Climate change impacts on coastal flooding around the UK and Ireland

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KEY FACTS

What is already happening

- Extreme water levels have become more frequent in the past 150 years, driven primarily by mean sea level rise.
- Mean sea level rise, along with coastal squeeze, changes in sediment supply, variations to ocean chemistry and pollution are contributing to a decline in the extent of saltmarshes and sand dunes, which act as a natural buffer to flooding.
- Exposure to flooding and vulnerability of ecosystems are being exacerbated by population growth, changes in land use and increasing asset values in the floodplains.

- Increased flood risk has largely been contained through improved flood defences, flood forecasting and emergency response. However, losses from major events that exceed design standards are growing in frequency.
- Preliminary results from ongoing research on compounded effects of flooding suggest that risk of flooding is significantly underestimated under today's climate and into the future.

What could happen in the future

- Extreme water levels are certain to increase during the 21st century and beyond, principally driven by accelerating mean sea level rise.
- Continued loss of natural habitat buffers will dramatically increase flood-defence capital and maintenance costs.
- By the 2080s, at current adaption levels, the cost of estimated annual coastal flood damages is likely to increase two-to three-fold from £360 million today, depending on temperature rise and population growth.
- 1,600 km of major roads, 650 km of railway, 92 railway stations and 55 historical landfill sites are likely to be at risk of coastal flooding or erosion by the end of the century.
- Socially vulnerable communities at the coast are disproportionally at risk, and this will increase more rapidly than for other communities, enhancing inequalities.
- For some coastal locations it will unfortunately no longer be technically or economically feasible to provide protection from flooding and coastal change. Initiatives such as the Coastal Transition Accelerator Programme are ongoing to explore, enable and accelerate the transition needed for coastal areas that cannot sustainably be defended in the long term.

SUPPORTING EVIDENCE

Introduction

Coastal floods are amongst the most dangerous natural hazards globally. This also applies to the UK where flooding is one of the highest priority risks for civil emergency (Cabinet Office, 2015) and to Ireland, where coastal flooding was identified as the top sectoral priority for marine climate services (Fitzhenry and Nolan, 2023). Recent floods (e.g. winters of 2013/14, 2019/20 and 2022/23) have demonstrated the ever-present threat of serious flood impacts in coastal regions, despite improved flood-protection measures and technology that has provided tools to forecast and mitigate risks. While flood-defence standards in the UK and Ireland are among the highest in the world, significant populations and assets in the coastal flood plain are threatened in the event of defence failure during events exceeding the standard of protection (e.g. major overtopping or a breach). Annual average economic damages from coastal flooding in the UK are around £540 million currently (Sayers et al., 2015). Furthermore, coastal flooding is a growing threat due to accelerating mean sea level rise and possible changes in tides and storminess associated with climate change (Palmer et al., 2018; Fox-Kemper et al., 2021). There is also a continued decline in natural habitats that act as natural coastal protection, such as saltmarshes and sandy shorelines (e.g., Masselink et al., 2016, 2022; Burden et al., 2020). Impacts of coastal flooding are projected to increase in the future with population growth, urbanisation, continued development in low-lying coastal areas (Stevens et al., 2016) and habitat degradation (Bednar-Friedl et al., 2022).

Throughout history, many severe flooding events have affected the UK and Irish coast (Haigh et al., 2015; 2017). In 1607, a major coastal flood on the west coast of the UK caused the greatest loss of life from any sudden-onset natural catastrophe in the last 500 years, resulting in the deaths of around 2000 people (Horsburgh and Horritt, 2006). The ‘Big Flood’ of 31 January–1 February 1953, killed up to 300 people in eastern England and 30 people in Scotland, 24,000 people had to evacuate their homes and damage cost £1.2 billion, at 2014 values (McRobie et al., 2005). In 2002, significant coastal flooding occurred in the Dublin region causing damage of 60 mEUR (Dublin City Council, 2021) and triggering a revision of Dublin’s coastal flooding defences. During the winter of 2013/14, the UK and Ireland experienced an unusual sequence of extreme storms and some of the most significant coastal floods in the last 60 years (Thorne, 2014; Spencer et al., 2015).

The multiple drivers of coastal flood risk can be considered using the conceptual Source−Pathway−Receptor−Consequence (SPRC) model (Figure 1) (Sayers et al., 2002). The ‘source’ describes the origin of a hazard, which in the case of coastal floods, is extreme total water levels (Moritz et al., 2017). The ‘pathway’ is the route that a hazard takes to reach the ‘receptors’, the processes mediating the magnitude of the hazard along that route and the characteristics of the coastline that influence the hazard. For coastal flooding it reflects how seawater makes its way onto normally dry land. The ‘receptor’ is the entity (e.g. people, property, environment) that may be harmed by the hazard (e.g. seawater inundation and/or wave impact). ‘Consequences’ entail the social, economic and environmental effects of the coastal flooding on the receptors, the calculation of which are extremely sensitive to small changes in the source conditions (Lyddon et al., 2020) and to changes in the pathways (Nicholls et al., 2015; Pollard et al., 2019).

This MCCIP report card is structured around the SPRC framework and updates the previous report cards on coastal flooding in 2013 (Donovan et al., 2013), 2017 (Haigh and Nicholls, 2017) 2020 (Haigh et al., 2020a) and 2022 (Haigh et al., 2022). We describe what is already happening and what could happen in the future using the SPRC components; we show how change can increase flood risk, and equally how management can reduce flood risk. We then state what qualitative level of confidence we can place in the science for 'what is already happening' and 'what could happen in the future'. Finally, we briefly highlight key challenges and emerging issues.

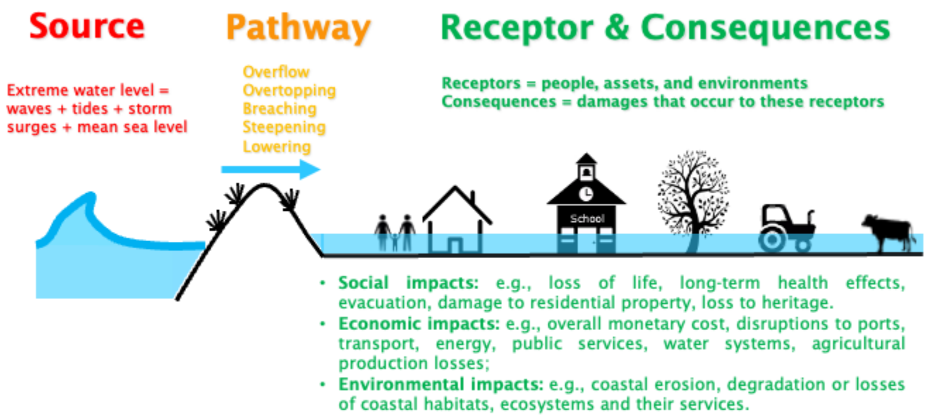


Figure 1: Source-Pathway-Receptor-Consequence (SPRC) conceptual model.

What is already happening?

Source: Coastal floods are driven by extreme total water levels, which arise as combinations of: (1) relative mean sea level; (2) tides and their low frequency anomalies; (3) storm surges; and (4) waves, especially setup (i.e., the average water level increase due to breaking waves) and runup (i.e., the maximum vertical extent of wave uprush on a beach or structure). These factors experience topographic amplification near the coast and there are non-linear interactions between the four components. The additional influence of rainfall and fluvial input may also be significant in some estuaries dependent on size, river regime and transmission time (Svensson and Jones, 2002; Hawkes, 2005; Hendry et al., 2019; Robins and Lewis, 2019; Harrison et al., 2021), showing the importance of considering flooding from both marine and fluvial/pluvial sources in some areas. These four components exhibit considerable natural seasonal and year-to-year variability. While the tidal component is deterministic, with predictable modulations on fortnightly, monthly, seasonal, 4.4-year and 18.6-year timescales (Haigh et al., 2011), the variability in the wave, storm surge and mean sea level components is stochastic and linked to regional climate cycles, such as the North Atlantic Oscillation (Hurrell, 1995). The seasonal and year-to-year variability in each component influences the potential frequency and magnitude of flooding (Wadey et al., 2014). Longer-term changes in any, or all, of the components can lead to variations in the frequency and magnitude of extreme sea levels. For the North Sea, Horsburgh et al. (2021) assessed “grey swan” extreme water level events (i.e., an event which is expected on the grounds of natural variability but is not within the observational record) and showed that over the next few decades, the natural variability of mid-latitude storm systems is likely to be a more important driver of coastal extreme sea levels than either mean sea level rise or climatically induced changes to storminess.

Extreme water levels are affected by changes in relative mean sea level both directly (e.g. with mean sea level rise, a lower storm surge elevation at high tide is necessary to produce a sea level high enough to cause flooding), and indirectly (e.g. changes in mean sea level alter water depths and therefore modify the propagation and dissipation of the tide and storm surge components (Lyddon et al., 2018a), or alter wave processes in shallow water (e.g. refraction, Dornbusch, 2017), without any change in the frequency of occurrence of extreme events). In addition, extreme water levels may change with variations in the speed, tracks and strengths of weather systems, which alter the frequency, intensity, and/or duration, of waves and storm surges (Palmer et al., 2018; Wei et al., 2020) and variations in rainfall and river discharge in estuaries (Robins et al., 2021; Harrison et al., 2021). Finally, the relative importance and duration of influence of any of the four components is linked to the local tidal range and wave exposure, with some (e.g. mean sea level rise) having higher impacts in low-energy micro-tidal than in high-energy macro-tidal environments.

Current trends in still water levels (i.e., the water surface elevations that exclude wave effects), and storms and waves, are detailed in report cards by Horsburgh et al. (2020) and Bricheno et al. (2025), respectively. In brief, there is overwhelming scientific consensus that observed increases in extreme still water levels around the UK, Ireland, and worldwide have been driven primarily by the rise in relative mean sea level (as illustrated for the UK’s longest high-frequency tidal gauge record – Newlyn in Cornwall, Figure 2). In Ireland, studies of extreme sea levels have been hampered by a lack of available data, meaning Irish extreme water levels are often not analysed as part of regional or global studies (e.g. Calafat and Marcos, 2020). However, historical data recovery efforts have the potential to fill this gap (Murdy et al., 2015; McLoughlin et al., 2024). Mean sea levels around Ireland have increased in line with UK studies with vulnerabilities highlighted for the major cities of Cork and Dublin due to isostatic effects exacerbating relative sea level rise at a local level (Pugh et al., 2021; Shoari-Nejad et al., 2022). As a result of mean sea level rise, extreme sea levels that previously had a long return period (>100 years) near the beginning of the 20th century now have much lower (~10 year) return periods. There is little evidence for long-term systematic changes in storminess or storm surge magnitude over the last 100 years above natural variability (Marcos et al., 2015; Mawdsley and Haigh, 2016). However, there is some observational evidence for small changes in tidal range at select sites around the UK and elsewhere worldwide (Mawdsley et al., 2015). This has slightly increased or decreased extreme high water levels. The drivers of these changes remain unclear, although it is likely that they relate to changes in local bathymetry (mainly dredging for navigation) and/or climate related variations (Haigh et al., 2020b). Since the 1990s, storm tracks in the North Atlantic have shifted poleward and storm frequency has increased. Significant wave heights have decreased in northern UK waters and increased in southern waters, though high variability means observed trends cannot yet be definitively attributed to climate change (Bricheno et al. 2025).

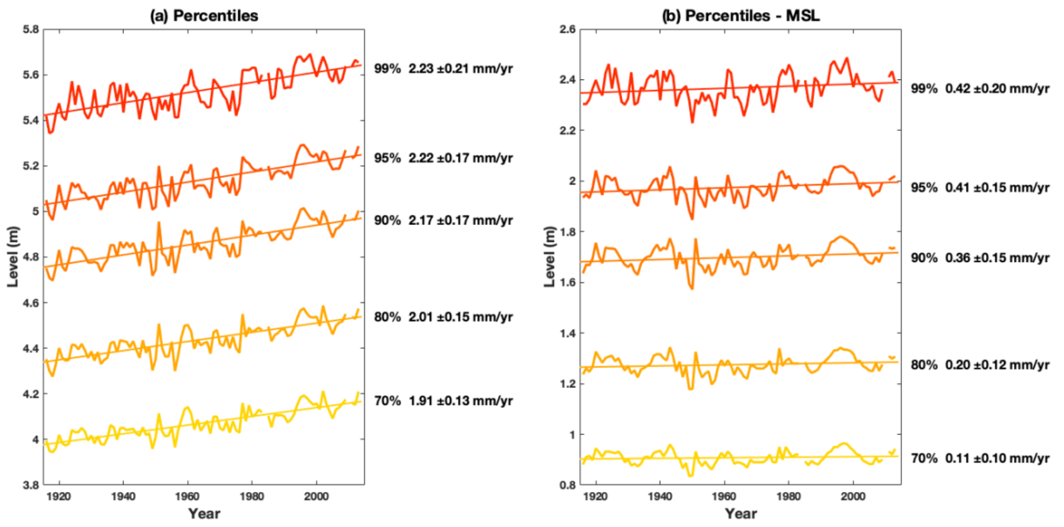


Figure 2: Trends in high water level percentiles at Newlyn, Cornwall (a) before; and (b) after, removing the influence of relative mean sea level rise. The magnitude of the trend is given in mm/yr with a standard error. Trends in the different high water level time–series are all statistically significant at 95% confidence (i.e. two standard errors), but after removing mean sea level none of the trends are statistically significant. This highlights that extreme water levels have increased at Newlyn and that the increase has primarily been driven by the rise in relative mean sea level.

Pathway: In a natural environment, the position of the pathway moves landwards with mean sea level rise (e.g. Orford et al., 1995) although pathways have been maintained in many locations for well over a century and have by now experienced mean sea level rise of ~0.3 m over the last 150 years (Hogarth et al., 2021). The nature of flood pathways varies around the coast and is primarily determined by natural features and their topography or engineered hard defences. Seawater can inundate normally dry land via several different pathways. First, by still water simply overflowing where the water height exceeds the elevation of the land or the barrier that normally separates them. Second, by overtopping of a natural (e.g. barrier beaches) or artificial (e.g. sea wall) barrier by waves (Brown et al., 2021). Third, by breaching and lowering of a natural or artificial barrier, often as a consequence of prolonged overwashing ('rollover') or erosion at the front-face of the barrier allowing more water to flow landward. Fourth, by the process whereby the cross-shore profile does not retreat or progress as an equilibrium profile, but develops towards a steeper profile or coastal steepening, allowing bigger waves to reach the shoreline or toe of coastal defence structures (Talor et al., 2004). Fifth, the lowering of the foreshore platform (Sayers et al., 2022).

Decline in natural features and deterioration in artificial ones over time impact flood pathways and can increase the flood hazard. In contrast, for example, artificial nourishment and stabilisation of beaches, replacement of beaches with hard defence (Dornbusch, 2019), building new or improving existing banks along estuaries, or providing more space for water through managed re-alignment can alter flood pathways and reduce flood risk (Huguet et al., 2018). Management interventions can increase flood risk if not appropriate for the site, and numerical modelling tools can be used to consider the site-specific impacts of new artificial features (Pontee, 2015). Larger scale changes in subtidal morphology like dredging (van Maren et al 2015; Ralston et al., 2018) can influence both the source (tidal range) and also flood pathways (changes in sediment regime; Philips et al., 2017).

Determining changes in historical, current and future flood pathways is more difficult than assessing variations in flood sources, due to the combined natural and human elements at play and the lack of appropriate long-term datasets in the relevant parameters (e.g. saltmarsh extents, alterations to shingle beaches, full history of flood defences, etc). However, innovative approaches are being developed to assess changes in flood pathways for more recent time periods, using, for example, social media (e.g., Brown et al., 2021) and novel measurement technologies (e.g., WireWall, which measures the speed and volume of overtopping; Figure 3), and holistic coastal morphological modelling for decision making (Environment Agency, 2019). It is increasingly recognized that natural systems, such as saltmarshes, shingle beaches and sand dunes, provide important buffering against floods (e.g., Masselink et al., 2016, 2022), and that their decline increases flood risk (Committee on Climate Change, 2018). These systems are part of the natural pathways and influence them by reducing wave height in some locations in front of human-made defences or reduce the water volume in case of a breach by maintaining a higher sill level in the breach area (Thorenz et al., 2013). Coastal ecosystems can migrate landward or grow vertically in response to mean sea level rise, but their resilience will be compromised by ocean warming and other anthropogenic drivers, and their migration by hard infrastructure (Bednar-Friedl et al. 2022).

Figure 3: A hard-engineered coastline with railway infrastructure and a new wave overtopping measurement system, "WireWall". Photo from the University of Plymouth's Dawlish camera installed as part of the Coastal REsistance: Alerts and Monitoring Technologies (CreamT) project.

Current flood risk, during events with the presently designed standard of protection, would be far higher without the decades of investment into extensive flood risk management infrastructure (Environment Agency, 2014). While hard defences to Hold the Line require increasing investment in maintenance and lock society into the cycle of failure and rebuilding, nature-based defences are more sustainably but require space to evolve (e.g. Le Cazannet et al 2022). Data on flood defences over time is not well-developed. It is clear that massive investments in defences have occurred over the 20th and early 21st century. Events such as the 1953 flood were an important trigger. It is estimated that about 720,000 properties were protected from the high sea levels during the 5–6 December 2013 event because of flood defences (Environment Agency, 2016). However, flood defences were damaged during the 2013/14 season and the cost of repair (including fluvial defences) has been estimated to be approximately £147 million (Environment Agency, 2020), thus more-proactive planning is now being promoted. Nearly a quarter of England's 4,500 km of coast is now defended (Sayers et al., 2015) and several new schemes are being built or are planned, such as those associated with Thames Estuary 2100 (Environment Agency, 2012) many of which are in protected areas. The UK also has movable storm surge barriers, including the iconic Thames Barrier, which became operational 1982, and smaller barriers in the Thames, Hull, Ipswich and Boston. The Thames and Hull barriers close on average two and 12 times per year, respectively. The Thames Barrier was closed an 'exceptional' 50 times in the winter of 2013/14, the maximum recommended number, but this was predominantly to manage high fluvial flows highlighting the fluvial/coastal relationship of the source in estuaries (Haigh et al., 2024).

Receptors and Consequences: Receptors and consequences are linked, and so we deal with them together here. For past coastal flood events, Haigh et al. (2017) record 15 types of consequences, broadly grouped into social (e.g. loss of life, number of people evacuated, damage to residential property), economic (e.g. overall monetary cost, disruptions to ports, transport, energy, public services, water systems, agricultural production losses) and environmental (e.g. coastal erosion, degradation or losses of coastal habitats, ecosystems and their services, damage or loss to cultural heritage) impacts. The consequences of a flood can be long lasting (e.g. injury or long-term physical and mental health effects, or financial; Jackson and Devadason, 2019; Quinn et al., 2023). For example, it is thought that anxiety and disruption of the evacuation and loss of belongings during the 26 February 1990 coastal floods in Towyn in Wales contributed to the premature death of about fifty people (Wales Audit Office, 2009). The consequences of a flood can cause damage to commercial/business properties but also affected businesses and people outside of the area of coastline directly impacted, because of for example, disruption to supply chains or transport (Dawson et al., 2016).

As rising mean sea levels increase flood risk, so does the growth in the number of receptors in flood-prone areas. Stevens et al. (2016) assessed changes in the incidents of flooding across the UK, from all sources (e.g. including fluvial) and found that the increase in the total number of reported flood events in the 20th century is dominantly controlled by growth in the number of receptors. From 2005 to 2014, the National Trust (2015) found this trend continued in coastal areas, with 15,000 new buildings built in areas subject to flooding and erosion. Changes in land use and increasing asset values in floodplain areas have also enhanced exposure to coastal flooding. Despite this growing loss potential, evidence from Haigh et al. (2017) suggests that the number and consequences of coastal floods appears to have declined since 1915 in the UK, reflecting better defences and improvements in flood forecasting, warning, emergency response and planning. Wider efforts at improved adaptation should also be noted, particularly in recent decades, which has resulted in a reduction in flood risk. Spatial planning and building codes are already very effective at reducing risk to new build properties in coastal flood plains (Sayers et al., 2015). For example, new properties in the coastal flood plain are generally raised above flood levels, including an allowance for mean sea level rise. However, adaptation options like Coastal Change Management Areas have had, 10 years after their introduction, limited take-up (Kirby et al., 2021).

What could happen in the future?

Source: Future trends in still-water levels, and storms and waves for the UK are detailed in the two previously mentioned companion report cards (Horsburgh et al., 2020; Bricheno et al. 2025). These draw significantly on the UKCP18 marine projections (Palmer et al., 2018). There is high confidence that regional mean sea level will continue to rise around the UK, and the likely range (90% confidence) is between 0.27 and 1.12 m by 2100 (excluding vertical land motions). Climate models project that mean wave heights may decline slightly by 2100, but extreme wave events and very severe winter storms, particularly in autumn, could become more frequent and intense, amplifying risks to UK and Irish coastal zones (Bricheno et al. 2025).

Recent regional and global sea level projections are available from the latest Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6; Fox-Kemper et al., 2021). Considering only processes for which projections can be made with at least medium confidence, relative to the period 1995–2014, global mean sea level rise estimated by AR6 by 2100 are between 0.38 [0.28–0.55, likely range] m (SSP1-1.9) and 0.77 m [0.63–1.02, likely range] (SSP5-8.5). In general, UKCP18 and AR6 give similar values of projected sea level rise both globally and for UK locations (Weeks et al., 2023). However, larger increases are considered possible (up to 2.3 m by 2100), due to uncertain ice sheet processes including marine ice sheet instabilities (MISI) or marine ice cliff instabilities (MICI) (Fox-Kemper et al., 2021), but assessing their likelihood is difficult. Palmer et al (2024) presented a range of sea level rise storylines for the UK, including physically plausible high-end storylines based on AR6 and van de Wal et al. (2022). While the Palmer et al. (2024) high-end storylines show less than 2 m of sea level rise by 2100, they show values that can exceed 15 m across the UK by 2300. Reducing human emissions of greenhouse gases could stabilise temperature in about a century but mean sea level rise will continue for many centuries even if temperature is stabilised, because it takes many hundreds of years for the cryosphere and the deepest parts of the ocean to adjust to increased air temperatures. The UK coast will be subject to at least 1 m of mean sea level rise, it is just a matter of when (Committee on Climate Change, 2018).

A number of modelling studies have predicted regional changes in tidal range resulting from future changes in mean sea level, stratification and ice-extent (see Haigh et al., 2020b for a review of these studies). These studies suggest that changes in tidal range will typically be in the order of plus or minus 10% of any changes in mean sea level, which could slightly enhance or lessen coastal flooding at some locations. Extreme water levels are therefore very likely to increase during the 21st century, driven primarily by the changes in relative mean sea level, rather than any changes in storminess, with some modifications at select sites due to changes in the magnitude and timing of tides. Future coastal flooding could also vary as a result of changes in sediment pathways (e.g. longshore transport) and morphology (especially in estuaries; Lyddon et al., 2018b), that may result from mean sea level rise or variations in the wave climate, or anthropogenic process (e.g. dredging).

Pathway: With mean sea level rise, along with coastal squeeze, changes in sediment supply, variations to ocean chemistry and pollution there is likely to be a continued decline in saltmarshes, shingle beaches and sand dunes over the coming century and beyond, although there are increasing efforts at coastal habitat restoration (Burden et al., 2020; Bednar-Friedl et al., 2022). Space for landward retreat is crucial for salt marshes and beach ecosystems. Nearly all tidal marshes of Great Britian are projected to retreat by 2100 under high emissions, with southern and eastern England expected to experience marsh retreat by 2040 (Horton et al., 2018). Jointly, this will lead to defence capital and maintenance costs increasing dramatically, as natural buffering effects are reduced.

Changes in flood pathways will be closely linked to future policy decisions. Strategic shoreline management planning has been in place in England and Wales since the 1990s to help manage coastal flood and erosion risks. Shoreline Management Plans (SMPs) help guide decisions over three future time periods spanning 100 years and include four management approaches for each coastal section: (1) Hold the Line; (2) No Active Intervention; (3) Managed Realignment (including Adaptive Management); (4) or Advance the Line, which is very rarely implement (Hosking, 2006). SMPs aim to balance environmental, social, and economic considerations while adapting to changing coastal conditions and climate change

The Committee on Climate Change (2018) calculated that implementing the current SMPs would cost £18−30 billion for England, depending on the rate of climate change. Maintaining the 1,460 km of coastline designated as Hold the Line to the end of the century, achieves a lower benefit-cost ratio than the flood and coastal erosion risk management interventions that the government funds today. Therefore, on this basis, funding to protect some of these coastal stretches is unlikely. In addition, more detailed Coastal Defence Strategies subdivide the Hold the Line approach into one that maintains the present defence crest height (accepting a decline in the standard of defence with climate change) and one that sustains the standard of defence. The increasing lengths of coastline where it is only justifiable to maintain crest heights automatically leads to a gradual increase in flood risk.

Sayers et al. (2015) assessed the relationship between mean sea level rise and the length of existing coastal defences that will become very difficult to maintain as mean sea levels rise (Figure 4). The analysis suggests that the length of coastal defences ‘highly vulnerable’ to failure would almost double under 0.5 m mean sea level rise, with the number of properties affected if these were lost rising by around 160%. Under a more extreme scenario (2.5 m of global mean sea level rise), the length of highly vulnerable defences is projected to treble and the number of properties affected by flooding if these defences where lost would increase by 490%. Many shingle beaches cannot be maintained under future mean sea level rise, primarily because they cannot naturally adapt by rolling back (Dornbusch, 2017), leading to an acceleration of replacing them with hard structures (Dornbusch, 2019) with impacts on the natural environment and their contribution to people. If the Thames Barrier continues to be used for managing both river flow and tidal flood events, future sea level rise is predicted to make the number of closures unsustainable by around 2034; if used only for tidal flooding, this life is predicted to extend to around 2070 (Environment Agency, 2016), but defences would need to be raised upstream of the barrier to reduce the number of closures to manageable numbers (Haigh et al., 2024). The Thames Estuary 2100 (Environment Agency, 2012) plan includes options for a new Thames Barrier, which would be built further downstream of the current barrier.

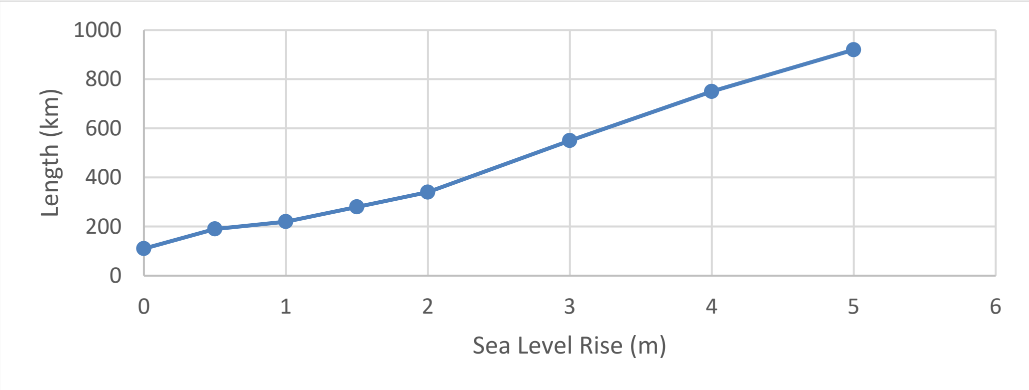


Figure 4: The length of coastal flood defences that may become highly vulnerable as mean sea levels rise (source: Sayers et al., 2015).

More recently Sayers et al. (2022) found that continuing to Hold the Line is likely to become increasingly difficult to justify. The assessment suggests 1,600–1,900 km (~30%) of England's shoreline is likely to experience increased pressure to realign by 2050s with implications for ~120,000–160,000 properties (excluding caravans). It is likely that a proportion of these properties will require relocation, although it is not possible to say how many this will be (as this will be a matter for national and local decision makers).

Receptors and Consequences: Population growth and accompanying development is likely to continue, particularly in areas that are currently defended and have a Hold the Line management policy (Sayers et al., 2015). Therefore, significant and growing populations and assets will remain located in the coastal flood plain and will be at increasing risk in the event of a defence failure (e.g. a breach). Furthermore, compared to the national average, more socially-vulnerable communities at the coast are disproportionally at risk and will see their risk increase more rapidly with climate change than elsewhere (Sayers et al., 2017). Adaptation measures can reduce the expected damage to the UK and the number of areas (or people affected) flooded dramatically (Vousdoukas et al., 2020); therefore massive investment in existing and new flood defence schemes are likely to continue, for heavily populated and developed regions but are unlikely for sparsely populated ones (CCC, 2018), and hard structures are not always preferred by local communities (Bude Climate Partnership, 2023). Nature based solution and sand-nourishment are increasingly being considered given their benefits for environments, and societal choices in the UK (Moraes et al., 2022).

Land-use planning decisions and insurance policies in particular will play a large role in determining future trends. Avoiding inappropriate development in the floodplain will reduce future exposure to flood risk and decrease the consequences when they occur (Donovan et al., 2013). If insurance policies are changed such that flooded properties are restored, but in more flood-resilient ways with property-level protection or in areas of less risk, this could reduce flood consequences over time.

Adaptation pathways for coastal flood risk can reduce the risk of future mean sea level rise by combining approaches to protect such as flood defences, early warning systems, ecosystem-based and sediment-based measures, with accommodation e.g. wet and dry proofing, and avoidance/retreat (Bednar-Friedl et al. 2022; Muccione et al., 2024). Mean sea level rise is a relatively gradual change, and thus provides the time and opportunity for rethinking coastal communities into ones that are adapted to live with water (Building Futures, 2010) by having, for example, houses on stilts or floating houses in areas of low wave exposure, and moving communities out of flood risk areas where wave exposure is higher or additional risk factors are also increasing (Buser, 2020). Continued improvements to the flood forecasting (particularly in regards to forecasting impacts) and warning service will allow evacuations and/or preventative measures to be appropriately installed prior to events, such as temporary flood barriers or pumping stations that reduce consequences of flooding. Note, however, that temporary barriers are not appropriate in open-coast locations where wave action is an integral part of flooding scenarios.

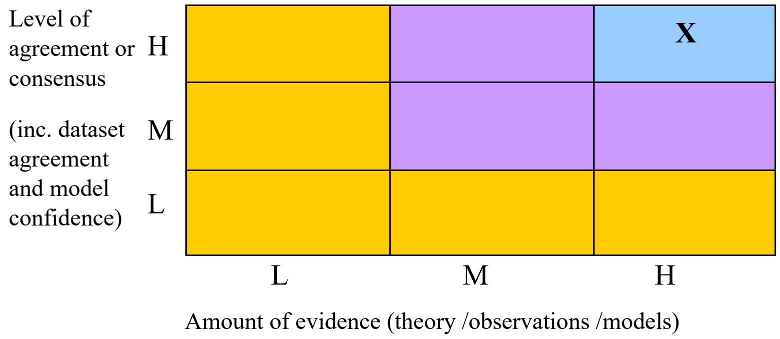
Projections of potential future coastal flooding impacts to the 2080s have been made by Sayers et al. (2015, 2020). The Sayers et al. (2015) analysis is based on three climate change scenarios (1.2ºC; 2.4ºC; and 3.0ºC, the higher scenario being based on a high end sea level scenario) and considers three population growths (low, high and no growth), and six adaption scenarios (including assumed enhanced and reduced adaptation levels when compared to present day); and Sayers et al. (2020) is based on two climate change scenarios (2ºC; 4ºC) and two population growth scenarios (lower growth and high growth projection). The analyses concluded that expected annual damages are estimated to more than double from £540m today to £1.2−1.7 billion by the 2080s in the high sea level scenario and more than triple to

£1.7−1.9 billion in a more extreme scenario, in the absence of adaptation. The Committee on Climate Change (2018) also recently made projections of potential future coastal flooding impacts. They concluded that around 520,000 properties are currently located in areas with a 0.5% (i.e. 1 in 200-year level) or greater annual risk from coastal flooding (not considering coastal defences) and by 2080s, this could increase to 1.5 million properties. By the 2080s, they estimate that the number of people living in England in areas at 0.5% or greater chance of coastal flooding in a given year is projected to increase from 0.95 million people to 1.10 million (2°C world with ambitious adaptions scenarios) and 1.55 million (4°C world with low levels of adaption). In addition, they estimate approximately 1,600 km of major roads, 650 km of railway, 92 railway stations and 55 historical landfill sites are likely to be at risk of coastal flooding or erosion by the end of the century. The critical Dawlish line is projected to suffer serious reliability issues due to flooding by 2040, with line restrictions increasing from 10 days per year to 30–40, and maintenance costs tripling or quadrupling (£6.9–£8.7m per year, including over £1m compensation to train operators; Dawson et al. 2016).

Recently, Sayers et al. (2025) presents a new, high-resolution dataset and methodological framework mapping climate vulnerability at neighbourhood scale across the UK. It quantified social factors (such as age, health, mobility, housing tenure, access to green space, and flood experience), to derive indices of vulnerability for both flooding and heat and includes a preliminary business-oriented vulnerability index. The findings revealed that the most vulnerable communities are disproportionately those with higher socio-economic deprivation, often already poorer areas, with housing, health, and insurance implications. This spatially explicit approach advances adaptation planning by helping target resources and interventions to the places where they are most needed.

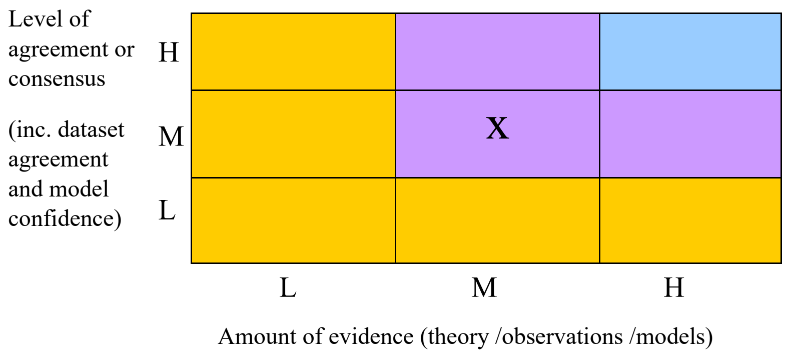
CONFIDENCE ASSESSMENT

What is already happening?



Confidence in understanding what is already happening with coastal flooding has increased from 'low' to 'high', over the duration of the MCCIP report cards. It remains 'high' here as there is a high level of consensus that: (1) extreme water levels are increasing in frequency due to rising mean sea levels, (2) that to-date we managed this sufficiently to contain growth in flood risk to human infrastructure, and (3) nonetheless losses in a major event – above defence design standards − are growing.

What could happen in the future?



Confidence in what could happen in the future remains the same as previous, 'medium'. While it is very likely extreme water levels and wave overtopping events will increase in frequency with mean sea level rise, possible changes in the wave- and storm surge-climate and their spatially varying contribution to flood hazard remain uncertain and there is considerable uncertainty in how flood pathways and receptors will change in the future.

KEY CHALLENGES AND EMERGING ISSUES

Top challenges:

1. Given that mean sea levels will continue to rise for many hundreds of years, we need to rethink how coastal communities can adapt to live with water. We need to consider how long-term aspiration can be realised in the planning system to deliver practical portfolios of adaptation options that are technically feasible, balance costs and benefits, can attract appropriate finance, are socially acceptable and can be prepared for and implemented before the need for adaptation becomes urgent. We need to move away from a coastal defence mindset (defence has a clear military connotation and it reflects our thinking that we are in a constant battle to protect coastal communities from the sea) to coastal management, where we consider a wider range of options in a more flexible and adaptable way, and in some specific cases take the radical decision to move away from the coast. In this context the Environment Agency's Coastal Transition Accelerator Programme is a step on the right direction by enabling Local Authorities to explore and trial innovative adaptation measures. The joint learning from the four different trial areas (East Riding, North Norfolk, Bude and Dorset) has the potential to provide key adaptation learning.

2. As we aspire to increase the use of nature-based flood management solutions, we need new monitoring to assess the flood resilience offered by schemes and how they evolve over time as well as better understand the limits of nature-based management in the context of their own vulnerability to climate change. In this regard, initiatives that build a better understanding of different types of natural coastal protection in a changing climate and with biodiversity loss are essential.

3. We need to identify the mechanisms, spatial extent and possible physical magnitude of low probability high impact extreme coastal flood events to inform emergency planning and calculate residual risk damages. We need to develop tools to accurately quantify expected annual damages and event losses due to coastal flooding historically, today and into the future, to better inform the national threat level, considering uncertainty in the future projections of mean sea level rise, changes in storm surge and wave climates. We need a more-complete assessment of future changes in the wave- and storm surge-climate, storm tracks, and river discharge in estuaries, based on improved atmospheric models, to improve understanding of natural variability and better isolate possible long-term trends. Finally, we urgently need more complete and systematic UK wide repositories of relevant data and coastal assets, including the extent and condition of current and proposed flood defence engineered infrastructure and natural features (e.g., beaches, dunes and salt marshes). Effective management of these assets is crucial for

mitigating risks and ensuring long-term coastal resilience to flooding.

Top emerging issues:

1. Over the last decade there has been a move towards more adaptable flood management. The Thames Estuary 2100 (TE2100) Plan was instrumental in introducing a novel, cost-effective approach to manage increasing flood risk by defining adaptation pathways that embraces uncertainty in sea level projections and can cope with large ranges of changes if needed (Environment Agency, 2012). In response, the concepts and the assessment of adaptive pathways and approaches to valuing adaptive capacity are increasingly moving mainstream (McGahey and Sayers, 2008; Ranger et al., 2010; Brisley et al., 2016; Haasnoot et al., 2019; Muccione et al., 2024) and are being considered elsewhere (e.g., in the Humber Estuary). Generating such adaptation pathways for different regions and settings in the UK and Ireland will highlight options which we already have to reduce risk, and where gaps of knowledge or legislation hinders implementation. At the same time adaptive management that aims to reduce future investment at the local scale is being implemented successfully (Creed et al., 2018). The Department for Environment, Food & Rural Affairs (Defra) has funded three Pathfinder projects located in Yorkshire, the South West and the Oxford Cambridge arc region, to raise awareness of the actions homeowners and businesses can take at a local scale to make their homes more resilient to flooding.
2. It is unrealistic to promote a Hold the Line policy for significant lengths of the Uk and Irish coastline based on a benefit-cost ratio (Committee on Climate Change, 2018), to preserve natures contribution to people, and for social justice considerations (Cooper & McKenna, 2008). Funding for these locations is thus unlikely and realistic plans to adapt to the inevitability of change are needed now. A major issue, relating to Hold the line policies, is the many (at least 1700) historical coastal landfill sites located in coastal areas (Brand et al., 2017). Where landfills are present, the shoreline is usually defended to protect the environment and people from hazards that may be realised if the landfill is flooded or eroded. Therefore, coastal landfill sites need to be protected, but this may be at odds with Shoreline Management Plans that recommend ‘managed realignment’ or ‘no active intervention’ (Beaven et al., 2018).

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