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Responding to climate change around England's coast - The scale of the transformational challenge

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ABSTRACT

Around the world coastal communities face an unprecedented challenge in responding to sea level rise and associated changes. For many responding through incremental adaptation may be appropriate (although not without limits). This may include progressively raising defences, nourishing beaches, and other conventional management measures. Such actions are well supported by existing governance structures and investment vehicles. For others however, continuing to provide protection from flooding may not be technically feasible or financially viable. For these communities, transformational adaptation will be needed (including realignment or relocation). Implementing transformational change, however, is difficult and requires a clarity of long-term planning and a means of supporting communities to take early action in making this transition.

This paper explores the scale of the transformational challenge in England through to 2100. The combined influences of relative Sea Level Rise and the local lowering of the foreshore platform due to increased wave-driven surface erosion are considered. The realism of published shoreline policies (set out within England's Shoreline Management Plans) are assessed based on projected changes in flood risk and benefit-cost considerations. The assessment suggests 1,600–1,900 km (~30%) of England's shoreline currently designated as a 'Hold-the-Line' policy is likely to see increasing pressure to realign (assuming a rise in Global Mean Surface Temperature of between 2 and 4 °C by 2100) with implications for ~120,000–160,000 residential and non-residential properties by the 2050s. It is likely that a proportion of these properties will require relocation. It is not possible to say how many this will be. This will be a matter for government and the associated policy and funding priorities that will influence local outcomes.

1. Introduction

Conflict between human development and the natural functioning of the coast is as old as civilization itself. Around the globe, many coastal lowlands have been drained for agricultural production and coasts and estuaries developed to facilitate trade and commerce. Consequently, many of the world's largest and most important cities are in low-lying coastal areas (e.g. Hallegatte et al., 2013, Brown et al., 2013). Around 230 million people live in areas less than 1 m above high tide (Kulp and Strauss, 2019) and an estimated US$1 trillion of global wealth is generated in low-lying coastal zones (Kirezci et al., 2020).

Development has led inextricably to structural interventions to constrain the natural dynamics of the coast and to reduce unwanted flooding (as evident from New Orleans, to London, to Bangladesh, to Shanghai). Invariably such attempts have been (or will be) overwhelmed or breached by the next *'great flood'* (*e.g.* the 1953 North Sea surge e.g. McRobie et al., 2005, to catastrophic failure of the levee system in New Orleans during Hurricane Katrina, 2005, *e.g.* Cigler, 2007). Climate change is exacerbating these risks. The Intergovernmental Panel on Climate Change (IPCC,2014) highlights with *'very high confidence'* that sea level rise will increase coastal flooding and that the pressure on coastal zones will increase significantly in the coming

Abbreviations: AtL, Advance-the-Line; BCR, Benefit-Cost Ratio; CCC, Committee on Climate Change; FCERM, Flood and Coastal Erosion Risk Management; FFE, Future Flood Explorer; GDP, Gross Domestic Product; GHG, Green House Gas; HtL, Hold-the-Line; IPCC, Intergovernmental Panel on Climate Change; MR, Managed Realignment; NAI, No Adctive Intervention; NCERM, National Coastal Erosion Risk Mapping; PCU, Policy Calculation Units; PMU, Policy Management Units; PV, Present-Value; rSLR, Relative Sea Level Rise; SLR, Sea Level Rise; SMP, Shoreline Management Plan; UKCCRA, UKClimate Change Risk Assessment.

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decades due to population growth, economic development, and urbanization (with *'high confidence'*). At global scale, analysis by Kirezci et al. (2020) suggests that in the absence of coastal protection 12–20% of the global Gross Domestic Product (GDP) would be affected by flooding during a 1 in 100-year return period event (an increase of 46% from today) given unmitigated future emissions (defined by Representative Concentration Pathway 8.5, van Vuuren et al., 2011).

Given these projections, governments and coastal communities face an unprecedented challenge in deciding how to respond; what is an affordable, fair, technically feasible, and desirable response. Realignment of the shoreline and relocation of communities is starting to receive serious attention as part of this discussions in England and internationally (e.g. CCC, 2018, Oppenheimer et al., 2019, Yin et al., 2020, Simms, 2021, Torabi and Dedekorkut-Howes, 2021, Nicholls et al., 2021). The framing of the discourse, however, often remains couched in the context of a question for future decision makers alone. This is a mistake. Initiating transformational change (where needed) is an urgent question for today. This urgency is often fudged in coastal policy, with clarity provided when associated with maintaining that status quo (*e.g.* protection) but *'too abstract'* on issues of relocation (Carey, 2020) or retreat.

This paper explores the scale of the transformational challenge in responding to changing coastal flood risks through to 2100 in England. The assessment evaluates the preferred shoreline management policy choices set out in the 2nd generation Shoreline Management Plans (SMPs) in the context of the combined influence of relative Sea Level Rise (rSLR, eustatic and isostatic change, Palmer et al., 2018) and the lowering of soft foreshores (due to wave-driven surface erosion) to identify those coastal communities likely to be under the highest pressure to relocate. The pressure for transformational adaptation, to realign the coast and relocate communities where necessary, is presented on a qualitative scale from *low* to *very high*.

The risks and issues presented, although conditioned by the context in England, echo those faced by coastal communities around the world. The SMPs grapple with the adaptation options of resist, accommodate and retreat that shape the international discussion (Klien et al., 2001), and address many similar considerations that play a central role in Integrated Coastal Zone Management planning processes (e.g. Rosendo et al., 2018) and national coastal policy debates (e.g. Doberstein et al., 2019; Siders, 2019). Given this, although the analysis presented here covers England, there are obvious parallels to the challenges faced elsewhere.

The focus throughout is on changing flood risk. Shoreline erosion and the impact on cliff top properties is excluded from the assessment. Although coastal erosion is a significant challenge in England it has received greater attention in terms of the associated adaptation challenges (e.g. Frew, 2012; Williams et al., 2018 amongst others) compared to communities that may face an uncertain future due to changing coastal flood risk.

2. Scale of the present and future coastal flood risk in England

Coastal management planning in England has evolved in response to major events (e.g. Sayers, 2017) and through continued improvements in understanding of coastal processes (e.g. Nicholls et al., 2013). Nonetheless, coastal flood risk remains a national priority (Cabinet Office, 2020). The third (and most recent) UK Climate Change Risk Assessment (CCC, 2021) reinforces coastal flooding (and flooding in general) as a priority, with Expected Annual Damages (to residential properties) from coastal flooding projected to more than treble by the 2080s (from £60 million today to £280 million assuming a 4 °C rise in Global Mean Surface Temperature (GMST) from pre-industrial times, high population growth and a continuation of Current Levels of Adaptation (CLA), Fig. 1). Yet, there is little national discourse on where it may be necessary to adopt a transformational approach to adaptation; moving beyond incremental adaptations in coastal management activities (focused around strengthening and raising existing defences and changes in maintenance regimes) to selectively realigning the shoreline and relocating communities.

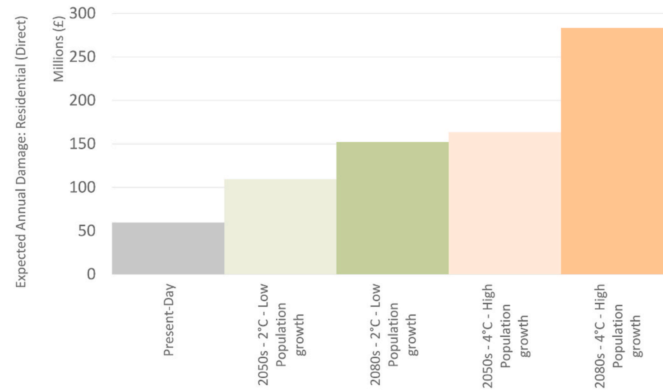


Fig. 1. Projected changes in coastal flood risk (direct residential property damage) assuming a continuation of Current Levels of Adaptation (CLA) Authors using data from Sayers et al. (2020). Present day refers to 2020.

3. Transformational challenge in context - present and future coastal flood risk

Many countries face significant decisions around how best to respond to coastal change. In the United States (US), SLR is projected to impact the livelihoods of 4–13 million people (Hauer et al., 2016). The significance of this challenge is recognised in the Fourth National Climate Assessment, noting retreat will be "unavoidable" for some communities (USGCRP, 2018). The IPCC (IPCC et al., 2014 and Oppenheimer et al., 2019) concludes that in a future with unmitigated emissions (RCP8.5) coastal societies (especially poorer, rural, and small islands societies) will struggle to maintain their livelihoods and settlements during the 21st century. Without emissions mitigation, sea levels will continue to rise for centuries, reaching 2.3–5.4 m by 2300 (*'likely range'*). In this scenario incremental adaptation is unlikely to offer a solution for many low-lying coastal areas, including more intensively developed urbanised coasts, and more radical action will be needed. Oppenheimer et al. (2019) goes on to note that even with ambitious mitigation (as represented by RCP2.6) the likely range of sea level rise is between 0.6 and 1.1 m by 2300. Consequently, adaptation will remain a significant challenge regardless of future reductions in greenhouse gas (GHG) emissions.

England also faces a transformation challenge. The third UKCCRA suggests there are 544,000 residential properties and 72,000 non-residential properties within England's coastal floodplain today (2018, Sayers et al., 2020). After taking account of existing coastal defences (including both their condition and standard of protection) around ~47,000 residential properties and ~11,000 non-residential properties remain exposed to flooding more frequently than 1in75 years on average (*ibid*). The analysis for the UKCCRA goes on to consider how these risks may change given a combination of climate change and adaptation assumptions. Assuming a 2 °C rise in GMST by the end of the century (compared to pre-industrial times), low population growth and limited adaptation (with present day protection standards reducing in all but major urban conurbations) the number of residential properties exposed to a significant chance of flooding increases six-fold to ~290,000 by the 2080s (*ibid*). Assuming a 4 °C rise in GMST, coastal risk is projected to increase tenfold to ~470,000 by the 2080s given the same limited adaptation effort and high population growth (*ibid*) – see Fig. 2. Not all areas communities will experience such limited adaptation investment. Many will continue to receive continued protection, but some will not. The analysis below builds upon the UKCCRA analysis to identify those areas where continued investment in Hold-the-Line is likely to come

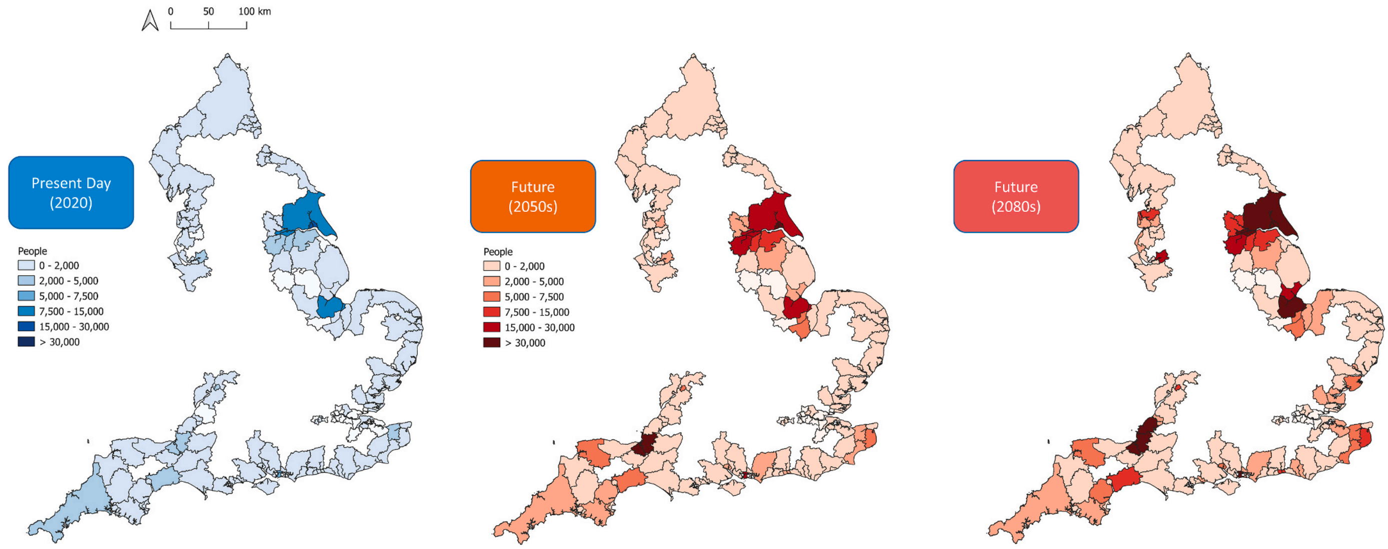


Fig. 2. Projected changes in people exposed to significant coastal flooding in England (1in75 year return period or more frequent)
Left: Present Day
Middle: 2050s assuming a 2 °C rise in Global Mean Surface Temperature (by the end of the Century from pre-industrial levels), low population growth and little additional adaptation action (defined as Reduced Whole System adaptation in Sayers et al., 2020)
Right: 2080s assuming a 4 °C rise in Global Mean Surface Temperature (by the end of the Century from pre-industrial levels), high population growth and little additional adaptation action (defined as Reduced Whole System adaptation in Sayers et al., 2020).

under the greatest pressure and realignment or relocation may be needed.

4. Coastal flood management policy framework in England

The UK government has set out a long-term ambition to create a nation more resilient to future flood and coastal erosion risk. This framework includes the 25 Year Environment Plan (25 YEP, Defra, 2019) and the Government policy statement on flooding and coastal erosion (HM Government, 2020) that articulates this ambition:

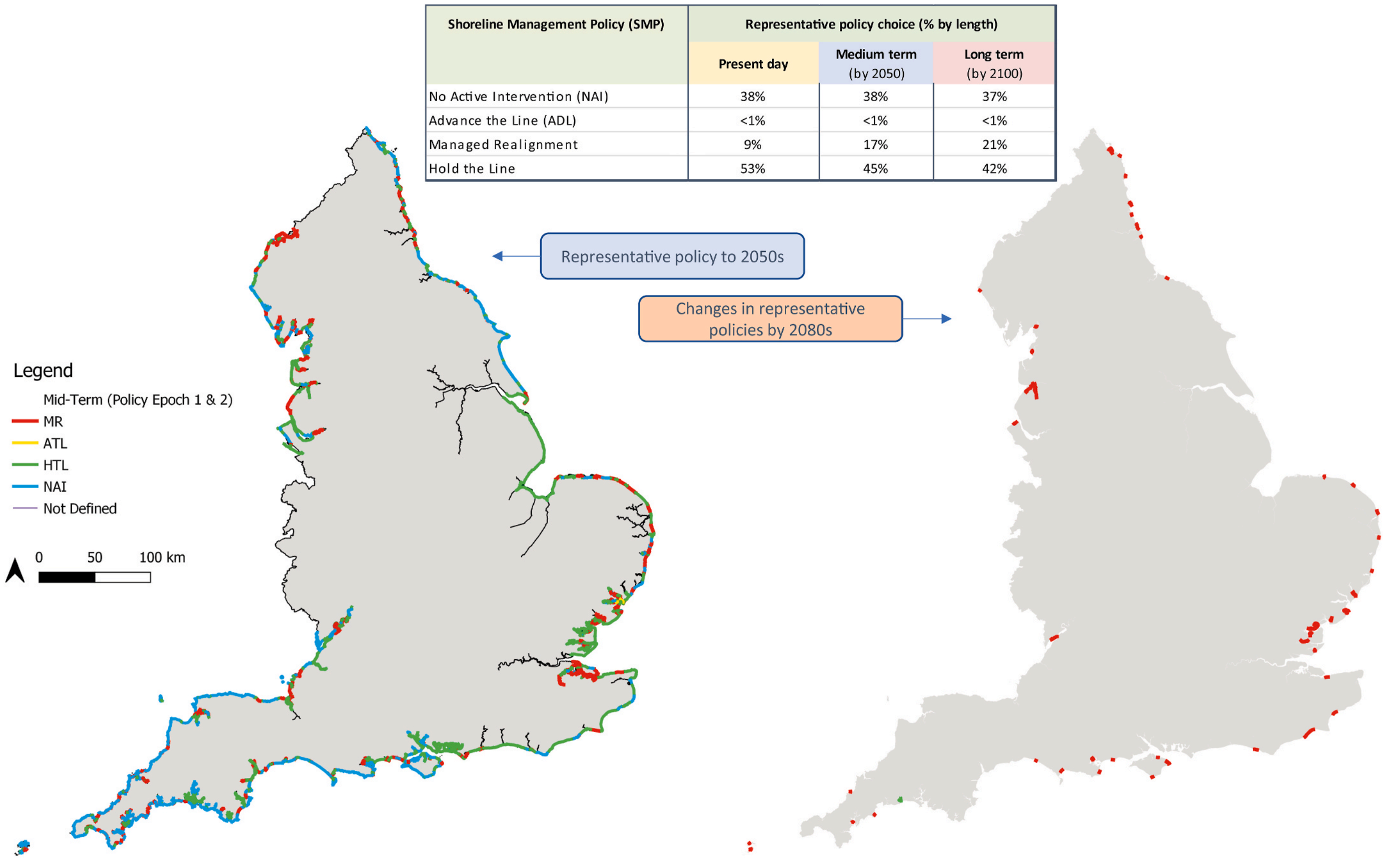
'To create a nation more resilient to future flood and coastal erosion risk. In doing so, reduce the risk of harm to people, the environment, and the economy. We will be better protected to reduce the likelihood of flooding and coastal erosion. We will be better prepared to reduce the impacts when flooding does happen.'

The National Flood and Coastal Erosion Risk Management (FCERM) Strategy for England (Environment Agency, 2020) sets out the approach to delivering these policy goals by creating '*climate resilient places*'; '*today's infrastructure resilient in tomorrow's climate*'; and a nation '*ready to respond and adapt to flooding and coastal change*'. This emphasis is welcome and embeds the concepts of adaptation (e.g. Holling, 1978), the notion that adaptation is an ongoing process (McGahey and Sayers, 2008; Haasnoot et al., 2012, 2021) and a focus on resilience (*e.g.* Dovers and Handmer, 1992; USAID, 2015; Sayers, 2017). However, little guidance, is offered on the role of transformational change (including the relocation of coastal communities) or how this would be supported where required (a gap shared by many coastal policies around the world; Carey, 2020). This lack of clarity around the need for, and the delivery of, transformational adaptation is also evident at more local planning levels. Many regional and local coastal strategies postpone difficult issues and cite uncertainty in the future climate as the reason for focusing on short-term actions. For example, the flood strategy for the Humber estuary in north-east England (Humber 2100+, Environment Agency, 2019) reflects this difficulty noting *'[the strategy] will primarily focus on outlining our strategic direction for the first 25 years, including a programme of investment)'*. Future sea level rise is, of course, uncertain, but is it is almost certain that England will have to adapt to close to 1 m of sea level rise by the end of the 21st Century or soon after (CCC, 2018) with the potential for significantly larger increases by 2300 (with projections ranging from 0.6 to 4.5 m across emissions scenarios, Palmer et al., 2018). There are example projects that have embraced the concept of adaptation pathways, such as management of flood risk through London as set out in the Thames Estuary 2100 programme (Ranger et al., 2013; Environment Agency, 2012; McGahey and Sayers, 2008). For cities such as London, adapting to sea level rise centres on how best to provide long-term protection; the transformation challenge arises when continued protection may not be viable or desirable.

SMPs emerged in the mid-1990s to support a strategic approach to the management of coastal erosion and flood risks (MAFF, 1995). Their introduction was in recognition that hitherto project-based management of coastal defences failed to work with the spatial and temporal dynamics that fundamentally shape the coast. In particular, the SMP process introduced two important aspects: (i) the adoption of management units based on physical (morphological) process boundaries (littoral sediment cells as defined by Motyka and Brampton, 1993) rather than administrative boundaries, and (ii) an extended time horizon, the short-term (*Epoch 1:* 0–20 years), medium-term (*Epoch 2:* 20–50 years) and long-term (*Epoch 3:* 50–100 years). Consequently, the notion of working with natural processes and delivering adaptation as a progressive process of change have been, and remain, central themes in the SMP process.

There are twenty SMPs covering England with each sub-divided into a series of Policy Management Units (PMUs). A preferred 'management policy' is assigned to each PMU for each epoch (Defra, 2006). The policy choice is drawn from one of four options: (i) *Hold-the-Line* (HtL): implies an aspiration to build or maintain built defences so that the current position of the shoreline remains (this can involve maintaining or changing the standard of protection of those defences); (ii) *Advance the Line* (AtL): implies reclaiming land seaward of the existing shoreline (this is rarely used and is limited to policy units where significant land reclamation is being considered, such as the reclamation at Samphire Hoe using the spoil from the construction of the Channel Tunnel)[1]; (iii) *Managed Realignment* (MR): used here to imply the shoreline position is allowed to evolve flexibly in response to coastal processes (adapted from MAFF, 1995; Esteves, 2014 and others), and (iv) *No Active Intervention*

[1] https://www.samphirehoe.com/about-samphire-hoe/.



Shoreline Management Policy (SMP)	Representative policy choice (% by length)		
	Present day	Medium term (by 2050)	Long term (by 2100)
No Active Intervention (NAI)	38%	38%	37%
Advance the Line (ADL)	<1%	<1%	<1%
Managed Realignment	9%	17%	21%
Hold the Line	53%	45%	42%

Fig. 3. Policy Management Units – Preferred SMP policy choices
Left: Medium term preferred policies (2050s); *Right:* Locations highlighted where the preferred policy changes to Managed Realignment in the longer term (2080s).

(NAI): implies no action will be taken to manage the shoreline position. In some cases the preferred policy for a PMU will change over time, for example from a HtL policy in the short-term to a MR in the long-term (Fig. 3). However, there is often a lack of clarity as to how this transition will be made, particularly when it would impact communities (returned to later in the discussion).

Since 2010, Local Planning Authorities in England have been required to consider the SMP policy choices as a '*material consideration*' in the planning process (CLG, 2010). Although SMPs must be formally considered they are non-statutory and are only one of many influences that guide local decision making at the coast. Consequently, their influence varies and is often undermined by a lack of transparency (about the assumptions and evidence used) and a lack of clarity on funding (Ballinger et al., 2020). These issues make it difficult for SMP policy choices to be readily carried forward into local planning processes and consequently their influence is often more limited that it should be (*ibid*).

The SMP process is now entering a third round of updates (although likely to be more of a refresh process rather than a major update).[2] This provides an opportunity to promote a more open discourse around the future of England's coast, including where it is feasible and desirable to maintain the existing shoreline to manage risk to communities in the long-term and where realignment or even relocation maybe necessary. These decisions will require many local and national issues to be addressed, from issues of social justice to the management of the complex physical process dynamics and socio-economic development interactions that will influence the choice. Given this complexity, transformational choices are often postponed, but doing so is not without consequence. Continuing to suggest a long-term commitment maintaining shoreline defences in an area when this may not be the case can encourage further (inappropriate) development or unfairly propagate the belief that protection will continue into the long term.

This connection has been recognised in a coastal erosion context (and cliff top development) for some time (e.g. Ohl et al., 2003). In 2012, for example, Defra reported insights from a series of Coastal Change Pathfinder Projects (Defra, 2012) into how the more transformational policy choices can be taken forward in areas of erosion (including trail lease back and buy back schemes, Frew, 2012). The lessons for communities facing increased flooding (rather than erosion alone) were less clear. This is not to say there have been no flood-driven realignments, there have, including Medmerry, Steart Abbotts Hall, Alkborough Flats, Freiston Shore (e.g. McAlinden, 2015; Kiesel et al., 2020). However, these have been driven by habitat creation or allied with a combination of improved protection and habitat creation. Community scale relocation based on a projected increase in flood risk is yet to be implemented in England. There are examples elsewhere in the UK where relocation is proposed. For example, in Fairbourne, Wales (a coastal community of 1, 700 people in Wales at the mouth the River Mawddach) the published SMP policy is to transition from a HtL, to MR, to NAI by 2100 but a lack of clarity (and consensus) of how to make this transition continues to make progress fraught (an issue highlighted by Pembroke County Council over a decade ago, PCC, 2012).

5. Assessment framework

A decision to realign the shoreline, and potentially relocate a community, will be determined by a set of circumstances rather than a single factor. The relative balance of the national and local political economy

[2] https://scopac.org.uk/wp-content/uploads/2019/11/Paper-I-151119-SMP-Refresh-Update.pdf Accessed 03 June 2021.

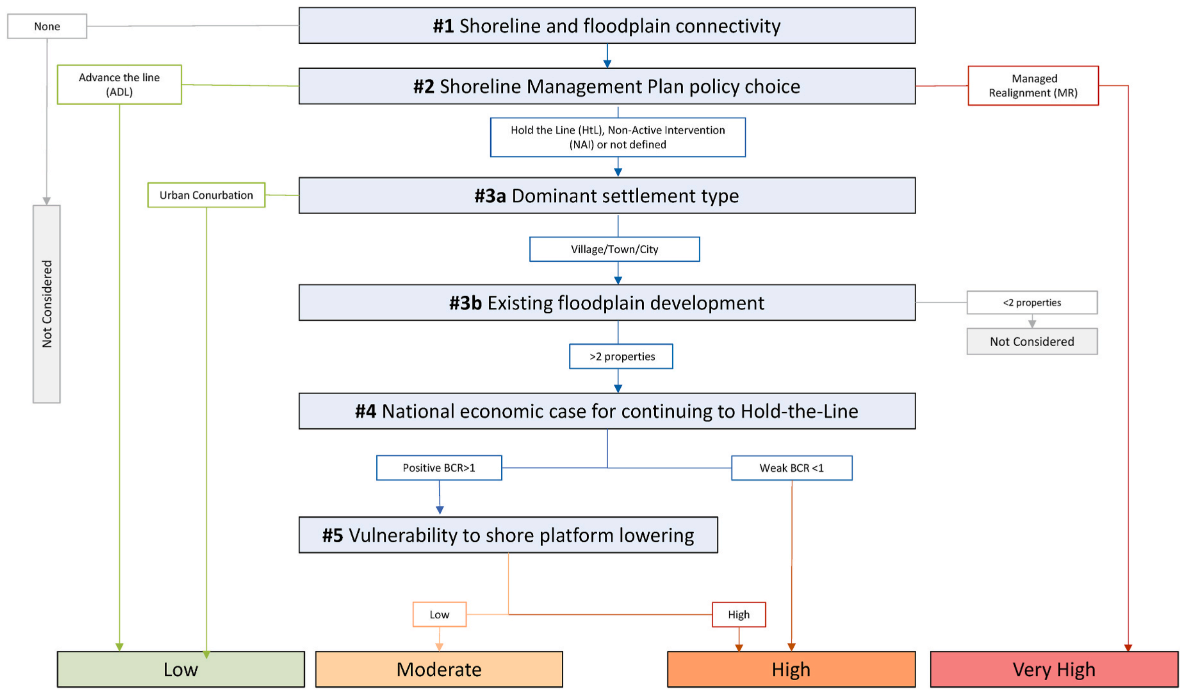


Fig. 4. Assessment decision tree used in this analysis to determine the realignment pressure.

as well as the rational assessment of risks and costs will all be influential. It is, however, the latter that is the focus here.

The assessment presented uses a hierarchy of six considerations to determine the likely pressure for relocation (Fig. 4), namely: *(i)* **Shoreline to floodplain connectivity** - the relationship between the shoreline features and communities they protect; *(ii)* **Shoreline Management Policy** - the existing SMP policy choices across all three epochs; *(iiia)* **Dominant settlement type** – the type development within the associated floodplain (urban or rural); *(iiib)* **Scale of existing floodplain development** - the number of properties that may be impacted by a decision to relocate away from the floodplain, *(iv)* **National economic case for continuing to Hold-the-Line** - the likely economic case for investment in maintaining existing protection (based on an assessment of the costs and benefits of action), and (v) **Shoreline vulnerability** - the potential for surface wave-driven erosion of the shore platform to exacerbate the challenge posed by of rSLR alone.

This combination of influences is used to determine the *'pressure for realignment'* for each PMU using a qualitative scale of:

- ***Low*** – implying there is a strong long-term case for HtL.
- ***Moderate*** – implying it is likely that HtL will continue to be a viable policy choice.
- ***High*** – implying that there is significant uncertainty regarding the ability to HtL given current investment rules and funding mechanisms.
- ***Very High*** - implying that MR is already the preferred policy choice within the SMP.

The likely *'pressure for realignment'* is assessed at two-time horizons; a mid-term future (20–50 years ahead) and a long-term future (50–100 years ahead). For each time horizon two projections of relative SLR (rSLR) are considered. The first assumes a 2 °C rise GMST by the end of the century from a pre-industrial baseline and the second a 4 °C rise (Table 1, Sayers et al., 2020 based Palmer et al., 2018). To determine the influence of rSLR on coastal flooding the change in the standard of protection afforded by the shoreline defences (where they exist) is assessed. This analysis takes account of the offshore wave climate, propagation to the shoreline and the typical structure type along each frontage (using the methods set out in Gouldby et al. (2017). The results are then applied to the average present-day standard of protection afforded to each PMU to determine the change in the standard of protection that would result in the absence of further adaptation (e.g. as shown in Table 1 assuming a 0.35 m rise in rSLR).

5.1. *Consideration 1 - Shoreline and floodplain connectivity*

In some instances the relationship between a particular coastal flood defence and the floodplain it protects is clear; for example, between dunes forming the backshore of a pocket beach and the floodplain behind. For many locations, this relationship is more difficult to establish. Along much of the east coast of England, for example, the coastal floodplain is continuous for many tens of kilometres (as illustrated by the blue shading in Fig. 5). In this situation, the overtopping of a shoreline defence at one location does not influence flooding across the whole connected floodplain. To provide a credible, and spatially resolved, analysis of the relationship between shoreline management and changing coastal risks the coastal floodplain has been subdivided to form a series of non-overlapping polygons, referred to here as Policy Calculation Units (PCUs). Each PCU establishes a link between the properties within the floodplain and the shoreline assets (the dunes, wall, and revetment etc) that protect them and hence how a change in shoreline management and/or climate change along a given frontage may impact their flood risk.

To define the spatial boundaries for each PCU, a shore normal has been projected inland across the undefended 1 in 1,000-year return period coastal floodplain (a notional present-day extent as defined by the Environment Agency Flood Zone 2[3]) for boundary between each frontage (as defined by a PMU). A manual review of the polygons was used to ensure a sensible sub-division in complex settings, such as at mouth of an estuary and around coastal inlets (see insert in Fig. 5). In some cases, this led to the merging of some PMUs to ensure a credible causal link between the shoreline defences and floodplain is maintained

[3] Flood risk assessment in flood zones 2 and 3 - GOV.UK (www.gov.uk) Accessed January 2021.

Table 1
Relative Sea Level Rise and impact on defence standards around the UK coast (after Sayers et al., 2020 based on Palmer et al., 2018).

	Typical values of rSLR (m) 50th percentile (10th - 90th percentiles)			
	2°		4°	
	2050	2100	2050	2100
England				
01 - Scottish Border to River Tyne	0.09 (0.05–0.14)	0.27 (0.16–0.39)	0.20 (0.13–0.27)	0.65 (0.47–0.85)
02 - The Tyne to Flamborough Head	0.12 (0.07–0.17)	0.32 (0.22–0.44)	0.22 (0.15–0.29)	0.71 (0.53–0.9)
03 - Flamborough Head to Gibraltar Point	0.13 (0.09–0.18)	0.37 (0.27–0.49)	0.24 (0.17–0.31)	0.75 (0.58–0.94)
04 - Gibraltar Point to Hunstanton	0.13 (0.09–0.18)	0.38 (0.28–0.49)	0.24 (0.17–0.31)	0.76 (0.58–0.95)
05 - Hunstanton to Kelling Hard	0.14 (0.1–0.19)	0.39 (0.29–0.5)	0.25 (0.18–0.32)	0.77 (0.6–0.96)
06 - Kelling Hard to Lowestoft	0.14 (0.1–0.19)	0.40 (0.3–0.51)	0.25 (0.18–0.32)	0.78 (0.61–0.96)
07 - Lowestoft to Felixstowe	0.14 (0.1–0.19)	0.39 (0.29–0.5)	0.25 (0.18–0.32)	0.77 (0.6–0.96)
08 - Essex and South Suffolk	0.14 (0.09–0.2)	0.38 (0.29–0.49)	0.25 (0.17–0.32)	0.77 (0.6–0.95)
09 - River Medway and Swale Estuary	0.14 (0.09–0.19)	0.38 (0.28–0.49)	0.24 (0.18–0.31)	0.76 (0.59–0.95)
10 - Isle of Grain to South Foreland	0.14 (0.09–0.19)	0.38 (0.28–0.49)	0.24 (0.17–0.32)	0.77 (0.6–0.95)
11 - South Foreland to Beachy Head	0.13 (0.09–0.18)	0.38 (0.28–0.49)	0.24 (0.17–0.31)	0.76 (0.59–0.95)
12 - Beachy Head to Selsey Bill	0.14 (0.09–0.19)	0.38 (0.28–0.49)	0.25 (0.18–0.32)	0.76 (0.59–0.95)
13 - Selsey Bill to Hurst Spit	0.14 (0.09–0.19)	0.38 (0.28–0.49)	0.25 (0.18–0.32)	0.77 (0.59–0.95)
14 - Isle of White	0.14 (0.09–0.19)	0.38 (0.28–0.49)	0.25 (0.17–0.32)	0.77 (0.6–0.96)
15 - Hurst Spit to Durlston Head	0.14 (0.09–0.2)	0.38 (0.28–0.5)	0.25 (0.18–0.33)	0.77 (0.6–0.96)
16 - Durlston Head to Rame Head	0.14 (0.1–0.19)	0.39 (0.29–0.51)	0.25 (0.18–0.32)	0.78 (0.61–0.97)
17 - Rame Head to Hartland Point	0.14 (0.1–0.19)	0.40 (0.29–0.52)	0.25 (0.18–0.33)	0.79 (0.61–0.99)
18 - Hartland Point to Anchor Head	0.13 (0.09–0.18)	0.37 (0.27–0.49)	0.24 (0.17–0.31)	0.76 (0.58–0.96)
19 - Anchor Head to Lavernock Point	0.13 (0.09–0.18)	0.37 (0.27–0.48)	0.24 (0.17–0.31)	0.76 (0.58–0.95)
22 - Great Ormes Head to Scotland	0.1 (0.06–0.15)	0.28 (0.18–0.4)	0.21 (0.14–0.28)	0.67 (0.49–0.86)
WALES				
21 - St Ann's Head to Gread Ormes Head				
20 - Lavernock Point to St Ann's Head				
Scotland:				
s1				
s2,s4,s5				
s3				

Note: The 50th percentile values shown as used in the analysis of risk presented here. Numbers and locations refer to the Shoreline Management Plans around the coast where they exist. In general, coastal flood defence standards in England are typically in the range – 1–50 years - 1–250 years.
Example: For a defence in SMP 12 (Beachy Head to Selsey Bill) with a current standard of protection of 1:50, the standard reduces to 1in11 years.

in the analysis. In total 1,525 PCUs (i.e. non-overlapping asset influence areas) are defined around the coastal of England.

5.2. Consideration 2 - Shoreline Management Plan policy choice

Those PMUs with a preferred published policy of MR (either by the 2050s or 2080s) are assumed to be under *'very high'* realignment pressure by the end of the century (see earlier, Fig. 3). This includes around ~1,150 km (21%) of the shoreline linked to ~30,000–35,000 properties in the associated floodplain. The current rate of MR (since 2000) would need to increase five-fold to achieve this (CCC, 2013). The focus here is not the reasons for slow progress in delivering MR policies (as these are explored in CCC, 2018) but to identify those locations where a preferred policy of HtL may be difficult to achieve. The PMUs with an existing SMP policy of MR are therefore excluded from the following steps.

5.3. Consideration 3a - Dominant settlement type

The UK Office of National Statistics (ONS) defines eight categories of settlement type using a combination of metrics (Bibby and Brindley, 2013). These settlement types are often used to differentiate the type of community at risk as part of a national scale analysis (NIC, 2018; Sayers et al., 2018, 2020) and are again used here to assign a dominant settlement to each PCU. The ONS settlement types include four rural and four urban types: (i) *Rural town and fringe*; (ii) *Rural town and fringe in a sparse setting*; (iii) *Rural village and dispersed*; (iv) *Rural village and dispersed in a sparse setting*; (v) *Urban city and town*; (vi) *Urban city and town in a sparse setting*; (vii) *Urban minor conurbation*, and (viii) *Urban major conurbation*. A simplified view showing *major urban*, other *urban,* and *rural* assignments is given in Fig. 6. For those PCUs containing a *'major urban conurbation'* it is assumed that the benefit-cost case for continuing to HtL will be strong regardless of climate change. This reflects high density of development associated with major urban conurbations but also the likely significant sunk investments in supporting infrastructure. This is recognised by Hall et al. (2019), highlighting for the Thames estuary an overall engineering limit to adaptation (as identified by Ranger et al., 2013) is unlikely to be reached across a wide range of sea level rise scenarios. Consequently, those lengths of shoreline fronting a *'major urban conurbation'* are assumed to have *'low'* realignment pressure and are excluded from the following steps. Nonetheless, although excluded here, it should be noted this may not the case in all urban areas when considered in the context of very long-term projections of rSLR.

5.4. Existing floodplain development

The number of properties (excluding caravans) within the coastal floodplain (assuming defences where they exist to be absent) varies significantly between PCUs (Fig. 7). Many PCUs include significant lengths of shoreline where the associated floodplain is either very narrow (and uninhabited) or rural (and very sparsely inhabited). Although sparsely developed floodplains may experience significant realignment pressure and rise issues of food security and biodiversity, few properties would be affected. Given this focus, PCUs containing fewer than 2 properties are excluded from further analysis.

5.5. National economic case for continuing to hold-the-Line

To explore the national case for continued investment the analysis presented here makes use of the Future Flood Explorer (FFE) as applied in support of the 3rd UK CCRA (Sayers et al., 2020). The FFE (first developed in support of the 2nd UK CCRA, Sayers et al., 2015) provides an assessment of flood risk that takes account of flood defences (both standard and condition) where they exist and is sensitive to climate

Typical values of rSLR (m) 50th percentile (10th - 90th percentiles)								
Impact on Present Day Standard of Protection (Return Period - Years) of a 0.35 m rSLR								
2	5	10	20	50	100	200	500	1000
England								
0	1	3	5	12	23	44	107	202
1	3	5	10	24	47	91	256	567
1	2	3	7	17	35	70	198	370
1	3	5	8	18	32	60	145	288
0	2	3	7	15	28	53	128	243
1	2	4	9	23	42	84	232	420
0	2	3	6	18	38	78	231	449
0	1	3	5	14	30	64	186	435
0	2	4	7	18	37	73	229	622
0	1	3	6	15	31	63	162	360
1	3	5	8	17	33	64	145	288
1	1	2	4	11	21	40	105	215
0	0	1	3	7	13	25	62	119
0	1	2	5	10	20	40	95	185
1	2	3	7	18	36	70	171	331
1	2	5	9	22	41	79	197	379
1	2	4	8	19	37	72	176	351
1	2	3	6	14	26	50	123	265
0	2	4	7	17	33	70	190	369
0	1	3	6	15	30	55	135	249
0.445365856914985	1.16341460274487	2.42731714248657	4.93658555658852	12.6463418448844	24.2292682926829	45.884878465606	110.918049472716	211.926337860852
0.330000010018165	0.880000003026082	2.23384620776543	3.96230768240415	9.32846175707304	18.0546157103318	35.053845508282	86.2092335627629	175.253845214844
EAST								
North and North-West								
South-West								

change, socio-economic growth, and the influence of adaptation measures (both structural and non-structural). The FFE is an exploratory model that uses nationally recognised source (water levels and wave conditions), pathway (defence overtopping, fragility, and inundation), and receptor (properties – residential and non-residential) data to construct an emulation of the present-day flood risk system that can be

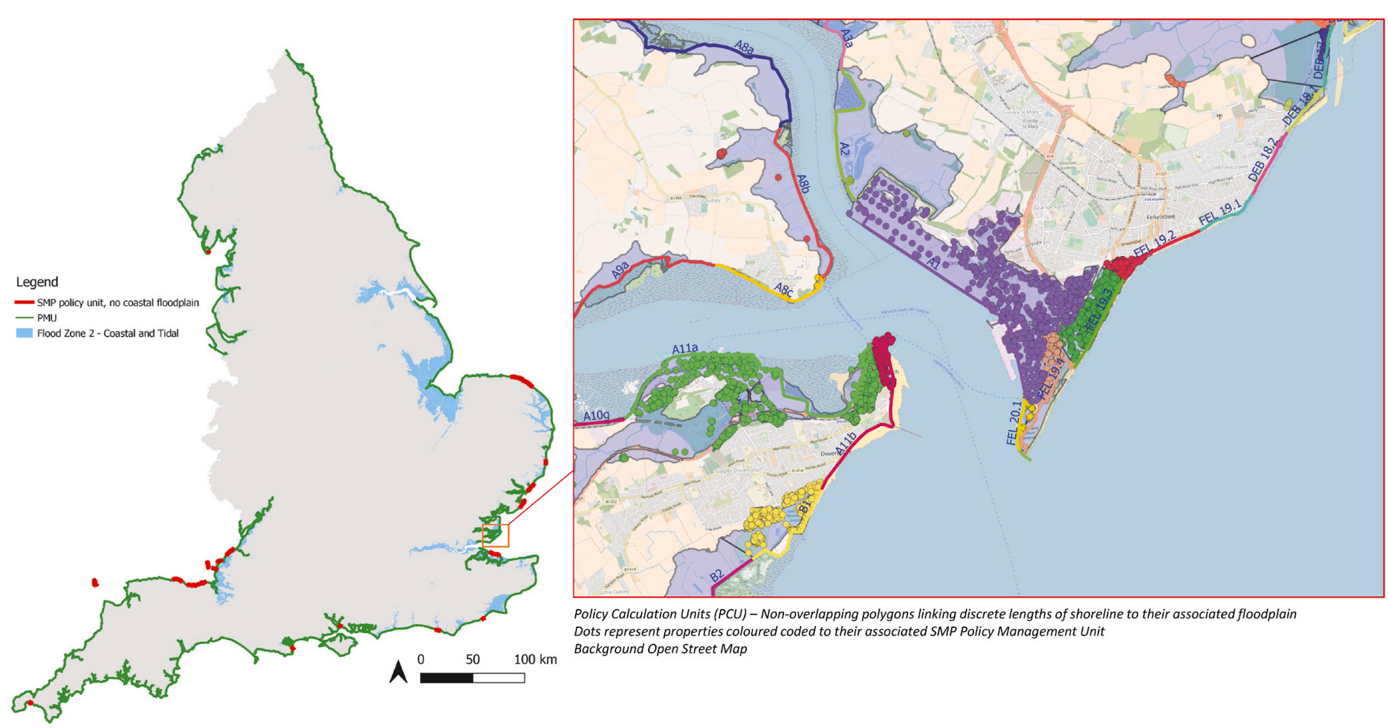


Fig. 5. Policy Calculation Units – PCUs are formed using the Policy Management Units (PMU) defined by each Shoreline Management Plan and their associated coastal floodplain.
Left: The shoreline of England. Blue: The 1in1000 year present day coastal floodplain (assuming the absence of coastal defence). Red lines highlight those frontages with no associated floodplain.
Right: Illustration of the definition of the Policy Calculation Units for the area around the mouth of the Stroud estuary.

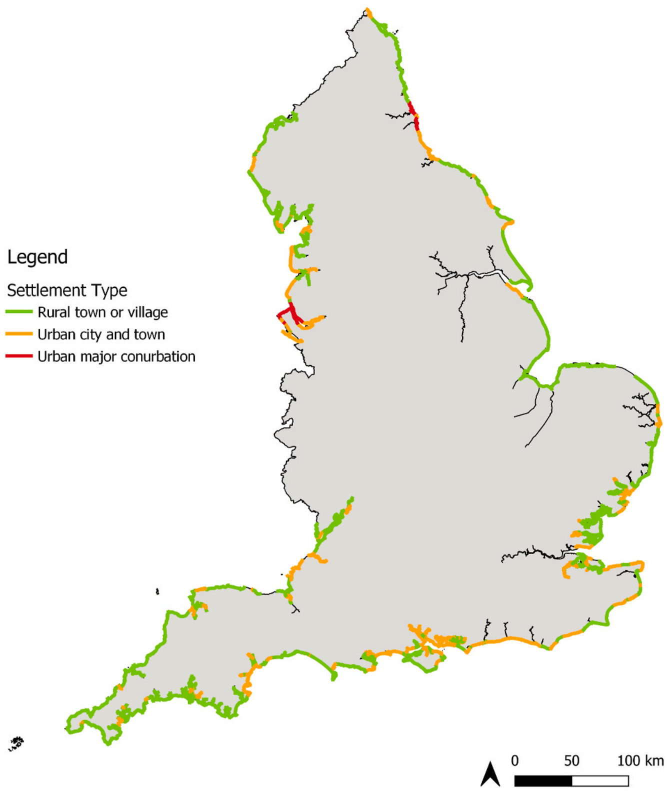


Fig. 6. Settlement types – major urban, urban, and rural - assigned to each Policy Calculation Unit
Note: SMPs 20 and 21 have been excluded from the analysis as they cover Wales.
Source: Sayers et al.,2018.

perturbed to explore the influence of future change on flood risk (building on the framing of the flood risk system set out in Sayers et al., 2002, Evans et al., 2004a,b, Hall et al., 2006). The FFE is fast to run (enabling multiple futures and a range of risk metrics to be calculated) and has been shown to provide a credible emulation when compared to damages incurred in past events (specifically the 2007 widespread fluvial flooding) and to published national assessments (Sayers et al., 2015, 2020).

In addition to the scenarios of rSLR (Table 1), assumptions regarding adaptation are of central importance to understanding how risks may change. The effectiveness of existing policy outcomes and those that may result from recent changes in policy (including the 25 Year Environment Plan, Defra, 2019 and the National Planning Policy Framework, Ministry of Housing, Communities and Local Government, MHCLG, 2021) were reviewed as part of the UKCCRA and used to define a central adaptation assumption based on a continuation of Current Levels of Adaptation (CLA, Sayers et al., 2020). The CLA scenario is reused here and sees flood protection standards continue to be maintained where the present-day standards are high (typically more than 1in75 years). Elsewhere standards fall in response to climate change to 75% of their present-day value before action is taken. At the shoreline some realignment takes place through the implementation of 'no active intervention' and 'realignment' policies set out in the SMPs but not all (reflecting the recent rate of implementation, Fig. 3).

The FFE also enables the investment need associated with implementing the CLA policy scenario to be assessed. The cost assessment uses a 100-appraisal period and capital and maintenance costs discounted using standard government Test Discount Rates (3.50%, year 0–30; 3.00% year 31–75 and 2.50% year 76–125, HM Treasury, 2018). If adaptation is needed to raise the standard of coastal defence (uniquely determined for each PCU by the rules that govern the adaptation scenario) the capital and on-going maintenance cost are determined using a high-level cost function based average cost per property protected (Sayers et al., 2018). The cost functions are based on a combination of mining real-world project costs (as recorded by the Environment Agency covering the period 2010–2015) and detailed scheme estimates (as recorded in Environment Agency's six-year Forward Investment Programme, covering 2016–2021). They are also differentiated by the dominant settlement type within each PCU (see above) to reflect the higher cost per property protection in rural locations compared to urban settings (as evident in the real-world project costs) and enhancement factors applied to account for the likely increase in capital and maintenance costs given more severe loading conditions as a result on sea level rise (Sayers et al., 2018). It should be noted however that although the cost functions set out in Sayers et al. (2018) provide a consistent assessment to support a macro analysis they do not consider localised

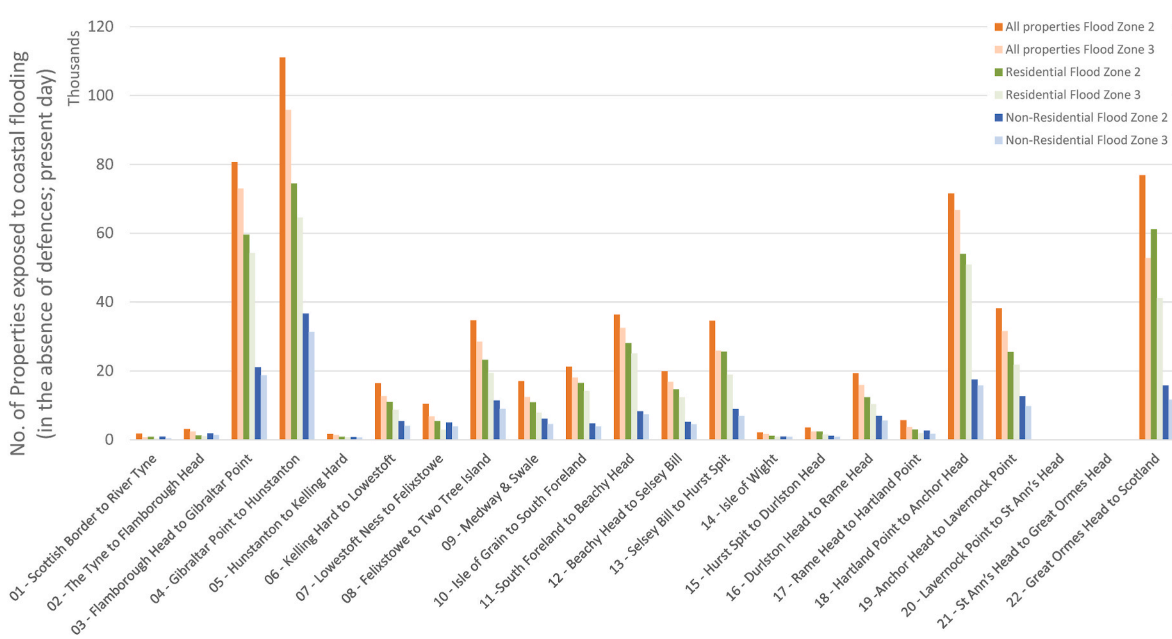


Fig. 7. Residential and non-residential properties within the coastal floodplain by SMP (assuming the absence of defences where they exist).

issues such as the availability of space to enable raising, or the need for additional pumping that may be needed to manage changes in groundwater flow paths or drainage of surface water (for example).

The Present-Value (PV) costs and benefits (determined as the difference between the residual risk assuming a continuation of current level of adaptation and a 'do nothing' counterfactual) are used to provide an approximate Benefit-Cost Ratio (BCR). A BCR of >5 is typically needed to attract national funding support for flood risk management (given competition with other national priorities). It may be the case that a compelling case could be made for investment below this threshold when the choice is between maintaining or relocating a community. If it is assumed this threshold is a BCR >3, ~2,100 km of shoreline currently identified as having a preferred policy choice of HtL would fail to secure investment in a 2 °C climate future and ~1,800 km in a 4 °C climate future (Fig. 8). If it is assumed that a BCR of at least 1 is needed to attract central government support, ~1,700 km of shoreline

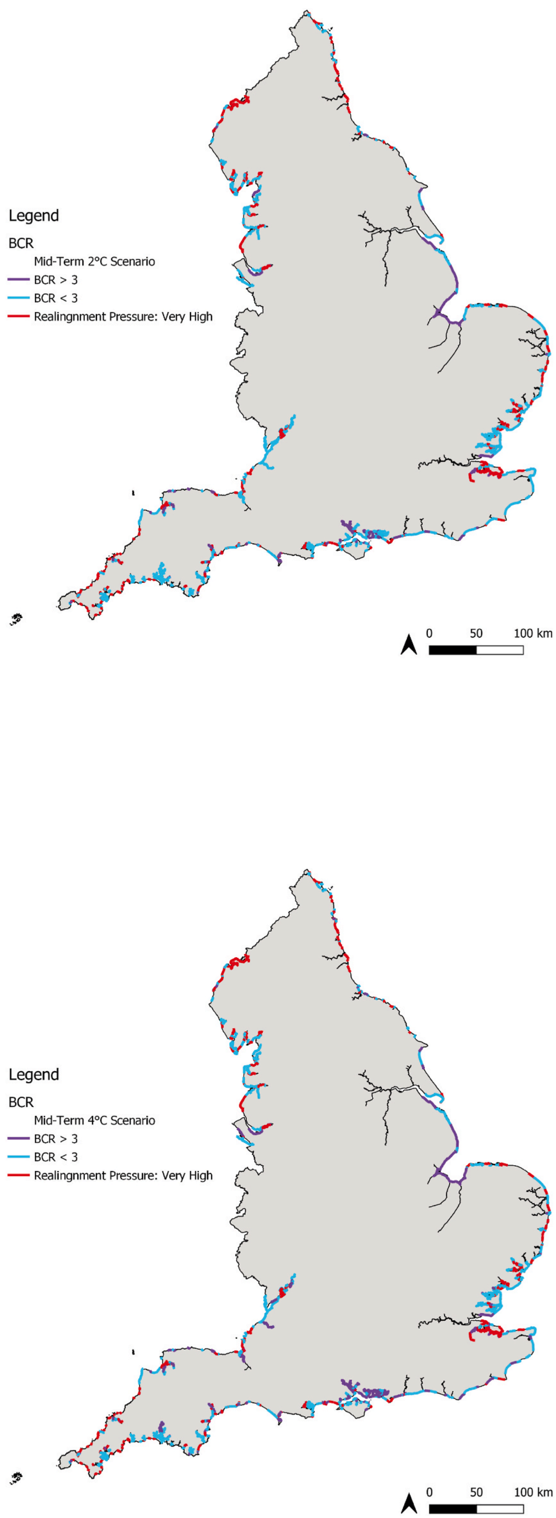


Fig. 8. Benefit-Cost Ratio threshold of 3 - Case for implementing a Hold-the-Line policy choice through to the 2080s
Top: Assuming a 2 °C and low population growth futureBottom: Assuming a 4 °C and high population growth future.

Fig. 9. Proportional increase in risk assuming a continuation of Current Levels of Adaptation.

currently identified as having a preferred policy choice of HtL would fail to secure investment in a 2 °C climate future. This reduces slightly to ~1,400 km in 4 °C climate future. This difference between a 2 and 4 °C future is initially counter-intuitive, however it reflects the significantly greater risk in a 4 °C future that more than offsets the increase in protection costs in some areas (Fig. 9).

5.6. *Vulnerability to shore platform lowering*

Most of England's shoreline defences experience incident wave conditions that are depth-limited (e.g. Burgess and Townend, 2004). Relative sea level rise acts to reduce the depth-limiting effect and can lead to increased overtopping and the potential for larger wave impact forces (and subsequent structural damage and increased breach potential). Isostatic adjustment is not the only geological consideration in determining relative SLR and the associated change in depth-limitation. At a local scale the downward erosion of the shore platform (platform lowering) will, in some locations, have a significant contribution.

Shore platform lowering adds cost to delivering a HtL policy and is considered here as an additional pressure for realignment. To determine the susceptibility of shoreline to platform lowering a combination of the present-day foreshore slope (from Payo et al., 2020), the surface erodibility of foreshore (using a qualitative erodibility score developed by Jenkins et al., 2017) and the projected rates of recession of the backshore (from the National Coastal Erosion Risk Mapping, NCERM) are used (see Supplementary Material). The assessment results in an indication of the potential lowering in the mid and long term (Fig. 10).

Estimate of platform lowering is combined with rSLR to reassess realignment pressure. To do so, it is assumed that the cost of maintaining backshore defences increases significantly when the mean water depth at the toe exceeds 0.2 m (a broad scale indicator of shoreline vulnerability as suggested by Sayers et al., 2015, not a local assessment). By the 2050s, assuming a 2 °C climate future the shoreline of North Norfolk and the Southeast coast of Devon becomes increasingly vulnerable to the combination of platform lowering and sea level rise. By the 2080s a significant portion of East Anglia and the south coast are also vulnerable (Fig. 11). In some locations, such as the Isle of Wright and northeast coast the coastal floodplain is very narrow and squeezed between the backshore cliff and shoreline. In most cases few (if any) properties exist in these areas. Along the Kent coast (south-east) shore platform lowering is an important driver of vulnerability (top left, Fig. 11) but as sea levels rise in the longer term or under more severe climate change, rSLR is the critical driver of vulnerability. The results confirm sea level rise is the dominant driver of future shoreline vulnerability, but platform lowering is also significant (Fig. 12).

These additional pressures are accounted for here by reclassifying those locations with a strong case for investment (from the previous step) but with a high vulnerability to shore platform lowering from being under a *'high'* realignment pressure (see earlier Fig. 4).

6. Discussion of the realignment pressure

The assessment suggests ~1,600–1,900 km of the shoreline currently associated with a HtL policy will be under a *'high'* pressure to be reconsidered for MR by 2080s (Fig. 13). A further ~700–1,000 km will experience more *'moderate'* pressure to reconsider. Consequently, in the coming 20–50 years those living and working in ~120,000–160,000 properties (residential and non-residential) may face uncertainty regarding the continued ability to HtL and it is likely that a proportion of these properties will require relocation (Table 2). It is not possible to say how many this will be. This will be a matter for government and policy, including changes in the funding regimes and support for innovative long-term solutions that may influence local outcomes.

The analysis here is at the national scale. Local issues will of course influence the reality of the future management choice (*e.g.*, the presence of a major cross channel communication cable or energy pipeline, or an important slipway or tourist activity). The influence of major critical infrastructure features has also been excluded, but these will continue to be protected into the long term and will influence the management of the adjacent coasts. For example, the development of the Hinkley C Nuclear Power Plant on the North Somerset coast will mean the immediate shoreline will be protected in the long-term. Nonetheless, as Table 2 implies the scale of the challenge is significant and not evenly distributed around the coast. In some locations the challenge will be around how to implement the published SMP policy choice and transition from a HtL to a MR policy. In other locations, a more difficult conversation may be needed to revisit the published policy choice and develop a pathway for transformational adaptation and transition from Hold-the-Line to relocate a community (Fig. 14).

7. Community typologies most likely to require some form of realignment

The exclusion local issues and influences mean it is not appropriate to use the analysis here to identify specific locations where realignment or relocation will be needed. The analysis does however highlight four

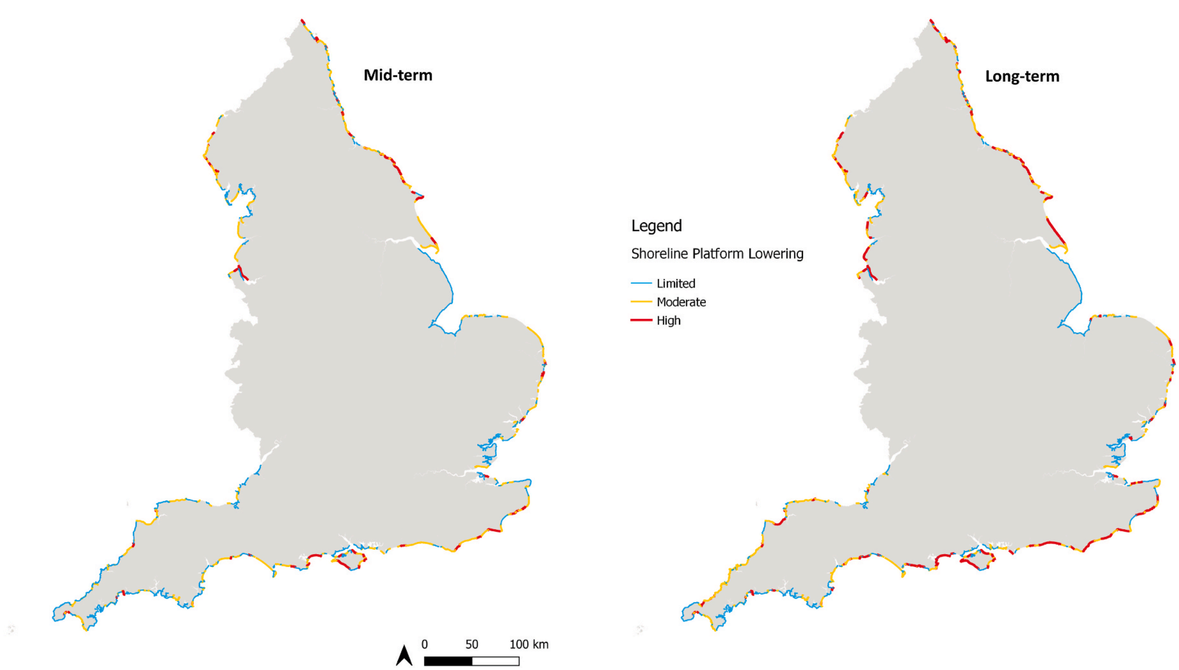


Fig. 10. Shore platform lowering in the mid- and long-term (Limited = 0–0.1 m, Moderate = 0.1–1 m, High = greater than 1 m).

Fig. 11. Coastal (flood) defences vulnerable to either sea level rise or wave-driven shore platform lowering.
Top: 2 °C rise in GMST – relative SLR and platform lowering. Medium and Long term
Bottom: 4 °C rise in GMST – relative SLR and platform lowering. Medium and Long term.

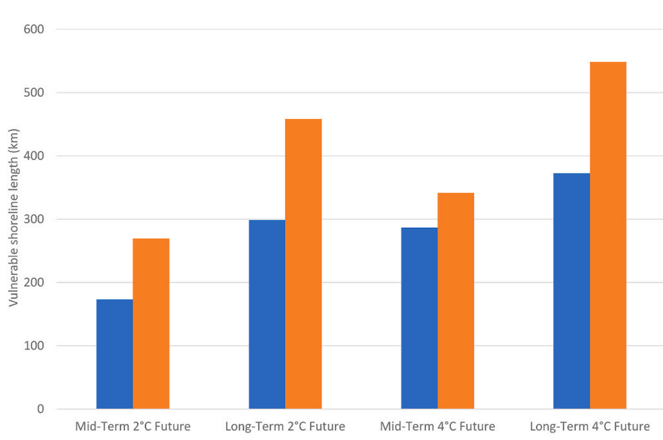


Fig. 12. Length of shoreline vulnerable to rSLR and the combination of rSLR and wave-driven shoreline platform lowering.

community typologies most likely to experience *'high'* realignment pressure (Fig. 15). Each typology is likely to experience *'high'* realignment pressure for different reasons, for example:

- **Type I - Single communities under pressure** – despite a significant number of properties at risk from coastal flooding, the complexity of the shoreline and floodplain suggest the level of investment needed to maintain the current shoreline is likely to be significantly greater than the benefits. Realignment may not impact the whole floodplain but nonetheless may require relocation of many properties.
- **Type II - Dispersed communities within an extensive coastal floodplain** – the shoreline defences protect an extensive floodplain containing multiple small communities. As the investment needed to maintain the shoreline position increases pressure will increase on finding a new realigned (and more easily maintained) defence position.
- **Type III Squeezed narrow coastal floodplain** – a narrow floodplain constrained between the shoreline and raising ground. Many

Shoreline Management Policy	0-20 years	20-50 years			50-100 years		
	Published	Published	Assessed		Published	Assessed	
			2°C future	4°C future		2°C future	4°C future
No Active Intervention (NAI)	38%	38%			37%		
Advance the Line (ADL)	<1%	<1%			<1%		
Managed Realignment	9%	17%	33%	29%	21%	33%	28%
Hold the Line	53%	45%	29%	34%	42%	30%	35%

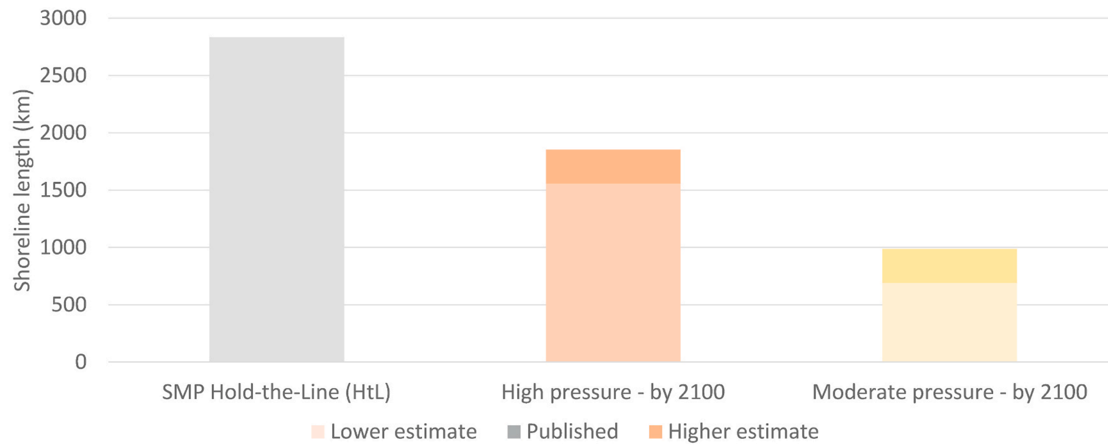


Fig. 13. Comparison of SMP published and assessed policies.

Table 2
Shoreline under pressure - Properties in the coastal floodplain that may experience significant uncertainty regarding the ability 'Hold-the-Line' in the longer term (accounting for length of shoreline and properties).

	2050-2C	2080-2c	2050-4c	2080-4c
England				
Properties (res and non-residential) - (000s)	159	171	124	133
Percentage of all properties in the coastal and tidal floodplain	0.20	0.22	0.16	0.17
Local Authorities with the largest challenge through to 2080s (properties, 000s)				
North Somerset	34			
Wyre	12			
Swale	9			
Tendring	3			
Maldon	3			
Suffolk Coastal	3			
North Norfolk	2			
Cornwall	2			
Medway	1			
Sedgemoor	1			

Note: This is based on top-down national assessment. Local issues that will impact both costs and benefits or the broader case for investment are not considered here.

location promenades, rail lines and roads are located within the narrow floodplain that will be increasingly costly to maintain as sea levels rise. Note: In some locations this is an artefact of the uncertainty in the definition of the shoreline and the floodplain, but in others that pressure is real.

Type IV Marginal quay and coastal harbours communities – low lying properties squeezed between a raising hinterland and harbour quay walls. Larger commercial harbours may be capable adapting to rising sea levels, but smaller historic coastal harbour communities present a particularly, and perhaps overlooked, adaptation challenge.

8. Responding 'fairly' to the coastal climate challenge

Notions of fairness have long been debated by philosophers and theologians. The aim here is not to provide new philosophical debate but rather to consider how issues of 'fairness' have a role to play in determining the preferred shoreline policy. Interpreting 'fairness' in this context is not straightforward; partly because the concept of fairness can be seen from many perspectives (e.g., Vojinović and Abbott, 2012; Sayers et al., 2017) and the difficulty in balancing the often competing dimensions (Johnson et al., 2007).

Protection from flooding in England is not a right or entitlement but authorities act through permissive powers. Under these powers, investment by central or local government is only permitted if it delivers an outcome for the 'common good'. In general, across public investment the common good is determined through a utilitarian lens of 'fairness'; prioritising investments that yield the greatest benefits of value per unit of resource input (a standard benefit-cost test). The national prioritisation of investment in flood and coastal risk management includes an incremental benefit cost approach that seeks to spread the available investment to many rather than a few locations and introduces an additional Rawlsian 'maximin' perspective (*i.e.* maximising the outcomes for the most socially vulnerable) by giving preferential weighting to schemes that reduce flood risk to deprived households (Defra, 2011).

Egalitarianism is interpreted in the approach to coastal management in England primarily as a consistent process that ensures all citizens have equal opportunity to have their risk managed and have equal input to decision-making processes. This becomes difficult when profound conflicts exist between those that make the decisions and those that are impacted by them. The residents of Fairbourne for example (a small community in Wales facing a SMP policy in transition from HtL to MR), feel their voice has not been heard in the decision to *'decommission'* their community (Buser, 2020). Regardless of the arguments for and against this specific change in policy, there is a clear moral hazard here. Since the devastating coastal floods of 1953 (Steers, 1953) many communities (including Fairbourne) have seen investment to significantly improve coastal defences and these continue to be well maintained. Where present, the protection afforded by well-maintained defence has, and continues, to encourage floodplain development. Those choosing to live in such areas could reasonably expect, in the absence of a clear statement

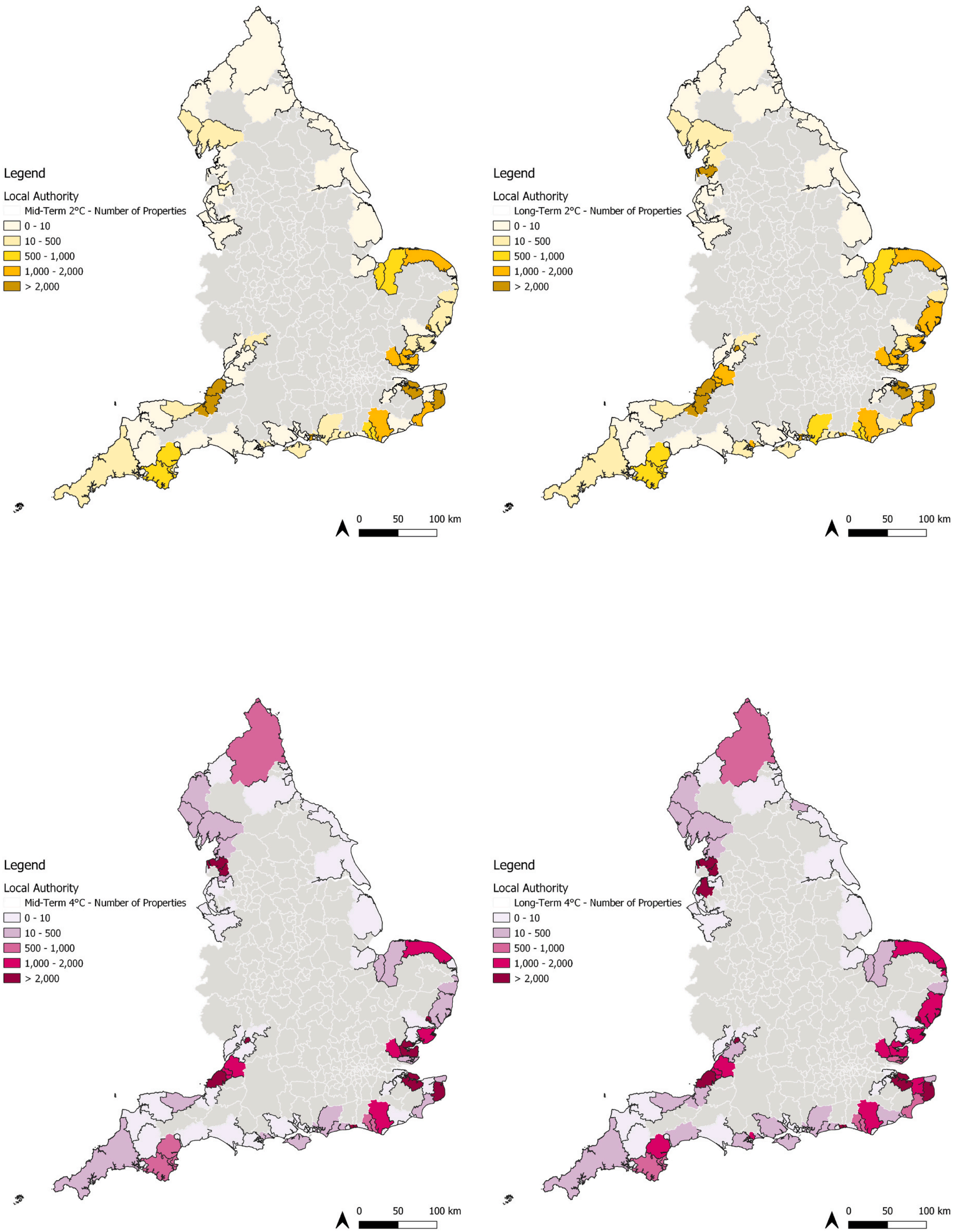
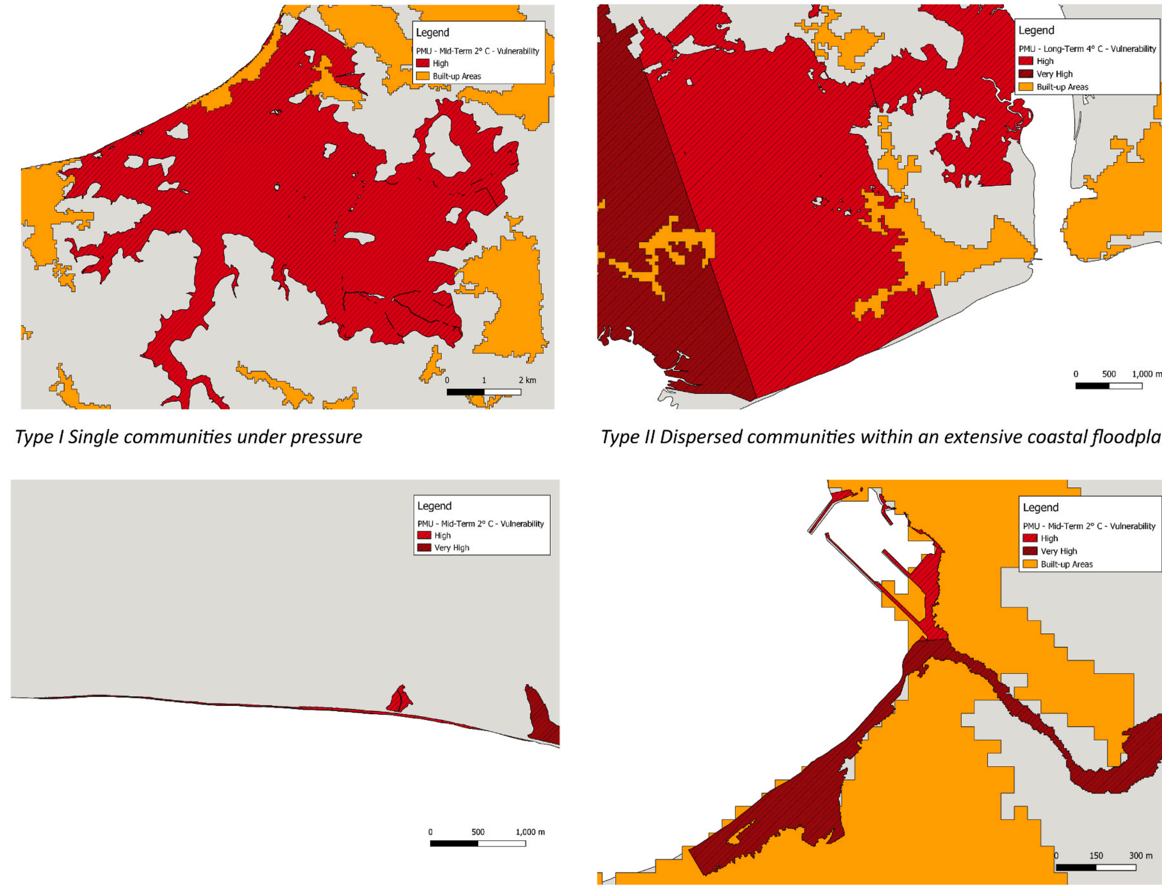


Fig. 14. Number of properties within Policy Calculation Units that could come under increasing pressure to transition from a Hold-the-Line to a realignment/relocation policy
Top: 2 °C climate future: Bottom: 4 °C climate future
Left: In the medium term (20–50 years ahead); Right: In the long term (50–100 years ahead).



Type I Single communities under pressure

Type II Dispersed communities within an extensive coastal floodplain

Type III Squeezed narrow coastal floodplains

Type IV Marginal quay and coastal harbours communities

Fig. 15. Four typologies most likely to experience high pressure to transition to a realigned shoreline position.

to the contrary, protection for the foreseeable future; but in some locations this will not be possible.

Some countries enshrine a principle of 'solidarity' in flood investment decisions that seeks to ensure everyone has their individual risks managed equally. For example, in the Netherlands a minimum standard of protection against dying from a flood is a legal right, regardless of cost; although this position is increasingly challenged based on its inefficient use of limited funds (van Alphen, 2014, Klijn et al., 2015). In England, the principle of 'solidarity' features more subtlety within the provision of non risk-based flood reinsurance (via the Flood Re scheme due to run until 2039)[4] but does not feature directly in flood defence standards in England. The issue of minimum standards has been explored several times, but both rejected on the grounds of resource inefficiency (Environment Agency, 2003 and more recently through concept of a resilience standard, National Infrastructure Commission, 2018).

9. Providing clarity in support of transformational change

Some aspects of the future are readily foreseeable and largely uncontested. As sea levels rise, for example, sea defences will become increasingly difficult and costly to maintain and the relocation of some communities will be inevitable. Seeking to respond through incremental adaptation is relatively easy; progressively raising defences, improving warnings, installing property flood resilience measures *etc.* Such actions are well supported by existing governance structures and investment vehicles and significant progress has been made embedding 'incremental adaptation' within our planning and policies. However, there is a gap around how to support the delivery of transformational change in the face of increasing coastal flood risk; accepting that for some communities, climate change will have profound impact and support is needed to help them address the transitional challenge it proposes.

Although the time horizons often appear long into the future, transformative change takes time (e.g. from HtL to one of realignment and relocation) and there are several moderating social factors that influence the move from incremental to transformative adaptation (Wilson et al., 2020). To help, many of the insights from the Coastal Pathfinder studies (Defra, 2015) based largely on the consideration of erosion risk are transferable to the case of communities exposed to increasing coastal flood risk, for example:

- **Planning** - Ensuring local planning choices are more closely in line with the long term SMP choices and identifying and purchasing or repurposing land (land banking) for future community development.
- **Engagement** - Ensuring the affected communities are meaningfully engaged in the decision process.
- **Economic** - Supporting property owners (and local authorities) in accessing assistance packages (for demolition and relocation) including buy-back or lease back-schemes and preferential access to development land.

Underpinning these findings is a recognition that implementing a relocation is a long process, requiring extensive engagement with the community to agree relocation is needed and to establish a viable transition programme, including incentives, the identification of

[4] https://www.floodre.co.uk/.

relocation sites, and support for repurposing the realigned coast to maximise natural values. In England, for coastal communities that face the prospect of relocation, compensation or compulsory purchase (at risk free market prices) is not generally available as a taxpayer funded coastal management options; even if such an option provides the least cost means of reducing the long-term flood risk. The Defra Coastal Pathfinder studies (Defra, 2015) suggested (but did not implement) 'leaseback'[5] (or buy to leaseback) schemes as an option in areas of coastal erosion (Frew, 2012). Internationally, examples of 'buy-back' have been in place for many years. In the US for example, the Federal Emergency Management Agency (FEMA) and the US Department of Housing and Urban Development (HUD) both administrate federal grant programs acquire flood-prone residential properties (Peterson et al., 2020), but the focus tends to be on individual homes and provided in response to recent flood events rather than precautionary community scale purchase. In Australia, part of the town of Grantham, Queensland was relocated following devastating floods in January 2011. The town council (the Lockyer Valley Regional Council) acquired a 377-ha (932-acre) site to enable a voluntary swap of equivalent-sized lots and streamlined planning processes to enable the relocation of a portion of the town (Sipe and Vella, 2014). Again the relocation was in response to a flood event rather than projected increases in risk.

Climate issues are however starting to play a central role in contemporary relocation debates. Indonesia continues to consider moving its capital from Jakarta to Kalimantan, partly in response to the projected coastal flood risk (Nirarta et al., 2019). The low-lying Pacific Island nation of Kiribati has bought land in Fiji to allow a future migration as a hedge against increasing coastal risk (Chand and Taupo., 2020). Louisiana has supported the resettlement of a small coastal community from Isle de Jean Charles to a site 40 miles inland north (Jessee, 2020) and in the aftermath of 2011 tsunami Japan are relocating approximately 145,000 homes to new towns being built outside the tsunami hazard zone (Pinter et al., 2019). Although not explicitly climate change driven, Japan's large-scale relocation away from the coastal floodplain reinforces transformational adaptation is possible, given an ambitious vision and commitment.

10. The opportunity to reset the future is now

In the coming years the Environment Agency will be working with Local Authorities to refresh England's SMPs. The recently published FCERM strategy that places climate adaptation as a central theme, the UKCCRA that highlights the increasing significance of coastal flood risk, and the near certainty of experiencing close to 1 m of sea level rise by the end of the century (or soon after)) and continued changes in the longer term (beyond 2100) will provide the backdrop to this refresh.

In this context, the importance of the next round of SMPs to set out a clear long-term future for coastal communities cannot be overestimated. This will require making policy choices that are technically feasible, locally accepted and balance national costs and benefits over the long term. But SMPs do not stand alone. They are only advisory and are not necessarily fully reflected in local planning policies. This lack of formal connection, although strengthened in recent years (Environment Agency, 2010), should be strengthen further. The limitations in the scope of the SMP process mean they say little about 'how' to transition to a future realignment policy (where necessary) will be facilitated (providing little clarity around funding support, incentives, or the national and local compensation mechanisms that will be accessed). Without a clear transformation pathway (supported by across national and local planning processes) progress will continue to be limited. This tactical handshake between strategy and implementation is a difficult and recognised challenge, but central to implementing adaptation in practice (Sayers et al., 2021).

The is a growing body of methods and planning techniques to help assess the changing risks and the appropriate adaptation response to climate change (from adaptation pathways, *e.g.* McGahey and Sayers, 2008, Haasnoot et al., 2012, 2021; robust decision making under deep uncertainty, *e.g.* Hall et al., 2012, Kwakkel et al., 2016)) and how to value the creation of adaptive capacity (*e.g.* Brisley et al., 2016). The ability to visualise alternative adaptation pathways (either in time or in response to thresholds of change) will provide an important aid to help communities understand how to progress. Such approaches all offer useful contributions but will require continued development (and piloting) to support transformational change as part of the SMP process.

The broader opportunity that transformative adaptation presents (if appropriately planned) at more regional scales is also an active debate beyond England. The need to act at scale is often highlighted. Siders (2019), for example, makes the case achieving large-scale retreat could have significant benefits and transform US social, economic, and ecological systems. The lack of knowledge and exemplar case studies is also being addressed. For example, there are growing number of platforms focused on sharing the science and practice of coastal adaptation (such as the European Environment Agency maintained site Climate-ADAPT[6]) and review studies that share of real-world examples and lessons (such as those across Europe collated by Pijnappels and Dietl, 2013). This evidence base and illustrative example provide useful context to the difficult decision around transformative approaches. As in England, however, the central challenge of who pays and who receives support continues to be highlighted together with the need to have difficult conversations about fairness.

11. Conclusions

For many estuary and coastal cities continuing to the Hold-the-Line is readily supported nationally and locally. The economic impact of flooding, sunk investment in infrastructure, commerce and housing will continue to justify protection as sea levels rise. Equally, in undeveloped floodplains, where opportunities exist to reduce management costs, restore natural processes, create habitats and other benefits, the case for Managed Realignment is gathering pace and presents a (relatively) easy case to make. The challenge that remains largely unaddressed is the fate of our coastal communities, those at increasing risk from coastal flooding but where continued investment to maintain the existing shoreline position and associated protection is unlikely to be justified (given current funding regimes).

Assuming a continuation of current levels of adaptation, the analysis suggests a significant acceleration in the scale of coastal flood risk towards the end of the century; with Expected Annual Damages (direct residential property damage) projected to increase from £60 m today to ~£120 m by 2050s (assuming a 2 °C/Low population growth future) and to ~£280 m by 2080s (assuming a 4 °C/high population growth future).

Given this context 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).

The decision to relocate a community will always be difficult and involve multiple complex trade-offs. This complexity should not however result in an absence of a serious national debate about the scale of the threat and what represents a fair and sustainable response. Instead, it should invigorate discussion, recognising that any decision to transition from Hold the Line to Managed Realignment takes significant time to agree and to implement. It also requires strategic planning that looks

[5] The process of purchasing an at-risk property and leasing it out for the remainder of its economic life.

[6] https://climate-adapt.eea.europa.eu/about.

beyond community-by-community choices.

The Environment Agency's FCERM strategy places an emphasis on resilience and climate adaptation. The 3rd UKCCRA highlights the increasing significance of coastal flood risk, and the near certainty of experiencing close to 1 m of sea level rise by the end of the century (or soon after) will provide the backdrop to this refresh. As the Environment Agency and Local Authorities refresh England's SMPs in the coming years there is an opportunity to provide clarity on where and when realignment will be needed and how it will be delivered. SMPs are well placed to assess the interconnected and dynamic physical and socio-economic process at the coast but need a greater voice in setting out preferred shoreline management policy choices linked to broader funding and spatial planning processes. Where necessary, this will include supporting communities in understanding the future risks and in making the transition from HtL to MR and potential relocation. This will not be easy, and the communities and individuals impacted will require financial support, but implementing transformational adaptation requires a clarity of decision today and cannot be delegated to the future.

Author contributions

Paul Sayers conceived the methods and drafted the paper. Charlotte Moss and Sam Carr undertook the spatial analysis and supported drafting. Andres Payo undertook the shoreline platform lowering analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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