studies needs systematic analysis to better understand opportunities for and barriers to adaptation (see also Section 5.6).

For both major and smaller communities and areas along the coast or affected by coastal processes, key decisions will need to be made in the middle of this century (e.g. see Box Box 5.6 for Fairbourne on the Welsh coast and Box 5.7 for the Thames Estuary as examples of how risks to locations from sea level rise are being managed).

Box 5.6. Case study of climate risks in a coastal community: Fairbourne, Gwynedd

Fairbourne is a community built behind a shingle bank on a low coastal plain, consisting of about 500 properties and about 1,100 people. Many of the residents are aged over 50. Fairbourne is vulnerable to coastal erosion, storm impacts and sea-level rise as well as some river-based risks. Baseline rates of coastal erosion are between 30 and 100 m per century (Royal Haskoning, 2011). With sea-level rise, the rates could be 1.75 – 2.5 times higher than the baseline due to strengthened wave action and other factors (equivalent to 52 – 250 m per century). The dominant factor in the future of Fairbourne is the **rate** of sea-level rise, about which there is much uncertainty (Hay et al., 2015).

A shoreline management plan (Haskoning UK, 2012) for the surrounding coastline began evolving in 2009 and was submitted to the Welsh Government in May 2013 (and then adopted). It states that while the village's defences can and should be maintained for several decades (c. 40 years), in the long term the village is unsustainable. At present, the village is just above the mean high water mark, but if there were 0.36 m sea-level rise then a good part of the village could suffer regular inundation. This could happen by the 2060s, but with higher rates of sea-level rise it would take place nearer to the early 2050s. With sea-level rise of 0.5m the threshold for sustaining Fairbourne would be passed, perhaps by around 2070. With sea-level rise of 2 m the whole village would be more than 1 m below mean high water.

The coastal policies emerging in the SMP provide several approaches for different parts of the coast near Fairbourne involving holding the line, managed realignment and no active intervention, to be brought in as sea-level rise proceeds. By 2105 there would be no active intervention along the whole of the Fairbourne section of coast. From 2055 managed realignment would include relocation of Fairbourne residents and businesses. For parts of the coast near Fairbourne managed realignment starts by 2025. In summary: "In the medium to long term communities would be relocated reducing risk of catastrophic flood risk in the long term" (Royal Haskoning, 2011). To implement the policy, it was suggested that, from the present day, work should be done to maintain existing defences and to develop adaptation and relocation planning (including work to assess sea-level rise implications as knowledge improves). Implementation in the medium term means realignment of defences and acting on plans for relocation.

There are many lessons to be learned from the Fairbourne experience:

Communication of risk to residents: Although local authorities at various levels communicated with one another about the risk during the evolution of SMP2, many residents did not become aware of the risks until after the storms of 2014. Both local authority documents (Gwynedd Cabinet report of 22 January 2013) and local media reports created an impression that Fairbourne would cease to be defended at present levels from 2025. The lack of communication to residents was, in their view,

Box 5.6. Case study of climate risks in a coastal community: Fairbourne, Gwynedd

detrimental to their interests.

Community engagement: Residents responded through a group that challenged local authority approaches to communication and action. They asked a number of questions and elicited responses indicating that, although SMP2 sets out a road map for managing coastal change, any works will still be the subject of an economic appraisal. Local authorities responded by forming a Multi-Agency Project Board.[23]

Community resilience and blight: There is a clear commitment to protecting the village until the mid-2050s, but it is a qualified aim given the uncertainties over the rate of sea-level rise and other factors such as complications linked to groundwater levels. Although managed realignment does not become necessary until after 2055 it is quite clear that blight is a current concern as the emerging Gwynedd and Anglesey Deposit Joint Local Development Plan (2015) has policies which limit development in Fairbourne and its area. Planning timescales may need to be as consistent as possible with the technical advice provided by consultants to avoid unintended consequences that constrain early moves towards adaptation. Various financial schemes are being explored to alleviate pressure on homeowners whose assets may devalue. There is insufficient data from house sales to indicate whether house prices are falling or residents are encountering insurance difficulties. There is also concern about community coherence and anxiety levels.

Technical guidance and its interpretation: The Royal Haskoning technical guidance, SMP2 and the interpretation and communication by local authorities to residents and the media may have been a source of confusion. For example, Fairbourne and its immediate vicinity is subject to three different SMP timescales. One of these does indeed refer to starting managed realignment in 2025 – but this is not actually within the confines of Fairbourne village. More sophisticated communication of the meaning of technical guidance may be required to ensure, in cases such as Fairbourne where substantial adaptation is needed, planning and implementation can begin early to minimise economic and social costs.

Planning and implementation: Royal Haskoning (2011) advises that action is needed in "the present day" to plan, implement and adapt. There is evidence that through the Fairbourne Moving Forward Project, Fairbourne Facing Change and in reports to the Welsh Government that current defences are being at least maintained (e.g. Welsh Government, 2014a). For example a recently completed flood alleviation scheme at Fairbourne involved both river and tidal works and reduced the risk of flooding to 410 houses and ten businesses. The scheme also delivered biodiversity benefits.

[23] www.fairbournefacingchange.com/downloads/Annual_Report_12-05-2015.pdf

Box 5.7. Case study of managing tidal flood risks through the Thames Esruary 2100 project

A range of options for managing the risk to London from tidal flooding have been considered. Dawson et al. (2005) argued, for example, that under conditions of extreme sea-level rise a barrier across the estruary at Sheerness might be cost-effective. The Environment Agency published the TE2100 Plan in 2012, which considers how to manage tidal flood risk in the River Thames area until 2100 (EA, 2012; Ranger et al., 2013) with a time line for key decisions such as raising embankments and reviewing the need for a new barrier for London. The Plan places climate change at its heart and includes the large uncertainty surrounding rates of future sea level rise. The Plan has a strong adaptive element so that plans can be adjusted as knowledge improves. It encompasses thinking on extreme sea-level rise plus storm surge water levels up to 2.7m. Lowe et al. (2009) and Ranger et al. (2013) set out the options diagrammatically (see Figure 5.8).

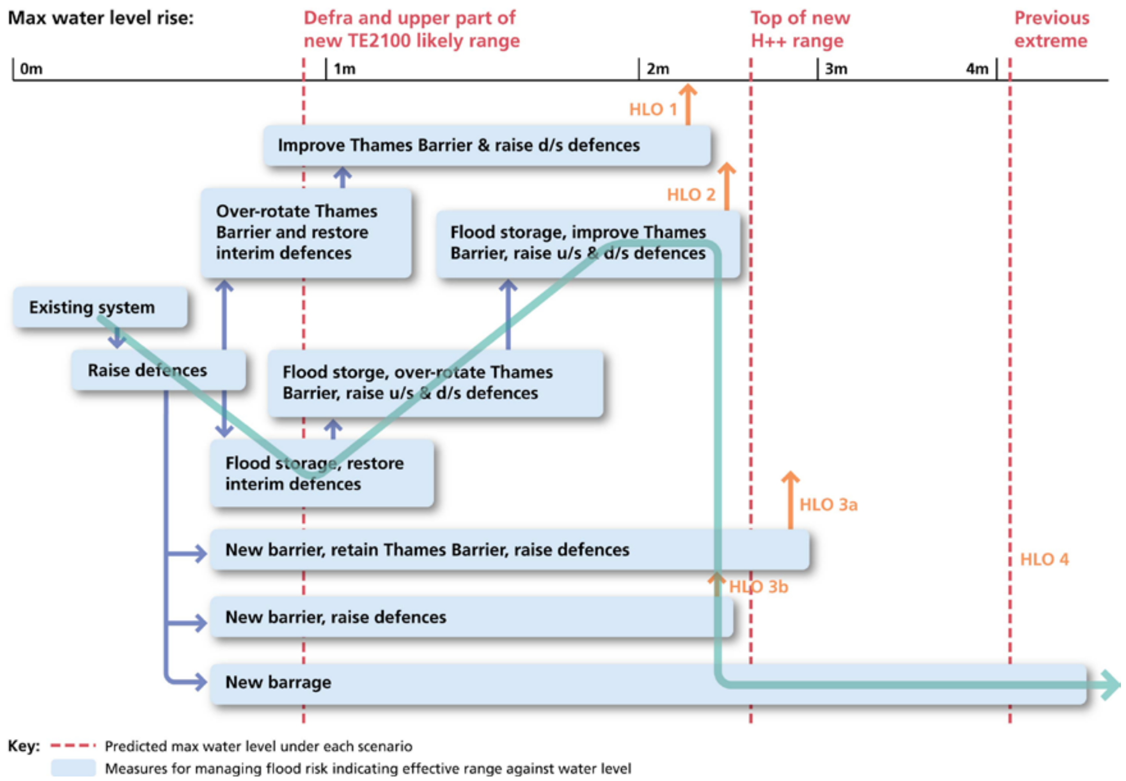
The plan has adopted the "Improve defences" or "New barrier" options as the preferred long term solutions. Based on a current best estimate planning assumption of a 90 cm rise in extreme water level by 2100, the plan has actions divided into three epochs. These move from maintaining the existing system in the early years to either substantially renovating the existing barrier or providing a new one, potentially downstream near Thurrock by 2070.

The plan also has a monitoring strategy that sets out ten key indicators of change (EA, 2012; Ranger et al. 2013). These include existing and projected rates of sea level rise. If increases in indicators suggest a rise in extreme water levels above the current planning assumption of 90cm, then the actions and interventions set out in the plan will need to be accelerated. Conversely actions could be delayed if sea level rise is slower than currently predicted when the Plan was formulated.

Beyond London, there is less information on the management plans to protect coastal cities. In rural locations, coastal managed realignment schemes that form part of the recommended actions in the TE2100 Plan, and non-managed realignment (as might occur at Cuckmere Haven in Sussex) are both likely to change the nature of the UK coastline in ways that are significant culturally, socially and economically. There is insufficient evidence on which to assess the economic, social and cultural adaptation that will be needed. Impacts may be significant for affected communities, even though the cultural values that affect individuals and communities are not completely immutable (Adger et al., 2009).

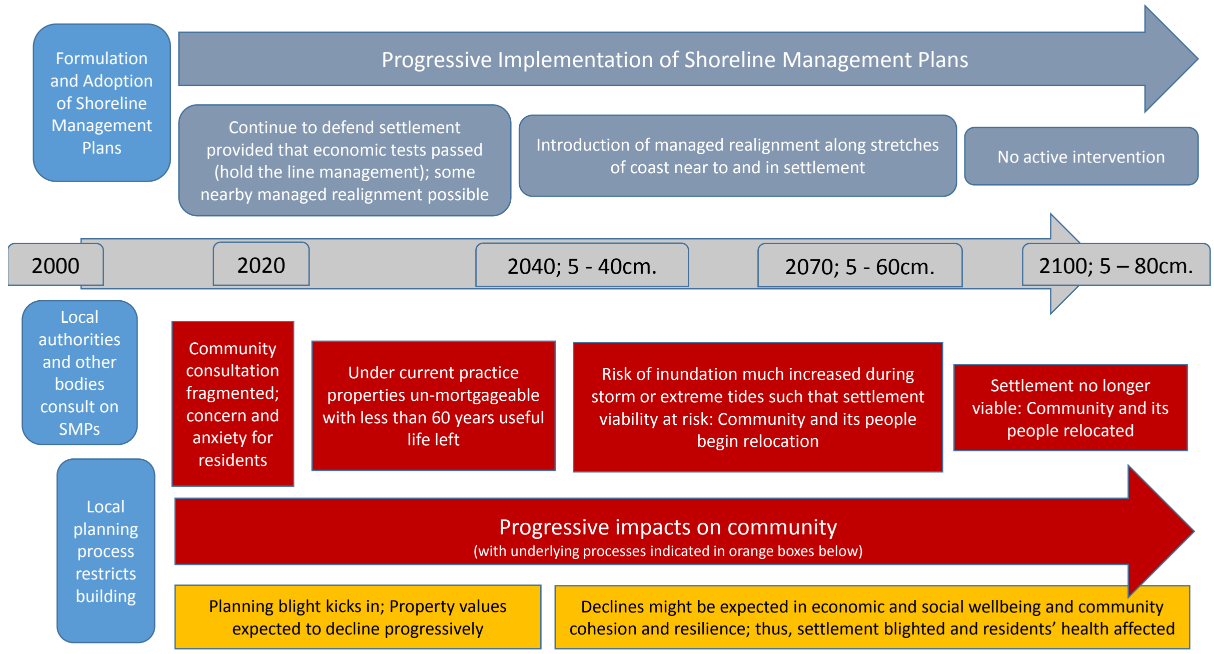
Box 5.7. Case study of managing tidal flood risks through the Thames Estuary 2100 project

Figure 5.8: The Thames Estuary 2100 study for London



Source: Lowe et al. (2009), based on the high level options report to support the TE2100 project (unpublished).
Notes: This figure presents high level options under the TE2100 project. The dark blue path shows a possible future adaptation route (or pathway) in the event of extreme change (>4 m rise). The vertical dashed lines show TE2100 scenarios including the new revised H++ range described in Chapters 3 and 4 of this report.

Figure 5.9. Social and economic effects of sea-level rise on communities



Notes: This diagram has been assembled from various evidence sources referred to in this section of the report and particularly from the material in Box 5.6. The diagram indicates that as development and implementation of a Shoreline Management Plan proceeds (dark grey boxes) then a number of events at local authority level (blue boxes) affecting the community will, together with implementation, drive adaptation (red boxes) with a range of consequences for the community (yellow boxes). The light grey boxes show a timeline and increases in sea-level. Exact timings of events depend on rate of sea-level rise and possibly also extreme weather events so should only be considered as indicative and not prescriptive. The estimates of sea level shown are taken from the UKCP09 sea level rise projections for the four UK capital cities. The range is the 5 – 95th% across all emissions scenarios.

5.3 Buildings

Key risks and opportunities – buildings

PB1: Risks to health and wellbeing from overheating in buildings

- Higher temperatures will increase the risk of overheating in houses, schools, hospitals, care homes, prisons, and other types of buildings, leading to adverse impacts on health and thermal comfort. The proportion of dwellings experiencing overheating is very likely to increase with climate change. Housing policy needs to address large-scale refurbishment of the housing stock to reduce the burden of overheating to avoid additional impacts from climate change. There has been much work to determine cost-effective adaptation responses at the house scale, but scaling-up to population-wide changes to housing stock is a complex issue and guidance is needed. There is a need to combine mitigation and adaptation measures when promoting the implementation of energy efficiency and ventilation interventions. PB9: Risks to health service and social care delivery
- Newly built hospitals are more at risk of overheating during periods of hot weather compared with older, traditionally built blocks. Information from care homes indicate that that these may also be at risk from high temperatures due to building design and management issues. The risk of overheating is likely to increase with increasing temperatures.

PB5: Risks to people, communities and buildings from flooding

- Buildings are at risk of damage from flooding. The rate of drying after a flood depends on the building characteristics. Long-term damage may occur, including mould. Property level protection measures can reduce impacts but uptake for houses is currently low.

PB7: Risks to buildings from moisture, winds and driving rain

- High winds damage buildings but future impacts of climate change are uncertain as high winds are not well described in climate models. Increased damage from moisture may occur from increased flood exposure and increases in driving rain.

PB2: Risks to passengers on public transport from overheating

- Overheating on public transport (mainly buses and trains) has adverse impacts on passenger health and welfare and can disrupt services. There is evidence that measures are being put in place in order to address overheating on the underground and buses in London, but evidence for other areas around the country is currently lacking

PB8: Risks to historic structures

- Climate-related hazards damage historic structures and sites now, but there is lack of information on the scale of current and future risks

This section of the chapter addresses buildings, in the context of risks and opportunities for people in the places they live, work and study. Buildings related to critical infrastructure are also covered in Chapter 4 and in relation to business locations and premises in Chapter 6.

5.3.1 Policy framework

Building regulations

In England and Wales, the Building Regulations set out the rules covering the safety, accessibility and sustainability of new homes, other new buildings and major renovations. Building regulations include separate parts that relate to adaptation to climate-related risks:

- Part C includes rules related to the resistance to moisture,
- Part F requires minimum ventilation standards,
- Part G requires minimum water efficiency standards,
- Part L requires some degree of solar shading to limit overheating, in order to help minimise fuel and power use rather than to protect health.

In 2015, based on the Housing Standards Review, the government proposed the following changes to the Building Regulations:

- Dual level Building Regulations (Access and Water), which give local authorities some choice to require developers to build to different (higher) standards than the minimum requirements set out in Building Regulations.[24]
- Abolition of the Code for Sustainable Homes.
- Removal of rights for local authorities to set higher energy efficiency standards for homes than is set out in Building Regulations.

Subsequently, the government also announced it was scrapping the standard for all new homes to be zero carbon by 2016, but stated it would keep energy efficiency standards under review (HM Treasury, 2015).[25]

In Scotland, the Building (Scotland) Act 2003 mandated Building Regulations that are specific to Scotland. The Building Standards System sets out the essential standards to be met when building work or a conversion takes place. The Technical Handbook which sets out the Building Regulations has standards related to flood resilience (standard 3.3), moisture penetration from heavy rain (3.10), heating and overheating (3.13), ventilation (3.14), condensation (3.15) and water efficiency (3.27).

Northern Ireland also has its own Building Regulations, the most recent of which were published in 2012. Part C contains conditions related to minimising damp penetration, part F relates to limiting internal thermal gains and part K to adequate ventilation.

Additional policies for homes (dwellings)

The Housing Health and Safety Rating System (HHSRS) is the method used in England and Wales for assessing the condition of dwellings. All social landlords operating in the UK must provide decent homes (DCLG, 2006), which includes meeting the requirements set out by the HHSRS in England and Wales. Private landlords must deal with any issues that arise in a HHSRS assessment, should the council undertake one on the property. Private home owners are not thought to have any legal basis to demand that their homes be brought up to Building Regulations standards or

[24] www.gov.uk/government/speeches/planning-update-march-2015
[25] www.gov.uk/government/uploads/system/uploads/attachment_data/file/443897/Productivity_Plan_print.pdf

to correct any hazards that would come up in an HHSRS assessment, unless their home is still under warranty.

Key housing policies also concern reducing fuel poverty (as a welfare issue) and energy efficiency (climate policy). The Government launched a new Fuel Poverty Strategy for England in 2015. It contains a target to ensure that as many fuel-poor homes as is reasonably practicable achieve a minimum energy efficiency rating of band C by 2030. Scotland also has a target that by November 2016, so far as is reasonably practicable, people are not living in fuel poverty in Scotland. There is no corresponding target for Wales, which has been investing £100 million per year to reduce fuel poverty through its 'Nest' scheme.[26] Northern Ireland's 'Making Life Better' strategy for health and wellbeing has an objective to improve the overall quality of housing, including interventions to help those most at risk from fuel poverty.

The Energy Company Obligation (ECO) will be replaced by a new "cheaper energy efficiency supplier obligation" from 2017 (see discussion on cold homes section 5.3.3 below). In Scotland and Wales, The ECO delivery is supplemented by a number of devolved policies, the majority of which are focused on fuel poverty alleviation. In Northern Ireland, energy efficiency policy is fully devolved.[27]

Indoor air quality is indirectly regulated at EU level through directives and regulations on construction products (CPR, Regulation (EU) No 305/2011) and on Energy Performance of Buildings (EPBD, EU-Directive 31/2010). In the UK, the building regulations for ventilation (Approved Document F) and for conservation of fuel and power (Approved Document L), as well as the Building Bulletin 101 for schools, cover the technical guidance for the construction of domestic and non-domestic buildings, which are intended to take into account indoor air quality issues.

Additional policies for schools and places of work

The 1974 Health and Safety at Work Act makes provisions to protect the health, safety and welfare of people in their workplaces in England, Scotland and Wales. The regulations are set out in the Health and Safety at Work Regulations (1999) and The Workplace (Health, Safety and Welfare) Regulations 1992. The latter includes provisions for weather-related risks, including adequate ventilation, temperature and supply of drinking water. Temperatures have to be 'reasonable', but no specific limits are set. The Health and Safety Executive (HSE) together with local authorities enforce health and safety laws for workplaces (see Chapter 6).

In Northern Ireland, the Health and Safety at Work (Northern Ireland) Order 1978 is the main piece of legislation related to the protection of health and wellbeing in workplaces. This legislation also gives employers responsibilities to ensure that ventilation, temperature and water supply meet health, safety and welfare requirements. The Health and Safety Executive for Northern Ireland (HSENI) undertakes a similar role to the HSE in Great Britain.

Schools are counted as workplaces and are therefore also subject to the Health and Safety at Work Act and Health and Safety at Work Act (Northern Ireland). In addition, in England and Wales the Education (School Premises) Regulations 1999 stipulate that the minimum temperatures in school rooms should not fall below 15 – 21°C depending on the type of room. There is no corresponding upper temperature limit for schools.

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[26] gov.wales/topics/environmentcountryside/energy/fuelpoverty/?lang=en

[27] d2kjx2p8nxa8ft.cloudfront.net/wp-content/uploads/2015/06/6.737_CCC-BOOK_WEB_030715_RFS.pdf

5.3.2 Overheating in buildings

Current climate risks and adaptation

Overheating (excessive indoor temperatures) can be defined in relation to thermal comfort, health or productivity. Higher temperatures are one of the most certain impacts of climate change and therefore it is likely that overheating in buildings will increase.

Recent evidence suggests that around 20% of homes in England already experience overheating even during relatively cool summers (e.g. Mavrogianni et al., 2012; Beizaee et al., 2013; Lomas and Kane, 2013; BRE, 2013). For example, summer indoor temperatures above recommended thresholds of 28°C in living rooms and 26°C in bedrooms were recorded in a monitoring study of 193 unheated dwellings of various types across England in 2007, even though this was a relatively cool summer (Beizaee et al., 2013). Although only 4% of living rooms experienced temperatures above 28°C for more than 1% of occupied hours, night-time bedroom temperatures exceeded 26°C for more than 5% of the time in 21% of dwellings, and exceeded 24°C (the temperature above which sleep is thought to be impaired) for more than 5% of occupied hours in 47% of dwellings. Similarly, a monitoring study of more than 200 unheated dwellings of various types in Leicester in 2009 (Lomas and Kane, 2013), reported that indoor temperatures in living rooms exceeded 28°C for more than 1% of the time in 27% of dwellings, and bedroom night-time temperatures exceeded 24°C for more than 5% of the night-time in 92% of dwellings. A study of 36 London dwellings during a hot spell in 2009 (Mavrogianni et al., 2012) found that 15 out of 36 monitored bedrooms experienced night-time indoor temperatures above 26°C for more than 1% of the time.

The 2010/11 English Housing Survey Energy Follow-up Survey (BRE, 2013) of 2,616 nationally representative English households indicated that 20% of the interviewed households reported summer overheating problems in at least one room and over 40% of households experienced some difficulty keeping one or more rooms cool in the summer. While these studies suggest that severe overheating (i.e. unprecedentedly high temperatures or high temperatures for prolonged periods of time) occurs only in a small percentage of the housing stock, it is worth noting that adverse health effects for vulnerable individuals may occur at lower temperatures than those reported in the studies (ZCH, 2015a). Under the current climate, the south of the UK is more severely affected by indoor overheating problems (DCLG, 2012b), but there are few studies of overheating in buildings in northern England and the devolved administrations.

Some evidence exists about overheating in specific building designs:

- Homes. Dwelling types that have been found to be more prone to overheating include 1960s – 1970s and newly built, post-1990s mid- and top-floor purpose-built flats that lack sufficient ventilation and protection from solar gains (CIBSE, 2005; Hacker, et al., 2005; Beizaee et al., 2013; Mavrogianni et al., 2012; NHBC, 2012; Orme and Palmer, 2003; Salagnac, 2007; Oikonomou et al., 2012).
- Offices. Typical 1960s, naturally ventilated, lightweight offices could exceed indoor overheating criteria even under the current climate, mainly because of lack of shading and ventilation control (CIBSE, 2005; de Wilde and Tian, 2010).
- Schools. Some schools also experience overheating under the current climate. A recent survey (NASUWT, 2012) found that one in three teachers are teaching in classrooms that regularly experience temperatures above 30°C. More than three-quarters of the survey

participants had experienced classroom temperatures above 24°C and it was suggested that this often resulted in lethargy and fatigue with adverse effects on the cognitive performance, behaviour and wellbeing of schoolchildren. Post-war schools are more prone to both overheating and poor indoor air quality due to their lightweight construction and large glazed areas (Teli et al., 2011, 2012; CIBSE, 2015). The risk of overheating was also found to be high in Victorian and early 20th century school buildings due to poor cross ventilation and high energy efficiency standards post-retrofit (Montazami et al., 2015).

- Hospitals. Newly built hospitals are also found to overheat during periods of hot weather, whereas 1920s, traditionally built blocks with open 'Nightingale' wards and 1960s blocks were shown to be more resilient to heat (Lomas and Giridharan, 2012; Lomas et al., 2012; Short et al., 2012).

A number of studies have examined high indoor temperatures in buildings following energy efficient retrofits, showing different retrofit types may increase or decrease the likelihood of overheating (Porritt et al., 2012; Taylor et al., 2014). A significant factor in the increased overheating risks in retrofit buildings is the reduced passive ventilation rate caused from making buildings more air tight (Taylor et al., 2015a). While there has been significant modelling work to examine overheating, research could benefit from further empirical summertime indoor temperature data, and an improved understanding of how energy-recovering ventilation systems such as mechanical ventilation and heat recovery systems may alter risks.

There is also some evidence of increased summertime overheating risk in retrofitted solid-walled dwellings following internal wall insulation. Approximately one-quarter of all English dwellings are solid-walled (Taylor et al., 2014) of which 98% have no wall insulation (Porritt et al., 2012). Solid-wall insulation may only be installed internally or externally. The latter is costlier, time-consuming and more disruptive. In England, in particular, it is often dependent on consent for planning permission. As a consequence, solid-walled buildings are classified as 'hard-to-treat'. In addition to potential overheating problems, installation of internal solid wall insulation can present a number of other risks, including an increased risk of damage due to water seepage between external insulation and the wall, interstitial condensation, and thermal bridging.

Future climate risks and adaptation

Overheating was identified as a key risk in the 2012 UK Climate Change Risk Assessment (Defra, 2012). The 2012 DCLG evidence review on overheating in homes (DCLG, 2012b) concluded there are substantial gaps in knowledge which would require significant research activity to improve the fundamental understanding of health and behavioural issues around heat, and the real performance of buildings. Since 2012, however, further evidence has been produced that considers the current and future risks from overheating. This suggests that the thermal performance of the UK housing stock and other building types must be dramatically and swiftly improved (Hills, 2012) (see Table 5.5). For example, Jenkins et al. (2014) suggest that by the 2030s, 59 – 76% of flats and 24 – 29% of detached properties in London could experience overheating(defined as internal temperatures > 28°C) during a heatwave event (high emission scenario). For the 2050s, the values increase to 80 – 92% of flats and 56 – 61% of detached dwellings (high emission scenario, median result).

The 2015 report for the UK Government by the Zero Carbon Hub (ZCH, 2015b) concluded:

"overheating cannot yet be considered to be a managed risk for much of the sector. There are gaps and uncertainties in current frameworks which mean inherently risky designs and buildings can be

approved. Secondly, despite evidence gaps, there is enough information and evidence about the causes, extent of, and solutions to overheating in homes to warrant taking careful yet concerted action to tackle the issue."

Modelling studies suggest that as the climate becomes warmer, it will be increasingly challenging for naturally ventilated buildings to maintain comfortable indoor thermal conditions using passive ventilation-based measures alone (CIBSE, 2005; ZCH, 2015b).

Passive cooling strategies include increased energy efficiency of appliances, shading, window upgrades and high-reflectivity roofs. It has been estimated that if air conditioning is used instead of passive cooling measures in both existing and new homes, it would cost society an additional £2 billion (existing homes) and £400 million (new homes) respectively, over 15 years, given future projected electricity prices (ASC, 2011).[28] Conversely, Porritt et al. (2013) found large variations in the costs of retrofit actions aiming to reduce current and future overheating in housing, depending on dwelling type. For instance, retrofit costs that eliminate overheating were estimated to vary from approximately £1,000 for a typical ground floor flat with north-facing windows, to £32,000 for a semi-detached house with west-facing windows. For certain high-risk dwelling types (mid- and top-floor flat, modern detached house), overheating could not be eliminated at any cost. Mechanical means of cooling may be required in the future to maintain acceptable levels of summer indoor thermal comfort. Mechanical cooling is energy intensive and so would increase carbon emissions if the energy required was not derived from renewable sources.

Several authors have produced estimates of the future market share of air-conditioning systems in the UK. Day et al. (2010) estimated that approximately 3,500 MW of cooling capacity may be installed by 2030, which corresponds to a 40% increase on the base case levels of the study. Despite the fact that the penetration of air conditioning in dwellings is currently low in the UK (3% according to the English Housing Follow-Up Survey), Peacock et al. (2010) suggested that this is likely to increase significantly in the future. Such an increase would require increases in system energy efficiency and reductions in the capital cost of a single unit.

The ASC has also identified overheating as a key risk for workers (Bu5: Risks to Business from reduced employee productivity), due to infrastructure disruption and higher temperatures in working environments (see section 6.4.4).

[28] These estimates include the full capital costs of air conditioning equipment. Future electicity prices are based on Committee on Climate Change modelling.

Table 5.5. Post-2012 studies on overheating risks for UK buildings

Study	Building type	Methods	Results
AECOM (2012) for DCLG – Investigation into overheating in homes	Homes	Systematic literature review of the evidence for overheating in homes	The report summarises what is currently known about overheating in homes from evidence sources, what is known anecdotally, what the views of stakeholders are and what areas of significant new research are needed.
Beizaee et al. (2013) National survey of summertime temperatures and overheating risk in English homes	Homes	Temperature sensors were distributed across a stratified sample of 200 homes in summer 2007 and the results of internal temperature readings were compared with external temperature, housing type and location	Despite the cool summer, 21% of the bedrooms that were monitored had more than 5% of night-time hours over 26°C, which is a recommended upper limit for bedrooms. The bedrooms of modern homes (i.e. those built after 1990 or with cavity walls) were significantly warmer.
Good Homes Alliance (2014) Preventing Overheating	Social housing	Surveys of environmental health officers, housing providers and consultants	Nearly half (61) of the 126 survey respondents each identified between one and six instances of overheating in homes. Converted and new build flats were found to be most at risk.
Mavrogianni et al. (2012) Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings	Homes	Dynamic thermal simulations of different building types, investigating the impacts of future temperature projections and building characteristics on the propensity of different buildings to overheat	The type and extent of insulation, as well as dwelling type, had a strong bearing on the propensity of the modelled building to overheat in the current and future climate.
McLeod et al. (2013) An investigation into future performance and overheating risks in Passivhaus	Homes	Modelling of the impacts of future extreme temperatures on Passivhaus dwellings using the UKCP09 weather	The results show that optimisation of a small number of design inputs, including glazing ratios and external shading devices, can play a significant role in mitigating future overheating risks.

Table 5.5. Post-2012 studies on overheating risks for UK buildings

Study	Building type	Methods	Results
dwellings		generator	
NHBC (2012) Overheating in new homes	Homes	Evidence review of overheating in new homes	Increasing evidence that new and refurbished properties are at risk of overheating, especially small dwellings and flats and predominantly single-sided properties where cross ventilation is not possible. New evidence that prototype houses built to zero carbon standards are suffering from overheating, which shows that overheating may also become an issue where cross ventilation is not achievable in lightweight, airtight houses with little or no solar shading.
ZCH (2015a) Assessing overheating risks	Homes	Systematic literature review of the evidence for overheating in homes	Studies are starting to link external thresholds more explicitly to internal temperatures.
Short et al. (2012) Building resilience to overheating into 1960s UK hospitals	Hospitals	Dynamic thermal simulation models and observations of internal hospital ward temperatures for four hospitals	A representative type (medium-rise ward block from late 1960s) has more resilience in the current climate than expected and it will remain resilient into 2030s. Relatively non-invasive measures could extend and increase its resilience while saving energy.
Gupta et al. (2016) Care homes fit for a future climate	Care homes (residential and extra care)	Dynamic thermal simulation of 4 schemes, analysis of design features using building surveys, continuous monitoring of indoor and outdoor temperatures over summer 2015.	The study found a mismatch between overheating risks predicted by modelling and those measured by empirical monitoring. Environmental monitoring in 2015 revealed instances of overheating occurring in short heatwaves across all sites (lasting 2-4 days). There was a lack of effective heat management for various reasons including organisational and structural reasons.

5.3.3 Cold homes

Current climate risks and adaptation

Cold-related illness is significant problem for the UK (see Section 5.5.4). Poor quality housing (cold homes) is a major determinant of the burden of cold-related mortality and morbidity (NICE, 2014; Wilkinson et al., 2001). The exact interactions between building fabric, systems, temperatures and energy use practices are complex, however. Interventions that are effective in improving temperatures in cold homes include: policy (such as providing free boiler replacements); services (such as local efforts to implement policy and changes to buildings and heating); and housing improvements made by individuals (NICE, 2014).

There has been some improvement in reducing the risks of cold homes in winter. For example, the average Standard Assessment Procedure (SAP) energy efficiency rating of homes has increased from less than 45 in 1996 to 60 in 2013. The percentage of homes with damp and mould problems has decreased from 10% of dwellings in 2003 to 5% in 2011.

Fuel poverty is a measure of the proportion a household spends on energy compared to their income. Therefore it is not an indicator of energy efficiency or risks to health from cold, though is used as a measure of exposure given the lack of other available data. The Department of Energy & Climate Change (DECC) supports fuel poverty schemes in local authorities. The main home energy efficiency policy, the Energy Company Obligation was amended in 2014 after just over one year of operation. The Autumn Statement 2015 announced ECO would be replaced by a “new cheaper energy efficiency supplier obligation” in 2017 to run for 5 years (Committee on Climate Change 2016). The new supplier obligation aims to upgrade the energy efficiency of over 200,000 homes per year (Committee on Climate Change 2016). The new obligation will primarily aim to improve energy efficiency for fuel poor households. Committee on Climate Change (2015) estimated that annual funding of at least £1.2 billion a year would be needed to meet the government's target of an EPC C rating by 2030 for fuel poor households in England.

In Northern Ireland, initiatives such as the Warm Homes Scheme and energy efficiency grants have been in place and helped several thousand households. A cold weather payment scheme has been set up to help households afford the cost of heating. However, there is as yet no evidence on how this scheme and the other initiatives have helped to reduce vulnerability.

While energy efficiency interventions and the introduction of more stringent building standards to decrease building fabric heat losses have been generally effective in reducing carbon emissions, they may have increased the risk of overheating and affected indoor air quality (section 5.3.5, Wilkinson et al., 2009; Ucci et al., 2011; Davies and Oreszczyn, 2012; Shrubsole et al., 2012; Milner et al., 2014; Hamilton et al., 2015).

The projected energy savings through insulating homes could also be lower than initially predicted due to the ‘take-back factor’ or ‘rebound effect’. This occurs when householders, in realising cost savings from improved energy efficiency, simply turn up their heating and therefore increase overall carbon emissions. Similarly, energy savings from reduced space heating due to warmer winters may also be lower than predicted by models for the same reasons.

Future climate risks and adaptation

Winters in the UK are projected to be milder and wetter (see Chapter 1 and section 5.1.5) and likely to lead to a decrease in seasonal thermal discomfort (a benefit in terms of reduced negative effects on wellbeing). However, the effects of milder winters on space heating demand (see above), fuel poverty and cold-related mortality (see section 5.5.4) are more complex to predict as non-climate factors are important.

Future policies on energy efficiency and housing quality (to address fuel poverty and climate change mitigation) are an important determinant of cold homes (see section 5.1.5 and section of 5.6.2 on challenges in the built environment). Changes to policies to reduce the proportion of cold homes are described above.

As discussed in relation to overheating, when dwellings become more airtight, the provision of effective ventilation methods is essential to prevent increases in indoor air pollution (see below). In addition, homeowners are expected to take responsibility for maintaining their own properties, which includes adaptations to reduce the effects of heat, cold, and flooding.

5.3.4 Risks to buildings from flooding and moisture

Current climate risks and adaptation

The geometry and fabric characteristics of dwellings can influence the risks from indoor damp following floods. Dwellings with reduced ventilation rates, such as flats or modern buildings, and those with glass-fibre insulated cavity walls or floors are difficult to dry (Taylor et al., 2013a). The rate of drying can influence the growth of potentially hazardous mould, while prolonging the survival of flood-borne pathogens deposited on the wall surfaces (Taylor et al., 2013b; WHO, 2010). The deposition of salts or sediment may further impede the rate of drying (Taylor et al., 2011).

The water content of the outdoor air changes seasonally in the UK. During warmer spring and autumn weather, the moisture removal capacity of outdoor air may be reduced due to increased vapour pressure, meaning additional ventilation may be required to adequately remove moisture produced inside a building (HM Government, 2012b). Reverse condensation, may also occur in spring and autumn seasons, when damp walls are heated by solar radiation to the extent that moisture may migrate towards the cooler interior of the building where it may lead to interstitial condensation (BSI. BS 5250 2002). Air tightening of housing may lead to increased indoor moisture and damp risk if adequate ventilation is not provided during moisture-generating activities such as cooking, bathing, or drying laundry.

In many locations across the UK, particularly in coastal areas, buildings may be exposed to driving rain. The installation of full-fill cavity wall insulation in locations with wind-driven rain can lead to damp, as the insulation retains water that penetrates the façade, and can bridge moisture into the inner leaf. Heavy rainfall may also increase the risk of damp due to, for example, poorly maintained guttering.

Indoor damp has been associated with health consequences for building occupants (WHO, 2010) and will also lead to degradation of building fabric and fittings. There have been no population-wide studies that link the prevalence of mould to flooding or other climate risks. Very little is known therefore about the current level of risk and adaptation to flooding and moisture in buildings.

Measures that improve the resilience of buildings to flooding may also help to prevent damage from moisture issues (use of waterproofing, etc.) (see discussion on PLP in Section 5.3).

Future climate risks and adaptation

Very little is known about the future risks to building fabric from climate change. Increased flooding frequency would increase the damage to buildings from moisture. Projected temperature increases should enable flooded or damp buildings to dry faster, however, provided they have sufficient ventilation. Alternatively, warmer temperatures may encourage the persistence of flood-borne contaminants on flooded surfaces (Taylor et al., 2013a). Projected changes to relative humidity levels due to climate change are small (Murphy et al., 2010); however changes in the absolute moisture content of the outdoor air may mean that increased ventilation may be required in order to adequately remove moisture from the indoor environment.

Good maintenance of historic buildings is important (see below). There is a risk of maladaptation through inappropriate or low quality renovations.

5.3.5 Risks to indoor air quality

As described above, housing interventions (which aim to reduce energy use and increase warmth in winter) can change indoor air quality in buildings by changing ventilation rates and the permeability of the building envelope. Buildings are likely to become more airtight where additional purpose provided ventilation (PPV) is not implemented. While this may reduce the ingress of externally sourced pollutants leading to possible reductions in risks, it will increase the concentrations of indoor sourced pollution and allergens (Wilkinson et al., 2009; Ucci et al., 2011; Shrubsole et al., 2012; Milner et al., 2014; Hamilton et al., 2015). Indoor sourced pollutants and their health impacts are listed in Table 5.6.

Table 5.6. Pollutants in the home and their indoor sources

Pollutant	Indoor sources	Health Effects
Nitrogen dioxide (NO2)	Heating and cooking appliances	Associated with respiratory symptoms
Carbon monoxide (CO)	Heating* and cooking appliances	Lethal at high levels, potential chronic effects at low levels
Particulate matter (PM)	Cooking , smoking , domestic activities	Reduced lung function and increased risk of heart and respiratory disease
Environmental tobacco smoke (ETS)	Cigarettes, cigars and pipes	Lung cancer, chronic obstructive pulmonary disease, asthma and reduced lung function
Allergens	Moulds and house dust mites	Worsening of symptoms of asthma; causation of wheezing
Volatile organic compounds (VOCs)	Cleaning products, paints and printers	Respiratory tract irritation, possible effects on asthmatics
Formaldehyde	Hair products, clothes, linen and air fresheners, particle board, plywood, and (MDF)	Associated with respiratory symptoms, known carcinogen

Source: Composed using data from: Weschler, 2009, Shrubsole et al., 2012.
Notes: *Unventilated mobile gas heaters allowed under part J of the Building Regulations.

When overheating increases, more windows are opened so that ingress of outdoor pollution and noise can also increase (Vardoulakis et al., 2015). This issue is particularly relevant to areas in cities with high outdoor pollution levels, which are often the site of low income housing, leading to possible social inequalities from the application of energy efficiency measures, where low income households are exposed to concentrations of outdoor air pollutants (Shrubsole et al., 2015). Higher temperatures reduce stack effect ventilation by lowering temperature differences and therefore buoyancy, thereby reducing the dispersion of indoor pollutants.

5.3.6 Risks to buildings from high winds

Damage to buildings from high winds is difficult to estimate as the metric reported (storm damage) includes both wind and rain damage (see Figure 5.5 above). The overall costs of windstorms incurred by the insurance sector is well-documented (see Prudential Regulation Authority 2015 and Association of British Insurers 2015, Figure 5.5), much of this cost being associated with damage to buildings. Other costs are not well-characterised. This is an important gap in knowledge, as the vulnerability of human populations may be increasing because of people moving to locations (such as the coast) where wind impacts may be more severe by the end of the century (Pinto et al., 2012). Changes to atmospheric circulation may shift storm tracks north or south but changes in wind speeds are uncertain. Higher winds could lead to extensive roof damage on some properties, with older properties at greater risk (Gething, 2010). Although the value of assets at risk are increasingly well-understood (e.g. Economist Intelligence Unit,

2015) there is little evidence on the costs of windstorms in terms of the impacts on people or their communities that result from the damage and disruption caused by wind.

Further, the uncertainty of future climate projections of wind speed mean that it is difficult to incorporate adaptation issues into formal legislation and building regulations. As with other climate risks, the culture of standardisation, which relies on well-established distributions of climate data, makes it difficult for British and European Standards to facilitate adaptation to the changing climate (Sanders and Phillipson, 2003).

5.3.7 Structural stability of buildings

Along with the saturation of the soil by increased rainfall during winter periods, projected hot summers will likely lead to drying out of the subsoil with slopes and retaining structures becoming unstable. Fluctuating rainfall patterns may lead to increased shrinkage of clay soils (or clay heave), which could lead to subsidence and structural damage requiring underpinning or in worse cases demolition. Underground pipework may suffer damage. Subsidence risk is covered in more detail in Chapter 4.

5.3.8 Risks to historic and listed structures, and gardens

Extreme weather already affects culturally-valued structures (e.g., buildings, bridges, towers) and their immediate surroundings (parks and gardens), and archaeology, through the effects of flooding, erosion, land instability, windstorms, wind-driven rain and cumulative damage to a building's assembly and materials (National Trust, 2015). Cultural heritage is a valued resource and impacts from environmental changes need to be assessed over long timescales based on adequate monitoring. Cassar (2005) provided an overview of threats to heritage from climate change in the UK and what steps might be taken by organisations and owners of historic buildings. The EU (Sabbioni et al., 2008) and Markham et al. (2016) have examined international situations and provided guidance relevant to the UK on actions that need to be taken to avoid losses.

As well as structures themselves and their surroundings, climate change may also affect indoor environments and threaten the collections that preserve cultural heritage (Lankester and Brimblecombe, 2012). It may also affect visitor behaviour (Grossi et al., 2010).

Although some strategic planning, risk assessment work, case and scoping studies have been done (e.g. English Heritage, 2008a; English Heritage, 2008b; Hunt (2011) for English Heritage; Powell et al., 2012; Historic England, 2015) and there is some understanding of how climate change might affect historic building materials (e.g. Viles, 2002), there is little or no systematically collected quantitative information on the level of current and future risk for the UK's historic building stock and their surroundings, or historic urban green spaces and gardens (such as the Royal Parks). The lack of monitoring data, surveys and analysis may lead to the loss or degradation of cultural assets and their social value. Table 5.7 shows some of the main risks reported by organisations responsible for historic buildings.

Table 5.7. Climate risks to historic/listed structures and gardens

Climate hazard	Examples of observed impacts	Technical actions to reduce the risk	Potential barriers to action by individuals and institutions
Driving rain	Many examples of driving rain penetrating solid stone walls in listed buildings (English Heritage, 2013).	Historic England provides guidance on preventing rain penetration when repairing or replacing building fabric.	Lack of skilled personnel to undertake repairs/improvements. Lack information on climate risks/poor communication.
Intense rainfall	In 2014 all cathedrals in England reported overtopping of rainwater goods that had never failed before. Many examples of driving rain penetrating solid stone walls in listed buildings (English Heritage, 2013)	Historic England provides guidance on preventing rain penetration when repairing or replacing building fabric. Maintenance and clearing out of gutters and drainage systems	Lack of skilled personnel to undertake repairs/improvements. Lack of information on climate risks/poor communication. New build 'innovative' designs in new listed buildings may not account for increases in intense rainfall. Reduction in knowledge of design features that increase resilience to heavy rainfall.
Flooding	Historic England estimates that there are 56,000 historic buildings sited in Flood Zone 2. The Church of England estimates that there are 1,240 historic churches at risk of flooding. Examples: damage and threat of collapse to Cockermouth Castle (grade I listed, & Scheduled Monument) from winter 2015/16 flooding in Cumbria. Partial collapse of 300-year old Tadcaster Bridge (grade II listed) in the winter 2015/16 floods (see also box 5.3). Abergeldie Castle almost	Historic England publishes guidance on flooding and historic buildings. Historic Scotland publishes a guide on flood damage to traditional buildings	Lack of skilled personnel to undertake repairs/improvements. Lack information on climate risks/poor communication Standard practices to repair buildings following a flood can be inappropriate for historic buildings, such as removal of wet timber or replacement of lime plaster (Historic England, 2015; Atkins, 2013).

Table 5.7. Climate risks to historic/listed structures and gardens			
Climate hazard	**Examples of observed impacts**	**Technical actions to reduce the risk**	**Potential barriers to action by individuals and institutions**
	collapsed into the River Dee during the winter floods on 2015/16; emergency work shored up the river bank.		
Pests and diseases	Although many pests only attack rotting wood, some (such as Ambeodontus tristis from New Zealand) can attack healthy wood in houses. See also chapter 3 section 3.3.5 for the impact on trees and plants.	The Forestry Commission publish regulations on checks that must be carried out on imported timber. The Forestry Commission maintains databases of threats to timber from pests and diseases. The Non-native Species Secretariat monitors invasive non-native species in Great Britain and coordinates th response strategy with input from governmental and non-governmental agencies, charities and universities.	Lack information on climate risks/poor communication Lack of oversight, risk of importation through timber packing cases.

Work is in progress to better understand risks and adaptation options (including weather proofing and additional flood protection). High level policy goals and strategies have been published in the past (e.g. English Heritage, 2008b (now Historic England)). Some estimates of the scale of buildings under threat have been made; Powell et al. 2012 report for example that based on coarse modelling, 5,000 listed buildings, 300 scheduled ancient monuments and 12,000 other archaeological sites are located in areas at risk from flooding in Wales. There are thought to be around 800 listed buildings at risk from flooding in Scotland (communication from SEPA). Historic buildings are included in other policy documents, such as surface water management plans. For example, a flood assessment in Canterbury included a description of the flood risk to local historic buildings (Jacob Engineering, 2012). Historic Scotland provide advice on flood damage to historic buildings (Historic Scotland, 2016). The implementation of guidance on adaptation, however, appears to be very low.

Many listed buildings are in private hands. There is no estimate of what risks these buildings are facing from climate change or how owners view adaptation.

5.3.9 Risks to passenger comfort and health on public transport

Higher temperatures have been cited as a risk to the effective functioning of transport networks, because of the direct risks not only to transport infrastructure (see Chapter 4), but also to commuter comfort and health (Carter et al., 2012), with implications for welfare losses. The first CCRA did not specifically include risks associated with public or private transport from the travellers' perspective.

The frequency of overheating public transport (buses, trains, trams) are not well-described in the scientific literature, although there is much anecdotal evidence of unpleasant journeys on hot summer days.[29] Underground trains, especially those operating in the 'deeper' underground lines in London (e.g. Central and Bakerloo Lines), are vulnerable to overheating in prolonged hot weather (URS, 2010, Jenkins et al., 2014). In the hot summer of 2015, Public Health England advised employers to let their staff travel to work at less busy times to avoid experiencing overheating on crowded public transport.[30] However, alternative transport or travel times may not be possible for many workers at present. Overheating may result in loss of work days (as susceptible individuals, such as pregnant women, may not be able to travel) or increased disruption to the network (e.g. trains stopped because passengers are taken ill).

Transport for London scored overheating as one of the two highest risks to tube services in its second Adaptation Reporting Power report, along with flooding (Transport for London, 2015). Under the 'Cooling the Tube' programme, future tunnel temperatures have been modelled by Transport for London using the UK Climate Projections to test the effectiveness of different cooling strategies, though this work is not published.[31] Many adaptations are already being put in place to mitigate the risks from heat on the underground. For example, in 2010, new S-stock trains started to replace older stock on the Circle, District, Hammersmith and City and Metropolitan lines, which have built-on air conditioning.[32] London Underground also publishes "beat the heat" guidance posters in the summer months. It was reported in September 2015 that Transport for London planned to replace the non-opening windows on Routemaster buses to improve ventilation at a cost of £2 million.[33]

Some studies have suggested that the risk of heat stress could cause a shift away from non-air-conditioned public transport to private cars (URS, 2010). However, there are also risks of more vehicles breaking down in hot weather as overheating is currently a key cause of breakdowns (URS, 2010). Again, these risks are not quantified. There is also no information available for other UK locations outside of London.

29 e.g. www.bbc.co.uk/news/uk-england-london-34293388, www.standard.co.uk/news/transport/on-the-hot-line-commuters-tell-of-brutal-heat-as-londons-transport-network-reaches-temperatures-too-9624717.html

30 https://www.gov.uk/government/news/keep-cool-and-carry-on-in-the-hot-weather

31 From notes taken from a meeting with London Underground in September 2013

32 https://tfl.gov.uk/corporate/about-tfl/what-we-do/london-underground/rolling-stock

33 www.bbc.co.uk/news/uk-england-london-34293388

5.4 Health and social care system

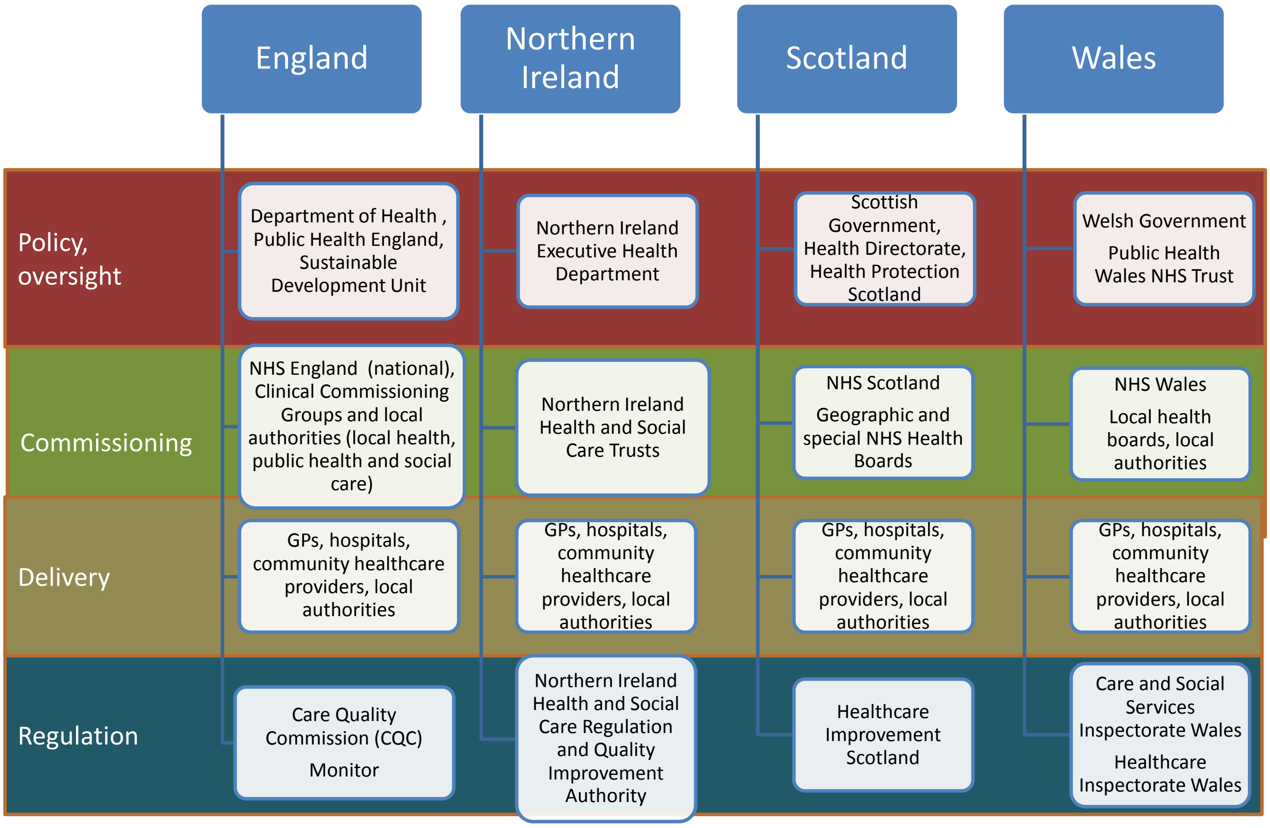
Key risks and opportunities – health and social care system
PB9: Risk to health service delivery and social care: • Floods, storms, snow and heatwaves already affect health system infrastructure and service delivery through effects on staff, buildings and equipment. • Heatwaves affect the functionality of hospitals and care homes. Health services will be vulnerable to an increase in the frequency and intensity of heatwaves. Care homes are at risk of overheating, and care management practices may not sufficiently address heat risks. • Flood risks to NHS and social care assets are likely to increase under climate change. Future projections indicate an increase in the number of GP surgeries, care homes, emergency service stations and hospitals in the flood risk zone, with the largest change in risk generally shown for care homes. England and Wales show bigger increases in risk than Scotland and Northern Ireland. • Cold spells and snow storms interrupt travel for patients and staff. Fewer cold events in future will benefit health system management. • The current and future capacity of the health and social care system to manage climate risks is unknown. In England there is evidence of gaps in planning. Overall capacity could also decrease due to fragmentation of services which increases the complexity of risk management.

The National Adaptation Programme makes specific reference to climate resilience in the health and social care system with stated objectives to 'promote climate resilience within the NHS, public health and social care system to ensure continuity of services and resilient assets/estates including the ability to deal with the increased demand for services associated with severe weather events'.

Health and social care systems in England and the devolved administrations are complex networks (Figure 5.9), many parts of which are at risk from severe weather that is likely to alter in frequency or severity with climate change. A range of different partners are therefore involved in preparation and response to severe weather in order to ensure continuity and accessibility of health and social care services, and adequate response to changes in the need for health services in the population.

The resilience of health systems is an emerging international topic. The World Health Organization (WHO) has a programme of work to make hospitals safe and operational in disasters (Comprehensive Safe Hospital Framework). WHO's collaboration with the World Meteorological Organization (WMO) to establish the WHO-WMO Climate and Health Office and implement the Global Framework for Climate Services to meet the climate information needs of the health sector should also contribute significantly to reducing risks to health of extreme weather, climate-related hazards and climate-sensitive diseases.

Figure 5.9. Organisation of health and social care across the UK



5.4.1 Policy framework

Institutional and social infrastructures are important for health and social care delivery. These include organisational protocols of public and private organisations for addressing severe weather risks and the governance structures through which these are produced, agreed and implemented at national and local scales. The roles of informal agencies and of individuals and their carers living in the community are also important.

England

The Health and Social Care Act (HM Government, 2012a) significantly altered the structure of healthcare delivery and regulation in England. Clinical Commissioning Groups (CCGs) are responsible for commissioning healthcare from acute hospitals, and NHS England is responsible for commissioning services such as specialist care mainly from NHS Foundation Trusts. Responsibility for public health now sits within local authorities. Each local authority has a Director of Public Health who sits on a Health and Wellbeing Board that determines local priorities, based on the Joint Strategic Needs Assessments (JSNAs). Local authorities also ensure that adequate services are provided for people who need care, and to place wellbeing at the centre of care provision (Care Act, 2014). Public Health England (PHE), an agency of the

Department for Health, advises government, the NHS and local authorities with respect to health improvement and health protection policies. PHE has a key role in long-term planning for and reduction of the health effects of climate change.

There are several mechanisms in England for providing improved information and guidance to organisations on emergency planning:

- Strategic Health Asset Planning & Evaluation (SHAPE) tool,
- Estates Return Information Collection (ERIC),
- Premises Assurance Model (PAM) to provide information on the resilience of healthcare estate premises.

The Department of Health published 'Arrangements for Health Emergency Preparedness, Resilience and Response from April 2013' (Department of Health, 2012), which sets out how the health sector will deliver safe and consistent emergency preparedness, resilience and response (EPRR) in England.

Since CCRA1, during recent revisions of Health Technical Memoranda and Health Building Notes, DoH has incorporated updated guidance with respect to climate change adaptation and mitigation. These revised documents are:

- HBN 00-01: General design guidance for healthcare buildings
- HBN 00-07: Planning for a resilient estate
- HTM 00-00: Policies and principles of healthcare engineering
- HTM 04-01: Safewater in healthcare premises (due to be published in April 2016)
- HTM 07-02: EnCO2de 2015 making energy work in healthcare

There are other documents that ideally require revision as resources allow, for example HTM 03-01: Specialised ventilation for healthcare premises. This is required in order to take account of increasing temperatures and pollution.

Under the NHS standard contract, service providers have to undertake a series of actions related to emergency preparedness and resilience, detailed in a set of core standards. These include maintaining a business continuity plan, ensuring that all reasonable efforts to maintain care are employed in the event of an emergency, and ensuring that staff are adequately trained.

The mechanisms for delivering local heath priorities are the JSNAs and the Joint Health and Wellbeing Strategies, which can offer a route to address climate risks. There is a non-mandatory standard contract for local government to use for commissioning public health services, but this does not contain provisions for adaptation or preparedness of assets for extreme weather. A recent review o fJSNAs found that explicit action orientated adaptation strategies were rare (Button and Coote, 2016).

Local Health Resilience Partnerships (LHRPs) deliver national emergency preparedness, resilience and response (EPRR) strategies in the context of local risks. The aim of these partnerships is to bring health sector organisations involved in EPRR to the Local Resilience Forum (LRF) and improve joint working (Department of Health, 2012).

Northern Ireland

Health and social care provision in Northern Ireland is mandated through the Health and Social Care (Reform) Act 2009. Services are provided through a number of health and social care trusts, regulated by the Health and Social Care Regulation and Quality Improvement Authority. The ten year 'Making Life Better' strategy for health and wellbeing has a general objective to enhance the capacity of physical infrastructure to protect, support and provide access to healthy and active living and wellbeing, including through climate change adaptation (DHSSPS, 2014).

Scotland

The Public Health (Scotland) Act 2008 places duties on health boards and local authorities to have a joint responsibility to protect public health. Health Protection Scotland is a division of NHS National Services Scotland and provides advice, support and information to health professionals, national and local government, the general public and a number of other bodies that play a part in protecting health. Local NHS boards produce guidance on responding to extreme weather including flooding, cold and hot weather.[34] Health Protection Scotland provides overarching guidance to the health boards.

Under the Scottish Climate Change Adaptation Programme (Scottish Government, 2014a), NHS Scotland Boards are expected to develop individual climate change adaptation plans in accordance with the NHS Scotland Sustainable Development Strategy. NHS Boards also have to produce property asset management strategies (PAMS) but these do not currently have to account for the risks to assets from extreme weather.

Wales

In Wales, seven integrated Local Health Boards are responsible for all healthcare services, overseen by NHS Wales, and for emergency planning within hospitals. NHS Wales had a set of standards for healthcare providers set out in its 2010 Standards for Health Services in Wales[35] that included contingency and emergency planning arrangements (standard 4), providing a safe and sustainable healthcare environment (standard 12), and managing risk, health and safety (standard 22). Since 2015, these have been replaced with a new set of standards[36] including managing risk and promoting health and safety (2.1), but not emergency planning or providing a sustainable healthcare environment.

The Health, Social Care and Well-being Strategies (Wales) 2003 regulations require Local Health Boards and local authorities to jointly produce a local health, social care and wellbeing strategy for each area. The response to extreme weather is outlined in the Extreme Weather, Public Health Alerts and Advice for Wales (Public Health Wales, 2015) (see below).

5.4.2 Current climate risks and opportunities

Severe weather may cause acute increases in demand for health and social care services which need to be managed. Flood events may also have longer-term implications for the provision of services (see below). Lack of preparedness for these risks could lead to inadequate or sub-standard care, or, in an extreme case, service collapse or failure. Severe weather can also damage

[34] e.g. www.nhsggc.org.uk/media/226417/nhsggc_adverse_weather_guidance.pdf
[35] www.wales.nhs.uk/sitesplus/documents/1064/Doing%20Well%2C%20Doing%20Better.pdf
[36] www.wales.nhs.uk/sitesplus/documents/1064/24729_Health%20Standards%20Framework_2015_E1.pdf

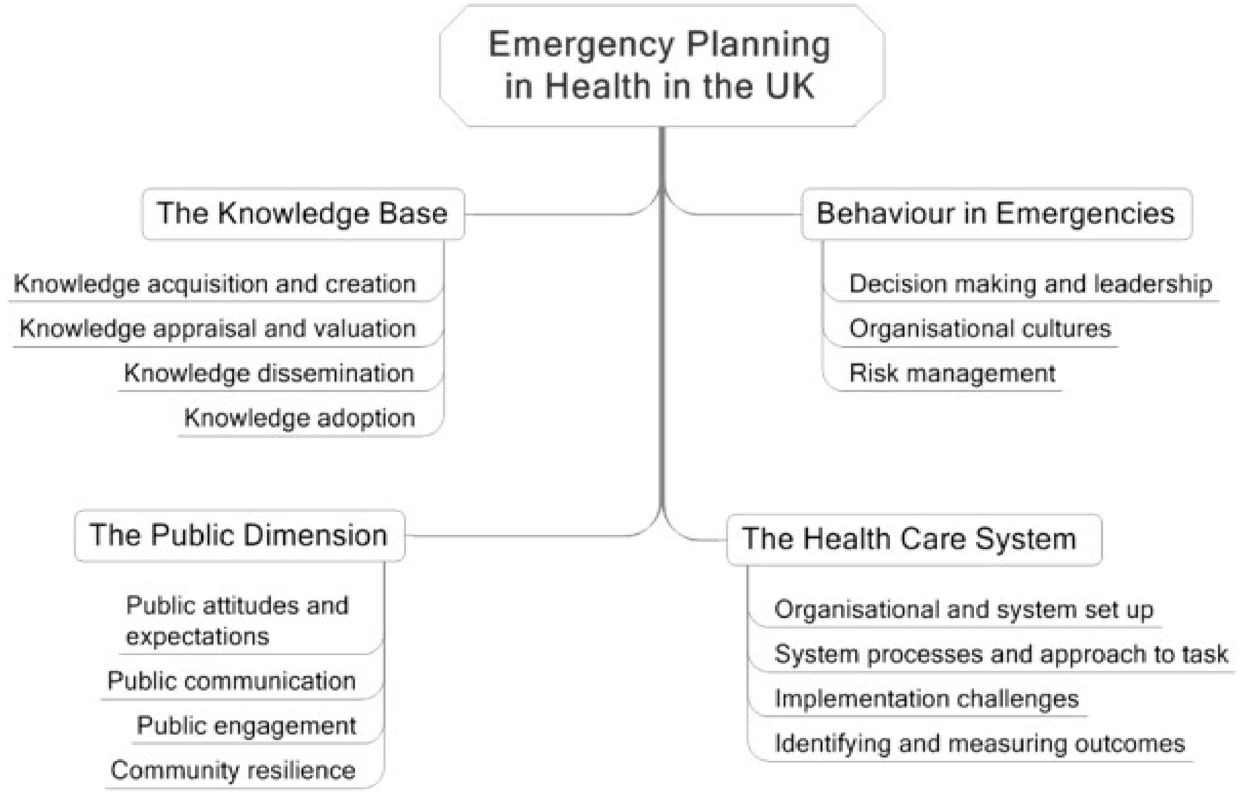
health infrastructure (buildings, equipment and medicines) and critical infrastructure (water, power, transport, ICT) that can adversely affect health care delivery.

The health and social care system operates very close to its limits, and therefore is vulnerable to shocks, or multiple shocks, as could be caused by extreme weather. Deficiencies in NHS emergency planning have been identified in relation to non-climate risks (Day et al., 2010; Williams et al., 2007; Lee et al., 2012). A scoping study found the evidence base for emergency planning to be very limited, with a lack of clear understanding of what type and structure of evidence would be of most value for emergency planners and policy-makers (Challen et al., 2012).

The capacity of the health system in England for adaptation to climate change has also been reviewed for the 2015 Adaptation Reporting Power report (SDU et al., 2015). 57% of NHS providers have a board approved adaptation plan (sometimes as part of the overarching sustainable development management plan (SDMP)). However, a survey of SDMPs found that only one third of providers had plans in place to addresss service delivery in the event of extreme weather. A survey of GPs also found that less than half (of those who responded) were confident about their resilience to extreme events. There is a lack of evidence regarding the adequacy of NHS plans to cope with extreme weather.

Figure 5.10 describes some key challenges to improving emergency planning in the health system, for climate and other risks (e.g. infectious disease outbreaks). A key challenge is the lack of evidence relating to the impacts of climate risks (flooding or heatwaves), and no systems in place to monitor such impacts. Another key challenge is the organisation of the health system, its increasing fragmentation and lack of resources (see below).

Figure 5.10. Key challenges in emergency planning in health systems the UK



Source: Lee et al. (2012).

Health system infrastructure

Higher temperatures

Heatwaves cause problems with the functionality of hospitals as well as the thermal comfort of patients and staff (WHO, 2009; Carmichael et al., 2013). Reported impacts of heatwaves in England include:

- Discomfort or distress of patients, and their visitors
- Equipment failure, such as failure of essential refrigeration systems
- Disruption of IT services
- Disruption of laboratory services
- Discomfort of staff (occupational health)
- Degradation or loss of medicines.

Hospital design and construction influence thermal comfort and ventilation during heatwaves. Hospitals in urban settings may also be affected by urban heat islands (see section 5.2.2). Research indicates that older designs are more efficient in this respect than more modern structures (Short et al., 2012; Iddon et al., 2015) (see section 5.3.2 on overheating in buildings, above). There is no information on the prevalence of overheating in relation to hospital design across the UK as a whole.

A qualitative study of hospital managers, nurses and healthcare assistants (from a single hospital in the South East of England) found that although hospital managers showed good awareness of the Heatwave Plan for England, this was lacking amongst frontline staff. (Boyson et al., 2014). However, frontline staff (doctors and nurses) were aware of the dangers of heat and felt that they individualised care accordingly. Poor communication of information between managers and frontline staff was identified as a potential barrier to implementing effective action during heatwaves. NHS staff also identified issues with hospital design and equipment that may limit effective implementation of the plan (Boyson et al., 2014).

The relative risk of heat-related mortality is higher in care and nursing homes than in the general population, even after accounting for the health status of residents (Hajat et al., 2007). Qualitative studies suggest that problems may occur associated with poorly adapted equipment, structural design and care practices. One study (based on four care homes in England) (Gupta et al., 2016) found that there was a risk of summertime overheating, especially during short-term heat waves (2-4 days) with indoor temperatures rising to nearly 30°C in communal areas and resident rooms. Non-structural factors that affected overheating risk include fixed daily routines of care home residents making it difficult to accommodate periods of intense heat; management structures and systems which do not always allow for front line staff to alter temperatures; and a culture which focuses on cold as the main climate risk so that high indoor temperatures are not always considered by residents or staff to be undesirable (Gupta et al., 2016).

More research is needed on the risks in hospitals, care homes and community based care from heatwavess, in terms of risk management, clinical practices, and how these relate to building design.

Cold and ice storms

Cold weather can also affect health service infrastructure. For example, in 2010/11, the cold winter in Northern Ireland reportedly led to the following (correspondence from the Department of Health, Social Services and Public Safety):

- Ventilation systems in hospitals were damaged by frost. This affected theatre and other ventilation systems, though with little impact on patient care.
- Water cooling equipment for one hospital was frozen and unable to produce isotopes for the PET/CT scanner. However, contingency plans were triggered to order isotopes from Dublin.
- A number of other reported problems with MRI cooling systems were reported.
- A number of facilities lost water supplies because of both burst pipes within the Trust Estates and loss of supplies from NI Water due to operational restrictions caused by frozen supplies and/or burst pipes. Contingency measures were required to ensure service delivery was maintained including the provision of bottled drinking water.

Another major factor for winter storms is the difficulty experienced by staff in travelling to hospitals.

Flooding

Flood events have damaged health system infrastructure (Menne and Murray, 2013). Impacts have been reported affecting the operation of GP clinics, hospitals and related services. The winter 2013/14 floods affected four GP surgeries, two care homes, two pharmacies and one clinic in Boston, Lincolnshire alone (PHE communication). There are five hospitals in the UK that are situated at or below 1m above sea level and at risk from coastal flooding.

In 2012, surface water flooding damaged a major NHS blood and transplant (NHSBT) facility in Bristol, leading to its immediate closure (Landeg and Lawson, 2014). It is expensive and complex to relocate healthcare infrastructure.

Flood events can disrupt the critical infrastructure on which health facilities depend even when the facilities themselves are not located in the flooded areas. Flooding or snowfall can disrupt utility networks (Oven et al., 2012), such as the water supply (Chapter 4 and 6), or cause power failures (Klinger et al., 2014; Royal Academy of Engineering, 2016). Following flooding in 2015, the hospital in Lancaster was able to manage the loss of power (over 24 hours), due to the use of back up generators.

Flood events can also prevent staff from getting to work, either due to transport disruption or because the staff member has been flooded at home (Chapter 6 reports that up to 40-60% of staff missed work days in organisations affected by flooding, for example).

The power and communications loss after flood can have implications for care homes and for vulnerable people that rely on home care providers (Royal Academy of Engineering, 2016).

Some population-wide estimates of risk are available. The ASC estimated that, accounting for community-level defences, approximately 10 – 14% of emergency service stations and 6 – 8% of hospitals, care homes and surgeries are located in areas that are susceptible to fluvial and coastal flooding in England and Wales (ASC, 2014). These estimates are similar to those estimated by Sayers et al. (2015) in Table 5.8 below.

Health service demand

During periods of hot weather in England there is a small increase in the use of health services as admissions for injuries and respiratory illness increase (Kovats and Hajat, 2008). During the moderate 2013 heatwave, increases in GP consultations for heatstroke or heat illness were detected (Elliot et al., 2014b). In hot weather, there is some evidence that emergency ambulance callouts also increase (Thornes et al., 2014). There was also an increase detected in attendance at emergency departments related to asthma associated with thunderstorms during the 2013 heatwave (Elliot et al., 2014a).

Cold weather is also associated with an increase in GP consultations (Hajat, et al., 2004). Emergency department activity increases during cold spells, and fractures among older people showed an increase after a drop in winter temperatures (Hughes et al., 2014) or during heavy snowfall (Hajat et al., 2016). Emergency hospital admissions due to injuries from falls on snow and ice vary significantly from year to year and reached 16,604 in England in the relatively severe winter of 2009/10, costing an estimated £42 million in NHS inpatient care (Beynon et al., 2011). Ambulance emergency response times also increase in very cold weather (Thornes et al., 2014).

Information on the ways in which health and social care demand is affected by flooding is limited, since the populations affected are relatively small (compared to heat and cold events) and it has not been possible to detect effects on hospital admissions or GP attendance. However, following the flooding and power loss in Lancaster in 2015, access to primary care services was disrupted which led to patients going to A&E as an alternative (for health care or advice) and it subsequently experienced a significant surge in demand (Royal Academy of Engineering, 2016). The Syndromic Surveillance System reported no increases in GP or emergency department contacts during the winter flood event 2013/14 at the local authority level in England, for example (PHE, 2014).

5.4.3 Future climate risks and opportunities

Future risks for health and social care systems associated with climate change will depend not only on the changing frequency and severity of severe weather events under climate change, but also on the extent to which health and social care providers are able to adapt. This in turn will be affected by government policies affecting governance expenditure and priorities for the sector in coming years. There is evidence that the health service will become increasingly fragmented in the future which may make resilience planning more challenging (see Section 5.1).

Health services will be vulnerable to an increase in the frequency and intensity of heatwaves. Modern built facilities are designed to support contemporary care models and to be thermally efficient in cold weather, but they create problems during heatwaves of thermal comfort for patients and staff in hospitals and care homes. The potential for adaptation is high, as technologically feasible options are available (see above). However, as with dwellings, there is a risk of lock-in regarding current sub-optimal designs. Low-energy and relatively low-cost options are available to adapt existing hospitals and design new buildings for improved thermal comfort and operational resilience during heatwaves. However, current government policy does not place responsibility on the relevant agencies to address overheating in hospitals and care homes.

There is currently no evidence available on how the changing incidence of cold weather and snow events may impact on the health and social care system. While cold weather is projected to decline in the long term, the implications of climate change for the future frequency of snow and ice storms is uncertain.

The proportion of health infrastructure at risk of flooding is likely to increase. Sayers et al. for the ASC (2015) has estimated projections of risk across a range of adaptation scenarios and for health infrastructure located in areas with different levels of flood risk. In England and Wales, the number of hospitals, GP surgeries, emergency service stations or care homes located in areas at or greater than a 1 in 75 annual chance of flooding are projected to increase by the 2050s by between 3% and 24% under a 2°C scenario, and between 27% and 110% under a 4°C scenario (assuming a continuation of current levels of adaptation). The risks are somewhat lower for health infrastructure in Scotland and Northern Ireland. The results shown in Table 5.8 (also from Sayers et al. for the ASC (2015)) show projections of risk across the full range of adaptation scenarios for assets located in areas with up to a 1 in 200 risk of flooding. These results assume no change in the number or position of current health infrastructure in the future.

As discussed above, there are uncertainties in mapping current and future flood risks (Box 5.4). SEPA estimates, for example, that 1-2 hospitals are currently located in areas at risk of flooding in Scotland (based on 1 in 200 year event) (SEPA communication).

Problems of organisational management and communication between different groups of health and social care personnel have been shown to make the response to severe weather events less effective (Castelli et al., 2011; Landstroem et al., 2011; Zaidi and Pelling, 2013). Although individual service providers may be familiar with severe weather plans and protocols, problems of communication between personnel in different parts of the complex health and social care system can result in difficulty in implementing extreme weather plans (EPSCR-ARCC and SCIE, 2011; Boyson et al., 2014; Wistow et al., 2015).

GP care is likely to continue to be important in the future as well as community-based speciality care facilities. The NHS may rely increasingly on the voluntary sector and with a network of providers to deliver health care. These trends support the argument that climate change resilience partnerships will need to involve co-ordination and engagement across a complex network of care and governance.

Table 5.8. UK Health and social care infrastructure at risk of future flooding

		2020s		2050s	
	Present day (%)	2 deg (AS1-AS5)	4deg (AS1-AS5)	2 deg (AS1-AS5)	4deg (AS1-AS5)
ENGLAND					
Emergency services	362 (14.0%)	360-366	410-415	399-418	414-448
GPs surgeries	1,434 (7.6%)	1419-1444	1620-1647	1594-1658	1650-1807
Hospitals	166 (11.6%)	165-167	182-185	180-187	187-200
Care homes	1163 (10.0%)	1155-1174	1302-1333	1276-1339	1338-1454
SCOTLAND					
Emergency services	84 (11.6%)	86-87	97-97	93-96	105-107
GPs surgeries	10 (7.5%)	10-10	11-12	11-12	12-13
Hospitals [a]	0 (0%)	0	0	0	0
Care homes [b]	53 (6.2%)	55-55	60-60	58-61	64-66
WALES					
Emergency services	95 (9.8%)	95-96	106-107	102-107	114-119
GPs surgeries	52 (18.2%)	58-63	63-63	62-70	72-76
Hospitals	10 (10.9%)	10-10	11-11	11-11	13-14
Care homes	45 (9.7%)	46-46	56-56	54-56	62-64
NORTHERN IRELAND					
Emergency Services	19 (8.6%)	19-19	21-21	21-22	23-24
GPs surgeries	37 (10.5%)	37-37	38-38	38-39	40-40

Table 5.8. UK Health and social care infrastructure at risk of future flooding

Hospitals	0 (0%)	0	0	0	0
Care homes	16 (7.4%)	16-16	17-17	17-17	18-19

Source: Sayers et al. 2015.
a SEPA estimates 1-2 hospitals in current flood risk zone (1 in 200 year event)
b SEPA may also provide updated estimates for care homes in Scotland at risk of flooding. The information is not available at the time of writing.
Notes: Properties shown are those located in areas at 1 in 200 or greater risk of flooding from rivers, the sea or surface water. Estimates are shown for the full range of adaptation options:
AS1 – Enhanced whole system adaptation (most ambitious scenario considered)
AS2 – Probability focussed adaptation
AS3 – Exposure focussed adaptation
AS4 – Vulnerability focussed adaptation
AS5 – Reduced whole system adaptation (least ambitious scenario considered
The baseline continued levels of adaptation scenarios sits between AS1 and AS5 so is also included in the range. Sayers et al. 2015 provides a detailed description of each of the adaptation scenarios.
The projections assume no change in number of properties over time and therefore no population growth. The baseline period is 2013 or 2014 depending on the country, and definitions may also vary (see Sayers et al. annex A)

The capacity of the health and social care system to manage climate risks needs further research. The 2015 Adaptation Reporting Power report from the Sustainable Development Unit (SDU) on adaptation in the health and social care sector in England made the following recommendations:

- The health sector needs to monitor the developing impacts of climate change, the effects on the population and the level of preparedness of services and communities.
- Further support should be given to embed climate change into local thinking and decision-making, enhanced by a sound platform of information from nationally collated information and intelligence.
- Co-ordination and communication of risks and opportunities could be improved.

5.5 Population health and health protection

Key risks and opportunities – population health and health protection

PB5: Risks to communities, people, health and buildings from flooding

- Flooding causes deaths and injuries, though risks from infectious disease caused by flooding are low. There is emerging evidence that impacts on mental health are significant and long lasting.

PB1: Risks to health and wellbeing from higher temperatures

- An increase in heat-related mortality is projected by several studies. Heat-related deaths due to climate change and population growth could increase by up to 257% by the 2050s (median estimate) assuming no adaptation, from a current annual baseline of around 2,000 heat-related deaths in the UK. Adaptation is likely to reduce these effects, but the level of autonomous adaptation is uncertain and is likely to vary over time. Public Health England publishes an annual heatwave plan, and guidance is provided in Scotland and Wales on protecting health in hot weather. Adaptation in the built environment is limited, as there are currently no policies and a lack of regulatory requirements to reduce overheating in buildings (see Section 5.3).

PB11: Risks to health from vector-borne pathogens

- Climate change may increase the capacity of UK mosquito species to transmit certain arboviruses, and increase the suitability of the UK's climate for invasive mosquito species. The risk of introduction of dengue and Chikungunya viruses is contingent on the risk of invasion by non-native mosquito vectors, which remains low in the near term. The risk of introduction of malaria remains low.

PB4: Potential benefits to health from warmer winters

- Cold is currently a significant public health problem, with between 35,800 and 49,700 cold-related deaths per year. Hard-to-heat homes are the major determinant of the burden of cold-related mortality and morbidity (see Section 5.3). The effect of climate change on cold-related mortality and morbidity is beneficial, but projections suggest that the total number of cold-related deaths per year is unlikely to decline significantly due to the ageing population.

PB10: Risks to health from poor air quality

- Climate change may lead to worsening air quality in some areas with high emissions but the risks caused by future emissions are a more important driver of risk than changing weather patterns. Climate change may also affect the pollen-related allergic disorders though changes in pollen abundance and seasonality.

PB13: Risks to health from poor water quality

- The the association between gastrointestinal pathogens and heavy rainfall has been reduced through better water management systems. We do not currently have any evidence related to the future risks from gastrointestinal pathogens in drinking water related to climate change. Increasing sea temperatures around the UK may result in an increase in marine vibrio infections.

This section has been divided into five main areas:

- Risks from flooding and storms
- Emerging infections
- Heat and cold
- Air pollution
- Food and water safety.

5.5.1 Risks to health and wellbeing from flooding and storms

Policy framework

Prevention and responding to flooding is complex and many agencies are involved, which are described in the Communities section above (5.2.5).

Public Health England (PHE) provides advice to the general public on avoiding the health implications of flooding in England. PHE produces a range of leaflets and undertakes enhanced surveillance in order to detect any health effects during flood episodes. PHE with the Environment Agency issue advice to the public for preparedness and response to protect health during flooding incidents (PHE, 2015b; Public Health England and Environment Agency, undated).

Health and safety messages are an integral part of the messages which SEPA provide to the public on preparing for flooding in Scotland. Together with Health Protection Scotland, SEPA have developed a fact sheet dealing with the potential impacts of flooding on health and wellbeing. A prompt card raising awareness of flooding impacts on health has also been distributed to heath authorities across Scotland through NHS Scotland. The Scottish Flood Forum also provides online and one to one advice and support for flood victims which includes health elements.

No information is available on the measures being taken in Northern Ireland and Wales to manage the risks to health from flooding.

Current and future climate risks and adaptation

Flooding is a threat to life. However, deaths directly attributed to flood events are difficult to ascertain and are not routinely reported. Studies from other populations have shown that significant mortality is mostly associated with flash flooding or with a major coastal flood (such as in 1953). There is no precise estimate of flood mortality for the UK, as the definition of a flood death can vary. Mortality associated with flooding can include related car accidents, other accidents (for example, persons falling into fast flowing water, and carbon monoxide poisoning (Waite et al., 2014; Goldman et al., 2014).

There is emerging evidence for the impacts of flooding on mental health. Systematic reviews of epidemiological evidence suggest that flooding has adverse and long term effects on mental health and wellbeing (Ahern et al., 2005; Stanke et al., 2012). The evidence relates to common mental disorders (i.e. anxiety and depression) and measurable posttraumatic stress disorder (PTSD) in the UK. Table 5.9 describes the studies published in the UK on the health effects of flooding.

In the UK at present, high winds cause a small number of fatalities, often as a result of accidents involving fallen trees or damaged buildings. Most of deaths associated with windstorms (such as during the great winter storm of 1953) are caused by storm surges and coastal flooding. There is limited information for the UK on injuries associated with flooding and windstorms either in occupational settings or in the general population.

Table 5.9. Epidemiological studies assessing the relationship between flood and health outcomes in the UK

Study (authors, year)	Flood event (area, year)	Study design	Main results
Bennet (1970)	Bristol, 1968	Controlled interrupted time-series study; 12 months pre- and post-flood event 316 flooded and 454 non-flooded households	Deaths: 50% increase in flooded area, no increase in non-flooded area, predominantly in people over 65 years old, especially in females over 75 years old Medical attention: GP attendance 53% increase in flooded area. Hospital admissions ≥ 200% increase in flooded area New psychiatric symptoms (self-reported): 18% of the flooded female and 6% of the non-flooded male reported. These rates include symptoms which might have been present before the flood
Reacher et al. (2004)	Lewes, 2000	Retrospective study; 9 months post-flood telephone interviews with 227 cases (house flooded) and 240 controls (non-flooded from same postcode)	Ear ache: flood associated with ear ache in all age groups (RR = 2.2, 95%CI: 1.1, 4.1) Gastroenteritis: association is less marked (RR = 1.7, 95%CI: 0.9, 3.0), p for trend by flood depth = 0.04 Psychological distress: fourfold higher risk in flooded group (RR = 4.1, 95%CI: 2.6, 6.4)
Milojevic et al. (2011)	England and Wales, 1994–2005 (319 flood events)	Controlled interrupted time-series study; 12 months pre- and post-flood event. Non-flooded area defined by <5km from flooded boundaries	Deaths: Ratio of change in flooded/non-flooded areas 0.90 (95%CI: 0.82, 1.00). The ratio consistent by subgroups of age, sex, population density or deprivation. Observed/Expected deaths show the similar post-flood `deficit' possibly due to population displacement (research artefact) or a beneficial effect of flooding

Table 5.9. Epidemiological studies assessing the relationship between flood and health outcomes in the UK

Study (authors, year)	Flood event (area, year)	Study design	Main results
Paranjothy et al. (2011)	England (South Yorkshire and Worcestershire), 2007 summer	Cross-sectional study on 3 – 6 months post-flood telephone survey; 2,265 individuals	Mental health: 2 – 5-fold higher prevalence of mental health symptoms in those flooded compared with those non-flooded. Highest prevalence was observed where water was above floor level (psychological distress OR 12.8, 95%CI: 9.3, 17.6; anxiety OR 13.9, 95%CI: 9.3, 20.8; depression OR 7.7, 95%CI: 5.2, 11.4; probable PTSD OR 11.9, 95%CI: 6.6, 21.5)
Mason et al. (2010)	England, location and year unknown	Cross-sectional study; 6 months post flood, n=440 flood-affected adults	Mental health: prevalent depression 35.1%, PTSD 27.9%, anxiety 24.5%. Females associated with higher risk in these prevalent measure and maladaptive coping styles (emotional and avoidance coping)

Source: Adapted from Milojevic (2015).
RR = relative risk, OR = odds ratio, 95% CI = 95% confidence interval.

Future flood risk is likely to increase with climate change – as described in the sections above. Flood prevention is discussed in detail in other sections. Our understanding of the future risks of injuries, fatalities and mental health impacts from flooding has improved since the publication of the first CCRA, though large uncertainties remain over future impacts on health.

Projections of injuries, fatalities and mental health impacts from flooding have improved since the publication of the first CCRA, and large uncertainties remain over future impacts.Various steps are being taken to get better traction on predicting and forecasting windstorms (Roberts et al.; 2014, Lewis et al., 2015). This should improve capacity to adapt to any increase in the damaging characteristics of windstorms.

5.5.2 Infectious diseases and pests

An emerging infection is defined as a disease that has newly appeared in a population or has been known for some time but is rapidly increasing in incidence. Several vector-borne diseases (i.e. diseases spread by insects and ticks) have emerged in Europe in recent years. These include vivax malaria, West Nile fever, dengue fever, Chikungunya fever, leishmaniasis, Lyme disease and tick-borne encephalitis. The vectors of these diseases are mosquitoes, sand flies and ticks. This section will also consider the implications of climate change for pest species (insects, ticks and rats).

Current policy

The Advisory Committee on Dangerous Pathogens advises the UK Government on the risks posed to people from pathogens. Surveillance, monitoring and research efforts are devolved as below.

England

Public Health England (PHE) has a programme of research and surveillance for new and emerging infections through passive and active surveillance systems. Monitoring of vector species is limited. The tick recording scheme (TRS), set up by PHE in 2005, is the only scheme that records tick distributions on a national scale, and relies on members of the public to report and submit ticks. The ticks are not routinely screened for pathogens. Surveillance of endemic and invasive mosquitoes is undertaken by PHE through programmes on port surveillance, surveys of used tyres and other ad hoc measures.

PHE advises on UK policy on emerging infections through membership of the cross-government Human Animal Infections Risk Surveillance (HAIRS) group, which provides advice to the Chief Medical Officer's Advisory Panel on Dangerous Pathogens. PHE is developing its capability to model and predict potential future changes in infection incidence related to climate change for some diseases. PHE is also involved in a global horizon scanning programme to identify emerging infectious disease outbreaks and their potential threat to the UK (ASC, 2014).

Invasive species policies do not currently consider human health. For example, the risk of invasion of the Asian hornet has only been highlighted because of the impact on bee health, but it may also affect human health and wellbeing. Thus, at present the contingency plan for introduction of the Asian hornet is likely to fail to address any health issues. There is a need for better integration of human health issues within the Non-native Species Directorate (part of Defra), as part of an inter-sectoral response.

Northern Ireland

The Health Protection Service within the Northern Ireland Public Health Agency (PHA) has the lead role in protecting the population from infection and undertakes surveillance and monitoring of pathogens.

Scotland

Health Protection Scotland (HPS) is the Scottish National Surveillance centre for communicable diseases, and has responsibility for pathogen surveillance. It monitors the extent and impact of infections and other risks to Scotland's health. HPS is responsible for co-ordinating the management of incidents and outbreaks which affect the whole country, multiple NHS boards or which have a significant impact in one NHS board area.

Wales

The Public Health Wales Communicable Disease Surveillance Centre (CDSC) is the epidemiological investigation arm of the National Public Health Service for Wales. It aims to protect the population from infection through surveillance of infectious disease, support for outbreak investigation, provision of health intelligence and applied research.

Current climate risks and adaptation

Human diseases most sensitive to climate are those where the pathogen spends a significant period of its life cycle outside of the human host, and is therefore subject to environmental influence. Key examples are those spread by arthropod vectors, in food, in water, in aerosol, on fomites, and those that have a free-living environmental stage (Baylis and Githeko, 2006). Many infections in Europe are affected directly or indirectly by climate and weather factors (Lindgren et al., 2012) and thus may be affected by climate change. Climate change also threatens agriculture: arthropod pests and climate-sensitive vector-borne and non-vector-borne diseases also threaten the health of livestock (Chapter 3, Section 3.3.4), crops (Chapter 3, Section 3.3.3), forestry (Chapter 3, Section 3.3.5) and aquaculture (Chapter 3, Section 3.6.2).

Climate sensitive diseases that are of potential interest to the UK vary in their symptoms and prognoses (Baylis, 2015). Chikungunya causes high fever, severe joint pain, aches, swelling and rashes, but is rarely fatal. There is no vaccine. Epidemics have occurred in recent years in Indian Ocean islands and India, North and South America and Caribbean islands. A handful of cases have occurred in Europe. Dengue causes clinical signs similar to those of Chikungunya, and differential diagnosis can be difficult. However, repeated exposure to dengue can lead to dengue haemorrhagic fever, a more severe disease which can be fatal. The first vaccine for dengue is currently under trial. Dengue is widespread in tropical parts of the world. A few cases have occurred in mainland Europe in recent years, and there has been a large outbreak on Madeira, where dengue's major vector, Aedes aegypti, is present (Tomasello and Schlagenhauf, 2013). Zika mostly causes mild clinical signs in adults, but a small proportion of infections give rise to an autoimmune reaction that causes temporary paralysis, called Guillain-Barré syndrome (Cao-Lormeau et al., 2016). There is now substantial evidence that infection of women with Zika virus early in pregnancy can cause foetal malformation, such as underdevelopment of the brain and head (microcephaly) (Mlakar et al., 2016). Zika has recently emerged in Pacific island states and South America and, in February 2016, was declared by the World Health Organization to be a Public Health Emergency of International Concern (Heymann et al., 2016). Most infections with West Nile virus go unnoticed. In about 20% of cases there are mild signs similar to those described above. In about 1% of cases, however, neuroinvasion leads to severe disease and risk of death. There is no vaccine available for use by people. West Nile virus entered the US in 1999 and rapidly spread across the entire country and elsewhere in the Americas (Hayes et al. 2006); nearly two thousand deaths have been reported to date. West Nile is endemic in parts of southern Europe (Calistri et al., 2010).

Climate extremes are known to have major effects on host–pathogen interactions in a variety of ecosystems. The 1976 heatwave, and 1976 – 1977 16-month UK drought, led to reduced river flows, ground and surface water levels. Disease impacts were detectable in animals (including livestock, wildlife and fish) and plants in terrestrial, freshwater and marine ecosystems. The greatest impacts were in freshwater ecosystems, related to increased effluent from sewerage, eutrophication, saline incursions and water quality deterioration from urban runoff. These impacts are expected to have some impact on human health (fishermen, farmers and people using wells for water supply). Generally, drought led to reduced disease in terrestrial ecosystems and increased disease in aquatic ecosystems. There was no evidence of an impact on tick-borne diseases (Morley and Lewis, 2014).

The ending of droughts by heavy rainfall is a significant risk factor for numerous vector-borne diseases outside the UK. For example, preceding year drought is a significant risk factor for mosquito-borne West Nile virus in the USA. The mechanism may be that drought reduces the population size of predators, allowing unchecked vector population growth when the rains bring suitable conditions (Wang et al., 2010). These conditions are often brought on by the El Niño Southern Oscillation (ENSO). One of the strongest ENSOs ever recorded occurred in 2015/16, and the large epidemic of mosquito-borne Zika in South America in the same time period may not be coincidental.

The transmission of vector-borne disease is also known to be affected by temperature. Higher temperatures shorten the incubation period of the pathogen within the vector and thereby increase their transmission efficiency (Baylis and Morse, 2012). The spatial distribution and seasonal activity of pest and vector species are also affected by temperature and humidity. Changing climate conditions may facilitate the introduction of new insect and tick disease vectors and pests to the UK. However, some vector species, such as the *Ixodes ricinus* tick that transmits Lyme disease, is already distributed throughout the UK (Medlock et al., 2013). The *Ixodes ricinus* ticks are mostly encountered in the countryside, but are also present in urban parks: for example in South London (Nelson et al., 2015).

Overall, current surveillance programmes for vector-borne diseases are largely passive, small scale and ad hoc. These factors will limit the capacity of the UK to detect invasive species and changes in distribution.

Future climate risks and adaptation

Higher temperatures in the future will increase the suitability of the UK's climate for invasive mosquito species, facilitating invasion by new species that can transmit diseases in the long term.

The key species are:

- The Asian tiger mosquito, *Aedes albopictus* – vector of Chikungunya virus and dengue (Caminade et al., 2012), as well as Zika virus (Chouin-Carneiro et al., 2016).
- *Culex modestus*, a species that has recently invaded south-east England, and is a known vector of West Nile virus (Medlock and Leach, 2015). It has the potential to expand its range.

Higher temperatures in the future may also increase the risk that one or more of the UK's indigenous mosquito species transmit diseases in the long term. The UK harbours mosquito species, such as *Aedes detritus,* that feed readily on humans and have been shown to be competent vectors of certain arboviruses that, while not present in the UK, could be clinically important if they were (Mackenzie-Impoinvil et al., 2015). Some potential vector species breed well in urban environments. *Culex pipiens molestus* is present in certain parts of London and in the London Underground system; it feeds readily on people and can transmit arboviruses. *Culex pipiens* breeds readily in water containers in urban gardens. While it rarely bites people, it feeds on birds and can contribute to the circulation of certain pathogenic viruses that affect people.

The risk of introduction of dengue and Chikungunya viruses is contingent on the risk of invasion by non-native mosquito vectors, which remains low in the near term, but risk may increase with more significant warming in later decades. The two most important species are *Aedes aegypti* and *Aedes albopictus*; both breed readily in urban environments (Caminade et al., 2012). Both species also transmit Zika virus (Chouin-Carneiro et al., 2016). *Aedes albopictus* is spreading northwards in Europe, and was detected in Paris in the summer of 2015. This species is known to transmit over 20 viruses of humans and animals although it is believed to only play a large role in the transmission of dengue and Chikungyunya (and probably Zika). It also transmits an important parasitic disease, dirofilariosis or heart worm, to dogs and occasionally to humans. This vector's feeding habits on both humans and animals means that it is a good 'bridge vector', able to carry pathogens from animals to humans, but is less efficient than *Aedes aegypti* at spreading human-only viruses like those causing dengue, Chikungunya and Zika. However, *Aedes albopictus* extends further into temperate climates than *Aedes aegypti*, including mainland Europe and the U.S.A, and is the main threat in such temperate regions, in terms of Zika, dengue and Chikungunya, and to the UK. The UK is currently at little or no risk as neither of these *Aedes* vectors are present in the country and there is no imminent threat of invasion of *Aedes aegypti*. By contrast, the gradual northward spread of *Aedes albopictus*, combined with or facilitated by climate warming, suggests it is only a matter of time before this species reaches the UK (Caminade et al., 2012). In addition to these exotic species, there may be the risk of transmission by the UK's native mosquitoes. This is currently under study. There is a risk of Zika transmission in the UK by means other than vectors, such as sexual transmission, in returning travellers who have been infected with the virus.

The risk of local transmission of malaria remains low. Projections for the 2080s, under a range of emission scenarios, only indicate a small risk of malaria transmission in the UK (Caminade et al., 2014). Parts of the UK that harbour sizeable populations of potential malaria vectors (e.g. *Anopheles maculipennis* group mosquitoes) are mostly rural.

Tick-borne Lyme disease is sensitive to climate factors but its response to climate change is not clear. Lyme disease may shift in altitude and incidence in the UK in response to climate change (Gilbert, 2010). However, future trends in agriculture, land use, wild animal (host) populations and tourism will play as large or a larger role in determining future patterns of human disease (Lindgren et al., 2012) because human–tick contact is thought to be the main factor that determines incidence. Ticks are mostly encountered in the countryside, but are also present in urban parks: for example in South London (Nelson et al., 2015).

Climate change may increase the abundance of pests (flies, rats and ticks) and other nuisance species (Defra, 2009). The ten "nuisance" species most likely to increase with climate warming are estimated to be: *Tinearia alternata* (moth fly), *Lasius neglectus* (invasive garden ant), *Thaumetopoea processionea* (oak processionary moth), *Linepithema humile* (Argentine ant), *Reticulitermes grassei* (Mediterranean termite), *Culex pipiens molestus* (urban mosquito), *Culex pipiens pipiens* (mosquito), *Aedes vexans* (wetland mosquito), *Ochlerotatus cantans* (woodland mosquito) and *Musca domestica* (house fly) (Defra, 2009). The ten species most likely to increase with changes in precipitation are the same as for increasing temperature with the exception of Musca domestica and inclusion of *Phlebotomus mascittii* (sand fly). This could lead to increased use of pesticides which in turn could have adverse effects on human health. At the local government level, pest control is becoming commercialised. Therefore there is a need to ensure that public health remains a focus for response measures.

There are very likely to be wider benefits to the UK population from improved monitoring and surveillance of emerging infections (Section 5.6).

More research would be beneficial of the eco-epidemiological drivers that determine the distribution of the UK's existing arthropod vectors and the pathogens that they might carry at finer spatial scales than is possible from current studies. Better ongoing surveillance for the importation of exotic arthropod vectors and pathogens would also be beneficial. Field-based research would help to understand the impact of environmental change and climate change adaptation strategies on disease vectors.

5.5.3 Health effects from hot weather and heatwaves

Risks to health from high temperatures are dependent on indoor and outdoor exposure which are, in turn, determined by factors related to behaviour and the design of the built environment as well as the weather (see Sections 5.2 and 5.3 above on overheating in buildings and urban heat islands).

Policy framework

Public Health England and the Department of Health publish the annual Heatwave Plan for England. The Heatwave Plan for England provides guidance to the public and, health protection and social care professionals (including care home staff) on steps to take to reduce exposure to heat and protect vulnerable people during a heatwave. It also gives substantial attention to preparedness actions at level 0 (year round) and level 1 (all summer action) including adaptations to buildings (see Section 5.3.2). The Plan also considers how the risk may increase due to climate change.

Wales no longer has a formal heatwave plan, but does have public health guidance for extreme weather events including heatwaves, cold weather and flooding (Extreme Weather Public Health Alerts & Advice for Wales, 2015).[37]

In Northern Ireland, advice on managing heatwaves is provided to health and social care professionals and for care home managers and staff.[38] [39]

Scotland does not currently have heatwave plans, though Local Health Boards in Scotland produce their own guidance for the public on what action to take during hot weather.

Responding to very extreme heatwaves is also covered under national emergency response plans in all four countries (see Section 5.2).

Current climate risks and adaptation

Past heatwaves in 1976 and 2003 were the most significant in terms of extreme temperatures and the resulting impacts on health, most notably the well-defined peaks in daily mortality. Over 2,000 deaths were caused by the 2003 heatwave in England and Wales (Johnson et al., 2005). The impacts of other heatwaves include approx 2000 excess deaths in 2006 in England (Green et al., 2016). The impact of the 2013 heatwave was smaller than expected (based ontemperature exposures), with an estimate of 106 excess deaths in England, but based on preliminary mortality data (Green et al., 2016) indicating that the population may be adapting to heatwaves (Arbuthnott et al., 2016).

The elderly are most at risk of heat-related mortality, and there is also evidence that people with some pre-existing chronic conditions are also at increased risk. However, there is little evidence

37 www.wales.nhs.uk/sitesplus/888/page/43886 , howis.wales.nhs.uk/sitesplus/888/page/33739
38 www.dhsspsni.gov.uk/heatwave-2015-advice-for-health-and-social-care-professionals.pdf
39 www.dhsspsni.gov.uk/heatwave-2015-advice-for-home-managers-and-staff-2.pdf

that persons who are more economically deprived are at higher risk of heat-related mortality (Hajat et al., 2007).

Sometimes heatwaves are associated with high pollution exposures (see below).

High temperatures contribute to around 1% of annual mortality across the UK. In Wales, Hajat et al. (2014) estimate that there are around 2.4 heat-related deaths per 100,000 population (which with a population of 3.1 million equates to 74 heat-related deaths per year). In Scotland, there are thought to be around 0.7 heat-related deaths per 100,000 population (which with a population of 5.4 million equates to 38 heat-related deaths per year). In Northern Ireland, there are around 0.9 heat-related deaths per 100,000 population (which with a population of 1.85 million equates to 16.7 heat-related deaths per year). Similar figures are given for English regions but not for England as a whole.

High temperatures cause the clinical syndromes of heat stroke, heat exhaustion, heat syncope and heat cramps (Kovats and Hajat, 2008). Severe heat stroke occurs when the core body temperature reaches 40.6°C and leads to multiple organ dysfunction and failure. There is less information on morbidity (non-fatal) impacts of heat for the UK population. However, hospital and GP visits do increase in hot weather. Approximately 1,166 (range 1,064 - 1,268) GP consultations for heat illness took place in 2013 in England (Smith et al., 2016) which decreases by about half in a non-heatwave year. There is an association between high temperatures and increases in emergency hospital admissions for respiratory problems (Kovats et al., 2004) and for injuries (Otte im Kampe et al., 2016).

Hot weather affects those people undertaking intense physical activity. Heat is an occupational hazard, particularly for jobs that are physically active. Studies from the US indicate that farm and construction workers are particularly at risk of heat injury. In order to cope with heat, a worker may reduce work intensity or increase the frequency of short breaks. Thus, one direct effect of a higher number of very hot days is therefore likely to be the 'slowing down' of work and other daily activities. Sport and leisure events are also affected by heatwaves (see chapter 6).

Evidence on adaptation so far is limited; as heatwaves are rare events, it is difficult to determine a long term trend in the population response. The Heatwave Plan for England will be formally evaluated in 2016/7 to assess the benefits in terms of health outcomes. Surveys of frontline staff about the heatwave plan indicate that there is a lack of coordination between services (Boyson et al., 2014; Abrahamson and Raine, 2009). A survey of heat protection behaviours also shows that younger people are more likely to take up heat protection measures (Khare et al., 2016).

Future climate risks and adaptation

The frequency and intensity of extreme heatwaves are expected to increase over this century (see section 5.1.5). Modelling studies (summarised in Table 5.10) show that the number of heat-related deaths is likely to increase due to climate change. However, most of these estimates do not include an assumption of a change in the population response to high temperatures (adaptation). When adaptation is included, the impact of climate change on heat-related deaths is reduced (e.g. Jenkins et al., 2014). There is much uncertainty about how quickly populations can adapt to a warmer climate; however, the health burden of hot weather will be amplified by the ageing population in the UK. Health impacts are likely to be greatest in London, and increased in the southern, central and eastern regions of England.

Table 5.10. Projections of temperature-related mortality and morbidity			
Populations (authors, year)	**Methods**	**Changes in heat-related mortality**	**Reductions in cold-related mortality**
UK wide (Hajat et al., 2014)	Time-series regression used to characterise current temperature–mortality relationships by region and age group. Functions applied to the climate and population projections to estimate temperature-related deaths for the UK by the 2020s, 2050s and 2080s.	In the absence of any adaptation of the population, heat-related deaths would be expected to rise by around 257% by the 2050s from a current annual baseline of around 2,000 deaths.	Cold-related mortality would decline by 2% from a baseline of around 41,000 deaths. Specifically, for each country under a medium emissions scenario and population growth, the study projects the following: England: the number of cold-related deaths in the 2050s may decline to 44.1 – 58.4 per 100,000 depending on the region. Wales: the number of cold-related deaths in the 2050s may decline to 55 – 75 per 100,000. Scotland: the number of cold-related deaths in the 2050s may decline to 34 – 54 per 100,000. Northern Ireland: the number of cold-related deaths in the 2050s may decline to 29 – 43.5 per 100,000.
England and Wales (Vardoulakis et al., 2014)	Time-series regression analyses on daily mortality in relation to ambient temperature to estimate relative risk functions for heat and cold and variations in risk parameters by age.	Heat-related mortality is projected to increase from 3 to around 9 deaths per 100,000 population per year by the 2080s, assuming no changes in susceptibility and structure of the population (no adaptation and population ageing).	Cold-related mortality is projected to decrease from 61 to 42 deaths per 100,000 population per year in the UK (45% decrease) assuming no population change.

Table 5.10. Projections of temperature-related mortality and morbidity

Populations (authors, year)	Methods	Changes in heat-related mortality	Reductions in cold-related mortality
UK wide (Hames and Vardoulakis, 2012)[CCRA1]	Time-series regression analyses were carried out on daily mortality in relation to ambient temperatures for UK regions.	Heat-related mortality is projected to increase by 70% in 2020s, 260% in 2050s and 540% in 2080s, compared with the 2000s baseline of around 2,000 premature deaths, assuming no adaptation.	Cold-related mortality is projected to remain substantially higher than heat-related mortality in the first half of the 21st century. It is estimated to decline by 2% in the 2050s and by 12% in the 2080s, compared with the 2000s baseline.
376 districts in England and Wales. Bennett et al. (2014)	Bayesian spatial methods to analyse association between mortality effects of environmental temperature at small area level. Effect of 2 deg change in temperature. [No change in population assumed.]	A 2°C increase in temperature is estimated to result in 1,552 (95% credible interval 1,307-1,762)additional deaths in a single summer. Additional deaths are concentrated in London and the South East, with more deaths in women than in men.	A 2°C increase in winter temperatures may result in 6,255 (5,963-6,581) in a single winter. Reduction in deaths is more evenly distributed across England and Wales.
Greater London Jenkins et al. (2014)	A probabilistic risk assessment of heat impacts using high spatial resolution projections of temperature, and demographic change	Adjusting response function by 1–2 °C, to simulate adaptation reduced annual heat related mortality by 32–69 % across the scenarios tested, relative to a no adaptation scenario.	-

Climate change projections often do not include the effects of the UHI, due to the difficulty in resolving city-scale detail in global models, which means that assessments of heat-related health effects which use these projections may underestimate the actual magnitude of future health impacts in areas with urbanisation (Heaviside et al., 2016). The UKCP09 climate projections do not include urban-surface schemes.

Impacts of future heatwaves on vulnerable people may be exacerbated by changes in social protection measures and the level of social care that elderly or vulnerable individuals receive at home. This population will likely increase due to population ageing and future changes in how health and social care is organised.

Scotland, Wales, and NI do not currently have specific heatwave plans but have plans for dealing with extreme weather. More research is needed to identify when heatwaves are likely to adversely affect health to such an extent that prevention measures need to be implemented.

5.5.4 Health effects from cold

Policy framework

In terms of health protection, in England, Public Health England produces the Cold Weather Plan (CWP) every year. The Plan aims toprevent the avoidable health effects during periods of cold weather (PHE, 2015b). The CWP includes an alert system to enable people to prepare and respond appropriately. It recommends a series of steps to reduce the risks to health from cold weather for the NHS, local authorities, social care and other public agencies; professionals working with people at risk; and individuals, local communities and voluntary groups. The CWP is complementary to guidance to healthcare workers issued by the National Institute for Health and Care Effectiveness (NICE). There are other government initiatives to keep people healthy and warm in their homes in winter, such as the 'Keep Warm, Keep Well' leaflets (PHE, 2015b).

The devolved administrations do not currently publish cold weather plans. NICE has issued guidance on measures to reduce cold impacts on health that applies across the UK.[40] Cold weather is included in national risk registers, and therefore planning is ongoing regarding the emergency measures required for extreme cold temperatures.

The level of cold-related mortality remains high for several reasons, including the high prevalence of cold homes. Policy measures to address cold homes, fuel poverty and household energy efficiency are described abovein section 5.3.3.

Current climate risks and adaptation

Cold weather leads to increases in heart attacks, stroke, respiratory disease, influenza, falls and injuries, and hypothermia. In the UK, between 35,800 and 49,700 deaths per year can be attributed to low temperatures[41]. Hajat et al. (2014) estimated that in Wales there are around 74 – 102 deaths per 100,000 population from cold (2,295 – 3,160 cold deaths per year). For Scotland, the study estimates that there are around 48 – 72 cold deaths per 100,000 population (2,590 – 3,890 deaths per year). And for Northern Ireland there are 40 – 60 cold deaths per 100,000 population (740 – 1,110 cold deaths per year). Similar figures are available broken down for each English region. Across England as a whole there are approximately 30,000 – 41,500 cold-related deaths per year (taking away the numbers above from the UK total). Adverse cold effects on health have been observed in all regions in England, with the North East, North West and London having the greatest risk of cold-related mortality (Hajat et al., 2016). Nationally, there was a 3.44% (95% CI: 3.01, 3.87) increase in all-cause deaths and 0.78% (95% CI: 0.53, 1.04) increase in all-cause emergency hospital admissions for every 1ºC drop in temperature below regional thresholds (below 4-8ºC). The very elderly and people with chronic obstructive pulmonary disease (COPD) were most at risk of dying or being admitted from low temperatures.

[40] https://www.nice.org.uk/guidance/ng6

[41] These estimates are based on Hajat et al. (2014). The range of cold-related mortality spans 59.4 per 100,000 to 82.5per 100,000 with a central estimate of 68.7 per 100,000 based on a UK population of 62 million in the 2000s.

It is important to note that mortality that is attributable to low temperatures is a component of excess winter mortality – but this latter metric includes seasonal factors, such as seasonal respiratory infections that are not directly related to cold (Hajat and Gasparrini, 2016). EWD (excess winter death), however, is used by both the NHS and PHE as an indicator of cold related health effects. Further, analyses of excess winter deaths cannot provide information about future effects of climate change on cold-related mortality (Hajat et al., 2016). The NHS prepares each year for a surge in demand in the winter; however, not all of this is cold related. Some of the winter pressure on beds is due to organisational issues rather than temperature. The social care sector is also affected by cold: for example, the impacts on wellbeing of patients isolated in their homes by snow and storms.

NICE has recently reviewed evidence for interventions to reduce cold-related health effects (NICE, 2014). This confirmed that housing is the most important determinant of cold-related mortality and morbidity (see section 5.3.3 for a more detailed discussion). Vulnerability to cold is also mediated to a significant extent by practical social support from family members. Qualitative research has shown the people are generally unaware of the health risks from cold (Jones et al., 2016).

One study has shown that the CWP for England is likely to be cost effective but these results are sensitive to assumptions about the extent of implementation of the CWP at local level, particularly its effectiveness in targeting of high-risk groups (Chalabi et al., 2015).

Future benefits

Climate change alone is likely to reduce the risks of cold-related health effects. This is a benefit of climate change, rather than an opportunity because policy responses will still be required to maintain activities to reduce cold effects, principally through housing interventions to reduce cold homes, as recommended by NICE. The benefit from climate warming will not be sufficient to reduce the need for public health interventions for cold.

Several estimates of the reduction in cold-related mortality are available for the UK population (Table 5.10). Hajat et al. (2014) estimated that cold-related mortality would decline by 2% in 2050 from a baseline of around 41,000 deaths.

Changes in population sensitivity to cold have been associated with improvements in housing and home heating (Arbuthnot et al., 2016). This is not adaptation because it is not in response to or anticipation of climate change. There is currently no evidence that populations will become more sensitive to cold with warmer winters due to a decline in frequency of cold winters, making them rarer events. Cold winters (and extreme cold winters) are still likely to occur in the UK and policies should be in place to ensure that health is not adversely affected.

5.5.5 Health effects from outdoor air pollution

Climate change will have complex regional and local effects on air pollution chemistry, transport, emissions and deposition. Currently, the UK has areas with poor air quality, despite reductions in emissions and improved pollution control. Outdoor air pollution has both anthropogenic (transport emissions, industry) and natural sources (dust, pollen, mould) which are both addressed in this section.

Policy framework

UK air pollution levels must comply with European standards. EU ambient air quality directives (2008/50/EC and 2004/107/EC) set limits and targets for concentrations of various pollutants in outdoor air for the protection of health and ecosystems, and the National Air Quality Strategy (NAQS) (Defra, 2007) sets out objectives for improving ambient air quality in England, Wales, Scotland and Northern Ireland, and how to achieve them. It also contains a section on climate change, with recommendations from the Air Quality Expert Group to: consider promoting measures that provide co-benefits for both air quality and climate change, though this is focused mainly on climate change mitigation rather than adaptation.

Scotland in 2015 produced its own national strategy, 'Cleaner Air for Scotland', that is complementary to the NAQS. CAFS also includes an objective in relation to a more joined up approach to air quality and climate change, 'Climate Change: A Scotland that reduces greenhouse gas emissions and achieves its renewable energy targets whilst delivering co-benefits for air quality'.

The increased proportion of diesel-fuelled traffic in the UK, and the failure of European emission standards for diesel cars to deliver the expected emission reductions of nitrogen oxides, have resulted in difficulties meeting EU air quality limit values for nitrogen dioxide (NO_2), prompting infraction proceedings by the European Commission against the UK (Supreme Court, 2015).

The 2014 House of Commons Environmental Audit Committee report on air quality calls for action at national and local levels to reduce air pollution, particularly through planning and transport policy, greater public awareness and changes in behaviour to mitigate air pollution, and a coherent cross-government approach.

Pollen exposures are addressed through public health activities such as health advice and a public warning system (pollen counts).

Current climate risks and adaptation

Air pollution is very damaging to human health and causes a significant burden to the health of the UK population. The harmful effects of short-term and long term exposure to particulate matter (PM) are well established. COMEAP has recently concluded that short-term exposure to ozone has an impact on all-cause mortality, respiratory hospital admissions and, with less confidence, cardiovascular hospital admissions (COMEAP, 2015). Ozone is a secondary pollutant which is not directly emitted into the atmosphere but is created and destroyed by chemical reactions of other emitted species (including methane (CH_4) and CO, nitrogen oxides (NOx) and non-methane volatile organic compounds). The rate of these reactions is affected by temperature and sunlight.

High pollution episodes are caused by reduced atmospheric dispersion in high pressure episodes, static atmospheric conditions and temperature inversions (McGranahan and Murray, 2004). Ozone levels were high during the 2003 heatwave in the south of England. Two air pollutions episodes in March 2014, associated with high levels of particulates and "Sahara dust", caused an increase in reported asthma, wheeze and difficulty breathing episodes, particularly in adults (Elliot et al., 2016).

The UK has a variety of plants (trees, grasses and weeds) that release pollen in different amounts at different times of year. Individuals vary in the scale and type of reaction that they may have to pollen, from mild itching, sneezing and redness through to asthma attack, anaphylactic shock and death. The effects of weather and climate variability have been studied but not for all pollen species (Osborne and Eggen, 2015). Higher temperatures, high concentrations of carbon dioxide, and different patterns of rainfall and humidity may be associated with extended growing seasons. Between 1970 and 1999, the onset of the birch pollen season in London has occurred earlier by four days every ten years (Emberlin et al., 2002). Some thunderstorms have been associated with increased hospital admissions for asthma exacerbations ('thunderstorm asthma') (Elliot et al., 2014).

Future climate risks and adaptation

The main concern for climate change effects on health through air pollution relate to ground level ozone – as it is climate sensitive. Although higher ambient temperature can lead to increased ground-level ozone concentrations (Heal et al., 2013), Doherty et al. (2015) have concluded that changes in emissions in the future will likely be more important than changes in the climate. The impact of climate change on ambient particulate matter (PM) and NO_2 concentrations is more uncertain (Kirtman et al., 2013). Reducing emissions is the best way to to address air pollution, and this also has a benefit for climate change mitigation.

Climate change is likely to affect air quality in urban and rural areas. It directly and indirectly modifies ground-level ozone concentrations through its influence on processes determining emissions (biogenic and anthropogenic), chemistry and dispersion (Fiore et al., 2012; Doherty et al., 2013; Fang et al., 2013). Recent studies have suggested that the occurrence and persistence of future atmospheric stagnation events in mid-latitudes which influence air pollution levels, may increase due to climate change (Dawson, 2014; Horton et al., 2014; Coumou et al., 2015).

In addition, higher temperatures may trigger regional feedbacks during stagnation episodes (still weather) that will increase peak ground level ozone. Average ozone levels over Europe are expected to decrease generally in future in conjunction with lower emissions of ozone precursors, except in one scenario where high methane emissions offset this decrease (Doherty et al., 2013). However, in polluted areas with high nitrogen oxide levels, warming is likely to trigger feedbacks in local chemistry and emissions, increasing levels of ozone. Research is needed to assess how changes to climate other than increasing temperatures, such as changing wind patterns and blocking episodes, could impact on air pollution levels.

Further warming and increases in atmospheric CO_2 concentration may increase plant productivity and lead to greater pollen release, provided other factors such as water availability do not prove to be more limiting. There is a very complex relationship between pollen abundance and seasonality and climate factors, and this also varies by pollen species (Osborne and Eggen, 2015). Climate change may influence the allergenicity of pollen for some species but the evidence is very limited and requires further research. The impact of climate change on the length of the pollen season and the total burden of pollen-related ill-health will depend on a range of factors.

5.5.6 Risks to health from contamination of water and food

Policy framework

There have been UK and international assessments on the risks to food safety from climate change (Lake et al., 2010; FAO 2008). Food quality in the UK is regulated by the Food Standards Agency. Its Foodborne Disease Strategy (Food Standards Agency, 2011b) includes a horizon-scanning element that considers the increased significance of, or risk from, other pathogens (bacterial or viral) or the emergence of new zoonoses.

Agriculture and food processing are strictly regulated to minimise food-borne disease risks in the UK. For example, the EU Food Hygiene Regulations (EC, 2004) sets down basic food hygiene rules across the EU.

The Water Industry Act 1991 (the 1991 Act) sets out the legal framework for ensuring good quality drinking water supplies. Water utilities are responsible for providing drinking water of sufficient quality. The Drinking Water Inspectorate within Defra is the regulator for drinking water quality in England and Wales. Drinking water from public supplies in the UK is of good quality. Outbreaks of illness linked to private and public water supplies are investigated by Public Health England and local environmental health departments.

The Water Health Partnership for Wales is an initiative that brings together relevant agencies to work together more effectively to protect public health by ensuring the provision of safe drinking water. Agencies in the Partnership include the Drinking Water Inspectorate (DWI), Welsh Government, local authority public and environmental health, the water companies and Public Health Wales.

In Northern Ireland, the ten year 'Making Life Better' strategy for health and wellbeing has an objective to provide safe and clean drinking water.

Private water supplies are not regulated in the same way as public supplies. Each private supply has an individual owner and local authorities can mandate owners to make changes to supplies that violate health and safety criteria.

Shellfish monitoring is undertaken by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS). In 2014 – 2015, CEFAS developed an early warning and forecasting tool for water-borne pathogens including vibrio, norovirus and harmful algal bloom toxins (ASC, 2015). The Welsh Government also has a pan-Wales response protocol for harmful algal blooms.

The Human Animal Infections and Risk Surveillance (HAIRS) group identifies and evaluates threats posed by new or re-emerging infectious diseases

Food safety has an important international dimension. As discussed in Chapter 7, a significant proportion of food-borne illness in the UK is from imported food or from food consumed abroad. For example, of the cases of infectious intestinal disease recorded in the UK (of which food-borne illness is a subset), 8 – 12% are estimated to have been acquired overseas (Food Standards Agency, 2011a). Furthermore the food supply chain is global and so any impacts of the food supply chain in one country can have impacts elsewhere. Only 53% of the food consumed in Britain is grown here (Defra, 2013a). The impact of climate change on food produced outside the UK is discussed in further detail in Chapter 7.

Current climate risks and adaptation

There are several sources of food-borne infections; in the UK infection by salmonella and campylobacter are the main sources of gastro-intestinal infections. There is good evidence that salmonellosis incidence is sensitive to temperature. Infection rates increase by 10% per degree increase in temperature above a threshold of about 6°C (Kovats et al., 2005). However, salmonella incidence is declining because of improvements in control measures. Across England

and Wales, there were approximately 7,500 cases of salmonellosis recorded in 2013, down from just over 14,000 in 2004 (PHE, 2015c).

Infection with campylobacter is now the most important source of food-borne disease in the UK. In 2012, there were 65,000 reported cases of campylobacter infection across England and Wales, the highest total level of infection since 2000.[42] Campylobacter shows a strong seasonal pattern but the reasons for the spring increase in infections are not well understood. Several epidemiological studies have reported a positive association with temperature (Kovats et al., 2005; Naumova et al., 2007; Lake et al., 2009) but the relationship is non-linear. An association with rainfall has also been reported (Weisent et al., 2014), although not in studies from the UK. Unlike other bacteria campylobacter does not multiply outside the mammalian gut. Overall, there are limited grounds for assuming that an increase in average temperatures would tend to increase the transmission of campylobacter.

The proliferation of pathogens in coastal waters are also sensitive to high sea surface temperatures. Most vibrio species of human health relevance grow preferentially in warm (>15°C) sea water. Evidence is very limited for the UK, although there is evidence from the Baltic Sea of an association between human cases and high temperatures (Baker-Austin et al., 2013).

There has been an expansion of the geographical ranges of some harmful warmer water phytoplankton species into higher latitudes. These are a cause of algal blooms and can be responsible for mortality in fish and animals. There is limited evidence that algal blooms or the individual phytoplankton species are harmful for human health, as generall contact with species is limited.

There is more evidence regarding the association between gastrointestinal pathogens and rainfall. Heavy rainfall can lead to the contamination of drinking water systems. In the UK outbreaks of cryptosporidiosis have been linked to heavy rainfall affecting public supplies, but this association is declining (Lake et al., 2009).

Private water supplies pose more of a risk from low water quality than public supplies. In 2014, only 0.05% of tests on public water supplies failed to meet EU and national standards, whereas 8.7% of private water supplies tested failed.[43]

Future climate risks and adaptation

The implications of climate change for food safety were recently reviewed by Lake (2015). Several studies project increases in the risk of salmonella with rising temperatures; however, this effect will be offset by the overall decline in incidence of this disease. Campylobacter transmission to humans is complex ecologically with multiple hosts and transmission pathways (Kovats et al., 2005), and currently is poorly understood; therefore there is limited evidence for assessing the implications of climate change.

Increasing sea temperatures around the UK may result in an increase in marine vibrio infections (Baker-Austin et al., 2013). However, the public health implications of this are not clear; that is, whether it would lead to a detectable increase in human disease.

The relatively high level of regulation regarding food safety from farm to fork provides the UK with a high level of capacity to adapt to climate change (Lake, 2015). However, as climate

[42] https://www.gov.uk/government/publications/campylobacter-cases-2000-to-2012
[43] dwi.defra.gov.uk/about/annual-report/2014/pws-wales.pdf

change moves the climate into unknown territory this could make current regulations and food monitoring inadequate to deal with future threats, such as emerging disease. Thus, activities such as horizon scanning are needed. Food early warning systems (Marvin et al., 2009) or food risk detection systems (Groeneveld et al., 2008) may also play an important role in mitigating and adapting to climate change-induced food threats.

In addition to gastrointestinal infections, climate change may have other impacts on food quality (Lake, 2015). For example, within agriculture one impact of climate change may be changes to the seasonal patterns and abundances of pest species and plant diseases in the UK and globally (see Chapter 3). Boxall et al. (2009) highlight that these changes will lead farmers to alter their use of chemicals (herbicides, pesticides and fungicides) in response.

5.6 Opportunities and challenges

5.6.1 Opportunities

Climate change will bring some opportunities to the UK in the way people live their lives. Significant opportunities exist to improve health and social care systems, and infrastructure and urban design to help people adapt to climate change.

Strengthening health and social protection

Strengthening health protection and social protection measures can increase resilience to climate risks. Increasing health protection is a low-regret adaptation option because it has been shown to be highly cost-effective in preventing disease and avoiding health costs from environmental hazards and health emergencies. There are likely to be immediate and obvious benefits from strengthening public health systems, including emergency planning. The shift of public health into Local Government is a significant opportunity for collaborative action on climate change (Button and Coote, 2016).

Strengthening health surveillance and monitoring of vector species can also improve health protection from imported infectious diseases and invasive vector species whatever the causes of introduction. Better integration of surveillance and monitoring for human and animal vector-diseases could help to address the risks from climate change (see also Chapter 3 and Chapter 7). Effective surveillance systems are currently absent for most arthropod-borne diseases, which prevents a detailed risk analysis, including the evaluation of the potential spread to new areas or the introduction of exotic species or diseases (IFAH, 2014). Further surveillance would also be beneficial to monitor if the controls implemented are effective. Investments in preventive measures contribute to the 'global public good' of reducing the risk of health emergencies (Campbell-Lendrum et al., 2009).

Benefits of green infrastructure for addressing climate risks

There is widespread evidence that communities would be better able to adapt if they were able to work with natural processes and systems as well as seeking technological solutions (see section 5.3). Green infrastructure (green roofs, urban green and blue space), and SuDS offer the opportunity to deliver more sustainable solutions so that communities can thrive and people can live healthy lifestyles. Green infrastructure benefits may also extend to the historic environment.

It is possible to build in flood zones and provide a good measure of flood resistance and resilience even when building is done close to a river. Examples of success include developments in Carlisle (Mcilmoyle Way and Milbourne Court), Cockermouth (The Laureates) and Yarn Street in Leeds. All were relatively unaffected by the winter storms of 2015 and 2016. Very innovative designs that could set a new standard in aspects of urban design have been considered in a competition organised by RIBA and Norwich Union in 2008[44]. Many of these designs accept some flood risk and could require residents' life styles to be adapted both in daily living and at times of flood. Almost all make use of normal building materials and techniques. Several of the projects featured in the RIBA competition and featured in the earlier government-

[44] www.architecture.com/files/ribaprofessionalservices/competitionsoffice/resultsbooklets/norwichunionfloodproofhouseofthefuture.pdf

funded guidance from RIBA (2007) use green infrastructure as well as more classical construction approaches to adapt to flood risk (e.g. surface water flooding).

The Green Infrastructure Partnership exists to help disseminate good practice in the provision of green infrastructure in the UK.[45] One of the roles it sees for green infrastructure is in adapting to climate risks. For example, as well as mitigating surface water flooding, SuDS can increase biomass and biodiversity and reduce throughput in water treatment plants – bringing benefits, respectively, for: air quality, ecosystem functioning and energy consumption (see earlier sections of this chapter for references and Table 5.11). There is evidence of health co-benefits from green infrastructure, such as reducing obesity in children (Lachowycz and Jones, 2011), preventing premature deaths (i.e. from heart disease) (Allen and Balfour, 2014), reducing stress and improving mental health (Thompson et al., 2011), and active recovery helping with chronic conditions (Buck and Gregory, 2013). For example, green and blue space in urban areas can be used to make corridors conducive to walking and cycling, and thus benefit health. Birmingham is one city that has made extensive use of the ecosystem approach and a range of practical tools to help gain full benefit from a strategic approach to green infrastructure.[46]

The full effectiveness of such schemes has not been assessed.

Table 5.11. The co-benefits of green infrastructure to address climate risks

Type	Main climate benefit	Effectiveness of interventions (UK only)	Co-benefits (in addition to main climate benefit)
Green roofs	Reducing outdoor temperatures and reducing urban heat islands	Green cover increase of 20% over present could eliminate 30 – 50% of expected extra UHI effect in 2050, reductions in surface temperature <2°C in Glasgow (Emmanuel and Loconsole, 2015). Increasing the current area of green infrastructure in Greater Manchester by 10% (in areas with little or no green cover) could result in a cooling of up to 2.5 °C under the high emission scenario (UKCIP02) (Gill et al., 2007). With green roofs in Manchester, temperature relative to adjacent conventional concrete roof, was (monthly median air temp.) 1.06°C less at 300mm above roof. Strongest cooling (1.58°C) occurred at night	Direct absorption of gaseous pollutants by interception of particles onto leaf surfaces, transpiration which can reduce the formation of ozone, and through the direct production of oxygen during photosynthesis (Forest Research, 2010; Lindley et al., 2006). Increasing habitats for biodiversity (Forest Research, 2010). Some disbenefits from pests/insects. Green roofs have potential for storm-water source control, in new developments and as a retrofit option. Green roofs led to an average volume retention of 34% and the average peak reduction was 57% (Stovin, 2010). Cumulative retention by green roofs could be 50.2%. Retention performance was greater when all

45 www.gip-uk.org/#about
46 neat.ecosystemsknowledge.net/birmingham2.html

Table 5.11. The co-benefits of green infrastructure to address climate risks

Type	Main climate benefit	Effectiveness of interventions (UK only)	Co-benefits (in addition to main climate benefit)
		(Speak et al., 2012).	storm events were considered) (Stovin et al., 2012). Green roofs could reduce urban runoff by 11.8 –14.1% (Gill et al., 2007). Rainfall retention by green roofs on a yearly basis may range from 75% for intensive green roofs to 45% for extensive green roofs (Mentens et al., 2006). Amenity benefits
Green roofs	Reducing indoor temperatures (Roberts, 2008)	Green roofs can reduce the amount of heat penetration through roofs and in this regard play a similar role to roof insulation. They reduce the roof temperature by absorbing heat into their thermal mass and because of evaporation of moisture (Roberts, 2008).	
Green spaces	Reducing storm water runoff	Gill et al. (2007*)* suggest that increasing green space would reduce runoff by 4.9%, increasing tree cover reduces runoff by 5.7%.	Benefits to mental and physical health (Lee and Maheswaran, 2011). Increases social capital. Amenity benefits to the local population. Biodiversity benefits, ecosystem services (see Chapter 3) Potential for benefits to historic environment.
SuDS	Reduce urban flood risk from pluvial flooding, and small urban rivers (Gill et al., 2007)	Increasing green space could reduce runoff by 4.9%, increasing tree cover reduces runoff by 5.7% and green roofs would have a significant effect in reducing runoff by 11.8 – 14.1%. Integrated 1D and 2D hydro dynamic modelling results indicate that SuDS reduce the flood hazard downstream for all three (1:15, 1:50 and 1:100) events, with the effect more pronounced for the lowest rainfall (1:15) event (Ahilan et al., 2015).	Benefits to mental and physical health (Lee and Maheswaran, 2011). Creation of biodiversity habitats Replenish water tables (Ashley et al., 2013; Kazmierczak and Cavan, 2011; Forest Research, 2010) Urban cooling (Charlesworth, 2010) Protects groundwater quality (Woods-Ballard et al., 2015) Rainwater harvesting and storm water re-use (Ashley et al., 2013).

Table 5.11. The co-benefits of green infrastructure to address climate risks

Type	Main climate benefit	Effectiveness of interventions (UK only)	Co-benefits (in addition to main climate benefit)
Natural flood management	Reducing flood risk from river flooding (large catchments)	Some evidence of effectiveness from Integrated catchment based approach in Pickering, Yorkshire (Defra, 2011; Defra, 2015). Limited evidence so far. A review due in 2016.	Benefits to mental health and limited evidence for benefits to physical health through increases in physical activity (Lee and Maheswaran, 2011). Amenity benefits to the local population (SEPA NFM Handbook) Stakeholder and engagement approaches (Lane et al., 2011) Benefits to the local economy from increase tourism and leisure activities Biodiversity benefits, ecosystem services (SEPA NFM Handbook, also see Chapter 3)

The importance of optimization

A very large range of adaptation strategies and measures are available to deal with the risks presented in this chapter. Table 5.12 shows the broad categories of adaptation options for responding to the key climate risks of heat and flooding that are likely to increase with climate change in the UK.

Within each category there is variation of the option available, in terms of costs, effectiveness and co-benefits (described above). There is little literature that considers multiple adaptation options and the various costs and benefits for a wide range of outcomes (see Chapter 8). Similarly, there is little literature on optimisation of options across the various strategies available.

Table 5.1. Adaptation options for dealing with climate risks

Climate change	Climate risk	Adaptation option
Higher temperatures	Hot weather, heatwaves	Managing UHI and outdoor temperature through planning, urban and building design and construction options
		Housing – building fabric, insulation and ventilation trade-off
		Improvements in health and social care service delivery
		Emergency planning and response (including heat health warning systems)
		Behaviour change (community).
Increased intensity of rainfall	Flooding, coastal erosion and/or inundation	Reducing development in flood risk areas through planning, settlement design options
Sea-level rise		Property level protection (PLP) measures
Windstorms		Flood defence (sea walls, etc.) and natural flood management
Storm surges		Increasing resilience in communities (e.g. governance, connectedness and cohesion)
		Emergency planning and response, including flood warnings.
		Managed retreat (relocation)

The Land Use Futures report (Foresight, 2010) recognised the increasing pressures on land use from a number of factors including from population growth, changing demography and climate change. It considered how flooding might best be managed in terms of land-use and concluded that a management framework was needed that took account of a number of trade-offs between urban, rural and coastal needs and considered opportunities for co-benefits that might arise through use of new kinds of catchment-based water storage systems or sustainable urban drainage arrangements. These considerations are important. For example, managing the Thames flood potential depends in part on trading off between risk from the sea and risk from the flow arising from the Thames' upstream catchment (EA, 2012).

To account for trade-offs and deliver co-benefits the Foresight study called for better understanding of the relationship between land use and flood risk management, better targeting of the appraisal of flood risk management options; a zoning approach to coastal and inland land-use arising through a more integrated inter-agency approaches; and delivery of co-benefits from a more integrated approach to land-use in flood prone areas involving a range of public and private stakeholders. It was thought such an approach would help develop new approaches covering difficult issues. Examples included insurance and compensation and providing opportunities for developing new services and payments for these, such as those concerning water management in rural areas that might reduce risk to urban areas sharing the same catchment system (e.g. paying for management practices that retain water in upland areas).

5.6.2 Challenges

There will be challenges to overcome in adapting to climate change in the health and social care system, and the built environment sectors in the UK. These challenges include human and institutional barriers that might limit the pace of adaptation or its success unless they are addressed (see also Chapter 8).

The evidence presented here suggests that adaptation to current climate risks is currently limited by:

- Limited incorporation of the full scope of planning policy and its means of implementation in local planning processes and construction practices in new developments (section 5.2).
- Fragmentation of sevices. For example in helath and social care sectors (see section 5.4.3).
- Gaps in building and construction codes (section 5.3).
- Lack of appropriate governance (e.g. co-ordination or integration of efforts between and within national and local authorities; limited links to local communities) (section 5.2.7).
- Lack of knowledge and research to provide greater granularity in flood risk and damage estimates (section 5.2.5).
- Poor housing quality and lack of or inappropriate retrofitting (section 5.3).
- Lack of co-ordination with other policies (e.g. energy efficiency in housing, invasive species policies that only focus on biodiversity) (section 5.3).
- Low public perceptions of risk (heatwaves and floods) (section 5.2.5, 5.5.3).
- Lack of skilled crafts people to address historic structures (section 5.3.8).
- Issues linked to the way climate change communication occurs between specilaists, non-specilaists and the public are picked up later in this section.

Future adaptation to climate risks may become limited by:

- Further fragmentation of services in both public and private sectors (section 5.4.3).
- Lack of clear policy on delivering green infrastructure solutions which have multiple health and wellbeing benefits for people and communities arising from more accessible green space, better surface water management, water conservation and reduced UHI effect (section 5.2).
- Housing and planning policies that do not sufficiently consider housing quality, and implications for welfare and households (sections 5.2 and 5.3).
- Low uptake of adaptation strategies by households (e.g. section 5.2.5).
- Lack of understanding when sustainability thresholds (sea-level rise or temperatures, for example) or capacities (heat, for example) have been exceeded (section 5.2.6, 5.3.2, 5.5.3).
- Lack of capacity or capability with respect to implementing adaptation technologies and strategies (such as property level protection) (section 5.2.5).

Poor housing quality

A community's existing resources and facilities are likely to play an important part in successful adaptation. One of the significant challenges facing the UK (alongside infrastructure issues dealt with in Chapter 4) is the highly variable nature of its housing stock and other buildings in which we live, work and play. In general, buildings have not been designed to be either well-insulated against cold or to prevent overheating (section 5.3.2). Buildings are also often not well-designed to be resilient to flooding or recover quickly after flooding (sections 5.2.5, 5.3.4).

Within the housing system, climate change mitigation and adaption policies are inextricably linked. In addition to the specific risks mentioned above, recent research reveals that current policies to reduce the carbon emissions of the housing stock could result in some unintended consequences (Davies and Oreszczyn, 2012) (Table 5.3), including impacts on health and wellbeing of building occupants and the wider population (Shrubsole et al., 2014).

Adaptation is inextricably linked to wider government objectives about housing (section 5.1.5). Some studies have suggested that a more integrated approach to decision-making could help to ensure that direct benefits and co-benefits can be optimised and made more explicit (Macmillan et al., 2015).

Developments for new and existing communities approved in the next few years will exist for up to 60 years or more. There is therefore a risk of lock-in by planning communities that exacerbate the risks from flooding, the urban heat island, drought risk and air pollution (sections 5.2, 5.3, 5.4 and 5.5).

Integration across relevant policy areas in local government

In England, there are no longer performance measures for local government in relation to climate adaptation. There is variation amongst English local authorities in approach to adaptation with some having formal responsibilities (as in London through the Greater London Authority Act, 2007) and others having to work more informally, such as through the Core Cities group. In Scotland, a central review of local authority adaptation actions has been undertaken by Climate Ready Scotland[47]. Both Wales and Northern Ireland are taking steps to determine how best to link local adaptation efforts with higher level policies.

Local Authorities in the UK seem to be at very different stages of maturity in developing approaches to adaptation (Heidrich et al., 2013). London has, for example, a detailed flood management plan to the middle of the century and a strategic view beyond that based on adaptive management options (EA, 2012) and is currently considering responses to its draft urban drainage strategy. Other cities, such Leicester, Birmingham, Aberdeen, Cardiff and Manchester score quite highly on either aspects of adaptation or aspects of mitigation and adaptation in combination. Overall, the 30 cities studied were more advanced in mitigation planning and action than they were on most aspects of adaptation (Heidrich et al., 2013). Local authorities in England lost 27% of their spending power between 2010/11 and 2015/16 in real terms, and 90% oflocal authority staff interviewed in a 2013 survey indicated that adaptation had been de-prioritised in their authority (ASC, 2015).

Although variations in approach amongst local authorities provide opportunities for developing best practice, the variation might make it more of a challenge to deliver on national policy

[47] www.gov.scot/Resource/0045/00451392.pdf).

responses aimed at tackling and adapting to climate change unless there were close integration across relevant local authority areas of responsibility. In the absence of sufficient integration there might be a risk that responses to climate change will be event-led and piecemeal and that opportunities to adapt effectively and at low cost will be missed due to failure to realise co-benefits. The chance of maladaptation might also be increased (see Chapter 8).

It is difficult to gather information about the level of integration and the extent to which local authority planning groups and others make use of information sources such as that at http://www.climateuk.net as aids to integration and decision-making. This means the evidence base on local authority capacity and capability in relation to making integrated responses to a wide range of climate adaptation issues is weaker than it might be and to some degree the UK is dependent for new evidence on studies being done in other countries with different cultural and political frameworks that may reach conclusions that are not applicable in the UK (e.g. Baker et al., 2012, who argue, on the basis of a study of seven local climate plans, that local authorities have limited capacity to develop geographically specific action plans).

The Royal Commission on Environmental Pollution (2010) discussed the principles associated with these issues and suggested a range of approaches, many of which relate to integration at local scales. Some analysis of multiple case studies (e.g. Measham et al. 2011) suggest that some of the leadership and institutional issues involved might be dealt with if land use planning departments took a lead, although these are the very parts of the UK local authority operations that the Royal Commission 2010 report identified as being under most resource pressure.

Fragmentation of health and social care services

The continuing trend towards greater levels of personalisation, devolution and fragmentation of health and social care is creating a more complex web of responsibilities for preparedness and response to climate-related risks. Problems of organisational management and communication between different groups of health and social care personnel may make response to severe weather events less efficient. It is important to take a ‘whole system’ perspective when considering the impacts of climate risks on health and social care delivery (Castelli et al., 2011; Landstroem et al., 2011; Zaidi and Pelling, 2013).

Although individual service providers may be familiar with severe weather plans and protocols, problems of communication between personnel in different parts of the health and social care system can result in difficulty in implementing severe weather plans efficiently (EPSCR-ARCC and SCIE, 2011; Boyson et al., 2014; Wistow et al., 2015).

Systems of service commissioning can ensure that the various agencies delivering healthcare exercise responsibility for risks associated with severe weather. There may also be gaps in service provision that will need to be addressed by individuals (Dominelli, 2013).

Communicating climate risks

Evidence is emerging about the challenges involved in engaging with people constructively in dialogue on climate change issues (Gifford, 2011; Rapley et al., 2014). Emphasis is being placed on how the scientific community can respond to the challenge to help improve policy interactions (Rapley, 2012; Rapley and Meyer, 2014) and on understanding more about how both the sciene and the risks might be communicated to people to help them respond. A range of approaches might be needed based on what is known in social and psychological sciences

(Pidgeon and Fischoff, 2011; Rapley and Meyer, 2014; Corner and Groves. 2014; van der Linden et al., 2015).

In the UK, much of the practical effort on communicating climate risks is directed to helping people respond to extremes such as flooding (Fisher, 2015) rather than to the longer-term trends in climate. A number of studies address how communities and the ways they are governed might help people act by involving them more in the decisions that affect their locality (e.g. Dooris and Heritage, 2013) and others indicate ways that at least some of the issues identified in Gifford (2011) might be addressed (van der Linden et al., 2015). Although there is no universal agreement on how best to proceed to help people and communities adapt, there is a growing understanding about how governments, communities and individuals might better engage to meet the challenges, adapt and build resilience (e.g. Royal Society, 2014; Brügger et al., 2015 and references therein). Psychologists are now addressing communication, perception and climate adaptation issues directly (e.g. Clayton et al., 2015).

5.7 Conclusions

This chapter describes a wide range of climate risks that affect people's health, communities, and the built environment. Climate change will affect the places that people value, where they live and places they enjoy. It will take many decades to enact change to the built environment, and some time to develop the governance and community structures necessary to overcome a number of the barriers to adaptation (including the human as well as the technical and financial ones). This means government and communities need to act now to adapt smoothly to climate change in a way that is likely to minimise costs and maximise opportunities.

We conclude that increasing temperatures, rising sea levels and changing flood risk will adversely affect the UK population, and that on the basis of current levels of action the risks will not be managed down to an acceptable level of impact, or that the pressures that affect the ability to adapt (Table 5.2) are not being managed (see Chapter 2).

Therefore, these risks require additional action in the next five years. There is some variation in risk between the different countries of the UK but, in broad terms, there is evidence that all the nations of the UK need to consider acting on climate risks. Different types of communities face a different range of risks (see section 5.2.6), which also has implications for national adaptation policies.

5.7.1 Priorities for action in the next five years

Risks from flooding

This evidence review has confirmed that despite adaptation efforts under way across the UK, flooding remains a major risk from climate change for people and the built environment, and also that this risk requires further urgent action (section 5.2.5). Flood risk management policy in the UK is focused on defending properties from river flooding and the breach or overtopping of coastal defences and advice to local authorities to avoid giving planning permission for development in high-risk locations. Property level technologies are available but uptake is low. There are concerns that Flood Re, the forthcoming subsidised flood insurance scheme, will largely remove the financial incentive for high-risk households to take up PLP.

Current evidence indicates that absolute flood risk increases under all climate and population scenarios assuming adaptation efforts continue at the same level as now. Population size and sea levels are increasing, whereas changes in rainfall patterns are more variable and also show changes in both directions. In the short term, adaptation can reduce risks but not eliminate them. It is difficult to manage risk from either surface water or groundwater flooding. In the longer term, adaptation may only hold back the rate of increase unless transformative innovations are deployed that would require substantial amendments to planning and building codes. This will be particularly true towards the end of the century – or sooner if the 4ºC climate change scenario is realised.

Flood risk increases will not be evenly distributed across all the countries and regions of the UK. Heavily defended urban centres are likely to attract further investment given the cost-benefit advantages whereas defending less densely populated areas is likely to be less cost-effective. By the end of the century some coastal communities and culturally valued assets could be unsustainable. From the 2020s, especially as Flood Re begins to be withdrawn as is planned, such communities and assets could be blighted or have reduced value with consequences for people's health and wellbeing. There is little or no systematic and robust evidence on the costs of flooding to health and wellbeing or to community cohesion or vulnerability. The vulnerability of the health and social care system to future flood risk has not been adequately assessed.

There are: (i) detailed plans to minimise flood risk for some regions such as the Thames area, and shoreline management plans for the coast; and (ii) growing networks of local organisations charged with or accepting responsibility for managing aspects of flood risk. Nevertheless, several barriers to reducing future flood risks have been identified:

- Despite widespread application of the sequential test and its equivalents in planning, housing and other buildings are still being built in flood risk zones.
- The uptake of property level protection is low.
- There is lack of early engagement of coastal communities at risk of flooding.
- There is evidence that adaptation has been deprioritised in many local authorities in England, and co-ordination between different aspects of local authority activity relevant to climate change is not occurring (planning, highways, health and wellbeing boards, local flood action groups, etc.).

Research is needed to better understand the health and other social costs of flooding and to better inform flood risk cost-benefit analyses.

There are opportunities to manage flood risk – for example, through coastal realignment or SuDS– that include benefits to health and wellbeing by creating new green and blue spaces.

Action will also be needed to reassess and implement new flood risk management plans as the evidence improves for both climate risks and effectiveness of specific measures. To avoid locking in risks and because of the long lead times needed to reappraise flood risk scenarios or shoreline management plans (and to implement these), research and monitoring is needed to ensure future flood risks can be reduced.

Coastal erosion and sea-level rise pose a threat to cultural and heritage assets that has yet to be quantified or appreciated. This could be important as coastal features are among the UK's most valuable natural capital.

Risks from heat

An increase in heatwaves and extreme high temperatures is one of the most likely impacts of climate change. An increase of hot days is likely to increase the burden of heat-related mortality and morbidity, and other adverse effects on wellbeing (from exceeding tolerable levels of thermal comfort). For example, overheating of the public transport system could lead to welfare losses that are not well quantified.

This risk from high temperatures is well understood but difficult to manage. There are a range of response and adaptation measures available and plans for dealing with the extra loading on the health system. The risk of hot day health effects is not evenly distributed across the UK, with poplations in the south of England and Midlandslikely to be most affected in the future.

The UK housing stock is currently experiencing overheating in summer, with an estimated 20% of homes already overheating even in a cool summer. Adverse impacts can be avoided by retro-fitting with passive cooling systems that do not increase greenhouse gas emissions. However, there are no regulatory or other incentives to ensure existing buildings are retrofitted and for new build developments to be designed and built to limit overheating. In London during a heatwave in the 2030s it is estimated that around two-thirds of flats and up to half of detached properties would overheat. The urgency of the response should be increased to avoid 'lock-in' due to the lack of policy and long life time of building stock.

Overheating in care homes and hospitals is not well managed, and managing future levels of overheating may prove more difficult. Policy and technological approaches are needed that will ensure homes and other buildings are well-insulated for winter but sufficiently ventilated in summer to keep internal temperatures down.

More research may be needed to assess the degree to which green infrastructure could reduce the urban heat island effect that can exacerbate climate warming in cities and overheating problems.

Potential benefits from cold

Currently there are between 35,800 and 49,700 cold-related deaths per year across the UK. The level of risk of cold-related mortality across the UK remains high compared to other NW European countries. Climate change alone is projected to reduce the health risks from cold, but the number of cold-related deaths is projected to decline only slightly due to the effects of a growing, ageing population increasing the number of vulnerable people at risk. Current projections suggest a decline in mortality of 2% by the 2050s under a medium emissions scenario and assuming population growth.

Fuel poverty levels are used as a proxy indicator for exposure to cold, and have seen little change over the last decade. It is important that policies are further developed and implemented to address fuel poverty without increasing the risk of overheating.

Disruption of health services and social care

Extreme weather (heatwaves and flooding) disrupts health and social care service delivery, and can damage health care infrastructure. Health services are vulnerable to an increase in the frequency and intensity of extreme weather events and the capacity of the system to cope with shocks could decrease with increasing pressures on the health service and local government. The number of hospitals, GP surgeries, emergency service stations and care homes at risk of flooding is likely to increase, particularly in England and Wales. Modern built facilities are designed to support contemporary care models and to be thermally efficient in cold weather, but this has led to problems with thermal comfort during heatwaves, for patients and staff in hospitals and care homes. Floods and storms cause significant disruption to health and social systems, and there is a lack of evidence that they are well addressed in emergency planning.

Infectious and emerging disease

As climate change progresses, the UK climate may become favourable for the survival and breeding of disease-carrying or transmitting organisms. There are particular concerns regarding insect and tick vectors of diseases such as Chikungunya virus and dengue fever as well as Lyme disease where diagnosis can be difficult. Some resident UK insects are potential hosts to a number of diseases. There are gaps in knowledge about the future capability of resident vectors to host pathogens in the UK, and about the extent of the risk from invasive pathogens and vectors.

Rising temperatures could expose people to increased risks from food-borne pathogens caused by poor food processing and handling and also from shellfish. Increased risk from vibrio organisms is already of particular concern. The magnitude of these risks is difficult to quantify.

Risks to building fabric and cultural heritage from extreme weather

Around 1 million homes in England currently suffer from problems with damp or mould. Numbers for the devolved administrations are unclear. More research is needed to better determine the future level of risk and what adaptation further steps might be appropriate. Climate-related hazards damage historic structures and sites now, but there is lack of information on the scale of current and future risk, including for historic urban green spaces and gardens as well as structures.

Risks from drought and water supply restrictions

The influence of climate change on droughts is difficult to determine. The possibility of multi-year droughts remains a risk as do decadal periods of lower than average rainfall. Overall, risks from drought are currently intermittent but may increase; in future such conditions would exacerbate the growing pressure on water supply in many parts of the UK and may affect green infrastructure and also have effects on wellbeing, health and communities. In combination, climate change and population growth are likely to lead to water supply deficits that may put the normal headroom that water utilities generally work within at some risk.

5.7.2 Key research gaps

This review has identified several key research gaps and challenges. These are summarised by section below.

Communities

- Better understanding of and accounting for the actual change in flood risk from new development on the floodplain in the devolved administrations.
- Better understanding of the need for long-term plans – in addition to shoreline management plans - for coastal communities that are at risk of being lost as a result of sea level rise.
- How local authorities can manage the trade-offs and develop opportunities in climate adaptation and how more integrated approaches might help communities adapt to climate change.
- Communication of climate risks, both in relation to climate change and also relation to addressing climate-related hazards, such as flooding.
- Improved, open-access datasets to help assess risk and manage flood events (e.g. river flows, flood damage, flood extents, social and health impacts)
- Risk of simultaneous flooding from multiple sources – coastal, river, pluvial surface water, snowmelt.
- Impact on flood risk assessments of sequences of rainfall events/mid-scale flows/flood events.

- Determining how flood risk to properties is likely to develop under a range of climate, social, economic and population scenarios.
- Improve knowledge of the links between climate change and increased rainfall from hourly to monthly and/or increased storminess (including the clustering of such events).
- New techniques to enable higher river flows to be translated into accurate flood prediction models at local scales so as to inform all stages of the planning and flood management processes.
- Wider appraisal of the costs of flooding, including the number of people and businesses at risk (current methodologies focus on number of properties in order to gauge immediate financial cost arising from damage rather than wider economic and social costs).
- Effectiveness and economic cost of upstream storage and land-cover change in mitigating river flooding.
- Resilience of local communities to recover from a major flood event and/or loss of key infrastructure such as bridges or causeways.
- Evaluation of the effectiveness of green and blue infrastructure and of other interventions (e.g. cool roofs) in reducing flooding and extreme heat exposure.

Buildings

- The total level of risk and the benefits of acting on overheating for all types of buildings in the devolved administrations. More information also needed on the risks in buildings other than homes in England.
- Further empirical summertime indoor temperature data, and an improved understanding of how energy-recovering ventilation systems such as mechanical ventilation and heat recovery systems may alter risks.
- The level of action underway and level of risk on overheating in public transport in areas outside London.
- Better quantification of the current and future risks to the historic built environment from climate change.
- Better understanding of the effectiveness of different measures to keep cool in summer and hot in winter.
- Continued monitoring of vulnerability and exposure needed, including through the continuation of current housing surveys
- Reduction in the level of uncertainty in increased cooling demand and the economic benefitis of uptake of passive ventilation measures vs. air conditioning.
- Impact of increased vapour pressures on required ventilation performance.
- Better understanding of 'comfort taking', and the household energy benefits of climate change.
- Impacts on and response to climate risks and historic environment and cultural heritage. Data from effective monitoring, surveys and imaging to identify current effects and early

warning of damage. Increased take up of the research and translation of research to make it useful.

Health systems

- A key challenge for improving emergency planning in the health system is the lack of evidence relating to the impacts of climate risks (flooding or heatwaves), and no method to monitor such impacts (Lee et al., 2012; Challen et al., 2012).
- Quantification of impacts of extreme weather on infrastructure at national or regional scale, and on health and social care delivery.
- More research is needed on the risks in hospitals, care homes and community based care from heatwavess, in terms of risk management, clinical practices, and how these relate to building design.
- Assessment of effective response options to develop accurate budget predictions for providing the necessary adaptation measures for the healthcare estate to enable the delivery of safe healthcare for patients
- The impact of high temperatures in care homes, and strategies to reduce the impact on the welfare of residents.
- Decision support modelling to address emergency planning to improve responses to extreme events.
- Assessment of how various local actors across the country are planning and preparing for extreme weather in a co-ordinated way and what are the barriers to implementation.

Impacts on population health and health protection responses

- Understand how people react in hot weather and the effectiveness of measures to encourage the public to protect themselves.
- How changes to climate other than increasing temperatures, such as changing wind patterns and blocking episodes, could impact on air pollution levels. Long-term data on the number of children and adults living with chronic respiratory conditions would also be valuable.
- Impact of climate change on fine particle concentrations in ambient air.
- Better understanding is needed of the eco-epidemiological drivers that determine the distribution of the UK's existing arthropod vectors and the pathogens that they might carry at finer spatial scales than is possible from current studies. Improved knowledge of which vectors transmit which pathogens is also required. Better ongoing surveillance for the importation of exotic arthropod vectors and pathogens would also be beneficial.
- Field-based research should be conducted to understand the impact of environmental change and climate change adaptation strategies on disease vectors.
- Health and wellbeing impacts of flooding, including the long-term consequences for mental health, and an improved estimation of the associated costs.
- Effectiveness of interventions for extreme weather events, including community based strategies, risk communication, and interventions to support mental health strategies.

- Understanding changes in vulnerability to heat and cold over time in order to better model future adaptation.
- Improved characterisations of temperature extremes in climate model outputs, such as UKCP18.

Beyond specific research needs, which in the main deal with individual components of climate change risk, there is a need for an integrative approach to problem solving and policy construction due to the dynamic complexity of the systems involved. Without such an approach, the likelihood of unintended negative consequences, caused by single solutions and different policies impacting each other, is high (Davies and Oreszczyn, 2012; Shrubsole et al., 2014). One such approach, with participatory system dynamics, has been successfully used to understand the connections between housing, energy and wellbeing (Macmillan et al., 2015).

Annex 5.A: Differences between CCRA2 and Environment Agency flood projection studies

Table 5A.1: Differences in major assumptions between Sayers et al. (2015) and the Environment Agency's Long-term Investment Scenario methodologies

	Sayers et al. (2015)	**EA Long-term Investment Scenarios**
Types of flooding	Focuses on fluvial, surface water and coastal (including tidal reaches), separate assessment of groundwater risk.	Focuses on fluvial and tidal flood risk, partial assessment of surface water risk, no assessment of groundwater risk.
Overlaps in areas at flood risk	Floodplains are classified as at risk from fluvial, pluvial or tidal flooding.	Properties at risk of fluvial or tidal flooding combined into one category. Pluvial flooding is covered in a separate analysis.
Future population/properties	Uses low and high population scenarios at the local authority scale derived from the Office of National Statistics alongside a no-growth scenario. Assumes that present-day occupancy rates remain the same in the future and therefore derives future numbers of residential properties from population projections. No change assumed in future number of non-residential properties due to a lack of suitable data.	Uses a no increase in population at risk scenario as the central scenario, underpinned by an assumption that new development does not add to flood risk. Also contains a population increase scenario where the assumption on development control is relaxed.
Future climate scenarios	Climate scenarios consistent with changes in global mean temperature of 2 – 4°C above 1961 – 1990 levels. Also includes an extreme high++ scenario.	Optimal investment profile is based on medium emissions, consistent with ~2.6 – 4.2°C change in global temperature by 2080 compared with 1961 – 1990 levels (though the EA state that they are looking at the "above-median probability estimate", so the scenario is likely to be closer to the high end. Sensitivity tests also include a high scenario.

Table 5A.1: Differences in major assumptions between Sayers et al. (2015) and the Environment Agency's Long-term Investment Scenario methodologies

	Sayers et al. (2015)	**EA Long-term Investment Scenarios**
Future time periods	2020s, 2050s, 2080s (set against a baseline of 2014)	Present day to 2060s
Adaptation assumptions	Uses six adaptation scenarios representing different levels of effort across a range of adaptation actions including: standard of protection provided by flood defences; development in flood risk areas; uptake of natural flood management and managed realignment; use of SuDS; and individual actions to reduce the chance of flood damage.	Works out the most cost-effective pathway for future spending on flood defences within each of the ~3,000 flood risk management systems in England, and from that works out the optimal total level of investment on flood defences in the future. Assumes optimal investment decisions are taken at each stage in cost-benefit terms and that adequate maintenance is performed.

Annex 5.B: Policy frameworks

Communities and settlements

Table 5B.1. Policy frameworks relevant to communities and settlements

Policy reference	UK nation	Key effects of this policy in addressing climate risks	Links to other policies
EU Floods Directive 2007	UK-wide	The EU Floods Directive came into force in November 2007 and establishes a framework for assessing and managing flood risk aimed at reducing the adverse consequences for human health, the environment, cultural heritage and economic activity. It was transposed in England and Wales by the Flood Risk Regulations 2009.	Flood and Water Management Act 2010 (England and Wales), Flood Risk Management (Scotland) Act 2009, The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009
Flood and Water Management Act (2010)	England and Wales	Sets up a process for enhancing the protection of communities and settlements from all types of flooding.	Water Act (2014) sets out the role of Flood Re. The DCLG is responsible for planning policy, including policy affecting the development of land which is at risk from flooding or coastal erosion.
Flood Risk Management (Scotland) Act 2009	Scotland	Gives local authorities discretionary powers to make and build flood prevention schemes, and provides guidance on the appraisal and impact of flood risk management schemes.	Water Act (2014) sets out the role of Flood Re.
The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009	Northern Ireland	Sets out responsibilities for implementation of the EU Floods Directive, including the preparation of flood maps and flood risk management plans.	Water Act (2014) sets out the role of Flood Re.

Table 5B.1. Policy frameworks relevant to communities and settlements

Policy reference	UK nation	Key effects of this policy in addressing climate risks	Links to other policies
Water Act (2014)	UK	Creates Flood Re, a reinsurance pool designed to provide insurance cover for the most at-risk households across the UK.	Flood and Water Management Act (2010)
EU Drinking Water Directive		The Water Resources Act 1991 was used to introduce the Drinking water directive into UK law. In Scotland, Water Supply (Water Quality) (Scotland) Regulations 2001.	Private water supplies have equivalent regulations
National Planning Policy Framework (2012) and associated guidance	England	Sets a framework for sustainable development in relation to land-use planning, encouraging local plans to take account of climate change over the long term. The NPPF states that new development should be planned to avoid increased vulnerability to the range of impacts arising from climate change.	Links to Flood and Water Management Act (2010) as the NPPF provides the framework for development to minimise impacts from flooding.
Planning Policy Wales (Edition 7, July 2014)	Wales	States that local plans and policies should enable change-resilient settlement patterns that minimise land-take.	
National Policy Framework 3 (2014)	Scotland	Promotes the need to ensure new urban and rural developments are resilient to climate change across its four themes of sustainable development.	
Scottish Planning Policy (SPP).	Scotland	Non-statutory, reflects how nationally important land use planning matters should be addressed.	
Northern Ireland Regional Development Strategy (2012)	Northern Ireland	Includes a strategic goal (RG9) to facilitate adaptation to climate change through land-use planning, including through re-use of land and buildings, adoption of grey	Regional Development Strategy 2035 Northern Ireland.

Table 5B.1. Policy frameworks relevant to communities and settlements			
Policy reference	**UK nation**	**Key effects of this policy in addressing climate risks**	**Links to other policies**
		water recycling, minimising development in flood risk areas, soil and habitat protection, and identifying key assets and areas that are most at risk from climate change.	
Strategic Planning Policy Statement (SPPS) for Northern Ireland – "Planning for Sustainable Development"	Northern Ireland	The subject policy for Open Space, Sport and Outdoor Recreation, as contained within the SPPS, provides for the protection of open space, the provision of new areas of open space in association with residential development and the use of land for sport and outdoor recreation. It embodies the NI Executive's commitment to sustainable development, to the promotion of a more active and healthy lifestyle and to the conservation of biodiversity. The SPPS is in general conformity with the RDS 2035.	
Civil Contingencies Act (2004)	UK-wide	Requires national and local processes for planning for and responding to extreme weather events (flooding, drought, heat, cold, wildfire, storms) now and over the next five years. Does not consider the effects of climate change on the level of risk.	
Cleaner Air For Scotland (CAFS)	Scotland	Sets out strategic policy and assessment methodology for Scotland on tackling air pollution.	

Buildings

Table 5B.2. Policy frameworks relevant to buildings

Building regulation and climate risks	UK nation	Key effects of this policy in addressing climate risks	Links to other policies
Building Regulations	England and Wales	Contains standards that new buildings and major renovations must conform to relating to moisture, ventilation, internal heat gains, solar gains and water efficiency.	
Building Standards System	Scotland	Includes standards related to flood resilience (standard 3.3), moisture penetration from heavy rain (3.10), heating and overheating (3.13), ventilation (3.14), condensation (3.15) and water efficiency (3.27).	
Building Regulations Northern Ireland 2012	Northern Ireland	Contains standards that new buildings and major renovations must conform to relating to ventilation, internal heat gains and damp.	
Housing Health and Safety Rating System (HHSRS)	England and Wales	Evaluation tool for local authorities to assess the condition of dwellings. Includes an assessment of damp, heat and cold, pests, food safety and water supply.	Building Regulations for residential buildings
Health and Safety at Work Regulations (1999) and The Workplace (Health, Safety and Welfare) Regulations 1992	England, Scotland and Wales	Includes general provisions for weather-related risks to health, including adequate ventilation, temperature and supply of drinking water.	Building Regulations for non-residential buildings
Health and Safety at Work (Northern Ireland) Order 1978	Northern Ireland		

Table 5B.2. Policy frameworks relevant to buildings

Building regulation and climate risks	**UK nation**	**Key effects of this policy in addressing climate risks**	**Links to other policies**
Education (School Premises) Regulations, 2012	England and Wales	Stipulates minimum temperature requirements for school rooms. No maximum temperature requirements are set.	Health and Safety at Work regulations
Planning (Listed buildings and conservation areas) Act 1990.	England and Wales	Sets out the listing of buildings and creation of conservation areas as well as the process for approving works within conservation areas or affecting listed buildings. Historic Scotland also has actions around Climate Change adaptation which are set out as part of the Scottish Climate Change Adaptation Programme	
Ancient Monuments and Archaeological Areas Act 1979' http://www.legislation.gov.uk/ukpga/1979/46	England, Wales and Scotland	The act relates to adaptation in so far as any works affecting scheduled monuments, and there are a number of bridges in this category, require consent from the secretary of state.	

Health and social care system

Table 5B.3. Policy framework relevant to the health and social care system			
Policy	**UK nation**	**Key effects of this policy in addressing climate risks**	**Links to other policies**
Health and Social Care Act (2012)	England	Places responsibility for health assets and delivery with clinical commissioning groups and NHS Trusts, and public health assets and delivery with local authorities. Includes the setting up of local health resilience partnerships (LHRPs) to deliver national emergency preparedness, resilience and response (EPRR) strategies in the context of local risks.	
NHS Standard Contract	England	Service providers have to undertake a series of actions related to emergency preparedness and resilience.	
Health, Social Care and Well-being Strategies (Wales) 2003 regulations	Wales	Local Health Boards and local authorities to jointly produce a local health, social care and well-being strategy for each area.	
Health Standards Framework	Wales	Set of core standards for healthcare providers including managing risk and promoting health and safety	
The Public Health (Scotland) Act 2008	Scotland	Places duties on local health boards and local authorities to take joint responsibility to protect public health. Local NHS boards produce guidance on responding to extreme weather including flooding, cold and hot weather.	
Health and Social Care (Reform) Act 2009	Northern Ireland	Restructured the provision of health and social care in Northern Ireland.	

Population health and health protection

Table 5B.4. Policy framework relevant to population health

Policy	UK nation	Key effects of this policy in addressing climate risks	Links to other policies
Pathogen surveillance programmes	England, Scotland, Wales and Northern Ireland all have separate programmes.	Early identification of new or emerging pathogens and the spread of infectious diseases.	
Heatwave Plans	Separate plans for England and Wales	Sets out guidance for organisations and the public on actions to build resilience and action to take during hot weather.	
EU ambient air quality directives (2008/50/EC and 2004/107/EC)	UK	Set limits and targets for concentrations of various pollutants in outdoor air for the protection of health and ecosvstems.	
National Air Quality Strategy (Defra, 2007)	UK	Sets national objectives for improving ambient air quality, and how to achieve them.	
Water Industry Act 1991 (the 1991 Act)	England and Wales	Sets out legal framework for ensuring good quality drinking water.	
Making Life Better strategy	Northern Ireland	Includes an objective to provide safe and clean drinking water.	
EU Drinking Water Directive	UK	The Water Resources Act 1991 was used to introduce the Drinking water directive into UK law.	

Table 5B.4. Policy framework relevant to population health			
Water Supply (Water Quality)(Scotland) Regulations 2001, Private Water Supply (Scotland) Regulations 2006	Scotland	Regulations related to the quality and safety of public and private water supplies respectively.	

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Committee on Climate Change
7 Holbein Place
London
SW1W 8NR

www.theccc.org.uk

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