Climate change impacts and adaptation

November 2018

"The costs of adapting are less than the cost of doing business as usual. And the benefits many times larger," - Ban Ki-moon, 8th Secretary-General of the United Nations.

Chair's foreword

Climate change is not a morality tale set in the dystopian future, it's already here. In December 2015, I was simultaneously taking part in the Paris Agreement and being briefed about the Environment Agency's response to severe flooding in the north of England.

The Intergovernmental Panel on Climate Change said even if we limit global warming to 1.5ºC above pre-industrial levels, the physical risks will increase significantly. Humanity's greatest challenge requires us to reduce carbon emissions and prepare for heatwaves, wildfires, storms, rising seas, shifting crop patterns, the spread of disease - and all of the ways those impacts will affect populations around the world.

Mitigation and adaptation are as inseparable in England as anywhere else: there's no point building an energy efficient house that could be washed away in a flood. The Government's National Adaptation Programme says: "while we continue to play a leading role in international efforts to keep global temperature rises well below 2ºC (by reducing our own emissions and supporting the developing world to do the same), our resilience will only be robust if we prepare for worse climate change scenarios."

The Environment Agency's first priority is people's safety, but our flood schemes and water resources management also support economic prosperity in a changing climate. For example, the Thames Barrier helps protect £275 billion of property and infrastructure; the Thames Estuary 2100 Plan will ensure this continues against sea level rise beyond the end of the century.

Long term resilience in infrastructure presents major opportunities for investors. According to the Institution of Civil Engineers over 45% of the National Infrastructure and Construction Pipeline to 2020/21 is financed through the private sector.[1] Worryingly few FTSE boards are disclosing the strategic risks to their shareholders brought by the physical impacts of climate change. Boards cannot continue to see extreme weather events, like floods and heatwaves, as purely operational. They need to put aside capital expenditure for resilience measures to ensure business continuity. They should also collaborate with other businesses, government, and local communities to drive down costs, and protect whole districts. Working in silos risks seeing investments and supply chains picked off one by one.

People should be encouraged to prepare. If strong locks on your doors help keep insurance premiums down, then property resilience measures such as water resistant insulation in walls and under the floor should do the same for flooding. This is not mandatory, but the value of climate resilience to individuals is under realised.

Resilience is vital. We can't wall up England. We increasingly need to look at "green" infrastructure, like natural flood management and soil improvement, to support traditional flood schemes. This work will also create better places for wildlife.

The UK climate projections, out today, will help the Environment Agency to prepare. So too will good policy from government; local partnerships with communities and business; and continued learning from experience. As climate change tests us, we will not shy away from difficult questions about our work, but we are in a strong position. Our operations team successfully responded to a 330% increase in environmental incidents during the hot, dry summer; our six year investment programme is progressing to better protect 300,000 homes from flooding; and our forecasting and warning capability is world leading.

This week, we launch our flood awareness campaign, urging people to learn about what our flood warnings mean. Please look it up because it could save your life. The message is "Prepare. Act. Survive." As climate change accelerates, this is not only good advice for you, but also for governments, businesses, and the whole of humanity itself.

Thank you to my colleagues for producing this report.

Emma Howard Boyd, Chair of the Environment Agency

Summary

England’s climate is changing and will continue to change as a result of greenhouse gas emissions. The Met Office's central England temperature series shows that the 21st century has so far been warmer than the previous 3 centuries. The summer of 2018 was the joint hottest ever recorded in England.

These changes are set to continue. Hotter drier summers, milder wetter winters, rising sea levels and more extreme weather events are expected in future. The hot summer of 2018, and flooding in recent years have been consistent with what is expected with a changed climate. The impacts are already being felt by communities, businesses, service providers and the natural environment.

Climate change is unavoidable, but action can be taken to avoid some of the extreme impacts that could occur. Further temperature increase is inevitable.

Unless we take action to reduce greenhouse gas emissions, global temperatures may rise to 4°C above pre-industrial levels by the end of the century. Summer maximum temperatures could rise by up to 10°C in parts of England by the 2080s. Sea levels will rise for decades and centuries ahead. Sea level rise is predicted to be between 0.4 and 1 metre by 2100, and possibly by as much as 4 metres by 2300.

Climate change will disrupt everyday life. Many people will experience climate change through its effects on water, and especially through floods and droughts. Heat related morbidity and mortality in the population are also expected to increase.

Society will have to adapt to the changing climate. Some adaptation is already taking place, but the pace and range of adaptation needs to increase. The more the planet warms above an increase of 1.5°C, the bigger the challenge will be.

Tough decisions need to be made to adapt to our changing climate. There could be unexpected consequences associated with some climate change impacts and adaptations. Tipping points could mean that gradual adaptation of natural systems or societal infrastructure is not possible.

Everybody needs to adapt and plan in the face of uncertainty. Adaptation strategies should be flexible so they can be adjusted as climate change unfolds. Things need to be done differently: climate change alters the way everybody needs to think about and plan for the future, and we all need to start planning and acting now.

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The changing climate

England's climate has changed, and will continue to change as a result of the emission of greenhouse gases by human activity.[2] In the future we can expect:

- hotter, drier summers
- milder, wetter winters
- rising sea levels
- more extreme weather events

As well as higher air temperatures, people will experience climate change through its effects on water, increasingly through floods and droughts.[3]

Based on existing syntheses and the latest climate science this report outlines what has happened and what is expected to happen to the UK climate and describes some of the impacts of these changes for England. It outlines the main adaptation actions that are being taken or are planned to prepare for the impacts of climate change. It does not replace the Environment Agency's formal reporting under the Climate Change Act on progress and future plans to adapt to a changing climate.

The updated climate change projections for the UK (UKCP18) confirm and refine the understanding of the changes that we all face. More needs to be done, doing nothing is not an option.

Higher temperatures

Global average temperatures increased over the 20th century, and continue to increase into the 21st. 2015 was the hottest year on record at over 1°C warmer than the pre-industrial average.[3,4]

In the UK, the average temperature in the most recent decade (2008 to 2017) was 0.8°C warmer than in the period from 1961 to 1990.[4] The 10 warmest years in the UK have all occurred since 1990.[3] In central England, the 21st century has so far been warmer than the previous 3 centuries, and 2017 was the 8th warmest year recorded.[4] Average air temperatures are expected to continue to increase across the UK, with the greatest increases in the summer (up to 4°C in the south and 2.5°C in the north by the 2080s).[3] The rate of change will be determined by the level of greenhouse gas emissions.

Global temperature increases are now inevitable, even without continued greenhouse gas emissions.[5] The Intergovernmental Panel on Climate Change (IPCC) have reported recently that it may still be possible to limit global warming to 1.5°C. However, this will require unprecedented international action.[5] Recent research estimates that without international action, there is only a 5% probability of meeting the 2°C target set under the Paris Agreement, with more than 4°C of warming a definite possibility.[6,7] If global average temperatures rise by above 4°C,[8] summer daily maximum temperatures in the UK could rise by 10°C by 2080.[9]

Atmospheric temperature increases also affect temperatures in the water environment. River water temperatures in the UK increased over the second half of the 20th century, and will increase further across the UK through the 21st century. This is broadly in line with changes in air temperature.[3] Sea surface temperatures around the UK rose at an average rate of 0.28°C per decade between 1984 and 2014.[10] Around 3°C increase from 1960 to 1989 temperatures is projected by 2069 to 2089.[11]

Changing rainfall patterns

Average annual rainfall has not changed since records began in the 18th century. However, rainfall patterns in the UK are changing. Over the past 50 years more winter

rainfall has fallen in heavy events while summer rainfall, which varies greatly, appears to have decreased.[3]

Annual average rainfall may not change much over the 21st century but the trend of more rainfall falling in heavy, more intense events is expected to continue.[3]

Extreme weather conditions

Climate change is expected to increase the frequency and intensity of certain weather events.[12] Global temperature increases mean that arctic sea ice is melting at an unprecedented rate.[13] The past 4 years have seen the lowest maximum sea ice levels on record.[14] There is some evidence that the melting of arctic sea ice has a direct effect on the weather experienced in England by altering the behaviour of Arctic winds that bring storms, resulting in persistent extreme weather conditions.[15]

England has recently experienced several extreme weather events. Heavy, prolonged rainfall, leading to significant floods in winter 2013 to 2014[16] and again in 2015 to 2016.[17] England experienced heatwave conditions in the summer of 2018, which was the joint hottest summer ever recorded in England, along with 2006, 2003 and 1976.[18] It is not possible to say that human-induced climate change has caused these events, but they are consistent with the weather expected with a warming climate.

Case study: Immingham docks

Immingham is a nationally strategic port, handling 10% of the UK's sea trade. The port is a vital part of the energy supply chain, supporting over 25% of the UK's electricity generation. It also provides over 25% of the UK's rail freight, connecting major manufacturers in the north of England.

In 2013 the east coast surge reached over 5 metres in height and the port was extensively flooded. The cost of damages and disruption was estimated at more than £115 million.* Climate change will raise sea levels and make events like the surge of 2013 more likely.

*https://www.nelincs.gov.uk/wp-content/uploads/2017/02/Urgent-Business-Port-of-Immingham-Flood-Defence.pdf

It is possible to quantify how much past emissions may have contributed to the probability of an extreme event occurring.[19] For instance, it has been estimated that climate change has increased the likelihood of record breaking warm years in central England by at least 13 times.[20] Severe heatwaves will become a regular event in the future. By the 2040s, heatwaves like that of 2003 could be experienced every other year.[21] By the end of the century over half of the UK may experience heat wave conditions every year.[22] Higher temperatures are also expected to lead to increased high-intensity rainfall, including thunderstorms.[3]

It is highly uncertain how climate change will affect the possibility of extreme events such as coastal surges or heavy rainfall happening at the same time. However, as the chances of individual events increase, so does the probability of them coinciding. The consequences can be severe when these events occur together.

Sea level rise and ocean acidification

Sea levels are rising, as a result of melting ice sheets and glaciers, as well as the physical expansion of the water as it warms.[23] Sea levels around the UK rose on average 1 to 2mm per year during the 20th century and this has increased to over 3 mm per year in the last decade.[3] This increase has not yet been directly attributed to climate change at the UK scale, because detection of human influences on sea level is difficult. However, the changes are consistent with global changes and the warming atmosphere.[3]

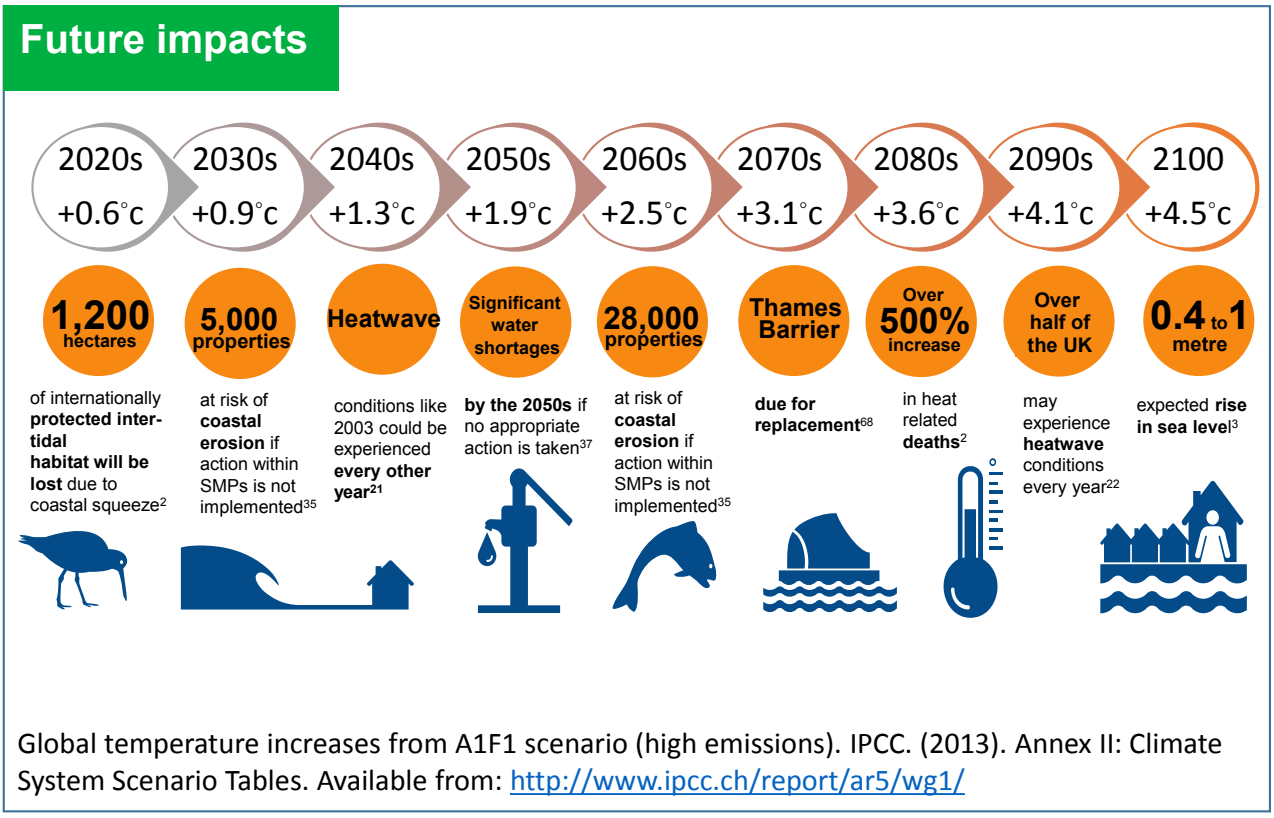
The Earth is already locked in to sea level rise for decades and centuries ahead. By the end of this century, global sea levels are expected to have risen by between 0.4 and 1 metres above the 1990 level.[3] Sea level will continue to rise around the UK, probably at a faster rate than experienced in recent decades. New research suggests that if action is not taken to reduce emissions, UK sea levels could rise by up to 4 metres by 2300.[24]

Oceans are absorbing carbon dioxide and becoming more acidic. Ocean acidification appears to be happening around the UK coast at a faster rate than in the rest of the northern Atlantic Ocean.[25] Globally oceans have increased in acidity by 26% since the Industrial Revolution.[26]

Current and future climate change impacts

Projected changes in climate are expected to have a range of impacts on the water environment as a result of changes in sea level, river flow, groundwater recharge and water temperatures. Flooding, caused by intense or prolonged rainfall, as well as by sea level rise and coastal storm surges, has become more likely in recent years and this trend is expected to continue.[3, 27]

These changes to the water environment, combined with increasing air temperatures will affect people and wildlife, in both urban and rural areas. This section outlines some of these impacts.



Global temperature increases from A1F1 scenario (high emissions). IPCC. (2013). Annex II: Climate System Scenario Tables. Available from: http://www.ipcc.ch/report/ar5/wg1/

Flooding and coastal erosion impacts

Warming of the atmosphere has increased the probability of flooding in parts of the UK. Flooding can devastate communities and have significant costs to the economy through business losses and lost working days as well as damage to properties and infrastructure. The total cost in England of the 2015 to 2016 floods is estimated to have been between £1.3 and £1.9 billion.[28]

Bigger, more frequent floods are expected over the 21st century, particularly during winter along with increased flows.[3] Summer flooding may become more common and rising sea levels will increase the risk of damage from storm surges.[3]

Coastal extreme flood events can result from individual extreme tide, surge or wave events, or a combination of these. Even under low projections of sea level rise, it is estimated that extreme high sea levels with a 1% per year chance of occurring on the coastline of the English Channel in 1990 will have increased to a 10% per year chance by 2100. Under higher projections of sea level rise this could increase to every 20 days on average by 2100.[29]

There are 240,000 homes and existing properties currently in high flood risk areas.[2] Even with significant long term investment in flood risk management, it is going to be difficult to reduce the number of properties in high flood risk areas. This is because of the combined effect of climate change and new development on the flood plain.[30] There will be a need to invest more to maintain defences that will be subject to wear from increases in peak river flows and rising sea level expected due to climate change. This will lead to increased maintenance and repair costs of approximately 20 to 50%.[31]

Damage to the environment from extreme flooding can be severe and long-lasting. Freshwater ecosystems are particularly vulnerable, with populations of plants and animals such as fish and invertebrates sometimes greatly reduced in numbers. For example, populations of the endangered freshwater pearl mussel in the north of England, can be devastated by extreme floods, which remove the mussels from river beds.[32]

The rate of coastal erosion is expected to accelerate as sea levels rise and more wave energy reaches the coast.[33] Wave heights at the coast will increase because less of their energy is lost via friction with the sea bed as the mean depth of water increases.

The extent of the impacts of coastal erosion on homes and communities will depend on the degree of future warming, [34] and what future adaptations are undertaken. Even if the shoreline management plans are fully implemented, there will still be an estimated 700 properties lost to coastal erosion over the next 20 years, and a further 2,000 after 50 years. Without these interventions, about 5,000 properties could be affected within 20 years and about 28,000 within 50 years.[35] For some of England's coastline it has been estimated that it will not be cost beneficial to protect or adapt as currently planned.[36] The impacts of sea level rise also greatly increase the risk of economic decline in affected communities.[34]

Water quality and resources impacts

Water quality and water resources are already under considerable pressure from a range of human activities, and the demands of a growing population. Climate change is adding to these pressures through changes to temperatures, rainfall patterns and river flows.

Average summer river flows may decrease across the UK and there may be less recharge of groundwater, leading to reduced water availability and lower river water quality.[3] Groundwater provides around 30% of England's drinking water. It is not known how drought frequency and length may change under a future climate although some studies indicate increases in the magnitude and frequency of droughts that last less than 18 months.[3]

Water demand for public water supply and agriculture is expected to increase with temperature in the future.[3] Projections for future water availability suggest that the country will experience significant water shortages by the 2050s unless appropriate action is taken to reduce demand and increase supply.[37] Climate change will lead to there being less water available to maintain healthy aquatic ecosystems.[38]

Sea level rise and associated tidal surges may affect the quality of groundwater supplies, as salt water increasingly intrudes into coastal aquifers.[2] Increased and heavier rainfall will increase the runoff of pollutants and nutrients from land to water, and increase the discharge of sewage effluent from sewage outfalls. Low river flows reduce the amount of oxygen in freshwaters as well as concentrating the levels of pollutants. Increased temperatures and sunlight, combined with lower summer river flows are likely to cause increased algal blooms and eutrophication, where excess nutrient concentrations in a water body cause an imbalance of the ecosystem.[39]

Biodiversity, soils and land use impacts

Many species are already in decline as a result of factors such as pollution and habitat loss. They may therefore be particularly vulnerable to the added pressure of a changing climate.

Species ranges and migration patterns will change with increases in temperature. Many species are being lost from areas where they have previously been found and others are threatened by invasive non-native species, which are expanding their ranges. The threats posed by both new and established non-native invasive species will increase in future as the climate becomes more suitable for them. These threats include insect crop pests, and diseases such as fungal infections of forestry trees and garden plants.[40]

Spring life-cycle events, such as leafing, flowering and egg laying, now occur earlier in most species than in the past. Changes to these life cycle events cause mistiming of interactions between species, for example plants and their pollinators or species higher up the food chain that rely on the availability of prey. This can in turn cause population declines.[40] These impacts are predicted to increase as the scale of climate change increases.[40]

Increasing sea temperature and acidification are having far-reaching effects on marine ecosystems, through changes to the biology and distribution of species at all levels of the food chain.[41] Sea level rise, coupled with range shifts in suitable habitat and prey populations, is already affecting coastal species such as sea birds.[42]

Sea level rise will alter wetland habitats, in some cases changing them into completely different environments. Approximately 1,200 hectares (ha) of internationally protected intertidal habitat and a further 500 ha of freshwater habitat will be lost due to coastal squeeze over the next 5 to 10 years.[2] Coastal squeeze happens when hard defences such as sea walls prevent intertidal habitats, for example saltmarsh, from migrating towards land as sea levels rise.[43] Projected losses of these habitats will have significant impacts on populations of invertebrates and wintering birds.[40]

Freshwater ecosystems may be responding to changes in water temperature, with reductions in some fish species in some catchments.[3] The recent summer temperatures have already caused some rivers to reach lethal temperatures for salmon and trout in places.[44] In future it is likely that there will be a decrease in salmon and trout and an increase in the proportion of coarse fish, such as common bream and roach, in freshwater habitats in lowland areas.[40]

The pressures of climate change are already beginning to have an impact on agriculture and forestry in England. Increasing temperatures and extreme weather events affect trees, crops and livestock, as well as on soil quality and structure. The hot dry summer of 2018 saw serious impacts on the agriculture sector. Challenges faced by farmers included irrigation, water shortage, heat stress on livestock, crop loss and a shortage of forage for livestock.[45]

Soil erosion is accelerating due to more intense rainfall, leading to the loss of valuable topsoil and the pollution of watercourses.[46] Flooding contributes to compaction,

waterlogging and erosion of soil.[2] Soils play an important role in the carbon cycle, having the ability to store carbon in the form of organic matter. However, increasing temperatures increase microbial activity in the soil, releasing the soil's stored carbon to the atmosphere.[47]

The productivity of agriculture and forestry is likely to decline.[46] The benefits of warmer temperatures and longer growing seasons will be outweighed by reductions in water availability, and increases in the frequency of extreme weather events. The threat posed by pests and disease will increase. Increased flooding, including that caused by sea-level rise, may lead to substantial losses in crop production in low-lying agricultural areas. The total area of agricultural land at risk of flooding in England is around 1.3 million ha, or 12% of the total.[39] Around 480,000 ha of the best agricultural land was at a 1% or greater annual chance of flooding in 2017. This area is projected to increase to about 550,000 ha by the 2050s under a 2°C temperature rise and to 680,000 ha under a 4°C rise.[2]

Careful water level management in England ensures that farmland, properties and infrastructure are protected from water logging and helps to ensure resilience to flooding. As sea levels rise some catchments that can currently be drained to the sea by gravity will need to be pumped with increasing frequency. Catchments that already require the assistance of pumped drainage will require additional pumping capacity.

Climate change will affect the range and quality of the ecosystem services that agriculture and forestry provide and rely on. These include climate control, flood regulation, biodiversity, pollination and nutrient cycling.[46] Hotter temperatures also increase the risk of wildfires.[27]

Infrastructure and human health impacts

Gradual shifts in long-term trends (for example a rise in average temperatures) and increases in the frequency of severe weather events can reduce the capacity or efficiency of infrastructure.[48] For instance, treatment plants and pumping stations may no longer be adequate. The reliability of existing reservoirs, groundwater sources and river intakes will change.[38] The electricity transmission and distribution network could experience an increase in the numbers of faults due to lightning, of up to 36%, by the 2080s.[2]

Case study: Gloucestershire floods 2007

The 2007 floods caused significant disruption in Gloucestershire due to the cumulative impacts of affected infrastructure.* Water treatment works were damaged causing water supplies to be cut-off for 17 days. Electricity supply was disrupted for 24 hours. Motorways and main roads were closed and there was widespread disruption to the railway network. Since then 2 new flood alleviation schemes have been completed and key infrastructure sites have installed additional flood protection measures as well as increasing the resilience of supply, which proved successful in the 2013 floods.

*Source: McBain, W. and others. (2010). Flood resilience and resistance for critical infrastructure. London: CIRIA.

Some infrastructure may be more vulnerable to flooding. There are currently 1,640 key infrastructure sites located within extreme flood areas in England.[49]

Sea level rise poses a significant risk to ports, which receive 95% of the UK's imports and exports.[6] Historic assets such as landfill sites also need to be protected against climate change. At least 1,700 known landfills are located within coastal flood and erosion zones in England and Wales.[50] For many historic landfills there are few records and much uncertainty about the scale of the legacy problems.

Health impacts will mainly be felt through changes in temperature, disease and pollution.[51]

Deaths and illness due to very hot weather are likely to increase. The growing number of older people means more of the population will be vulnerable to hot weather. If adaptation actions are not taken, for example to reduce overheating of buildings, annual UK heat-related mortality could increase by over 60% in the 2020s, and by over 500% by the 2080s as a result of climate change and population growth.[2] Milder winters, on the other hand, may result in fewer cold-related deaths.

Climate change may increase the likelihood of new diseases in the UK,[51] in combination with other important factors that increase this risk, such as the movement of people and goods around the world. For example, increased areas of stagnant water during droughts, coupled with higher temperatures, could lead to the spread of mosquito borne diseases should they be introduced.[52]

There may be an increase in the number of episodes where high levels of air pollution are caused by particular weather patterns such as heatwaves.

Flooding can have a significant impact on mental health.[51] One study found that one fifth of people who have experienced a flood were suffering from depression one year after the flood, over a quarter from anxiety and over a third were affected by post-traumatic stress disorder (PTSD).[53] Fear of being flooded again is a persistent problem, uncertainty of the effectiveness of adaptation measures can lead to people not implementing them, especially if it will increase their anxiety.[54]

Adapting to a changing climate

Adaptation is the process of adjusting to the actual or expected climate and its effects.[55] The government is already planning and undertaking specific actions to adapt to current and future climate change. The National Adaptation Programme (NAP)[27] sets out the measures currently planned to try to prepare the country for changes to the climate.

Successfully adapting involves understanding the risks and quantifying the likely impacts, so that informed decisions can be taken about the costs and benefits of reducing those risks. Taking the impacts of a changing climate into account in all medium and long term planning is an investment to save money.

Actions to increase resilience help to maximise the capacity to adapt, and need to be kept under regular review. Adaptation will become increasingly important if appropriate mitigation is not put in place in time.

Flooding and coastal erosion

England has always experienced episodes of flooding. Adapting to increased risk of flooding from rivers and the sea is already underway. Building new flood defences and improving existing ones is ongoing. Many of the adaptations to increased flood risk from rivers and coastal surges are also required to deal with sea level rise.

Traditional hard defences such as flood walls, sea defences and embankments should continue to be combined with natural flood management,[56] including temporary on-farmland flood water storage to better manage risks in future. Sustainable drainage systems (SuDS),[57] which help reduce downstream flooding, should be incorporated into all new developments.

Individual properties and infrastructure can be designed or adapted to be resilient to flooding. Property-level measures can include installing flood gates, fitting pumps, or

raising vulnerable electrics and even whole buildings.[27] In some situations it will not be possible to adequately protect properties and infrastructure, and the only realistic option will be relocation.[2]

As with other forms of flooding, coastal flood risk is managed using a combination of hard defences such as sea walls and tidal barriers (for example, the Thames Barrier) and more natural approaches such as managed realignment such as Medmerry in Sussex.[58] These schemes reduce the wave and tidal energy reaching the shore and reduce the impact on defences.

Case study: Calderdale flood recovery and resilience programme

Communities can better adapt and manage their flood risk through proactive engagement between the public and relevant stakeholders. Community engagement can improve preparedness and capability to respond to future flood risk. The Calderdale programme was set up in response to the 2012 flooding. It brings together the local community and relevant stakeholders to increase resilience, and reduce the impact of future flood events. The programme oversees work relating to natural flood management, flood risk reduction, resilient infrastructure and community resilience. There are several flood alleviation and risk reduction schemes in progress, which reduce run-off waters and waterproof buildings next to the river.

*Source: https://www.calderdale.gov.uk/v2/residents/environment-planning-and-building/flooding/flood-recovery-programme

Water quality and resources

There are a number of actions that can be taken to protect the water quality of our inland water bodies against climate change. They include:

– reducing unsustainable abstractions
– farmers and land managers changing their land management practices to minimise nutrient and agrochemical runoff
– water companies reducing pollution incidents from sewer systems and sewage treatment works

It is essential to reduce future water demand and improve water use efficiency to maximise water supply resilience. Ongoing actions to do this mainly involve reducing demand from water users, reducing leakage and being prepared for drought.[27] In some places more water could be abstracted from rivers to increase available supplies, but this could have damaging effects on freshwater ecosystems. [2]

Longer-term adaptation is needed to ensure people and the environment get the water needed during droughts and heatwaves.

Case study: working with water companies

The Environment Agency works with water companies to produce guidance, and on research to inform their planning for the impacts of climate change. For example, we worked with them on Water UK's long-term water resources planning framework.* The work showed that the costs of this forward-looking approach are much lower than the costs of dealing reactively with future droughts. As well as managing future demand, longer-term measures set out in the framework to increase supplies include increased water transfers and trading, and building reservoirs. Desalination of seawater may be considered in some areas. However, it is highly energy intensive and can produce considerable amounts of greenhouse gases.

* Available from: https://www.water.org.uk/policy/environment/water-resources

Biodiversity, soils and agriculture

Measures undertaken to help wildlife and habitats adapt to climate change predominantly involve increasing their resilience by reducing the other pressures on them.

Protected conservation areas provide a vital network of sites for wildlife ranges to move north as the climate changes.[59] Creation, restoration and enhancement of freshwater and intertidal dependent habitats such as mudflat saltmarsh, wet woodland, floodplain meadows and grazing marsh are ongoing and play an essential role.[39] Planting new woodlands will increase the resilience of many plants and wildlife.[27] Tree planting on river banks can prevent excess warming of water temperatures in summer and reduces fish deaths from high water temperatures.[39] Controlling non-native invasive species will enhance the resilience of our native biodiversity to climate change.

Case study: keeping rivers cool project

The Environment Agency has worked with charitable trusts such as the Woodland Trust and Rivers Trust to minimise the effect of climate change on river temperatures by planting trees along river banks. This has been shown to reduce the water temperature by up to 5.5°C.* It also provides wider environmental benefits such as stabilising the banks, reducing nutrient run-off, providing leaf litter for invertebrates and woody debris for fish refuge. The project has been trialled in the Wye, Hampshire Avon, Tyne, Ribble, Frome and Tywi catchments. It is an example of a low-risk reversible action that can be used in conjunction with other measures to adapt to the changing climate.

*see http://caba.dbdstaging.site/learn/keeping-rivers-cool/

It will not always be possible to mitigate impacts or build resilience through the management of habitats or by reducing other pressures. Action will be needed for species and habitats at particular risk. In some places it will be necessary to translocate rare and isolated populations of climate-sensitive species.[27]

The agriculture and forestry sectors have already introduced new genotypes, varieties, breeds and management practices. As the climate changes, there will be a need for more anticipatory adaptation measures.[46] Further actions planned include wildfire prevention training for fire and rescue services and land managers.[27]

Infrastructure and human health

Infrastructure owners and operators are already implementing measures in response to climate change. However, the design and implementation of new infrastructure can take many years. It is therefore important to consider the scale of possible change and variability in the future climate in the context of risks to existing and future infrastructure. Flexible solutions are needed that can deal with a wide range of future weather conditions and allow for the introduction of new knowledge and technologies.

Some of the actions that are being put in place by infrastructure providers include[60, 27]

- ongoing monitoring of adverse weather through visual and thermal imaging
- building pumping stations to mitigate future flooding impacts
- building in measures to address flood risk in new railway lines
- installing equipment at higher levels to avoid flood damage

Health adaptations include the implementation of more and better green infrastructure across the country to keep people cooler in towns and cities.[27] Green infrastructure is a term used for urban networks of features such as green spaces, rivers, street trees and parks.[61]

Adaptation plans are being developed for all hospitals. Future infrastructure adaptation work could include the creation of systems for different infrastructure providers to communicate about interdependent vulnerable assets.[6] To prevent increasing health effects, buildings need to be designed or modified to prevent or reduce overheating. People may need to adapt our lifestyles in order to avoid the worst impacts of overheating.

There is more to be done

A 2017 report by the Adaptation Sub-Committee[6] highlighted the need for increased adaptation planning and actions in a range of areas. The most urgent issues, where vulnerabilities are increasing are:

– protection of soil health and carbon sequestration
– surface water flood risk and alleviation, and the planning of new developments
– property-level flood resilience
– biodiversity and ecosystem resilience in freshwater, terrestrial and farmed habitats
– protection of coastal and marine habitats

Future challenges and opportunities

It is vital that people are aware of the risks and understand what they need to do to adapt to the impacts of climate change. Communities and governments around the world have to adapt and plan in the face of climate uncertainty, as it is not possible to know the exact extent to which our climate will change. Adaptation plans must incorporate the full range of climate risks, and take account of uncertainty over timing and severity. Current plans will need to be extended to cover gaps such as the resilience of soils and biodiversity.

Some climate change impacts could happen sooner than current plans have accounted for. This will force more reactive rather than proactive changes. For example rates of polar ice sheet melting and collapse are quite variable and uncertain, and so their contribution to rising sea levels is hard to predict. There is some evidence that melt rates have accelerated in recent decades, thereby contributing to faster sea level rise.[62] The time between when a problem is recognised and when action is needed could shrink to the point where gradual adaptation of natural systems or societal infrastructure is not possible.[63] There is increasing evidence that the climate could cross critical thresholds or 'tipping points', leading to abrupt and irreversible regional-scale changes in marine, terrestrial and freshwater ecosystems.[64]

Potential opportunities could arise from a modest level of climate change, through extended growing seasons and improved productivity in agriculture, forestry and fisheries. However, these opportunities will only be realised if limiting factors such as water availability, soil health and pests and diseases are managed.[27] Measures taken to adapt to climate change could lead to other unexpected environmental problems.

Climate change is a global issue and England will be indirectly affected by the impacts of climate change in other countries.[65] In the next few decades similar events to the Russian heatwave of 2010, which caused global wheat prices to double, can be expected.[65] Global markets and supply chains are likely to be disrupted as transport and trade routes suffer disruptions from climate change.[65] This raises concerns over food security since over half of food consumed in the UK is imported,[66] and UK production will also be affected by climate change. Climate change has been linked to violent conflict, where prolonged droughts have led to scarcity of resources, leading people to seek refuge.[65] Climate change-related extreme weather events globally will also increase the likelihood of crop failures and water shortages, as well as the destruction of homes and businesses from

natural disasters and will lead to further increases in movement of people between countries.[65]

Adaptation reduces the risks from climate change impacts, but there will also be impacts which England is unable to protect against, especially at the higher projections of likely warming. Flooding and coastal erosion cannot be entirely prevented, even with enhanced adaptation measures. Many landscapes have changed and evolved due to regular flood and erosion patterns.[27] Continuing to maintain all the current coastal flood defences over the next 100 years is unsustainable, as the numbers of defences highly vulnerable to failure will increase by around 20% under 0.5 metres local sea level rise.[36] This means that some currently defended land may not be defended in the future.[67]

We expect the Thames Barrier to continue to protect homes and businesses in London to its current standard up until 2070, when it is likely to become more cost effective to build a new barrier.[68] However, continuing to use the barrier to manage flood risk from non-tidal rivers in west London could mean the number of closures becomes unsustainable before 2070. Work is underway, with communities and partners, to consider alternative options to using the barrier to manage this flood risk from 2035.

There will be serious consequences for biodiversity and wildlife. For example trout and many cold blooded species will struggle to survive,[69] and non-native invasive species could proliferate.[40] Decisions will have to be made on where adequate adaptation and protection from climate change cannot be provided.

If global warming can be limited to 1.5°C above pre-industrial levels then less adaptation would be required than for the Paris Agreement target of 2°C. However, even if warming can be limited to 1.5°C, the UK will still need to pursue the adaptation strategies that have already been put in place. At 4°C of warming, the impacts on future generations would be extremely difficult to adapt to. There is still time to prevent this from happening. **The time to act is now.**

Case study: Thames estuary 2100 plan

The Environment Agency have pioneered an adaptation pathways approach,* which manages the uncertainty in adaptation planning, in our Thames Estuary 2100 Plan.** The plan makes recommendations for managing tidal flood risk within the Thames estuary up to the end of the century. It has been designed using current climate change guidance, but it can factor in changes in projections of sea-level rise and other climate change effects throughout the century. We lead in delivering the Plan, but rely on partnership working, particularly with councils whose spatial planning role is vital to manage tidal flood risk in the future.

*see Bloemen, P. and others. Mitig. Adapt. Strateg. Glob. Change (2018) 23: 1083.

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