

Impacts of climate change on coastal flooding

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EXECUTIVE SUMMARY

As we reported in 2010/11, extreme coastal water levels and hence the increasing likelihood of coastal flooding in the future are likely to be dominated by climate driven changes to the mean sea level, rather than waves or storm surges. There is a great deal of uncertainty surrounding the magnitude of changes in mean sea level and wind waves (thus extreme events), but not the direction of change for mean sea level. This will increase the likelihood of coastal flooding. Without adaptation this will lead to significant losses to economic, social and environmental assets by the end of this century and beyond. Since sea-level rise is committed to continue beyond 2100, even with immediate stabilisation of greenhouse gas emissions, then policy and adaptation measures require a strategy over a much longer period.

The number of residential properties at significant risk of coastal flooding now is 115,300. This could rise to between 345,000 and 470,000 depending on climate change with no change to population size and location, by the 2080s. Considering population growth too, the number of residential properties at significant risk could be up to 910,000 by the 2080s.

Over the past century, natural variations in storm frequency and magnitude over 10-20 year cycles have been an important climatic factor driving coastal flood risk. In addition the roughly 14 cm rise in mean sea level during the 20th century has significantly increased (as much as doubled) the risk of flooding since 1901 at many locations around the UK coastline.

Development in the floodplain has continued over the last ten years. While the majority (87%) of all new development in England occurs outside the floodplain, the rate of development in the floodplain between 2001 and 2011 was higher (12%) than outside the floodplain (7%). Since 2008, there has been a decline in this rate,

The decline in the rate has been more rapid in the coastal floodplain than in that of rivers, although it still remains above the national average (0.8% per year versus 0.6% per year); and

There has been a noticeable decrease in the rate of development behind eroding coastlines, which is now well below the national average.

1. WHAT IS ALREADY HAPPENING?

January 2013 was the 60th anniversary of the 1953 East Coast floods, when defences were breached by a combination of high tides, storm surge and large waves. It was the UK's worst natural disaster of the 20th Century.

Coastal towns and villages in Lincolnshire, Norfolk, Suffolk, Essex and Kent were devastated as sea water rushed through them. Over 600km² of land were flooded, 307 people were killed and 200 industrial facilities were damaged by floodwater. Over 32,000 people were safely evacuated. A month after the flooding the estimated cost was £40-50

million, the equivalent of around £1 billion today, not including the cost of relocation and interruption of business activity.

Following the wake-up call of 1953, the nation has improved flood and coastal defences, developed forecasting and warning services, exercised and tested integrated emergency management, and engaged with local communities.

Consequently, the likelihood of defences failing or being overtopped by extreme coastal water levels is now substantially lower. In particular, the construction of the Thames Barrier in London and associated flood defence systems along the

east coast of England now means that there is a good level of protection against storm surges and exceptionally high tides. The flood defences through the Thames Estuary were largely designed to manage the water levels that have a 1:1000 chance of occurring per annum.

In Wales large-scale coastal defence schemes are being progressed at a number of locations including Borth in Ceredigion, Colwyn Bay in Conwy, West Rhyl and Denbigh in Denbighshire and Riverside in Newport. These schemes are being taken forward with the support of the European Regional Development Fund and are part of a programme aiming to reduce risk for over 3,000 properties across Wales.

In Scotland, there has also been an expansion of coastal flood defence with the new Bo'ness scheme on the Forth estuary complete (protecting 270 homes and businesses). The part-tidal phase of the Inverness flood prevention scheme commenced construction in late 2012. When complete the entire river Ness Scheme will protect 950 homes and business to a 1:100 year standard (water levels expected once every 100 years). In addition, flood risk in the tidal reaches of the Clyde, which is also prone to storm surge, has been reduced by new flood defence works at North Renfrew. Schemes have been promoted by Local Authorities with 80% grant aid from the Scottish Government.

However, the risk of flooding from the sea on the East Coast remains a threat which has a high impact, even if it has a low probability. This risk is recognised by government and is the most geographically specific risk (H19) on the “National Risk Assessment”. The improvements in flood defences have led to significant development of homes, businesses and infrastructure behind them. The Cabinet Office assessment is that we are less likely to experience such flooding due to improvement in flood defences but, were a storm surge on such a scale to breach coastal flood defences, the impacts would be potentially more serious than in 1953.

The 1953 flood, the following response and the changing vulnerability of the coastal floodplain show that coastal flood risk depends on a number of factors:

- the hazard source—extreme coastal water levels,
- the hazard pathway—presence, performance and condition of coastal defences as well as,
- the receptor of the hazard—the number and vulnerability of people and property exposed to a flood.

We structure this report card around that source, pathway, and receptor framework. We also consider the management plans in place to address current and future flood risk and the key groups coordinating coastal management.

Current trends in the sources of coastal flood risk

Coastal flooding is a present and real risk. Figure 1 shows flooding following a storm surge and sea wall failure in Walcott, Norfolk.

The main source hazards of coastal flood risk are mean sea level, storm surge and wave climate. In estuaries, the interaction of the tide with river in flows is also important.



Figure 1: Walcott flooding November 2007.

Trends in mean sea levels show an increase from the 19th to the 20th centuries. Global sea level rose by about 1.8 mm/y during the 20th century, and the rate of sea-level rise observed by satellites since 1993 is 3.2 mm/yr (for more details, see Horsburgh and Lowe, 2013).

Whether the faster rate of increase during the latter period reflects decadal variability or an increase in the longer-term trend is not clear.

The 14 cm rise during the 20th century has significantly increased (as much as doubled) the risk of flooding since 1901 at many locations around the UK coastline, Defra (2010). In terms of risk, the most affected regions are those where relative land movement due to glacio-isostatic rebound is adverse, such as the south (as opposed to Scotland), or where extreme levels increase only slightly with return period. In fact, recent investigations show that uplift rates in Scotland are modest and are less than rising sea levels while there are long lengths of the Scottish coastline where glacio-isostatic effects are small but enhancing (Rennie and Hansom, 2011).

Mean sea level is driven by many climate-change related processes, i.e. global warming leading to oceanic thermal expansion, glacier and ice-cap melt, modifications to hydrological exchanges between land and ocean, etc. Consequently, if MSL is changing, it points to major changes in one or more of the drivers of that change. Ultimately, anthropogenic climate change appears to be the fundamental issue, although the attribution of the ‘budget’ of sea-level rise remains a major research question (Bindoff *et al.*, 2007).

While changes in storminess can contribute to changes in sea level extremes, the uncertainty associated with storminess—and in particular the dominant effect of decadal variability—means that there is no evidence for systematic changes in storminess resulting in any detectable change in storm surges or waves (IPCC, 2012). Most UK records do not present evidence for long term changes in statistics of surges (non-tidal variations from mean sea level), including that from the UK’s longest time series (from Liverpool since 1768). Woodworth and Blackman (2004) demonstrated that trends in high water extremes measured over several decades at most locations tend to follow the corresponding trends in mean sea level. This has been confirmed by Menéndez and Woodworth (2010).

Joint Defra/Environment Agency work on future river flows suggests that river flows are likely to increase, and in some locations very significantly. This could be an additional issue in estuaries where the tidal/fluviol interaction is important, e.g. The Thames in West London (Defra, 2009).

Current trends in the hazard pathway of coastal flood risk

Anything that acts as a barrier between the sea and the land can be considered to be a coastal defence. Often only the hard structures, such as sea walls and rock armour, were considered but recently the value of natural defences, such as sand dunes and saltmarsh, has become more widely recognised.

Approximately 44% of the England and Wales coastline, and 6% of the Scottish coastline, is defended by hard structures (Defra, 2010).

Beach nourishment is also part of the set of activities to manage coastal flooding and erosion. Between 2005 and 2009 in England and Wales 75 licences were issued for beach nourishment schemes compared to 30 for coastal erosion protection, 15 for sea and flood defences and 19 for scour protection—this gives an indication of the amount activity on the coast in recent years (Defra, 2010).

These activities sit within a hierarchy of shoreline management. Typically this hierarchy consists of,

- Large-scale plan is the Shoreline Management Plan (SMP). It sets the policies for managing coastal risks.
- Where appropriate a Coastal Strategy Study may be produced. The Strategy identifies appropriate Schemes to put the policies into place, and suggests a coordinated programme of work for that stretch of coastline.
- At a local level a Scheme will then develop and implement a coastal defence proposal for a particular location.

An SMP is a 'living' document used by the operating authorities and other organisations (e.g. the Local Authority, Environment Agency, Natural England, Scottish Natural Heritage) to consider the planning and implementation of sea defences and other maritime works. It is also used by Defra and the Environment Agency, and the Scottish Government, when considering applications from the operating authorities to fund various coastal defence works.

Shoreline Management Plan is a non-statutory document that provides a broad assessment of the long-term risks associated with coastal processes.

Once the SMP has set sustainable policies for how the shoreline should be managed, the works required to implement the policies are assessed for each stretch of coast, to develop a coordinated programme of works.

SMPs provide a long-term framework for dealing with coastal flooding and erosion over a large area. SMPs take into account risks to people and the developed, historic and natural environment. They also take climate change into account in planning long-term coastal management.

There were originally 28 SMPs for the coastline around England and Wales which were produced between 1995

and 1999. There are a further 8 in Scotland. In England and Wales, the plans have since been updated and replaced by 22 second generation SMPs under Defra's Making Space for Water strategy. Local authorities have produced 18 of the new SMPs, whilst the Environment Agency produced the other four (those where coastal flooding presents the predominant risk in the SMP area).

All of the new SMPs can be found via the Environment Agency's website. The new SMPs are more rigorous in addressing the consequences of shoreline management on the natural environment, such as local habitats and Special Sites of Scientific Interest (SSSIs).

<http://www.environment-agency.gov.uk/research/planning/105014.aspx>

A map showing the location of different SMPs around the coastline of England and Wales is available on the Defra website. <http://archive.defra.gov.uk/environment/flooding/documents/who/cgsmp2.pdf>.

And for Scotland, on the SNH website

<http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/6.1.shtml#figure6.2>

Current trends in the hazard receptor

Risk can change either if the probability of an event occurring changes, or if the consequences of an event alter. Continuing to locate vulnerable assets in areas that are exposed to flooding will increase the consequences when a flood occurs, in terms of damages to people and property. Land use planning decisions can reduce exposure to current and future flood risk by avoiding inappropriate development within the floodplain and other areas at risk from flooding and coastal erosion. Where development in flood prone areas is considered necessary, the land use planning system can potentially reduce risk by requiring it to be designed in a way that minimises damages should flooding occur, and does not increase risk elsewhere. This is, in essence, the UK and Scottish Governments' policy on flood risk and development, as set out in the National Planning Policy Framework, and in the new Scottish Planning Policy. For infrastructure providers, Defra encourage operators to increase their site resilience: that is the ability of the site to maintain operation, or return to operability quickly, even if flood waters enter.

Development in the floodplain has continued over the last ten years (Climate Change Committee, Adaption Sub-Committee, 2012). While the majority (87%) of all new development in England occurs outside the floodplain, the rate of development in the floodplain between 2001 and 2011 was higher (12%) than outside the floodplain (7%). There have been some changes in the annual rate of development since 2008:

- the rate has declined slightly in the river floodplain, in line with the national fall in the rate of development due to the recession;
- the decline in the rate has been more rapid in the coastal floodplain, although it still remains above the national average (0.8% per year versus 0.6% per year); and

- there has been a noticeable decrease in the rate of development behind eroding coastlines, which is now well below the national average.

Most floodplain development has been within built-up areas that are already protected by flood defences. Just over 80% of development in the floodplain since 2001 has been in locations where the current chance of flooding is low or moderate, either due to the presence of existing flood defences or because of floodplain topography. In the sample of 42 local authorities development plans, 70% of allocations in the floodplain were on previously developed (brownfield) land within existing built up areas (Climate Change Committee, Adaptation Sub-Committee, 2012). Equivalent figures on floodplain development are not published for Scotland.

Although there is evidence of local authorities requiring safety and resilience measures for floodplain development, there is no national dataset available to assess uptake.

Although development in the floodplain generally appears to be well protected from flooding, it could leave a legacy of rising costs of protection and residual flood damage in the face of climate change. The local authorities studied generally assume that the benefits of continuing to develop in the floodplain outweigh the costs rather than looking at alternative locations first. At some point in the future this will change as sea levels continue to rise and protection becomes extremely expensive. These long-term costs may outweigh the short-term benefits of development in some locations. Local authorities are required to set out and consider such trade-offs when preparing their development plan through the Sustainability Appraisal process. None of the Sustainability Appraisals studied had attempted to estimate the long-term costs from development in the floodplain in a quantified way (Climate Change Committee, Adaptation Sub-Committee, 2012). This means that some development decisions being taken today are likely to be inadvertently increasing the costs of adaptation in the future.

Coastal Groups

Coastal Groups are partnerships composed of coastal local authorities, the Environment Agency (in Scotland, the Scottish Environment Protection Agency, SEPA) and other organisations with coastal management responsibilities.

Coastal Groups, termed Forums in Scotland are key to maintaining a partnership approach to both strategic and local coastal management. National and regional coastal teams regularly meet with them to discuss coastal management. There are seven covering the coastline of England and Wales, slimmed down from 16 in 2008. In Scotland the national Scottish Coastal Forum provides a coordination role for the 7 local coastal partnerships. They provide a forum both for showcasing local initiatives and for strategic coastal management, principally by developing Shoreline Management Plans (SMPs):

- to be a source of expertise on the coast, and to advise and influence Regional Flood and Coastal Committees on matters relating to the coast;

- to contribute to the Environment Agency's preparation and implementation of a long term investment strategy for the management of flood and erosion risks;

- to develop Shoreline Management Plans (SMPs) that provide a strategic, joint approach to the management of coastal flood and erosion risks;

- to involve all parties with a vested interest in coastal management so that they can achieve the best long-term results for local residents, business, industry and wildlife.

Local Coastal Group information is available on the 'Standing Conference on Problems Associated with the Coastline' (SCOPAC) website.

A map showing the areas of the coastline covered by the different Coastal Groups is also available on the SCOPAC website.

<http://www.scopac.org.uk/coastalgroups.htm>

In Scotland, Wales and Northern Ireland, responsibility for flood and coastal erosion risk management policy has been devolved to the respective Devolved Administrations. In England, the responsibility rests with the Department for Environment, Food and Rural Affairs (Defra).

2. WHAT COULD HAPPEN?

It is expected that the greatest driver to the source of coastal flooding will be the impact of global warming on mean sea levels, through various processes including thermal expansion of the oceans and loss of land ice to the sea. Projections of future sea level rise are provided in UKCP09 and summarised by Horsburgh and Lowe (2013). UKCP09 is based on IPCC 4AR sea level projections. All UKCP09 projections of future sea-level rise show an increase in mean sea level over time. Although, the rate of rise is uncertain, we can be very certain that decade by decade the risk of coastal flooding, without additional action, will increase.

There is mixed evidence on the issue of whether sea-level rise will exceed the IPCC range in 4AR. This is discussed in the 2013 MCCIP report on sea level (Horsburgh and Lowe, 2013). The AVOID programme, Met Office 2010, reported to UK government that sea level increases of up to around 2m cannot be ruled out by 2100, but such large rises are currently considered to have a low probability.

The AVOID researchers advised that given the significant uncertainty in future projections and rate of sea-level rise:

- Monitoring of sea level should continue.
- Physical model improvements are a scientific priority, especially ice sheet processes.

For those involved in the management of the coast, Defra and the Environment Agency recommend a managed adaptive approach. The aim of the approach is to build flexibility into our decisions today so that they can be 'adjusted' depending on what happens in the future.

There are two elements of the managed adaptive approach. One approach is to build in the ability to adjust an option should it be required—flexible options. Examples include

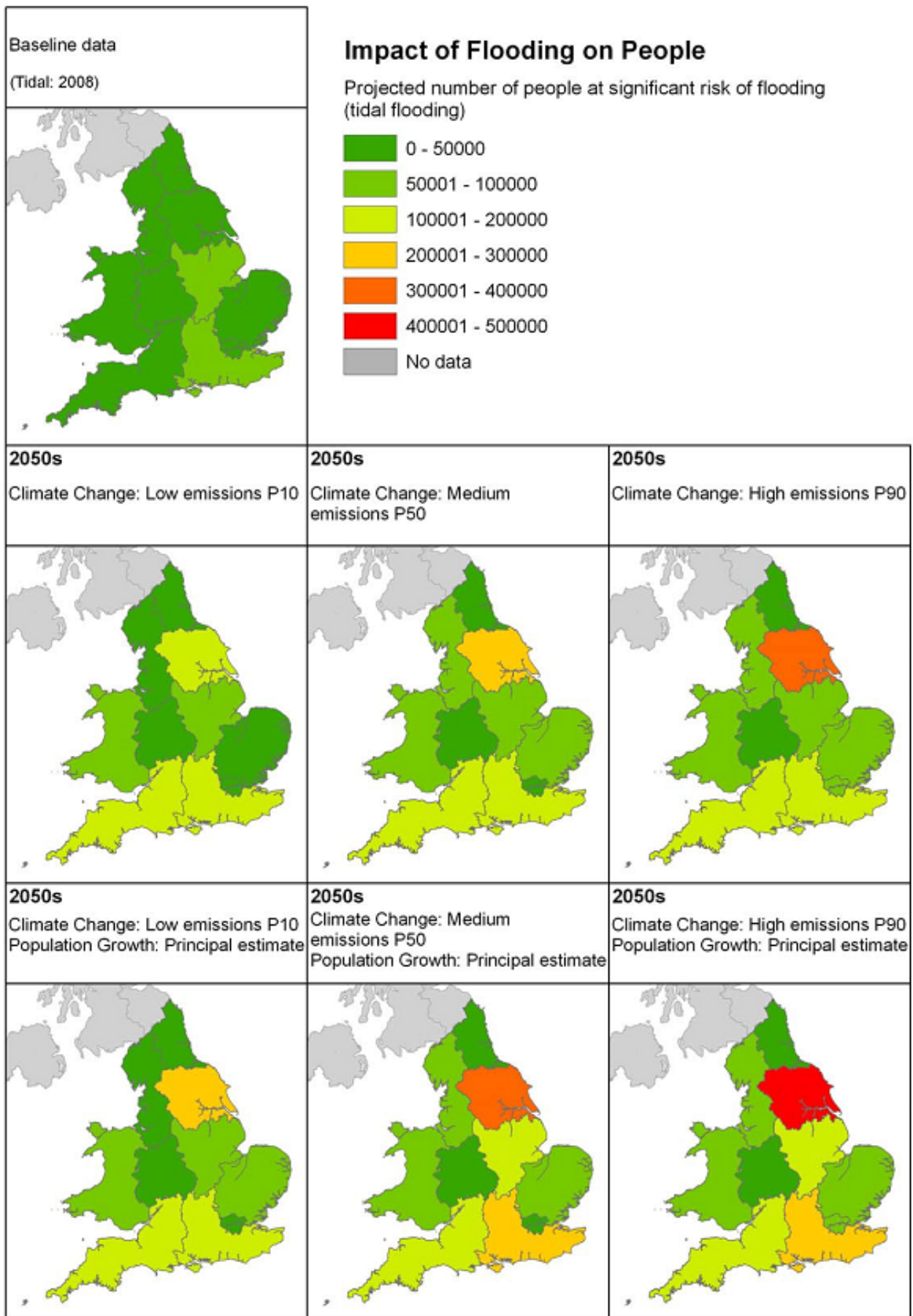


Figure 2: Number of people, in England and Wales, at significant risk of tidal flooding for different climate change scenarios today and for the 2050s. Taken from the National Climate Change Risk.

purchasing a small additional strip of land to the rear of a new flood bank to enable it to be raised if necessary or providing larger foundations to a flood wall to enable later raising with minimal work and disruption.

A complementary approach is to build flexibility into the decision process itself through waiting and learning — flexible plans. For example, sequencing options so that no or low regret options are taken earlier and more inflexible measures are delayed in anticipation of better information. The approach is described in detail in Environment Agency guidance, and all new schemes that may potentially receive Government funding are required to consider the approach in England.

Future impacts of coastal flooding

Government's National Climate Change Risk Assessment (CCRA) (Defra, 2012) provided a new assessment of the future risks from flooding. The purpose of the CCRA is to provide underpinning evidence, assessing the key risks and opportunities to the UK from climate change, to identify priorities for action and to implement climate adaptation policies for current and future policy development as part of the statutory National Adaptation Programme.

The CCRA presents quantified analysis of the potential future impacts of flooding in the UK from all sources under different climate change scenarios as well as different socio-economic scenarios. Detail analysis is provided of the potential impacts of coastal flooding to a series of metrics. Most of the analysis is based on information for England and Wales, which is supported by quantified models. Suitable information for analysis was not available for Scotland and Northern Ireland, which together represent about 6% of the flood risk to the UK as a whole, by number of properties at risk.

The CCRA reported that flooding is one of the most significant risks the UK faces from climate change. Increases in the frequency of flooding would affect people's homes and wellbeing, especially for vulnerable groups (e.g. those affected by poverty, older people, people in poor health and those with disabilities), and the operation of businesses and critical infrastructure systems (Figure 2). Annual damage to UK properties due to flooding from rivers and the sea currently totals around £1.3 billion. For England and Wales alone, the figure is projected to rise to between £2.1 billion and £12 billion by the 2080s, based on future population growth, a medium emissions scenario and if no adaptive action is taken.

A 0.1% (1:1000) coastal flood in the East of England could occur about 5 times more frequently in the 2080s based on a P50 Medium Emissions Scenario. The range for different scenarios is about 2.4 to 14 times the present day frequency.

A 0.1% (1:1000) coastal flood in Wales could occur about 8 times more frequently in the 2080s based on a central estimate (50th percentile) of the medium emissions scenario. The range for different scenarios is about 3 to 40 times the present day frequency.

The number of residential properties at significant risk of coastal flooding now is 115,300. This could rise to between 345,000 and 470,000 depending on climate change with no change to population size and location, by the 2080s. In addition to the increase in flood risk to existing properties and infrastructure, it is projected that the overall increase in flood risk could be substantially greater if new development occurs in the floodplain at the same rate as elsewhere, based on projected population growth and the number of homes and other buildings that would be constructed in floodplains. Considering population growth too, the CCRA suggests that the number of residential properties at significant risk could be up to 910,000 by the 2080s.

The CCRA lists a number of mechanisms through which rising sea levels could impact the coastal zone. These include,

- increased tidal inundation impacting coastal populations through loss of life, loss or damage to properties, damage to agriculture, business disruption and social/community disruption;
- loss of land through coastal inundation or land being submerged;
- loss of habitats both through coastal squeeze against raised land or coastal defences, as well as inundation of landward freshwater habitats;
- damage to infrastructure, notably energy, transport, water, health and communications networks;
- loss of architectural or cultural sites;
- increased pumping costs for land drainage, and increased risk of inundation behind coastal defences; and,
- impact on recreational, leisure and tourist activities.

Rising sea levels may accelerate coastal erosion and the deterioration of coastal flood defences through a number of mechanisms, such as beach scour, cliff stability, near shore morphological change and increased wave overtopping.

Climate change has been taken into account in flood and coastal erosion risk management legislation, policy and guidance for several years, and the concept of responding to a changing climate is well established. For example, allowances for climate change in the planning of new capital works have been applied since the 1990s. The impacts of climate change on flood risk are also taken into account by planning authorities in local planning decisions. The CCRA did not assess these current adaptation activities, rather it painted a picture of the risks we face if no consideration of climate change is undertaken.

A key challenge, however, is the fact that most of the people and assets at risk from flooding are already present in the UK's floodplains. Furthermore, measures to reduce this risk (e.g. flood defence schemes) can be very expensive. Overall, adaptation in this sector is likely to be a gradual process where defences are improved a little at a time, resilience of critical infrastructure is steadily enhanced and planning decisions take account of increasing flood risks. Decisions over the long term viability of coastal protection especially

for land with low economic value will be a challenge for coastal communities and Government too.

3. KNOWLEDGE GAPS

Key research requirements to improve our understanding of coastal flooding are:

Understanding the potential changes to the hazard source

- Monitoring of sea level should continue.
- Physical model improvements are a scientific priority, especially ice sheet processes.
- A more complete examination of the future wave and storm surge climate projected.
- Improved understanding of change to joint probabilities of extreme water levels.

Understanding the potential changes to the hazard pathway

- Improved understanding of the impact of climate change on coastal defence deterioration rates, fragility and failure.
- Improved understanding of the flood management contribution from natural systems such as inter-tidal habitats.

Understanding the potential changes to the hazard receptor

- A reliable prediction of new coastal development, the siting of new infrastructure and the required level of protection.
- An integrated assessment of the potential flood losses arising from these projections, including ecosystem goods and services.

Understanding of the interaction between coastal flooding and coastal evolution

- Detailed scientific understanding of sediment transport processes and coastal morphology over long (decadal-centennial) timescales.
- Improved understanding cliff stability and morphology.

In addition, some decisions require the consideration of very long planning timescales, such as new nuclear power stations or nuclear waste depositories. Understanding how sea levels may change beyond 2100 is an increasing requirement to support these decisions.

4. SOCIO-ECONOMIC IMPACTS

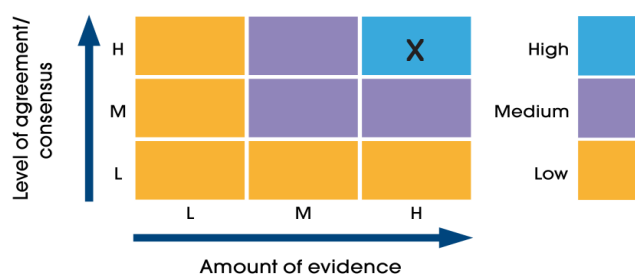
The assessment described above has taken an integrated approach in assessing coastal flood risk and how it may change. Both vulnerability and exposure are key to understanding flood risk. The current human response to that risk and planned adaptation to the risks are also part of that picture.

5. CONFIDENCE ASSESSMENT

What is already happening?

Observational evidence for present day sea level (including land movement), storm surge and waves processes are of the highest quality. Present day flood risk (including exposure) is also quantified to a high degree of precision helped by numerical flood mapping and precision LIDAR shoreline

data, so our understanding of what is already happening is high. We are less certain of the long term resilience of new development within the coastal floodplain; there are no national statistics to quantify this, although evidence is available that generally new development is appropriately designed.



What could happen?

Projections of the future rely on the accuracy of (i) our projections of mean sea level combined with the uncertainty surrounding future surge and wave climates and (ii) estimates of coastal development and land use. Both of these are known poorly but the projected trend in mean sea level has certainty about its direction (despite a range of values for its rate) so an increased risk of coastal flooding has high certainty.



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