

# THE UK'S FIRST CLIMATE CHANGE RISK ASSESSMENT AND THE IMPLICATIONS FOR THE COAST

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## ABSTRACT

In 2008 the Climate Change Act was passed into law in the UK. This provides a legally binding framework for reducing carbon emissions. Much of the focus of the Act is on reducing emissions and hence on mitigation measures, however, the Act also requires a risk assessment to be undertaken every five years. The assessment of the risks (including opportunities) from climate change has to address those things that have social, environmental and economic value in the UK. The objective is to create an enabling environment in which the capacity to adapt can be developed in an informed manner and identify priorities for Government action. The risk assessment informs the National Adaptation Programme and will be updated every five years. This paper outlines the method of analysis, presents some results and draws some conclusions, with particular reference to those aspects that are likely to be of interest to the coastal community.

## INTRODUCTION

The Climate Change Act 2008 makes the UK the first country in the world to have a legally-binding long-term framework to cut greenhouse gas emissions and a framework for building the UK's ability to adapt to a changing climate. As part of this, the Act requires:

- A UK-wide climate change risk assessment that must take place every five years, with the first one having to be laid before parliament by January 2012; and
- A national adaptation programme (NAP) which must be put in place and reviewed every five years, setting out the Government's objectives, proposals and policies for responding to the risks identified in the CCRA.

The UK Climate Change Risk Assessment (CCRA) 2012 is the first of the risk assessments and it was successfully laid before parliament in January 2012. The CCRA has assessed the main risks and opportunities in the UK from climate change. This independent analysis provides a good starting point, providing an overview and assessment of risks in and across sectors, and enables comparison between different sectors. It provides underpinning evidence that can be used by the UK Governments to help inform priorities for action and appropriate adaptation measures. It also highlights where more work is needed to understand better the scale and nature of the risks, and to help Government to consider what action – if any – needs to be taken.

The CCRA is being followed by national adaptation programmes in England, Wales, Scotland and Northern Ireland. Further economic analysis is currently underway to supplement the findings from the CCRA, to inform Government about the costs and benefits of a number of options for adaptation to climate change.

## METHOD AND OUTPUTS

The methodology was developed in early 2010 to meet the specific requirements of the CCRA, taking due account of the timescales available for the first assessment. A simplified overview of the approach is shown in Figure 1 and the key steps are elaborated below.

**Risk screening** involved literature reviews and consultation in each of the eleven research areas considered, which collectively developed a list of approximately 700 potential climate change risks (Tier 1 list). A systematic mapping methodology provided a simple form of systems analysis to describe links between potential risks within sectors and between sectors. This helped to identify some additional risks across sectors and provides a starting point for more detailed research, including systems modelling to support future risk assessments.

**Risk selection** involved a simple scoring exercise that considered the perceived magnitude and likelihood of risks and also the perceived urgency of adaptation action. This process, which involved gathering feedback from stakeholders, selected a more manageable list of approximately 100 risks to study in greater detail. For each potential risk a 'risk metric' was defined to describe risk magnitude under a range of future scenarios.

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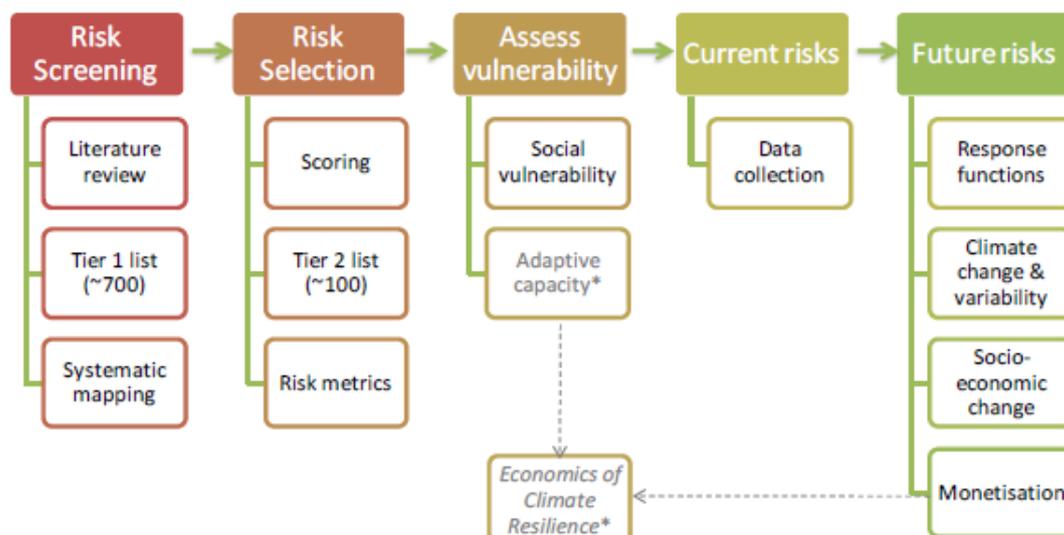


Figure 1 – Summary of the methodology (Defra, 2012)

**Assessment of vulnerability** was related to collecting further evidence on other non-climate factors that influence future risks, such as the social vulnerability of different groups of people in the UK, the capacity of organisations to respond to information about future climate change and information about existing Government policy on adaptation.

**An understanding of current risks** was the starting point for the assessment in each sector. This involved collecting the best information available on current risks from Government departments and the regulated industries. In some sectors, such as floods and coastal erosion risk management, extensive national data sets were available for England and Wales, whereas in other sectors, such as Business, Industry & Services very limited information was available. The main gaps in evidence were recorded in each Sector Report (see below).

**Future risks** were assessed using a staged approach that involved understanding the sensitivity to climate variables using ‘response functions’, considering the effect of future climate change and variability of the current population, and then considering population changes to estimate the total climate risk for future time periods. This is explained further in Box 1. The difficulty of assessing long term socio-economic changes was recognised and the project included a qualitative assessment of the main drivers of potential risks. Some potential risks were monetised to aid comparison across sectors and themes. In addition, a broad categorisation of potential risks as ‘high’, ‘medium’ and ‘low’ was completed against a set of social, environmental and economic criteria.

**The Economics of Climate Resilience (ECR)** is a separate and ongoing research study to inform the National Adaptation Programme (NAP). The work on adaptive capacity (Ballard, Black and Lonsdale, forthcoming) and some of the monetisation findings will be used in this study to estimate the most cost effective adaptation policies.

**Box 1 – The approach to assessing future risks**

There were essentially three key components to the risk assessment, namely:

- The development of functions to describe the climate sensitivity of individual consequences (referred to as response functions);
- The use of these functions in conjunction with climate projections to estimate the change in risk relative to the present day baseline; and
- The scaling of these ‘response’ projections to take account of how they may be influenced by future changes in socio-economic conditions and any autonomous or planned adaptation.

These components of the assessment were considered individually and collectively, so that the relative contribution of each component could be clearly identified.

The CCRA method focused on understanding the sensitivity of selected risks to current and future climate and which, collectively, make up the ‘risk landscape’. In both the process of identifying the risks and developing response functions, consideration was given to identifying aspects of the risk landscape that were particularly vulnerable and so likely to be susceptible to, or unable to cope with, adverse effects of climate change. In many instances, this depends not only on the sensitivity of the particular risk (i.e. how quickly the consequence changes in response to a change in some climate variable) but also whether the consequence is likely to be pushed beyond some critical threshold, or whether the relevant system has some inherent capacity to adapt.

The advantages of the CCRA method are that:

- It is relatively simple to understand;
  - The analysis can be done with the data and knowledge currently available; and
  - It allows a clear presentation of relative risk that may arise as a result of climate change.
- However, the 'reductionist' nature of the method also carries some disadvantages:
- There is limited analysis of the interaction with other non-climate drivers of change; and
  - The approach has a limited ability to capture complexity, non-linearity and systemic risks.
- Overall this approach means that the influence of climate is explored in detail but the influence of social, political and economic changes is less well developed. Future CCRA cycles are expected to improve this aspect of the risk assessment.

**Project reporting**

The main report presents the evidence of current and future climate change risks for the UK as a whole to 2100. This is supported by detailed assessments in each of eleven sectors and a number of additional components that summarise findings for different audiences, Figure 2. All of these reports can be accessed from the Defra web site ([www.defra.gov.uk](http://www.defra.gov.uk)).

**Sectors**

- Biodiversity & Ecosystem Services
- Agriculture
- Forestry
- Water
- Floods & Coastal Erosion
- Built Environment
- Energy
- Transport
- Marine & Fisheries
- Health
- Business, Industry & Services.

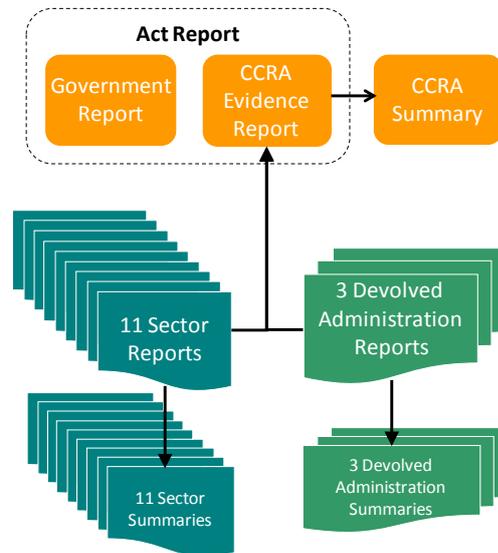


Figure 2 - Project publications (Defra, 2012)

**FINDINGS RELATED TO THE COAST**

As with the reports on climate change prepared by the IPCC, much of the analysis has had to rely on existing studies and research. This means that whilst the study does provide the first comprehensive overview that compares disparate risks in a consistent way, there are inevitably limits and significant areas of uncertainty in what could be achieved in the time available for this first assessment. Identifying these gaps in knowledge, highlights what needs to be done to support future risk assessments as part of the on-going five year cycle.

In the coastal context the study identified a sustained increase in flood risk. For many areas around the UK coast this is already a significant risk, which is simply exacerbated by sea level rise. This brings with it increased risk of overtopping damage and risk to life. The study also identified a significant mental health risk as a consequence of this exposure and significant impacts on businesses as a result of disruption due to flooding. Whilst climate change may bring a number of benefits for tourism (extended season, etc) there is also the potential for key assets to be put at risk. These risks are discussed in more detail below.

**Bio-physical impacts**

**Sea level rise and flooding .** Sea levels around the coast have gradually risen at rates of 1 to 2mm per year over the last 80 years. This rate of rise is projected to increase in the future and the CCRA used sea level rise projections based on UKCP09 to assess potential future impacts.

The UKCP09 sea level rise projections relative to land level ranged from about 0.05m to 0.12m by the 2020s compared with a 2008 baseline for the thirteen scenarios used in the analysis. The projected increase was between about 0.1m and 0.35m by the 2050s, and between 0.18m and 0.6m by the 2080s.

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It was assumed in the analysis that these increases apply to the full range of tidal water levels including high surge tides.

Whilst the increases appear relatively modest, the impact on the frequency of extreme tidal flood levels is significant. For example, a sea level with an annual probability of 1% (or '1 chance of occurrence in 100 years on average') might increase to an annual probability of between 3% and 12% (1 in 8 to 1 in 30 years) by the 2080s depending on location. This would have a very serious effect on some coastal communities.

The projected rises in sea level would lead to increases in coastal and estuary flooding which in turn would cause increases in property, infrastructure and other damages. The number of people at risk of flooding from the sea in England and Wales with an annual probability of 1.3% (1 in 75 years) or greater is projected to increase from a baseline of about 300,000 to between 800,000 and over 2 million by the 2080s.

The number of properties at risk of flooding from the sea in England and Wales with an annual probability of 1.3% or greater is projected to increase from a baseline of about 170,000 (115,000 residential and 55,000 non-residential) to between 450,000 and 1.2 million by the 2080s of which between 350,000 and 900,000 are residential properties. The corresponding Expected Annual Damage (EAD) is projected to increase from a baseline of about £400 million to between £1.0 billion and £4.0 billion in the same period.

The projected increase in coastal flooding would also affect agriculture, business, transport and infrastructure. For example, the area of agricultural land with a 10% annual probability or greater of flooding to a depth of 0.5 m or more in England and Wales is projected to increase from a baseline of about 50,000 ha to over 200,000 ha by the 2080s. The total for Grade 1, 2 and 3 agricultural land (primarily arable and horticulture) is about 170,000 ha by the 2080s from a baseline of about 30,000ha.

Sea level rise also affects long-term coastal evolution, which is the combined influence of a range of events including gradual change and storms that may result in both coastal erosion and flooding. This in turn influences the transition from marine to terrestrial habitats. Extreme storm events (in addition to frequent events) also have the potential to cause extensive saline inundation.

Coastal flooding, under current or future climatic conditions, has the potential to flood coastal habitats inland of the natural and defended coastline. The majority of the habitats that would be affected are terrestrial or freshwater and open water habitats that have variable but generally limited ability to tolerate saline inundation. Inundation of these habitats with brackish / saline waters has the potential to result in changes in species composition (loss of salt-intolerant species) impacts on growth through alteration of soil-water interaction, changes in soil structure and changes in fauna (e.g. loss of invertebrate populations) and in turn this may lead to transition and then change to other habitat types. The result would be a change in the distribution of coastal habitats at the country-wide level.

The joint Defra/Environment Agency NEOCOMER project (Defra, 2006b) estimated potential losses of habitats from coastal flooding in Natura 2000/SSSI/Ramsar sites to be over 32,000 ha. Although not quantified by NEOCOMER, climate change may exacerbate this vulnerability with sites flooded sooner or more regularly than is currently the case. Furthermore, this study did not include an assessment of the sensitivity of habitats to the frequency or duration of inundation, but assumed that all inundation would result in loss.

The Defra project CR0422 assessed the risks of flooding due to sea level rise on selected coastal BAP habitats (Defra 2011). Over half of the national resource of coastal and floodplain grazing marsh and reedbed and saline lagoons are situated in the coastal floodplain and are sensitive to sea level rise, saline intrusion and changes in wave energy. Coastal habitats play an important part in the buffering and prevention of flood flows.

A series of sensitivity matrices were developed as part of the Defra project CR0422, using existing empirical observations, scientific data and expert judgement, which describe the risk to the BAP habitats of exposure to a range of inundation events in terms of flood frequency and duration. Of those BAP habitats in the coastal floodplain, 81% of the total selected BAP habitats projected to be at risk under any climate scenario are already at risk from prevailing climatic conditions and, hence, could be lost to flood events in the next 10 to 20 years.

**Coastal erosion and habitat loss.** The UK coastline comprises areas that are predominantly stable (e.g. those comprising hard rock formations) and those that are either eroding or accreting (e.g. soft rock coast, beaches). Sea level rise will lead to an increase in the rate of erosion of some areas and may also lead to an increase in the rate of accretion in others, speeding up the long-term reconfiguration of some coastlines in the UK that is already occurring. This will result in the loss of some habitats and the creation of others.

As sea level rises, the response on the coastline varies depending on the geomorphology, but in all cases will result in some form of marine transgression. Beaches, dunes and shingle ridges will tend to “roll” landwards whereas cliffs will slowly erode allowing the beach shore face to migrate landwards. Where this is constrained, either by slowly eroding cliffs or sea defences, the area of beach and other natural coastal assets will reduce (Townend et al, 1990). The combination of higher sea levels and greater loading from wave action would increase damage to natural and built assets (Townend & Burgess, 2004). These issues are being addressed by the introduction of softer defences where possible and the development of habitat creation through managed realignment.

For coastal locations one of the primary assets is the beach. Under rising sea levels and whilst shorelines are maintained in a (relatively) fixed position in order to protect coastal infrastructure and buildings, there is a risk that beaches may narrow and become steeper (Townend et al, 1990, Taylor et al, 2004). In order to gain an appreciation of the magnitude of the risk from projected sea level rise to these natural tourist assets, a high level assessment of the potential loss of beach area was undertaken. Using the UKCP09 climate projections for future sea level rise, there is a risk of beach loss across the UK of 3 – 16 km<sup>2</sup> by the 2020s, rising to 12 – 61 km<sup>2</sup> by the 2080s (which is between approximately 3% and 7% of total beach area). The regional breakdown of these figures is provided in Figure 3, which shows that the greatest area of beaches at risk of loss is in England.

One consequence of coastal erosion can be the loss of habitats seaward of the coastline (such as saltmarsh) or inland of the coastline, whether natural or defended (such as coastal and floodplain grazing marshes, reedbeds, fens, etc). Conversely, accretion of sediment can result in the creation of habitats, such as saltmarsh or coastal vegetated shingle. Currently, around 17% of the UK coastline is experiencing erosion (Eurosion, 2004) and 28% of the combined English and Welsh coast is experiencing erosion rates greater than 10 centimetres per year (Thorne et al, 2007). Lee (2001) used a simple model to project areas of habitat change, concluding that there could be a net gain of intertidal habitats (saltmarsh and mudflat/sandflat) of some 2,220 hectares and a net loss of coastal dry land, wetland and open water habitat of approximately 4,000 hectares from protected sites (under European and international designations) in England and Wales over the next 50 years. Analysis for the CCRA indicated that the greatest proportion of habitat loss through coastal erosion would be for saline lagoons, where between 2 and 20% of the resource is projected to be lost in East England alone by the 2080s.

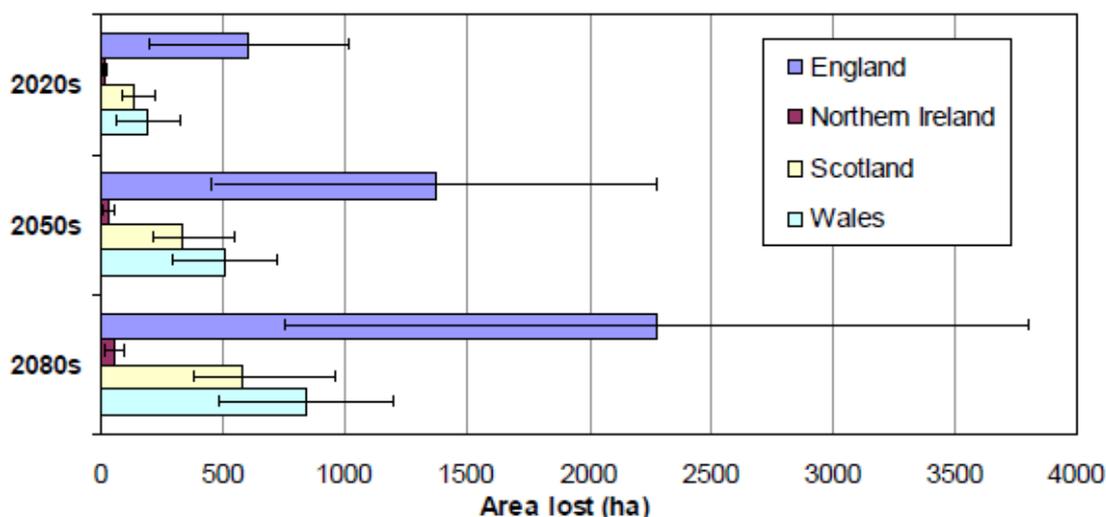


Figure 3 – Projected loss of beach area (Defra, 2012)

### Social wellbeing and health

**Vulnerable communities.** A number of socio-economic factors, such as health, financial resources and access to services, can make communities particularly vulnerable to flood and erosion hazards. The Index of Multiple Deprivation (IMD) brings together a number of these factors (Walker et al,

2006) and was used to map the social vulnerability of communities across the UK. For England and Wales, this indicator shows that there are concentrations of 'deprivation' in coastal and tidal areas in the east, south east and south west of England and in parts of Wales. These include a higher proportion of elderly people that may have poorer health and live in single storey accommodation, making them particularly vulnerable in the event of flooding.

While most large towns on the open coast have flood defences and coastal protection, many smaller communities do not, for example those on raised ground in sheltered bays. People who live in these areas may be disproportionately affected by future climate change. In the event of major flooding, adequate warning and evacuation of coastal communities would be difficult. With regard to coastal erosion<sup>6</sup>, there are already some well known examples of coastal communities where properties have been lost to the sea, and a number of other communities around the coast are already threatened.

**Deaths and injuries due to flooding and overtopping.** Flood events in the UK that lead to a large number of deaths and injuries are few and far between, and are heavily driven by the type of flood event and/or warning and the local characteristics of the area. Although past flood events, such as the 1953 North Sea tidal surge resulted in significant loss of life and injuries (Baxter, 2005), improvements in coastal defences driven by this event, as well as improvements in flood forecasting and communication via several media has significantly reduced this risk (Defra/Environment Agency, 2003 and European Environment Agency, 2005). The potential for a repeat of the levels of loss of life and injuries as a result of a similar magnitude event of 1953 would therefore be unlikely, and these would be more as a result of problems of evacuation or a refusal to evacuate (e.g. Sorensen, 1991 and HR Wallingford, 2010).

Evidence presented in the CCRA (Hames and Vardoulakis, 2012) therefore indicated that loss of life and injuries due to coastal flooding would be linked to very extreme events, probably in excess of the magnitude of the 1953 event. Although these events would occur rarely, possibly measured in timescales of 100s of years, they would be associated with large loss of life and injuries. On a yearly average timescale it was estimated that this would result in a current estimate of around 2-5 deaths and 40-100 injuries per year due to coastal flooding, with best estimates of 3 deaths and 60 injuries respectively.

In terms of the change in risk as a result of a changed climate, a review of historic flood events indicates that the number of deaths and injuries due to flooding is approximately proportional to the number of people at risk (Defra/Environment Agency, 2003 and Frieser et al, 2005). Linking in with research undertaken for the CCRA (Ramsbottom et al, 2012), this indicated that coastal flood related deaths and injuries were therefore projected to increase by approximately 6 and 130 by the 2050s and 8 and 160 by the 2080s respectively.

In addition to the deaths and injuries at the coastal linked to flooding, coastal wave activity was also identified as a risk (Hames and Vardoulakis, 2012). Although changes in wave heights were considered uncertain, this impact was noted as being mainly driven by the increased occurrence and duration of severe wave activity at the coastline linked to a rise in sea levels, a conclusion also recently observed by Chini and Stansby (2012).

Examining four years of records over two different periods from the Violent Overtopping of Waves at Seawalls Project (<http://www.vows.ac.uk/>), deaths reported by the media indicated that after the removal of accidental deaths, approximately seven people died a year as a result of coastal wave activity. Examining these records, it was noted that these deaths tended to occur near high water, when the tide level was near mean high water springs (MHWS). For future risk, fatalities would be expected to be related to the increase in wave activity nearshore, which in turn due to depth limited effects, could be considered a function of sea level rise (e.g. Townend, 1994; Chini and Stansby, 2012). Taking MHWS as the baseline for significant wave activity, projections of future increases in deaths at the coastline due to coastal wave activity were therefore given as 6 by the 2050s and 14 by the 2080s. With no information available to assess injuries as a result of coastal wave activity, the same relationship as for coastal flooding was assumed resulting in a projection for injuries at the coastline due to coastal wave activity of 120 by the 2050s and 280 by the 2080s.

**Mental health issues.** Attempts to quantify estimates of the effect of flooding on mental health are difficult, and hampered by varying definitions used in different studies (Hajat et al., 2003). Within the UK, the most widely used methodology for measuring a mental health effect of flooding (as well as mental well-being generally) is the 12 point General Health Questionnaire (GHQ-12), which indicates

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<sup>6</sup> The CCRA included a relatively simple assessment of coastal erosion including the assumption that existing coastal defences would be maintained and improved. Better data has since become available via the Environment Agency's National Coastal Erosion Risk Map (NCERM). There is scope to improve local projections of erosion and flooding for threatened communities and provide better assessments of future impacts at local, regional and national scales.

an unspecified mental health effect due to flooding if there is a change in the GHC-12 from below 4 to 4 or above as a result of a flood event. This methodology has been used in a number of studies of flood victims within the UK and was therefore adopted in the CCRA as the most appropriate measure for mental health effects of flooding due to a changed climate (Hames and Vardoulakis, 2012).

Similar to coastal flood related deaths and injuries, the numbers of people who suffered a mental health effect as a result of flooding was estimated based on the research undertaken for the CCRA (Ramsbottom et al, 2012). For England and Wales only, it was projected that approximately 2,000 to 3,500 additional people would suffer a mental health effect as a result of coastal flooding by the 2050s, which was projected to rise to approximately 3,000 to 4,000 by the 2080s.

### **Business and infrastructure**

**Tourism.** The tourism industry forms a large part of the local economy for many communities in the UK, particularly on the coast and contributed £115.4bn to the UK economy in 2009 – equivalent to 8.9% of total UK Gross Domestic Product (Deloitte and Oxford Economics, 2010). Increasingly, the impacts of climate change may offer both challenges and opportunities for the tourism sector. Whilst river flooding and coastal storms are more likely to occur outside the traditional *summer tourist season*, *the risk of summer flooding may increase and sea level rise is an ever increasing threat*.

At the same time, tourism is climate-sensitive and changes in the weather, seasons and climate would impact on the tourism industry affecting the health of destinations, choice of trip and tourist spending. Modelling studies that utilise the Tourism Comfort Index (TCI) indicate that future climate change may result in an improvement in the attractiveness of the UK as a tourism destination and furthermore, extend the tourist season.

On balance, the benefits should outweigh the additional costs. However, projected changes in climate will need careful consideration in both regional and local tourism development, management and planning. Climate change may not only affect tourism through changes in thermal conditions, but also through ecosystem change, impacts on infrastructure and services, effect on access and transport prices, and even changes in economic growth and prosperity.

**Major infrastructure at the coast.** Coastal floodplains contain the types of infrastructure to be found throughout the UK including transport and utilities together with health, education and other services. In addition, coastal floodplains are particularly attractive for certain types of infrastructure including large installations such as power stations and refineries, and transport links in areas with steep inland topography.

As a result, a relatively high proportion of certain types of infrastructure are in areas at risk of coastal flooding and in some cases coastal erosion. For example, about 10% of UK power generation capacity is in the coastal floodplain and this would double by the 2080s if there were no changes in the location or capacity of power stations compared with present day.

Five of the eight sites selected for the next generation of nuclear power stations are in the coastal floodplain and three of these sites are in areas with a high risk of coastal erosion. Whilst these vital strategic installations will be provided with adequate flood and erosion protection, there will be an ongoing need to maintain and improve this protection as the climate changes.

There are important road and rail transport links on the coast throughout the UK, particularly in North Wales, South West England and Scotland. Not only are these vulnerable to sea level rise and coastal erosion, but also they limit the scope for allowing the coast to retreat naturally in many areas. This causes the foreshore to narrow with a consequent loss of intertidal habitats, a process often referred to as coastal squeeze.

### **CONCLUSIONS**

This CCRA is the first in what is to be a 5 year cycle of risk assessments. It was recognised from the outset that the analysis would have to be based on existing data and analyses, with little scope for new research. A key aspect of the reporting was therefore to highlight any limitations or constraints, in order to identify how the next analysis could be improved and where new research could be expected to provide a stronger evidence base.

Implementation of the methodology required the use of a wide range of data, from historical climate observations and future climate projections through to population projections, health questionnaires and industry turnover by sector. The availability of data for some aspects of the research and in some sectors enabled detailed quantitative assessment of future risks but a number of data problems and barriers in other sectors limited the amount or detail of the work that could be done. For example, the most recent coastal erosion data for England and Wales was not available due to licensing problems and there were no suitable data available in Scotland and Northern Ireland.

There is clear evidence from tide gauges and more recently satellite data that sea levels have risen, and linked to rises in global mean temperatures these will continue into the immediate future. Although the magnitude of rises in sea levels are like other climate variables uncertain, we are locked into a certain change, with projected increases from UKCP09 of at least 5cm by the 2020s, and 0.18 to 0.6m by the 2080s. Projected changes in future wave heights are however highly uncertain. This is particularly the case for extremes, with offshore extremes projected to change from a 1.5m decrease to a 1m increase around the UK by the 2080s. However, with the projected rises in sea levels greater wave heights will be experienced at the coastline, resulting in more damage and flooding.

**Need for more work on extremes.** The projections in the CCRA are based on the UKCP09 Low, Medium and High climate projections. These provide projections of increases in mean sea level relative to the land. There is however a concern that future extreme events may become more extreme and the rate of change of extreme high sea water levels may be greater than the values used in the analysis.

This is dealt with to some extent by the use of a range of scenarios. For example, the median sea level rise projection for the 2080s in East Anglia is 0.35 m but the range of scenarios tested was 0.19 m to 0.59 m. However flooding is caused by high surge tides and the change in peak surge tide level may be greater than these projections. In addition, changes in the rate of ice melt might lead to an increase in the rate of rise of the mean sea level. In addition to the UKCP09 scenarios referred to above, a High++ (extreme) scenario range for sea level rise and storm surges was developed. This provides an additional amount of change above the likely range of current models.

The High ++ scenario is intended to provide an extreme but physically plausible range of change for users wishing to investigate contingency planning and the limits of adaptation. However, it is thought very unlikely that the upper end of the High ++ ranges for sea level rise and surge will be realised during the 21<sup>st</sup> century. A simple estimate undertaken in the CCRA analysis suggested that the number of properties at significant likelihood of tidal flooding in England and Wales for a High++ scenario could be more than twice the projected number in the 2080s for the UKCP09 scenarios used in this analysis.

Another concern that has arisen in the CCRA is that wind storms could increase leading to higher waves. The UKCP09 projections suggest that there will be little change in average wind speeds. However it is understood that this work does not cover extreme wind speeds and this remains as an evidence gap.

There is a need to improve the understanding of how future extreme sea levels and storm conditions might change, as these are the main conditions that lead to flooding and high rates of coastal erosion.

**Potential for combined fluvial and tidal (storm surge) events.** The combination of flooding from different sources is of concern, particularly in coastal areas where river flooding and surface water flooding can occur at the same time as high tidal water levels. In this case river and drainage discharges are restricted or prevented by high sea water levels, thus causing an increase in flooding. This type of flood has not been specifically assessed in the CCRA, where the analysis has concentrated on independent projections for tidal and river flooding. However these combinations are likely to increase as a result of sea level rise and projected increases in the frequency and severity of extreme rainfall events.

Tide locking of drainage outfalls is a particular example of combination flooding, where tide flaps on drainage outfalls are closed by high tidal water levels and fluvial flows 'back up' in upstream watercourses or drains, thus causing flooding. The impacts of tide locking will be affected by sea level rise, leading to longer closure periods for tide flaps, and increases in the magnitude and duration of storm rainfall. This will lead to higher fluvial flows during tide lock periods. For these reasons it is likely that flooding from tide lock could increase.

A further type of combined event that was not considered in the CCRA analysis is wave action during periods of high tidal levels. In this case wave overtopping would increase the flood volume. The projected increases in sea level would lead to increases in flooding from wave overtopping, which would be exacerbated if wave heights increase in the future as a result of deeper water near the coast and potential increases in storminess.

There is a need to understand how combination flooding could affect future projections of flooding and, if the effect is significant, improve the national flood modelling used in the CCRA analysis.

The CCRA reports (Defra, 2012) provide a comprehensive statement of the risks facing the UK in a way that allows intercomparison across sectors, whilst retaining an appreciation of the relative confidence in the assessment of the various risks. Inevitably there were many areas that would merit further investigation or research. These were noted in the Sector reports and summarised in the

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Evidence report. These should help guide future research efforts and help inform the next CCRA that will be published in 5 years time.

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