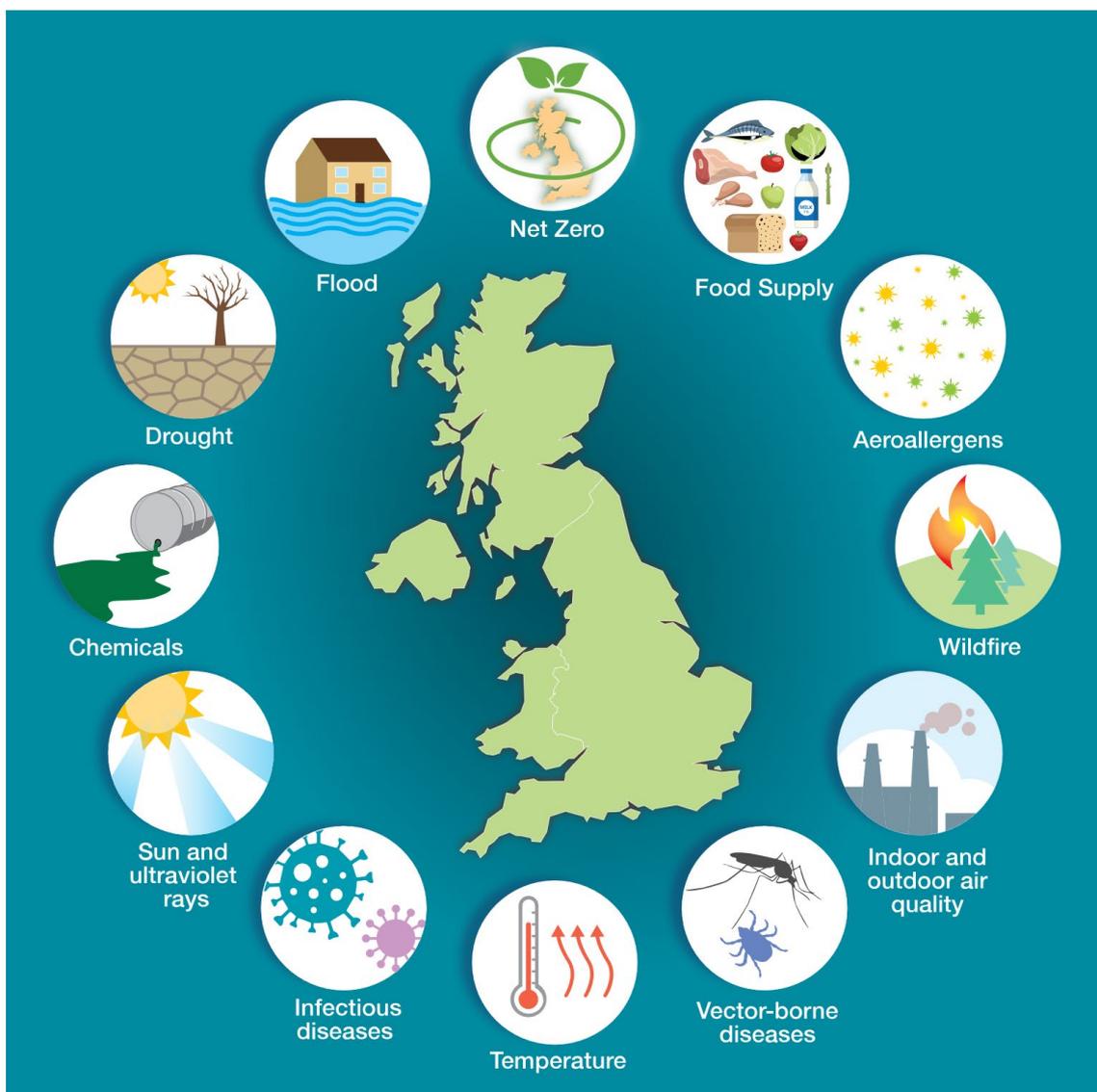




UK Health
Security
Agency

Health Effects of Climate Change (HECC) in the UK: 2023 report

Chapter 3. Climate change, flooding, coastal change and public health



Summary

Flooding is one of the most important climate change challenges facing the UK, and people affected by flooding are more likely to experience adverse health outcomes including long-term impacts on mental health and wellbeing. This chapter contains a review of the evidence on the risks to health posed by flooding, and how these risks might be affected by our changing climate. The chapter was led by expert academics from the London School of Hygiene and Tropical Medicine, with contributions from the UK Health Security Agency (UKHSA) and IPSOS. The chapter synthesises new evidence published since the last HECC report, including updated analyses of sea-level rise projections and increased evidence on high-impact low-probability flood events and surface water flooding.

The chapter highlights the range of adverse impacts that flooding from rivers, surface water and coastal waters, can have on health. These include direct (such as death and injury) and indirect (for example, increased risk of infectious disease outbreaks) impacts, as well as distal impacts for example from interruption of water or power supply and disruption in access to health and care services. Flooding has a major and protracted impact on mental health and wellbeing. People who experience flooding are at higher risk of depression, anxiety, and post-traumatic stress disorder (PTSD), with mental health effects made worse by certain factors including displacement particularly without warning, extent of flood damage in the home, disruption to utilities or health services and secondary stressors including dealing with insurance claims.

The frequency and magnitude of flooding events is projected to increase in the UK, with the consequent harmful impact on health. Approximately 6.1 million people in the UK currently live in flood prone areas, with additional at-risk areas identified due to sea-level rise. Increased flooding will mean that people and properties, health and social care facilities, transport lines and schools will become at risk of flooding. Flood risk is projected to increase more steeply under high-warming scenarios (4°C of warming, or limited global decarbonisation) compared to a scenario where warming is limited to 2°C. The number of people in the UK significantly at risk of flooding is projected to increase 61% by 2050 under a modest warming scenario (2°C) and 118% in a high warming scenario (4°C). The extent to which sea levels are projected to rise depends largely on how much the planet warms: there is a 1 metre to 1.5 metre difference in projected sea level rise between scenarios of low and high levels of warming. The latter would require relocation of some UK coastal communities and have significant impact on infrastructure and services with consequent adverse health effects. The increase in flood risk in the UK is largely driven by coastal flooding and will predominantly impact England.

This chapter considers the evidence of interventions to increase resilience and protect health from the effects of flooding. The most common protection measures against flooding include flood defences, flood forecasting and warning, spatial planning to reduce building in flood-risk zones and protection of floodplains. There is growing evidence that harnessing natural process can be effective to reduce flood risk, such as river and wetland restoration. These nature-based solutions are frequently associated with health co-benefits, including thermal regulation,

improved air and water quality, and benefits for mental health. Identifying and supporting those people at highest risk from flooding will be critical in reducing associated health impacts, including planning for targeted support of vulnerable people (such as those with chronic illness), places (including prisons, schools, social care facilities), and spaces (those located in or near floodplains).

This chapter highlights a number of research gaps and priorities, including the need to:

- improve understanding of the health impacts of flooding, drivers of vulnerability including attitude and behaviours to inform public health action and localised planning and response efforts
- develop and facilitate the provision of data or indicators of risk and vulnerability to support decision-making at local levels
- develop and evaluate interventions to protect health from the longer-term physical and mental health impacts of flooding
- assess the economic impacts of flooding on health and include the economic benefits in evaluation of interventions to understand the most effective approaches to protect people, infrastructure, and services in at-risk area
- understand and consider health co-benefits and implications for equity when assessing the impacts and effectiveness of interventions to protect health from the effects of flooding
- integrate health considerations and implications in research related to land use planning, maintenance and upgrades to ageing infrastructure, coastal degradation, ecosystem restoration, ecosystem functioning, and flood resilience
- improve our understanding of the health implications for communities forced to relocate due to coastal change

UKHSA launched the '[Adverse Weather and Health Plan \(AWHP\)](#)' for England in April 2023. The AWHP outlines areas where different sectors (including public, independent, voluntary, health and social care organisations and local communities) can work together to maintain and improve integrated arrangements for planning and response to deliver the best outcomes possible during adverse weather. The AWHP includes health protection advice to manage flood impacts once a flood has occurred and to inform health professionals' response to flood warnings issued by the Environment Agency. UKHSA has also published guidance for specifically addressing [the mental health impacts of flooding](#). It provides information on the health impacts of flooding, the measures needed to prevent major psychological effects on health by alerting people to the adverse impacts of flooding and enables them to prepare and respond appropriately.

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Chapter 3. Climate change, flooding, coastal change and public health

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1. Introduction and scope

This chapter addresses the impact of flooding on public health and the likely impacts of climate change on population health through increased flood impacts, considering current impacts and future projections for river, coastal and surface water flooding. The impacts of coastal change, which is driven by coastal flooding and coastal erosion, are also considered. The chapter covers the whole of the UK (England, Scotland, Northern Ireland and Wales), with impacts considered up to the end of the century (relevant for sea-level rises and population displacement).

There have been several advances in our understanding of flood risks to health since the last 'Health Effects of Climate Change (HECC)' report ([1](#)). These include:

- greater risk from coastal flooding – sea-level rise projections have been revised upwards
- greater recognition of risk from high-impact low-probability (so called 'grey swan') events
- greater risk from surface water flooding – projections of extreme precipitation events have been revised upwards
- new evidence on the negative long-term mental health impacts of flooding from the National Study of Flooding and Health
- increased understanding of community resilience, following the shift in government policy to resilience from building defences
- more recognition of negative health impacts on professionals who work to reduce flood risks and respond to flood emergencies
- increased evidence regarding the effectiveness of nature-based solutions to reduce flood risk and their health and social benefits

This chapter discusses the 3 main types of flood events: river flooding (fluvial); coastal flooding, including storm surges; and surface water flooding. Flooding from rivers has been the dominant source in terms of the current burden of health and social costs, but a greater number of properties are at risk from surface water flooding. Coastal flooding is the most dangerous in terms of impacts, due to the risk of a catastrophic event that could cause a large number of fatalities. Groundwater risk dominates flood risk in some areas but has a limited contribution to the scale of UK risk and is not addressed in this chapter.

In response to climate change and the other drivers of flood risk, there has been significant investment in flood defences in many locations. Whilst such measures have significant benefits ([2](#)), it is not sufficient to address the risks from climate change. The Climate Change Committee's (CCC) 'Progress Report to Parliament' on adaptation ([3](#)) examined the level of implementation of adaptation measures with respect to flooding. The report stated "plans for flood defences and improved flood risk mapping are typically credible but maintaining defences and managing surface water flood risk will require further funding commitments. Evidence suggests flood risks are rising across the country and developments are still being built in areas

at future risk. Most plans for new developments do not thoroughly regulate or track adaptation for future climate resilience. Plans to ensure developments at the coastline are protected remain non-statutory, and there is insufficient funding to enable affected communities to adapt” (3).

In addition, there is an increasing move away from a risk-focused approach that relies on protection, to a more holistic, resilience-based approach that recognises the need to live with water and provide a range of measures to better enable communities and businesses to plan, prepare, protect, recover and adapt. It is important that communities are able to adapt to cope with future flood events, although in some cases there may be limits to adaptation, leading to the relocation of populations.

1.1. Current flood risks

Table 1 lists recent major flood events in the UK. The winter of 2019 and 2020 experienced several major storms.

There has been some work on attributing flood events to anthropogenic climate change. For example, the heavy rainfall of the wettest day in 2020 is estimated to have become about 2.5 times more likely because of human influence on the climate (4). Currently, the likelihood of such an event is approximately 1%, but is projected to increase to about 3% by 2100 (4). Attributing actual flood events is more complex. For example, an analysis of the 2013 and 2014 winter floods in England using climate and hydrological modelling was fairly inconclusive in detecting an anthropogenic climate change signal (5).

Thunderstorms and intense rainfall are more likely to occur during the summer. In July 2021, thunderstorms and heavy rainfall caused 2 serious flash floods in London, with some areas reporting more than twice the average July rainfall in 2 hours (6). The floods caused major disruption, with more than 1,000 homes and properties flooded by stormwater and sewage, and more than 30 underground stations closed or partly closed (6). In addition, 2 hospitals in London were affected, some hospital wards evacuated, and health services were disrupted (6).

The specific health and social costs of these flood events are discussed in more detail below. There is a need to better describe and quantify the health impacts of flooding. The ‘Sendai Framework for Disaster Risk Reduction 2015 to 2030’ is a voluntary United Nations agreement which guides countries in multi-hazard management (7). The framework has recommendations to improve monitoring and reporting on the impacts of flooding. Quantifying the morbidity and the economic costs to households of health impacts or social disruption would be beneficial for managing the health risks from flooding.

Table 1. Important flood events across the UK (2017 to 2022)

Data comes from the Environment Agency (EA), Department for Infrastructure (DfI) Northern Ireland, Scottish Environment Protection Agency (SEPA) and National Resources Wales (NRW) (based on (8) and updated for 2023).

Event and date	Properties flooded (number)	Location
August 2017	400	Northern Ireland: Foyle and Faughan river catchments
May 2018	520	England: South East, Midlands
October 2018	302	Wales: Lampeter, Llanybydder, Llechryd, Carmarthen, Newcastle Emlyn, Llandysul
June 2019	380	England: East, Midlands, South East
November 2019	1,100	England: Yorkshire, Northern England
Storm Ciara, February 2020	1,350	England
	224	Wales
Storm Dennis, mid-February 2020	1,570	England
	160	Scotland
	2,765	Wales
Late February 2020	520	England
Storm Jorge, February to March 2020	141	Wales
Storm Francis, August 2020	55	Northern Ireland: County Down, County Londonderry
Storm Bella, December 2020	400	Across England
	70	Wales: Dinas Powys
Storm Christophe, January 2021	675	England: Northern and Central England
Heavy rainfall July 12 and 25 2021	More than 1,000 (includes schools and businesses)	England: London
Heavy rainfall, October 26 to 31 2021	40	England: Cumbria
Storms Dudley, Eunice and Franklin, February 2022	372	England, Wales and Northern Ireland

1.2 Future flood risk

The most recent comprehensive assessment of current and future flood risk was published by Sayers and colleagues, which was commissioned for the 'Third Climate Change Risk Assessment (CCRA3)' report (9). Estimates of populations at risk and expected annual damage (EAD) were quantified at the regional level and for 2 future time periods (2050s and 2080s), where EAD is estimated by direct damage to buildings (dwellings) and includes a consideration of health costs.

Climate change will increase the number of properties at risk of flooding from all sources and occur in areas that have not previously been at risk of flooding. Figure 1 describes the projected increase in the number of people at significant risk (defined as experiencing flooding 1 in 75 years or more frequently) for the 2050s and 2080s for +2°C and +4°C climate scenarios and low and high future population growth scenarios. By 2050, the UK population exposed to flooding is projected to increase by 61% and by 118% by 2080 compared to current exposures (Figure 1). These projections include explicit assumptions regarding adaptation using the 'reduced whole system' (RWS) adaptation scenario which assumes minimum intervention. There is a large projected increase in the population at significant risk of flooding from all sources and scenarios in England, with the largest increase in coastal flooding (Figure 1). The at-risk population is projected to decrease in the other 3 nations from fluvial flooding in a 'low warming, low population growth' scenario, meaning that risk could reduce in some nations under these scenarios (Figure 1). Under a 'high warming, high population growth' scenario, all 4 nations are projected to have an increase in the population at risk from all sources of flooding (although a very small increase in Scotland from coastal flooding) (Figure 1). The RWS scenario is equivalent to a 'low effort' scenario, but it is not a 'no adaptation' scenario so population reduction and minimal adaptation 'cancels out' any potential increase in risk from climate change in the aggregate estimates.

England accounts for the greatest increase in the number of people at significant risk of flooding (and has the largest baseline) for nearly all climate futures and sources of flooding. Current risk is most prevalent for surface water flooding and therefore future increases here result in substantial numbers at risk. However, the direct economic damage for households is generally lower for surface water flooding compared with river and coastal flooding due to the water depths and velocities involved, although the frequency of flooding may be higher.

Flood risk is location specific. Figure 2 shows the regional pattern of increases in flood risk for all 3 types of flooding: currently; in 2050 with a 2°C warming projection; and in 2080 with a 4°C warming projection. The current and projected patterns are similar, with some regions particularly at risk of flooding and climate change-related increases in risk, including London, North East England and South West England.

Figure 1. Projected increases in the population at significant risk of flooding (all sources, fluvial, coastal and surface water flooding) for the 2050s and 2080s by country

The Reduced Whole System (RWS) scenario, for low population growth and a pathway to 2°C and 4°C temperature increases (adapted from (8) using data from (9)).

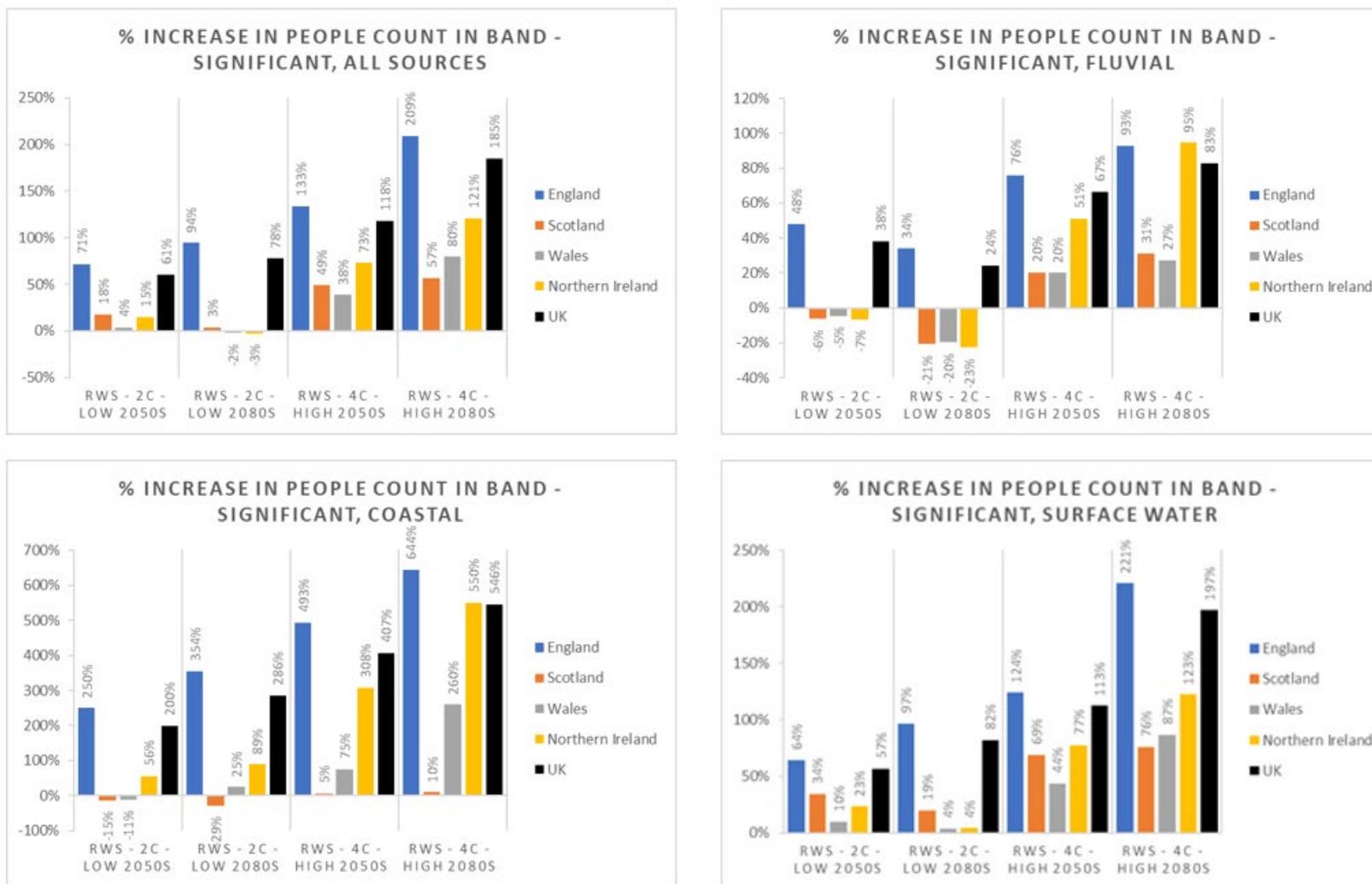
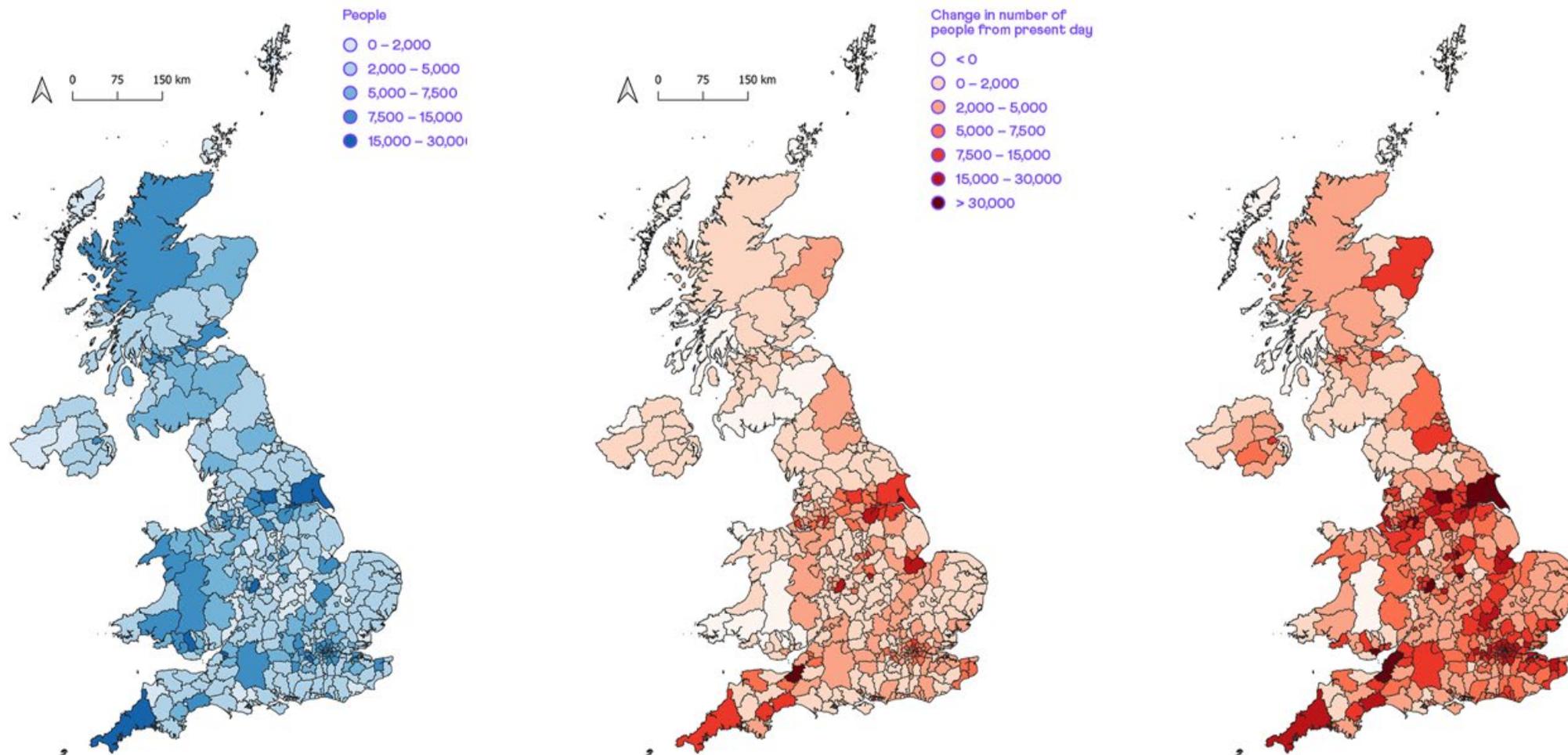


Figure 2. Change in number of people at risk from flooding

The left-hand graph shows present day risk (using 2021 as a baseline). The centre graph shows projected number of people at risk in 2050s on a pathway to 2°C global warming by the end of the century. The right-hand graph shows projected number of people at risk in 2080s on a pathway to 4°C global warming by the end of the century (produced by CCC ([10](#)) using data from ([9](#))).



1.3 Sea-level rise and coastal change

Parts of the UK coast are highly vulnerable to climate change due to coastal flood risk, temperature increases, and increased precipitation but also changes to wave height, storm surges and accelerated coastal erosion. As outlined in Table 2, coastal change can be affected by a range of physical, socio-economic and environmental factors, as well as the policies and strategies that determine local environmental quality.

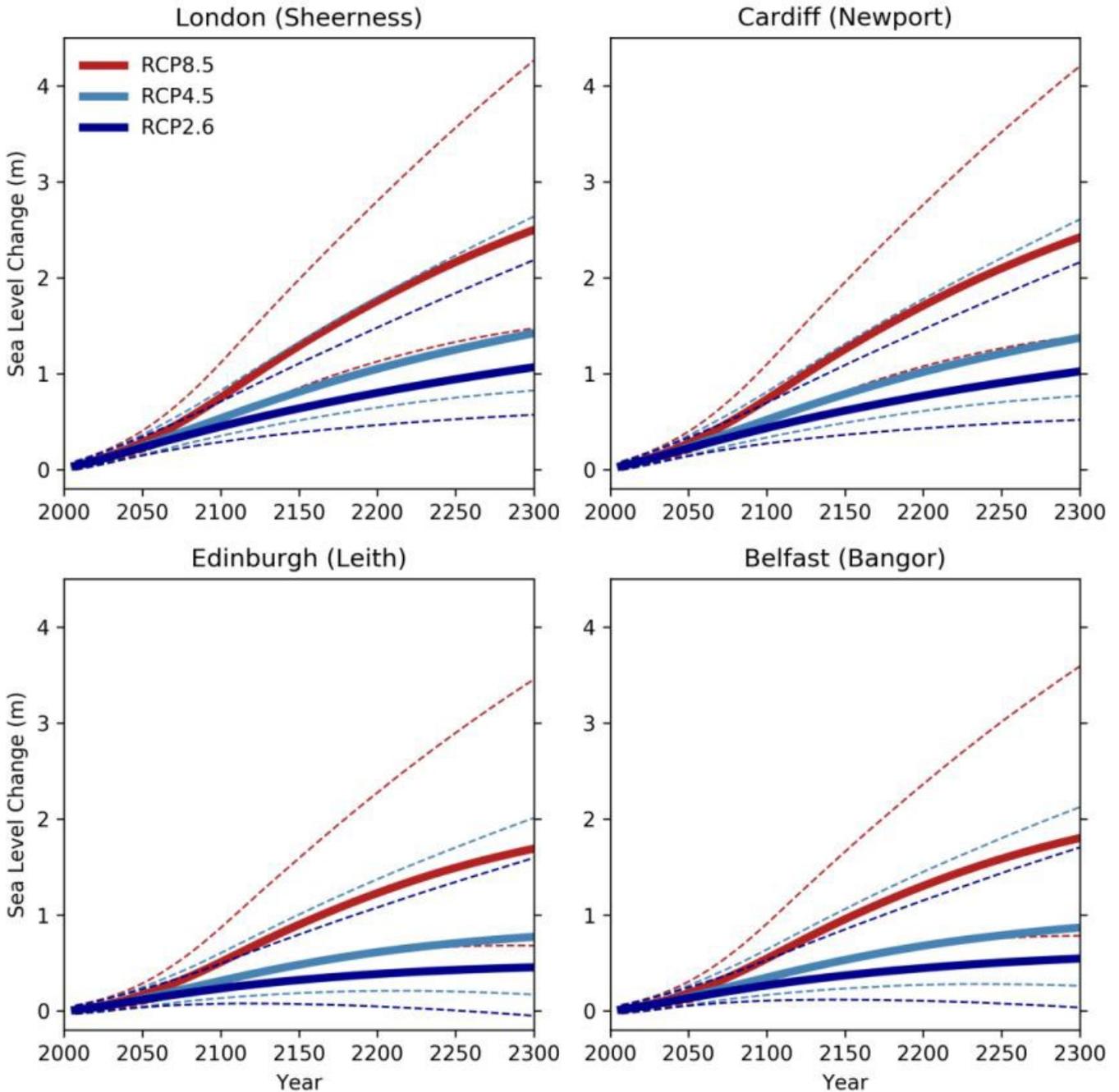
Table 2. Drivers of coastal climate risk for communities: physical, environmental and socio-economic factors (Turner and others, unpublished data)

Physical processes	Socio-economic factors	Environment and other factors
Sea-level rise	Growth or regeneration of coastal towns and cities	Permeability of surfaces, ageing coastal defences
Storm surge	Industrial investment	Elevation of home
Waves	Social deprivation	Mobile, temporary buildings (housing quality)
Coastal morphology and sediment supply	Socio-economic change	Greenspace and agricultural land – hazards control and flood protection
Temperature increases	COVID-19 implications	Buildings in coastal floodplain
Drought	Leisure and tourism investment	Coastal landfills

The Met Office's UKCP18 projections (see Chapter 1) suggests greater sea-level rise than in previous projections. Figure 3 shows sea-level rise projections for the 4 capital cities within the UK (London, Cardiff, Edinburgh, and Belfast). London and Cardiff have similar patterns with around 1m mean sea-level rise in a low warming scenario and 2m in a high warming scenario. Edinburgh and Belfast are instead projected to have 0.5m mean sea-level rise in a low warming scenario and 1.5m in a high. It is important to note that significant further sea-level rise will occur beyond the end of this century.

Figure 3 Extended sea-level rise projections under a range of emissions scenarios for UK capital cities (London, Cardiff, Edinburgh and Belfast)

Solid lines indicate the central estimate and dashed lines indicate the 5th to 95th percentile range for each Representative Concentration Pathway (RCP) scenario as indicated in the legend (top left panel). All projections are presented relative to a baseline period of 1981 to 2000 (11, 12).



Coastal climate risks can harm physical and mental health through 3 main pathways:

- coastal hazards such as flooding or landslides cause injury, morbidities, poor mental health or death (see below)

- solastalgia¹ health consequences in coastal communities that have to relocate due to loss of land, amenities or income
- economic and social impacts that can drive subsequent poor health, where (for example) changes in industry or tourism leading to job losses which can increase stress, anxiety and substance abuse in the local population

In England, 370,000 residential properties are situated in areas at 0.5% or greater annual risk of damage from coastal flooding, and 8,900 properties are in areas at risk of being lost through coastal erosion, not considering coastal defences (13). The ownership of coastal defences varies as does their management. Without effective investment, many of England's coastal defences are likely to be at risk of failure as sea levels rise and changes in management plans may exacerbate the risks to coastal communities further (14, 15).

Coastal communities are also at risk from river and surface water floods. Compound flooding is when different sources occur concurrently or in close succession, often resulting in a more serious flood event. One study has shown that the likelihood of compound flooding (both river and coastal) is greater in the western and south-western coasts of the UK, compared to the eastern coast (16). In addition, many cities, including London and Hull, are at risk of fluvial and surface water flooding due to increased precipitation and limited draining capacity due to impermeable surfaces and old drainage systems (16).

Many UK coastal communities are heavily protected by flood and coastal defences. Whilst many areas are protected using hard defences against the risks of coastal flooding, erosion and other hazards, maladaptation may arise. Many property developers now build up to these defences on floodplains due to perception that the community is protected but this relies upon the defence not failing. As sea levels and temperatures rise, coastal events such as floods will inevitably increase in frequency and severity leading to the potential failure of sea walls and other defences. However, due to increased development behind these defences, a higher number of households are at risk of being flooded or displaced which places increased strain on emergency services and health systems to cope if failure occurs.

Many coastal towns are often geographically isolated, with a poor infrastructure preventing effective links with the health and social care system, education and employment opportunities, which can be an additional driver of poor mental health (17). It is known that coastal areas have a higher proportion of older individuals; by 2031, it is expected over 40% of the population in coastal areas will be aged over 65 (18). Looking across 4 common measures of ageing (percentage aged 65 years and over, percentage aged 85 years and over, median age and the Old Age Dependency Ratio (OADR)), 10 of the 11 local authorities that appear in the top 10 on at least 3 of the 4 measures are coastal (19). This has implications on the vulnerability of coastal areas as the elderly, retired community are prone to poorer health.

¹ Solastalgia is defined as the effect on mental health of loss of place or environmental degradation (86).

The 2021 'Health in Coastal Communities' report for England described the multiple causes of deprivation in seaside towns (20), and highlighted that the gap in quality of life between coastal and non-coastal communities is growing. In addition, socio-economically disadvantaged households are over-represented in areas defined as at risk from coastal flooding.

Changes in climate risks and weather patterns can lead to occupational health hazards due to working in more unpredictable conditions and for longer periods of the year. As climate-driven changes to industry and the economy occur across UK coastal communities, employment opportunities may diminish further, motivating the outward-migration of residents (21). This phenomenon is most common in younger age groups, particularly university graduates, which limits the available work force and may drive businesses away from coastal towns. As a result, there can be reduced investment in these communities, possible redundancies and fear of job loss, which suggests economic decline in coastal areas to be a secondary stressor of poor mental or physical health. There are complex linkages between environmental and social vulnerability that also change over time. Coastal areas can have difficulty in securing investment for much needed housing developments, due to the disadvantages these areas face from being at risk from coastal flooding. Conversely, investment may be targeted at these areas due to government policy (22).

2. The health and social costs of flooding

Flooding is a threat to life as well as to health and wellbeing, the economy and the environment. The CCRA3 describes the main risks to people, communities and buildings from flooding (8). These risks include:

- death or injury from flood events
- long-term and severe impacts on mental health from flooding, displacement, and being affected by flooding, solastalgia
- damage to property:
 - structural damage and the costs of rebuilding or repair
 - upheaval and financial implications of cleaning up
- distress and financial implications of displacement from home (temporary or permanent)
- loss of and damage to possessions and burden on household costs
- disrupted access to employment, education, and wider facilities
- disrupted access to health and social care services
- illness from biological and/or chemical contaminants arising from floods
- illness from infections or other disorders arising from floods
- risk of carbon monoxide (CO) poisoning in the clean-up phase due to inappropriate use of generators
- damage to agriculture or livestock, leading to loss of food supplies (see Chapter 9)

The social costs of flooding include the direct impacts on health (including treatment costs), and the indirect health impacts (such as days of work lost), as well as damage to property and possessions. The 'Sendai Framework for Disaster Risk Reduction' supports the estimation of disaster impacts that extend beyond property damage.

2.1 Flooding impacts on mortality

Deaths may occur from drowning and physical injury through contact with flood waters. Mortality attributable to flooding can also include car accidents and falling into fast flowing water, hypothermia, and injuries or death associated with cleaning up after a flood (including CO poisoning). The total annual impact is uncertain as data on UK deaths resulting from flooding are not routinely reported in health or vital registration data systems, but are included within post-flood event reporting. In England, flooding during June and July 2007 was linked to the deaths of 13 people (23), but it has been estimated that flood events since have resulted in fewer than 5 deaths per incident (8).

One of the biggest flood disasters in the UK in the last century was the 1953 North Sea coastal flood, when more than 300 people died (24, 25). Higher storm surges have occurred since this event, but improved coastal defences and warnings have prevented major flooding and loss of

life. The risk of coastal flooding is high and significant evacuations can occur when a storm is forecast, for example in Lowestoft in December 2013. More than 5,000 households were evacuated in Suffolk in the winter of 2017 in anticipation of a storm surge that coincided with a high tide. The Environment Agency said things were not as bad as predicted because the "combination of the peak surge, strongest winds and largest waves didn't coincide in all areas and did not reach the most dangerous levels that were possible all along the East coast" (26).

High-mortality flood events have a low likelihood but are considered within UK and local emergency planning. A plausible high-impact event would be a high storm surge associated with significant failure of coastal defences. For example, the failure of the Thames Barrier would potentially lead to many deaths in London if combined with failures in the warning or evacuation response. The National Risk Register does not publish its scenarios for flood disasters. Flood risk emergency management would also consider, however, cascading impacts of such an event, including loss of power, dam failure, or a transport disaster.

Recent high-mortality flood events have occurred in Germany (180 died in July 2021 during Storm Bernd) and France (Storm Xynthia caused 47 deaths in February 2010). Storm Bernd was caused by a slow moving storm that overwhelmed the river system, with up to 150mm of rain within 48 hours, and the high mortality was associated with inadequate warnings to the population, a lack of information to households about flood risk, as well as failures in critical infrastructure (27). Data from an online survey (n = 1,315) shows a significant proportion of respondents (35% in North-Rhine Westphalia and 29% in Rhineland-Palatinate) did not receive any warning; of those who were warned, 85% did not expect a very severe flooding and 46% did not know what to do (28). The impact of the coastal flooding in France (Storm Xynthia) included 47 deaths from drowning, hypothermia, and trauma (falling trees or masonry), and 79 people injured, including 7 seriously. In some houses, the water level rose to 2.5 metres within 30 minutes (29). The high mortality was also associated with inadequate warnings and emergency response plans, and the failure of a coastal dune that led to the flooding of the town La Faute-sur-Mer. Other dykes were overtopped but did not fail.

There is no evidence that all-cause mortality rates are likely to increase in a population following a flood event. Although a study on the 1968 flood in Bristol found an increase in mortality (30), subsequent studies have not confirmed this type of health impact from flooding. A study looking at the 319 flood events from 1994 to 2005 in England and Wales, using a controlled interrupted time-series design, observed an apparent (10%) reduction in mortality in flooded areas in the year after flooding (31). One possible explanation is that there is a possible bias in the ascertainment of mortality from the nationwide administrative death registry data which records usual residence at the time of death. If a person who experienced flooding was displaced to a non-flooded area following a flood event, and a subsequent death occurred at the new residence after several months, the death would be classified as occurring in a non-flooded area, even though the person has been exposed to flooding. Misclassification of exposure could happen due to the nature of the study design looking at long-term health impacts using residential information at date of death as opposed to when the flood exposure occurred. Displacement following flooding can be significant and persistent, however, the effects of

population displacement are unlikely to fully explain the reduction in deaths following flooding. The response to flooding and the population's resilience to its adverse impacts might have changed appreciably over time; for example, community resilience may have increased post-flood that led to a reduction in general mortality. However, the question of unobserved long-term impacts on mortality, and other outcomes, remains unresolved and deserves further study (32).

In England, CO poisoning remains a significant cause of death following flooding. The risk of CO poisoning can occur during flooding and in the recovery phase afterwards (Table 3) and is often associated with inappropriate indoor use of portable generators. A literature review found that any room in a building can harbour a CO-emitting appliance in flooding. Wood burners and rarely used chimney flues may become problematic following a flood (33).

Table 3. Risk of carbon monoxide poisoning associated with flooding (33)

Phase of flooding	Source of carbon monoxide
Pre-disaster and impact	<ul style="list-style-type: none"> • use of portable generators as power supply • cooking • heating and warmth • lighting
Emergency and recovery phase	<ul style="list-style-type: none"> • pumping and cleaning activities • dehumidifying and drying activities
Post-recovery and delayed phase	<ul style="list-style-type: none"> • use of flood damaged boilers and furnace

2.2 Flooding impacts on mental health

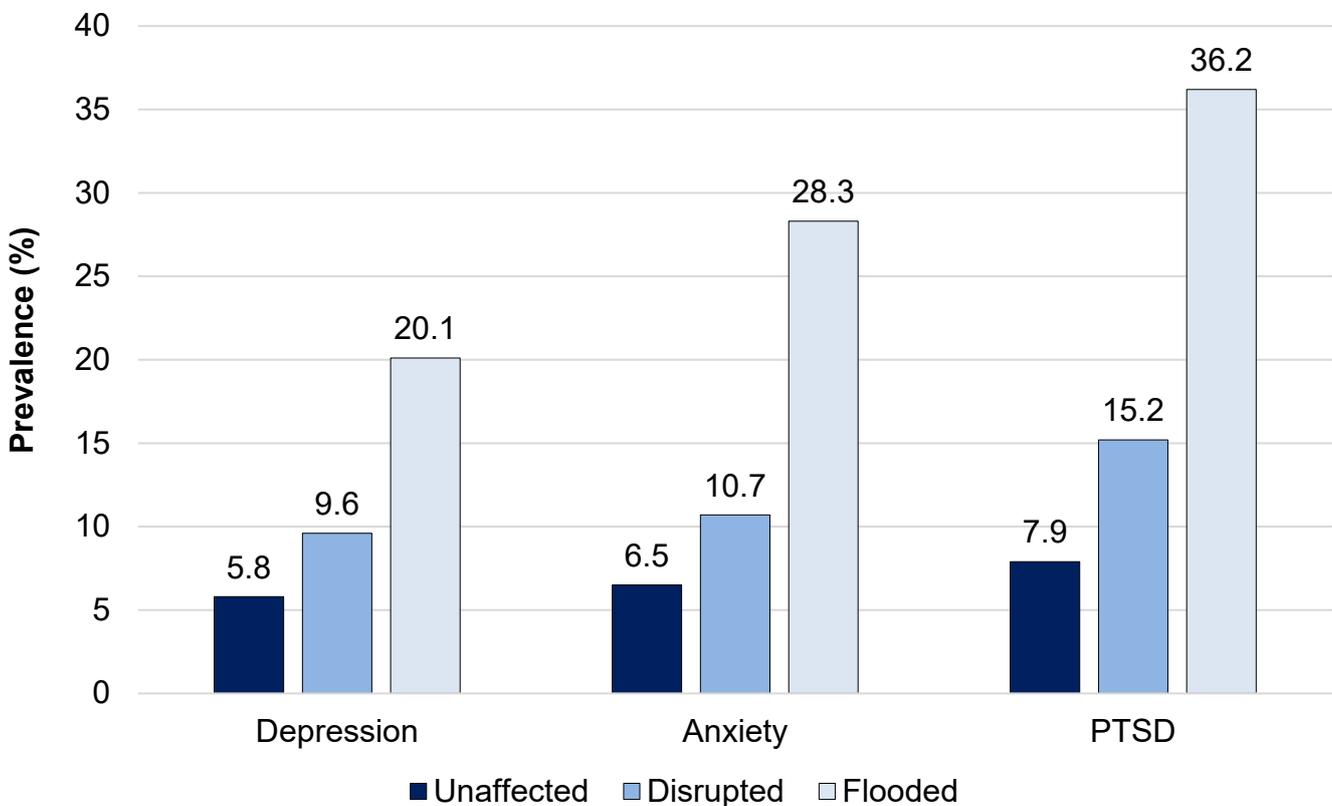
In the UK, the greatest burden of ill health from flooding is likely to be due to the long-term mental health impacts. There are still relatively few studies on the mental health impacts of flooding in the UK. Systematic reviews confirm strong evidence that exposure to flooding increases the risk of post-traumatic stress disorder (PTSD), anxiety and depression (34, 35). There is also evidence that children's mental health is severely affected by flooding and the subsequent loss of familiar surroundings and friends, as well as witnessing the stress and strain affecting adults (36).

The storms of winter 2013 to 2014 brought the wettest winter to England in 250 years. Following the storms, Public Health England (PHE) established the English National Study of Flooding and Health, working with academic partners to understand more about mental health impacts following a flood. The Study found that mental health impacts are significant in magnitude, persist for several years, and there are key factors that increase the risk of adverse mental health outcomes (37). There are some limitations to this study due to recall bias and other biases, and further studies are needed.

The main findings of the National Study on Flooding and Health include:

- the prevalence of probable depression amongst those whose homes were flooded was 20.1%, with 28.3% anxiety and 36.2% PTSD, compared to 5.8% depression, 6.5% anxiety, and 7.9% PTSD in those unaffected (Figure 4) (38)
- 3 years after flooding, the prevalence of negative mental health outcomes in affected persons is reduced but still significant (39)
- evacuation and displacement, particularly without warning, increases the risk of anxiety and post-traumatic stress disorder (40)
- many people experience persistent flood-related damage to their homes, and this is associated with worse mental health outcomes (39)

Figure 4. Prevalence of psychological morbidity one year after flooding (38)



There is no evidence that flooding increases the risk of suicide or self-harm in the UK, as currently there are no specific UK-focused studies. A systematic review by Fernandez and others found only inconsistent evidence that flood events are associated with an increased risk of suicide (34). There is also inconsistent evidence on whether flood events may increase the use of tobacco, alcohol, or substance abuse in individuals who have been flooded (34).

A study of GP prescription medicine indicated an increase in the use of anti-depressant medication in GPs in flooded areas in the year after the flood (2011 to 2014) compared to the GPs in non-flooded areas nearby, with the increase greater in more deprived areas (41). An analysis of data from the 'UK Adult Psychiatric Morbidity Survey' found that (self-reported) exposure to flooding was associated with having a common mental disorder (42). A cross-

sectional study of serious mental health outcomes found no association with flood risk (43). The lack of flood exposure data is a limitation on conducting population-wide epidemiological studies using routine data.

Qualitative research has shown that institutional support plays an important role in how individuals experience their post-flood mental health (44). However, support during the recovery period does vary over time and there is often a 'recovery' gap when institution and other support have disappeared in the aftermath of the flood but when mental health and other needs are still apparent (45).

Many factors are known to increase the risk of adverse mental health impacts associated with flooding. Secondary stressors that increase mental health impacts of flooding (46, 47) include:

- loss of sentimental items
- loss of domestic utilities such as electricity, water, gas
- concerns about health and the health of others
- financial concerns, including concerns about house repairs and value
- difficulties with home repairs
- health-related stressors, such as lack of access to healthcare, new or continuing health concerns or conditions, and lack of access to prescription medications can place people at greater risk of psychological effects of flooding – this could be particularly acute for those with learning disabilities, autism or dementia due to a change in routine and surroundings
- family and relationship stressors, such as interruption of normal routines, separation from friends and family, and difficulties with neighbours
- stress relating to education and schooling, such as loss of educational facilities and loss of socialisation associated with attending school
- feelings of loss of control and fear of recurrence of another extreme event, and heightened anxiety, especially those with existing anxiety or past trauma
- economic stressors such as problems with insurance claims and compensation, recovery of and rebuilding of homes, loss of employment and or income, and loss of physical possessions and resources
- stress arising from exposure to media reporting
- being evacuated or displaced

2.3 Flooding and other health risks

Following flooding events in other countries, outbreaks of infectious diseases have been observed. However, there is little evidence of such outbreaks being associated with recent flood events in the UK. A systematic review on flooding and infectious disease in Europe found that flooding has been associated with outbreaks of leptospirosis, and West Nile virus as well as diarrhoeal diseases (48). Large-scale disasters are more likely to incur infectious disease outbreaks due to loss of access to water and sanitation services. For example, there were

several cases of diarrhoeal disease, and an increase in hospital admissions after Hurricane Katrina in the USA (see (49)). Although flood water is often contaminated with sewage (human and animal waste), the contaminants are usually diluted. Surveys of those who have experienced flooding in the UK indicate that individuals report an increase in diarrhoeal and skin diseases (50). However, enhanced surveillance after flood events has not detected any outbreaks of diarrhoeal disease, or other types of infectious disease.

Flooding mobilises chemicals in the environment and may lead to increased contact between persons and industrial or agricultural chemicals (such as pesticides) (see Chapter 12). Flooding and heavy rainfall may also negatively affect indoor environmental quality (see Chapter 5), including increased exposure of households to mould (51). Changes in the absolute moisture content of the outdoor air may mean that increased ventilation may be required to remove moisture from the indoor environment. Heavy rainfall events increase the risk of rainwater ingress into buildings (52). Wind-driven rain is associated with winter storms and the intensity of rainfall in storm events is projected to increase, although the effect of climate change on storm frequency and storm tracks is uncertain. An increase in damp homes will depend on the level of ventilation in dwellings, and this may be affected by large scale installation of energy efficiency measures (see Chapters 5 and 14).

2.4 Flooding and health inequalities

Flooding does not impact populations equally. Floods are often very localised and so can have large effects on specific neighbourhoods. The mapping of flood risk by Sayers and others indicates some inequalities in flood risk (53). The authors use the concept of 'flood disadvantage' which is a combination of geographic disadvantage, for example, living in an area at flood risk, and systemic flood disadvantage – the degree to which socially vulnerable communities are disproportionately affected by flooding (53). Ten local authorities account for 50% of the socially-vulnerable people living in flood risk areas: Hull, Boston, Belfast, Birmingham, East Lindsey, Glasgow, Leicester, north-east Lincolnshire, Swale District and Tower Hamlets. Coastal towns, declining urban cities and dispersed rural communities represent the greater concentrations of flood disadvantaged communities, whilst rural communities are more likely to lose access to services due to transport disruption from flooding.

There is more evidence regarding the differential impacts of specific flood events. For example, there are reported differences in loss of access to services, including health and social care, loss of school and workdays, travel disruption and displacement (54). There is some evidence that black, African and Caribbean ethnic groups experienced risk that is greater than the population average (55). There is little epidemiological information that quantifies the different impact of flooding on health in different population groups.

2.5 Projecting future flood health impacts

There are few quantitative estimates of the future adverse health impacts of climate change due to flooding. The burden of flooding has been estimated as 18 deaths per year and 360 injuries per year in England ([1](#), [56](#)). This was projected to increase by the 2050s to annual additional impacts of:

- 6 to 34 deaths, 120 to 680 injuries with baseline population
- 8 to 49 deaths, 160 to 980, assuming population growth ([1](#), [56](#))

The estimated deaths and injuries are based on data from the UKCP09 projections, where low, medium and high emissions scenarios were used. It should be noted that the estimates are highly uncertain in term of the health burden, which will vary by the type of flood event. The most robust estimates of future flood risk (populations at risk of flooding) are the estimates described earlier in section 1.2 from the CCRA3 ([9](#)). The EA also publishes its own scenarios of climate change impacts to inform flood risk management (LTIS – the long-term investment scenarios (see [57](#))). The most recent scenarios include a plausible extreme climate change scenario (referred to as ‘high++’) and are broadly consistent with the UKCP18 projections.

Global future flood mortality models have been developed and used to estimate increases in deaths due to flooding in relation to different emission scenarios (such as river flooding estimates ([58](#))) or to quantify the benefits of adaptation ([59](#)). In these types of models, mortality is related to the depth of flood (inundation models) and mortality estimates are derived from disaster databases such as the global EM-DAT international disaster database ([60](#)). Mortality associated with coastal flooding is even more difficult to model as an annualised estimate as mortality is heavily concentrated in a few very significant disaster events ([61](#)).

An ‘event-based’ approach focuses on a single flood event and uses more detailed data to describe flood characteristics (such as depth, velocity), area-specific conditions such as buildings, evacuation routes), and the exposed population (such as age distribution). There have been few studies that have modelled mortality associated with floods in the UK.

3. Flood response measures and current gaps in adaptation

There are 5 main strategies for addressing flood risks to households and communities (8). This chapter will not discuss these in detail except for the measures specifically related to health protection:

- planning policy and guidance to minimise new dwellings and assets in flood risk areas
- flood risk management policy, investment and interventions, including:
 - structural measures
 - natural flood management (NFM) and sustainable drainage systems (SuDS)
 - property flood resilience (PFR)
- flood insurance provision
- emergency preparedness, resilience and response (EPRR)
- health protection measures

3.1 Flood defences

The CCRA3 (2022) acknowledges that there has been considerable investment in flood prevention, and advances in strategic management of flood risk at UK and local levels from the 'Second Climate Change Risk Assessment (CCRA2)' in 2017 (see also (62)). In addition to the increased investment, there has been a policy shift from protection to risk management approaches in the UK. The current policy focus is to increase resilience in communities to flooding, particularly in England (63). Resilience includes planning, protection, response and recovery. Collectively these elements all come together to improve community resilience. For example PFR enables householders to take responsibility for retrofitting and upgrading their dwellings. The full implications of a resilience framing are still being explored (64, 65).

Conventional flood defences (requiring both capital and revenue investment) remain the most common management approach. Flood forecasting and warning provide an essential component of managing flood risk. Warnings in England are managed by the EA who support this work through research and extensive engagement to ensure flood messages are understood. Effective spatial planning remains the only measure that can avoid flood exposure due to built infrastructure development. The residual risk of flooding is then managed by insurance provision (9).

As the CCRA3 chapter on Health, Communities and the Built Environment noted, there has been significant progress in building flood defences in the UK (8). However, the CCC has noted that more investment is required to address the additional risks from climate change. The CCC also identifies planning issues (building in flood plains) and the poor uptake of PFR as factors that will increase future flood risks.

NFM can be effective in reducing flood risk. The evidence for the effectiveness of different natural processes, including river and wetland restoration, is complex and has been summarised in a review commissioned by the Environment Agency (66). The health benefits of greenspace and blue space are now considered by public health as an important co-benefit to health and the environment of strategies to address climate change. The increased use of greenspace and access to the sea promotes increased physical activity, exposure to sunlight that helps the body produce vitamin D, and use of blue and greenspaces has been associated with improved mental health outcomes (67). However, the potential disbenefits from some measures (such as wetland restoration may increase vector habitats) also need to be considered (see Chapter 8).

The 'National Flood and Coastal Erosion Risk Management (FCERM) Strategy' (2020) published by the EA, sits alongside the Policy Statement and has a vision of "a nation ready for, and resilient to, flooding and coastal change – today, tomorrow and to the year 2100" (68). The strategy reflects government policy that has shifted from flood risk management to flood resilience. The Strategy refers to 4 pillars of resilience that all risk management authorities can implement with partners. They are:

- improved place making
- better protection
- ready to respond
- recover quickly

3.2 Managed retreat of communities

Relocation of communities or households may result from changes in flood defences or management thus support systems are no longer enforced and can lead to increased isolation and segregation of coastal communities. Considerable work has been conducted to enhance both an understanding of coastal risk and policy and strategy development, particularly at the UK level (see (8)).

There are several locations that have been identified as at risk from sea-level rise before the end of this century. It is important to note that sea levels will continue to rise beyond the end of the century and long-term planning decisions near the coast need to take climate change into account (69).

Fairbourne in Wales is considered the first community in the UK that needs to plan a managed retreat or relocation due to sea-level rise (70). Relocation can be a sensitive topic and difficult to manage at the local level. There are also negative risks to communities who wish to plan for relocation (such as economic blight). It is only recently that communities have begun to manage this risk in a long-term strategic approach (8).

3.3 Fairness in flood and coastal response measures

There are several response measures that may increase inequalities in flood risk because they are not equally accessible or taken up (71). The evidence regarding flood risk and flood defences is complex (see section 3.1). Insurance is known to be particularly differential because low-income households are less likely to have flood insurance (72, 73). This situation will be made worse by the end of Flood Re (in 2039), which is the government scheme to increase access to flood insurance. Since its introduction, Flood Re has reported that 96% of households that had previously flooded could access flood insurance quotes from 5 or more insurers whereas before the scheme, only 9% could get quotes from 2 or more insurers. In addition, 4 out of 5 households were reported to have seen more than a 50% reduction in their insurance premium (74). Those less likely to have flood insurance include those living in rented properties (72).

3.4 Emergency preparedness, resilience and response (EPRR)

Emergency preparedness is a core part of the flood response. Under the Civil Contingencies Act 2004, UKHSA is responsible to the Secretary of State for Health as a Category 1 Responder in the event of a national emergency. In Scotland, Category 1 responders include Territorial Health Boards and Scottish Ambulance Service. In flood response, UKHSA has a supporting role to the Department for Environment, Food and Rural Affairs (Defra) and the Department for Levelling Up, Housing and Communities (DLUHC) and provides technical and specialist advice to all partners at UK and local levels, raises public awareness about the risks, monitors the impact on health and aims to maintain business continuity. There has not been much evaluation of the effectiveness of the emergency response measures for flooding, and also whether climate change is being sufficiently considered in such measures.

The literature suggests that there are 7 broad areas for improving emergency planning in the context of climate change (75):

1. Risk assessments need to consider a broader range of events and changing likelihoods (for example, new climate hazards include wildfires, heavy rainfall events or flash flooding).
2. A long-term perspective is necessary.
3. Response capabilities may need to be enhanced, which requires investment.
4. Some types of events will become less frequent but will not be eliminated.
5. Training and exercises need to consider novel events.
6. Public engagement and messaging needs to be revised to reflect increased severity of events.
7. Improving community resilience is necessary to reduce the need for emergency response.

The 'Multi-Agency Flood Plan Review' found that existing emergency planning processes and arrangements are effective in responding to small- and medium-sized flood events but the response to major events affecting multiple local authorities and thousands of people, needed improvement (76). Studies have shown that persons may not be aware of risks of flooding, and of their own flood risk and may be unprepared. Individuals with chronic illness need to be prepared for loss of access to energy, medicines, water and other services. In addition, there have been difficulties for first responders to operationalise the local registers of vulnerable people, which are often out-of-date and with no clear agreement about which 'vulnerabilities' should be prioritised (77). In addition, the term 'vulnerable' to describe individuals at disadvantage from flooding and other extreme events does not necessarily support appropriate changes in behaviour and may be actively rejected (Ellis-Logan and others, in preparation).

3.5 Community resilience

Community resilience involves working with local people and businesses to assess, plan for emergencies and act to manage flooding. In England and Wales, Local Resilience Forums (LRFs) develop emergency plans and provide information on what to do before, during and after a flood at the local level, which should support recovery from flood events. The Local Health Resilience Partnerships (LHRPs) are established to deliver national EPRR strategies in the context of local risks. The LHRPs aim to bring together the health sector organisations involved in EPRR at the LRF level and ensure both local coordination and a UK level consistent approach to support effective planning of health emergency response.

There has been little research to assess the effectiveness of the work of LRFs in emergency responses when floods occur. However, analysis of emergency responder (ambulance and fire services) times under various flooding scenarios identifies how even low magnitude floods can lead to a reduction in mandatory response times, which is particularly marked in large cities (78).

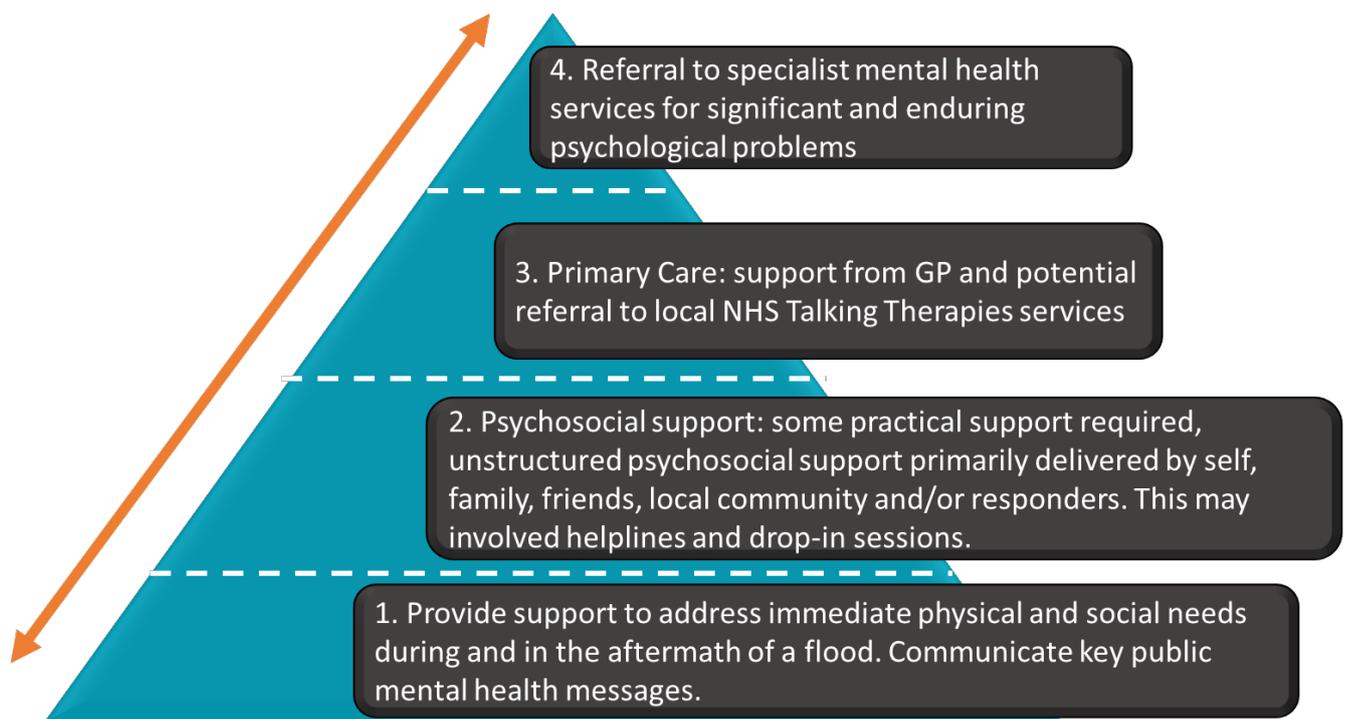
In the context of climate change, community resilience should be considered as more than a 'bounce-back' to the previous state of the community, but should consider long-term adaptation to climate change. A report for the Joseph Rowntree Foundation recommends that intersectoral policy on community resilience is needed, with a cross-government approach that moves beyond emergency planning, is proactive, and clarifies stakeholders' roles, particularly local authorities (65).

There have been strategies to support community resilience as this is associated with better flood outcomes (79). Flooding has been shown to have positive and negative impacts on community cohesion (80). An evaluation of local projects supported by the EA Pathfinder initiative found that community engagement was a key part of increasing local resilience (65, 81). Further, interventions led by community priorities are likely to lead to more effective flood resilience in the long-term.

3.6 Public health measures

In 2023, UKHSA launched an updated weather plan (the Adverse Weather and Health Plan (AWHP)) (82). The Plan outlines the important areas where the public sector, independent sector, voluntary sector, health and social care organisations and local communities can work together to maintain and improve integrated arrangements for planning and response to deliver the best outcomes possible during flood events, and other adverse weather events. The AWHP includes health protection advice to manage flood impacts once a flood has occurred and to inform health professionals' response to flood warnings (which are issued by the EA). UKHSA has also published guidance for specifically addressing the mental health impacts of flooding (47). The guidance includes measures that should be implemented locally to prevent major psychosocial effects on health through raising awareness and allow people to prepare and respond appropriately (47). Figure 5 illustrates the 4-tiered approach to response measures.

Figure 5. Four-tier approach to flood response (47)



Text version of Figure 5.

There are 4 tiers. From the bottom up, they read:

Tier 1. Provide support to address immediate physical and social needs during and in the aftermath of a flood. Communicate key public mental health messages.

Tier 2. Psychosocial support: some practical support required, unstructured psychological support primarily delivered by self, family, friends, local community and or responders. This may involve helplines and drop-in sessions.

Tier 3. Primary care: support from GP and potential referral to local increasing access to psychological therapies (IATP) services (now called NHS Talking Therapies).

Tier 4. Referral to specialist mental health services for significant and enduring psychological problems.

End of text version of Figure 5.

UKHSA is also undertaking measures to prevent deaths from poisoning associated with flood events. A review on risks from CO at different stages of a disaster recommended that CO poisoning form part of syndromic and event-based surveillance systems for flooding and should be included in measures of the health impact of flooding ([33](#)). Domestic CO monitors should be sited not only in proximity to known CO emitters, but also where mobile or short-term CO emitting appliances may be placed, including wood burners and infrequently used fireplaces.

Additionally, public health workers and policy-makers could consider establishing toolkits using the Centres for Disease Control and Prevention (CDC) toolkit approach, and acceptability of interventions could be evaluated further to inform policy.

4. Conclusions

Flooding presents a risk to health and wellbeing in the UK. The UK government's National Risk Register 2020 identifies coastal and river flooding as the 2 highest impact risks facing the UK after pandemics and large scale Chemical, Biological, Radiological and Nuclear (CBRN) attacks. Climate change will increase flooding in the UK. Flood risk was identified as a priority risk in the 'Technical Report' for the UK's 'Third Climate Change Risk Assessment (CCRA3)' (8). The government outlined its response to address flood and coastal erosion risks in the 'UK Climate Change Risk Assessment 2022' (83), which draws heavily on the '2020 Flood and Coastal Erosion Management (FCERM) Strategy' (68).

Climate change is likely to adversely affect population health through increases in flood risks for all types of flooding (river, surface water, and coastal). The increased risk is reflected throughout the UK, but some locations and some people are particularly vulnerable to the adverse health impacts of flooding. The different types of flooding have different causes, present different risks to health and may also be managed with different response measures (Table 4).

Climate change in the UK will entail the relocation of populations and assets due to sea-level rise, although these adverse impacts may not be of great magnitude compared to other countries, they are locally important. The CCRA3 identifies the future viability of some coastal communities as a key risk in the face of climate change. Some evidence is already available of the vulnerability of specific communities in the south and east coasts of England and the west coast of Wales, but there remains no long-term assessment of viability across the UK (8). Sea-level rise and coastal change will have significant effects on health in the UK. However, managing risks in coastal communities is a complex task due to changing UK level and local policies, complex administrative arrangements and jurisdictions, the need for effective and inclusive community involvement, and the availability of funding at local and national level (84).

Since the publication of the 2012 HECC report, UKHSA has launched an updated weather plan ('Adverse Weather and Health Plan', AWHP) (82). This was a recommendation of the 2012 report (1), and also an objective of the second National Adaptation Programme. The AWHP includes health protection advice to manage flood impacts once as flood has occurred and how health professionals should response to flood warnings (which are issued by the EA).

Table 4. Summary of impacts by type of flooding

	River flooding	Coastal flooding	Surface water flooding
UKCP18 projections	Not included	Sea-level rise for UK	Not included
Current population at risk of flooding (1 in 75 year risk) (UK)	578,000	126,000	1,185,000
Other climate drivers	Heavy rainfall, storm processes	Storm frequency, sea-level rise, coastal erosion	Atmospheric rivers, thunderstorms
Damage: property damage to buildings	High	High	High
Damage: health implications	High risk of death	Highest risk of mass mortality	Low risk of death
Non-climate causes	Building in flood zones, poor planning decisions	Coastal flood defences not well maintained	Sewers are poorly maintained, loss of greenspace
Adaptation measures (hard infrastructure)	River defences, natural flood management.	Coastal flood defences, managed retreat, natural flood management	SUDS – sustainable urban drainage systems
Health protection: covered by AWHP	Yes	Yes	Yes

4.1. Research priorities

The following priorities build on the assessment in this review as well as suggestions from published studies (1, 8, 32, 85), which include the need to:

- improve understanding of causes and types of flood-related adverse health effects with improved understanding of the longer-term health effects of flooding, particularly on mortality risk, mental health care for flooded populations, and for vulnerable groups
- more epidemiological studies are needed with novel methods for the linkage of health data to flood exposures
- research is required on implications for persons with chronic diseases affected by the disruption to health services and infrastructure following a flood
- research is required on the causes and outcomes of population displacement via evacuation and relocation, including long-term follow up of flooded households
- standardised systematic methodology (such as the use of routine clinical health records) needs to be developed to understand mental health impacts associated with flooding
- improve understanding of the mental health and physical health impacts of the potential loss of communities as a result of coastal change
- improve understanding of vulnerable or at-risk individuals and sub-groups and their health needs
- the impacts of flooding on mental and physical health of children and effective response measures
- wider benefits, including health benefits and risks, of natural flood risk management measures
- evaluation of the effectiveness of related health policy and practice interventions as at present, there is a paucity of evidence, which hinders comparative learning
- impact of storm runoff and floods on water treatment efficiency, mobilisation and transport of pathogens, and potential to negatively affect quality of water supply and sanitation infrastructure

4.2 Implications for public health

The chapter has highlighted several implications for public health, including the need to:

- ensure that flood emergency plans are coordinated with relevant local partners and public health agencies are involved in flood recovery
- ensure local flood planning has robust measures to identify individuals at risk, with consideration of the various types of barriers to warnings and evacuation, and the range of health and social needs. Improve planning to identify at risk individuals for flood events

- improve the targeted advice for high-risk persons on how they should prepare for flooding
- invest in information systems to support health surveillance of flood impacts on mortality, injuries and mental health, both in real time or to allow for research and evaluation retrospectively, including:
 - improved CO poisoning surveillance
 - record health status at baseline, during and after floods on various health outcomes, including deaths and injuries
 - development of clear definitions for deaths from flooding, including immediate and delayed causes
 - development of clear definitions for the attribution of injuries to flooding, including complete information on the causes and types
 - a comprehensive information system needs to record factors that are known to effect health, including population displacement (timing, duration and places) and support for flood recovery
- realise co-benefits of flood risk management; for example, nature-based solutions such as implementing green infrastructure also has potential positive benefits for physical and mental health
- promote measures to ensure the continuity of the NHS services and health care facilities including residential care homes during floods

Acronyms and abbreviations

Abbreviation	Meaning
AWHP	Adverse Weather and Health Plan
CCC	Climate Change Committee
CCRA	Climate Change Risk Assessment
CO	carbon monoxide
EA	Environment Agency
EAD	expected annual damage
EPRR	emergency preparedness, resilience and response
LHRPs	local health resilience partnerships
LRFs	local resilience forums
NFM	natural flood management
PFR	property flood resilience
PTSD	post-traumatic stress disorder
RWS	reduced whole system

References

1. Health Protection Agency (HPA) (2012). '[Health Effects of Climate Change in the UK 2012](#)' Vardoulakis S, Heaviside C, editors
2. Wadey MP, Haigh ID, Nicholls RJ, Brown JM, Horsburgh K, Carroll B, and others (2015). '[A comparison of the 31 January to 1 February 1953 and 5 to 6 December 2013 coastal flood events around the UK](#)' *Frontiers in Marine Science*: volume 2, page 84
3. Climate Change Committee (CCC) (2023). '[Progress in adapting to climate change - 2023 Report to Parliament](#)'
4. Christidis N, McCarthy M, Cotterill D, Stott PA (2021). '[Record-breaking daily rainfall in the UK and the role of anthropogenic forcings](#)' *Atmospheric Science Letters*: volume 22, page e1033
5. Kay AL, Booth N, Lamb R, Raven E, Schaller N, Sparrow S (2018). '[Flood event attribution and damage estimation using national-scale grid-based modelling: winter 2013 to 2014 in Great Britain](#)' *International Journal of Climatology*: volume 38, pages 5205 to 5219
6. Greater London Authority (GLA) (2022). '[Surface water flooding in London: roundtable progress report](#)'
7. PHE (2017). '[Public Health England and the Sendai Framework for Disaster Risk Reduction 2015 to 2030](#)'
8. Kovats S, Brisley R (2021). '[Health, communities and the built environment](#)' In: Betts RA, Haward AB, Pearson KV, editors. *The Third Climate Change Risk Assessment Technical Report*
9. Sayers PB, Horritt M, Carr S, Kay A, Mauz J, Lamb R, and others (2020). '[Third UK Climate Change Risk Assessment \(CCRA3\): future flood risk](#)'
10. CCC (2021). '[Independent assessment of UK climate risk: advice to government for the UK's third climate change risk assessment \(CCRA3\)](#)'
11. Palmer M, Harris GR, Gregory JM (2018). '[Extending CMIP5 projections of global mean temperature change and sea level rise due to thermal expansion using a physically-based emulator](#)' *Environmental Research Letters*: volume 13, page 084003
12. Palmer M, Howard T, Tinker J, Lowe JA, Bricheno L, Calvert D, and others (2018). '[UKCP18 Marine report](#)'
14. Flood and Coastal Erosion Risk Management Research and Development Programme (FCERM), Environment Agency (EA) (2021). '[Impact of climate change on asset deterioration](#)'
15. Sayers P, Moss C, Carr S, Payo A (2022). '[Responding to climate change around England's coast - the scale of the transformational challenge](#)' *Ocean and Coastal Management*: volume 225, page 106187
16. Hendry A, Haigh ID, Nicholls RJ, Winter H, Neal R, Wahl T, and others (2019). '[Assessing the characteristics and drivers of compound flooding events around the UK coast](#)' *Hydrology and Earth System Sciences*: volume 23, pages 3117 to 3139
17. Depledge M, Lovell R, Wheeler B, Morrissey K, White M, Fleming L (2017). '[Future of the](#)

- [sea: health and wellbeing of coastal communities'](#)
18. Oven KJ, Curtis SE, Reaney S, Riva M, Stewart MG, Ohlemüller R, and others (2012). ['Climate change and health and social care: defining future hazard, vulnerability and risk for infrastructure systems supporting older people's health care in England'](#) Applied Geography: volume 33, pages 16 to 24
 19. Office for National Statistics (ONS) (2020). ['Living longer: trends in subnational ageing across the UK'](#)
 20. Department of Health and Social Care (DHSC) (2021). ['Chief Medical Officer's annual report 2021: health in coastal communities'](#)
 21. House of Lords (2019). ['The future of seaside towns'](#)
 22. Swinney P, Enenkel K (2020). ['Why big cities are crucial to "levelling up"'](#)
 23. Pitt M (2007). ['Learning lessons from the 2007 floods: an independent review by Sir Michael Pitt, interim report'](#)
 24. Baxter PJ (2005). ['The east coast Big Flood, 31 January to 1 February 1953: a summary of the human disaster'](#) Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences: volume 363, pages 1293 to 1312
 25. Wadey MP, Brown JM, Haigh ID, Dolphin T, Wisse P (2015). ['Assessment and comparison of extreme sea levels and waves during the 2013 to 2014 storm season in 2 UK coastal regions'](#) Natural Hazards and Earth System Sciences: volume 15, pages 2209 to 2225
 26. BBC News (2017). ['Storm surge: severe flooding avoided in Essex, Suffolk and Norfolk'](#)
 27. Fekete A, Sandholz S (2021). ['Here comes the flood, but not failure? Lessons to learn after the heavy rain and pluvial floods in Germany 2021'](#) Water: volume 13, page 3016
 28. Thieken AH, Bubeck P, Heidenreich A, von Keyserlingk J, Dillenardt L, Otto A (2022). ['Performance of the flood warning system in Germany in July 2021: insights from affected residents'](#) Natural Hazards and Earth System Sciences: volume 23, pages 973 to 990
 29. Kolen B, Slomp R, Van Balen W, Terpstra T, Bottema M, Nieuwenhuis S (2010). ['Learning from French experiences with storm Xynthia: damages after a flood'](#)
 30. Bennet G (1970). ['Bristol floods 1968: controlled survey of effects on health of local community disaster'](#) British Medical Journal: volume 3, pages 454 to 458
 31. Milojevic A, Armstrong B, Kovats S, Butler B, Hayes E, Leonardi G, and others (2011). ['Long-term effects of flooding on mortality in England and Wales, 1994 to 2005: controlled interrupted time-series analysis'](#) Environmental Health: volume 10, page 11
 32. Milojevic A (2015). ['Health climate change impacts report card technical paper 8. Flooding and health'](#) In: Kovats RS, editor. LWEC health climate change impacts report card: living with environmental change
 33. Waite T, Murray V, Baker D (2014). ['Carbon monoxide poisoning and flooding: changes in risk before, during and after flooding require appropriate public health interventions'](#) PLoS Currents: volume 6, page ecurrents.dis.2b2eb9e15f9b982784938803584487f1
 34. Fernandez A, Black J, Jones M, Wilson L, Salvador-Carulla L, Astell-Burt T, and others (2015). ['Flooding and mental health: a systematic mapping review'](#) PLOS One: volume 10, page e0119929
 35. Cruz J, White PCL, Bell A, Coventry PA (2020). ['Effect of extreme weather events on](#)

- [mental health: a narrative synthesis and meta-analysis for the UK](#) International Journal of Environmental Research and Public Health: volume 17, page 8581
36. Mort M, Walker M, Lloyd Williams A, Bingley A, Howells V (2016). '[Children, young people and flooding: recovery and resilience](#)'
 37. PHE (2020). '[The English National Study of Flooding and Health: summary of the evidence generated to date](#)'
 38. Waite TD, Chaintarli K, Beck CR, Bone A, Amlôt R, Kovats S, and others (2017). '[The English National Cohort Study of Flooding and Health: cross-sectional analysis of mental health outcomes at year one](#)' BMC Public Health: volume 17, page 129
 39. Mulchandani R, Armstrong B, Beck CR, Waite TD, Amlôt R, Kovats S, and others (2020). '[The English National Cohort Study of Flooding and Health: psychological morbidity at 3 years of follow up](#)' BMC Public Health: volume 20, page 321
 40. Munro A, Kovats RS, Rubin GJ, Waite TD, Bone A, Armstrong B (2017). '[Effect of evacuation and displacement on the association between flooding and mental health outcomes: a cross-sectional analysis of UK survey data](#)' Lancet Planet Health: volume 1, pages e134 to e141
 41. Milojevic A, Armstrong B, Wilkinson P (2017). '[Mental health impacts of flooding: a controlled interrupted time series analysis of prescribing data in England](#)' Journal of Epidemiology and Community Health: volume 71, pages 970 to 973
 42. Graham H, White P, Cotton J, McManus S (2019). '[Flood- and weather-damaged homes and mental health: an analysis using England's mental health survey](#)' International Journal of Environmental Research and Public Health: volume 16, page 3256
 43. Cruz J, Li G, Aragon MJ, Coventry PA, Jacobs R, Prady SL, and others (2022). '[Association of environmental and socioeconomic indicators with serious mental illness diagnoses identified from general practitioner practice data in England: a spatial Bayesian modelling study](#)' PLoS Medicine: volume 19, page e1004043
 44. Butler C, Walker-Springett K, Adger WN (2018). '[Narratives of recovery after floods: mental health, institutions, and intervention](#)' Social Science and Medicine: volume 216, pages 67 to 73
 45. Medd W, Deeming H, Walker G, Whittle R, Mort M, Twigger-Ross C, and others (2015). '[The flood recovery gap: a real-time study of local recovery following the floods of June 2007 in Hull, North East England](#)' Journal of Flood Risk Management: volume 8, pages 315 to 328
 46. Lamond JE, Joseph RD, Proverbs DG (2015). '[An exploration of factors affecting the long term psychological impact and deterioration of mental health in flooded households](#)' Environmental Research: volume 140, pages 325 to 334
 47. UKHSA (2023). '[How to recover from flooding](#)'
 48. Suk JE, Vaughan EC, Cook RG, Semenza JC (2020). '[Natural disasters and infectious disease in Europe: a literature review to identify cascading risk pathways](#)' European Journal of Public Health: volume 30, pages 928 to 935
 49. Ramesh B, Jagger MA, Zaitchik B, Kolivras KN, Swarup S, Deanes L, and others (2021). '[Emergency department visits associated with satellite observed flooding during and following Hurricane Harvey](#)' Journal of Exposure Science and Environmental

- Epidemiology: volume 31, pages 832 to 841
50. Reacher M, McKenzie K, Lane C, Nichols T, Kedge I, Iversen A, and others (2004). ['Health impacts of flooding in Lewes: a comparison of reported gastrointestinal and other illness and mental health in flooded and non-flooded households'](#) Communicable Disease and Public Health: volume 7, pages 39 to 46
 51. Whittle R, Medd W, Deeming H, Kashefi E, Mort M, Twigger-Ross C, and others (2010). ['After the rain: learning the lessons from flood recovery in Hull. Final project report for "Flood, vulnerability and urban resilience: a real-time study of local recovery following the floods of June 2007 in Hull"'](#)
 52. Orr SA, Young M, Stelfox D, Curran J, Viles H (2018). ['Wind-driven rain and future risk to built heritage in the United Kingdom: novel metrics for characterising rain spells'](#) Science of The Total Environment: volume 640 to 641, pages 1098 to 1111
 53. Sayers P, Horritt M, Penning-Rowsell E, Fieth J (2017). ['Present and future flood vulnerability, risk and disadvantage: a UK scale assessment'](#)
 54. Szönyi M, May P, Lamb R (2016). ['Flooding after Storm Dennis \(PERC UK\)'](#)
 55. Sayers PB, Carr S, Moss C, Didcock A (2020). ['Flood disadvantage: social vulnerable and ethnic minorities'](#) Research undertaken by Sayers and Partners for Flood Re. London, UK
 56. Hames D, Vardoulakis S (2012). ['Climate change risk assessment for the health sector'](#)
 57. Environment Agency (2021). ['Long-term investment scenarios \(LTIS\) 2019'](#)
 58. Zhang J, Xu W, Liao X, Zong S, Liu B (2021). ['Global mortality risk assessment from river flooding under climate change'](#) Environmental Research Letters: volume 16, page 64036
 59. Kinoshita Y, Tanoue M, Watanabe S, Hirabayashi Y (2018). ['Quantifying the effect of autonomous adaptation to global river flood projections: application to future flood risk assessments'](#) Environmental Research Letters: volume 13, page 14006
 60. Jonkman SN, Vrijling JK, Vrouwenvelder ACWM (2008). ['Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method'](#) Natural Hazards: volume 46, pages 353 to 389
 61. Lloyd SJ, Kovats RS, Chalabi Z, Brown S, Nicholls RJ (2016). ['Modelling the influences of climate change-associated sea-level rise and socioeconomic development on future storm surge mortality'](#) Climatic Change: volume 134, pages 441 to 455
 62. EA (2023). ['Flood and coastal erosion risk management annual report'](#)
 63. EA, Defra (2023). ['Flood and coastal resilience innovation programme'](#)
 64. Townend BIH, French JR, Nicholls RJ, Brown S, Carpenter S, Haigh ID, and others (2021). ['Operationalising coastal resilience to flood and erosion hazard: a demonstration for England'](#) Science of The Total Environment: volume 783, page 146880
 65. Twigger-Ross C, Brooks K, Papadopoulou L, Orr P, Sadauskis R, Coke A, and others (2015). ['Community resilience to climate change: an evidence review'](#)
 66. Burgess Gamble L, Ngai R, Wilkinson M, Nisbet T, Pontee N, Harvey R, and others (2018). ['Working with natural processes – evidence directory'](#)
 67. PHE (2020). ['Improving access to greenspace: a new review for 2020'](#)
 68. EA (2020). ['National flood and coastal erosion risk management strategy for England'](#)
 69. Weeks JH, Fung F, Harrison BJ, Palmer MD (2023). ['The evolution of UK sea-level projections'](#) Environmental Research Communications: volume 5, page 032001

70. Fairbourne Moving Forward (2018). '[Fairborne preliminary coastal adaptation masterplan](#)'
71. FCERM, EA (2021). '[Applying behavioural insights to property flood resilience](#)'
72. Blanc A (2020). '[Independent review of flood insurance in Doncaster](#)'
73. FCERM, Defra (2021). '[Investigating whether flood insurance is available and affordable](#)'
74. Flood Re (2018). '[Securing a future of affordable flood insurance](#)'
75. Arnell NW (2022). '[The implications of climate change for emergency planning](#)'
76. Defra, EA (2018). '[Multi-Agency Flood Plan \(MAFP\) review](#)'
77. Landeg O, Whitman G, Walker-Springett K, Butler C, Bone A, Kovats S (2019). '[Coastal flooding and frontline health care services: challenges for flood risk resilience in the English health care system](#)' *Journal of Health Services Research and Policy*: volume 24, pages 219 to 228
78. Yu D, Yin J, Wilby RL, Lane SN, Aerts JCJH, Lin N, and others (2020). '[Disruption of emergency response to vulnerable populations during floods](#)' *Nature Sustainability*: volume 3, pages 728 to 736
79. Ntontis E, Drury J, Amlôt R, Rubin GJ, Williams R, Saavedra P (2021). '[Collective resilience in the disaster recovery period: emergent social identity and observed social support are associated with collective efficacy, well-being, and the provision of social support](#)' *British Journal of Social Psychology*: volume 60, pages 1075 to 1095
80. Walker-Springett K, Butler C, Adger WN (2017). '[Wellbeing in the aftermath of floods](#)' *Health and Place*: volume 43, pages 66 to 74
81. Defra (2015). '[Flood resilience community pathfinder evaluation: final evaluation report](#)'
82. UKHSA (2023). '[Adverse Weather and Health Plan \(AWHP\)](#)'
83. Defra (2022). '[UK Climate Change Risk Assessment 2022](#)'
84. Day SA, O'Riordan T, Bryson J, Frew P, Young R (2015). '[Many stakeholders, multiple perspectives: long-term planning for a future coast](#)' In: Nicholls RJ, Dawson RJ, Day (née Nicholson-Cole) SA, editors. *Broad Scale Coastal Simulation New Techniques to Understand and Manage Shorelines in the Third Millennium*
85. Ramsden S (2021). '[Living with Water Hull Household Flood Survey Autumn 2018](#)'
86. Galway LP, Beery T, Jones-Casey K, Tasala K (2019). '[Mapping the solastalgia literature: a scoping review study](#)' *International Journal of Environmental Research and Public Health*: volume 16, page 2662

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