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Research to Assess the Economics of Coastal Change Management in England and to Determine Potential Pathways for a Sample of Exposed Communities

Final report

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For the Committee on Climate Change

Coastal change

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Executive Summary

ES.1 Introduction

This is the report for the study *Research to Assess the Economics of Coastal Change Management in England and to Determine Potential Pathways for a Sample of Exposed Communities*.

The study was commissioned by the Committee on Climate Change's (CCC) Adaptation Sub-Committee (ASC) to assess the assets at risk of coastal change, conduct a national cost-benefit analysis (CBA) of measures to manage these risk, and supplement this with a series of case studies which outline the development of adaptation pathways for communities with particular coastal challenges.

Coastal change (flooding and erosion) was identified in the ASC's UK Climate Change Risk Assessment (CCRA) 2017 Evidence Report (ASC, 2016) as an area with a high magnitude of risk where more action is needed. More recently, the Government 25-Year Environment Plan set an objective for the UK to reduce its risk of harm from flooding and coastal erosion, with a focus on natural flood management solutions (HM Government, 2018).

In this context, the ASC are preparing a progress report on coastal adaptation which will draw on the findings from this study with the aim of (i) reviewing and assessing current policies and practices related to coastal flooding and erosion, and (ii) developing recommendations on what effective adaptation looks like.

ES.1.1 Shoreline Management Plans (SMPs)

Shoreline Management Plans (SMPs) are a key tool for managing coastal change risks over the next century. These were produced and adopted around the coast of England and Wales between 2006 and 2011. SMPs involve a large-scale assessment of the risks associated with coastal processes and provide a 100-year policy framework for their sustainable management, taking into account potential impacts of climate change and rising sea levels, which in turn impact the coastline.

SMPs aim to manage the risks of flooding and erosion in the long-term to built assets, while conserving those assets important to us along our coastlines such as our natural environment, amenity beaches and recreational areas. It is important to note that SMPs are non-statutory policy documents for coastal defence management planning which inform wider strategic planning.

Each SMP is broken down into smaller policy units (PUs) for which the procedural guidance requires one of the following four policies to be defined.

Policy	Description
Hold the line (HTL)	Maintaining or changing the level of protection provided by existing coastal defences in their present location
Advance the line (ATL)	Building new defences on the seaward side of the existing defence line to reclaim land
Managed realignment (MR)	Allowing the shoreline position to move backwards (or forwards) with management to control or limit movement
No active intervention (NAI	A decision not to invest in providing or maintaining defences.

One of these polices is defined for each PU over the following timescales:

- Epoch 1 in the short-term (2005 to 2025);
- Epoch 2 in the medium-term (2026 to 2055); and
- Epoch 3 in the long-term (2056 to 2105).

Policy scenarios are chosen based on technical, environmental, social, and economic factors as well as local characteristics.

ES.4 Key findings

The key findings and conclusions from the study are presented in the following sections.

ES.4.1 Assets and land at risk of coastal change

The study estimated the different types of assets and land at risk of coastal flooding and erosion. Notable results include:

- Along England's coastline, there are over 500,000 properties (residential and non-residential) with a 1:200 risk of flooding and potentially up to around 9,000 properties at risk of erosion.

- The number of properties at risk of erosion is forecast to increase to more than 107,000 at risk properties within the next century excluding the impacts of complex cliffs in some areas. In addition to this, there are potentially around a further 100,000 properties at risk of recession of complex cliffs that could occur at any time in the next century, although the timing and magnitude of recession in complex cliff areas is uncertain. Irrespective of this, the trend over the next century is for an ever-increasing number of residential and non-residential properties at risk of erosion.

- The scale of risk of erosion is however much smaller by comparison to the risk of coastal flooding, in general.

- There are nearly 190,000 ha of Grade 1 and Grade 2 agricultural land at risk of flooding (1:200 risk) which represents nearly 9% of such land in England[1].

- There are significant areas of designated land at risk of flooding (1:200 risk) for example:

  - 163,000 ha of Priority Habitats which represent 7% of Priority Habitats in England[2];

  - 105,000 ha of Sites of Special Scientific Interest (SSSIs) which represents nearly 10% of SSSIs in England[3]; and

  - 42,000 ha of Areas of Outstanding National Beauty (AONBs) which represents around 2% of AONBs in England[4].

  These types of designations include rich ecosystems and productive natural capital assets which in turn provide valuable benefits to the rest of society in terms of biodiversity, recreation, climate regulation, etc.

[1] Based on data from Natural England on Provisional Agricultural Land Classification (ALC). See Natural England (2018c).
[2] Based on data from Natural England on the Priority Habitat Inventory. See Natural England (2018b).
[3] Based on data from Natural England on Sites of Special Scientific Interest (England). See Natural England (2018d).
[4] Based on data from Natural England on Areas of Outstanding Natural Beauty (England). See Natural England (2018a).

- Currently available data does not allow future flood risks in Epoch 2 and Epoch 3 to be estimated for the assets and land mentioned here. Further research is required to fill this important gap.

ES.4.2 Coastal adaptation projects from 2015 - 2021

The study also assessed the extent of capital projects planned or underway during the period 2015 – 2021 to manage the risks identified above. It is important to note that although the 2015 – 2021 capital works take place within Epoch 1, they are not necessarily attributable to or driven by specific SMP policies given that SMPs are not statutory. The key findings from the assessment are:

- The 2015-2021 FCERM capital works programme shows only 228 capital projects are planned or have been completed in the period 2015-2021 across SMP areas. This is possibly a lower figure than would be expected given that more than 1,000 policy units require such projects in Epoch 1.
- More than 200,000 homes will be better protected once the expected works have been completed by 2021 assuming that all 228 projects are delivered. More than 127,000 of these homes are located in just three of the 20 SMPs in England.
- The total cost of all 228 capital projects planned/completed in the period 2015-2021 across all 20 SMPs is £1.4 billion.
- Of this total cost, approximately £976 million will come from FCERM grant-in-aid (GiA) funding. The balance of approximately £464 million is required to come from third-party contributions as part of partnership funding arrangements. The published data does not include any details of where this additional funding is expected to come from. Evidence from the PDUs suggests there are significant challenges in achieving this level of third-party contribution to enable the full capital works programme to be delivered by 2021. To put this into some context, as part of granting the six-year funding for 2015-2021, HM Treasury required £600 million pounds of third-party contributions to be raised in this period; as of September 2016, it was confirmed that £270 million of this target had been achieved (Priestley, 2017).
- There is a disparity around the coast in terms of total costs and numbers of properties protected. For example, some SMPs have high costs and a relatively small number of properties better protected.

ES.4.3 SMPs in Local Plans

In investigating the extent to which Local Plans reflect SMPs, the study found that 78% of the Local Plans identified and reviewed refer to SMPs. This leaves 22% of Local Plans that do not refer to SMPs for unspecified reasons.

Overall, while it is positive that a large number of coastal Local Plans make reference to the evidence and policies set out in the relevant SMPs, further work is needed to integrate the evidence base from SMPs and implement Coastal Change Management Areas to set a framework for guiding and driving future adaptation in areas at greatest risk of coastal change. In doing so, there is a need for greater recognition of residual risks in areas that are expected to continue to be defended. This can help drive adaptation and improve resilience to the increase in coastal hazards to remaining communities.

ES.4.4 Cost-benefit analysis of SMP policies

The study undertook a cost-benefit analysis (CBA) of the polices set out in SMPs. The costs included in the CBA reflect the cost of measures in SMP documents. The benefits included in the CBA reflect avoided damage to properties from flooding and the benefits of the delayed damages of erosion. Environmental impacts are not included in the CBA. The limited scope of the CBA is the result of the lack of available data to assess these impacts at the national level.

Economic appraisal in SMPs

In SMP documents, the preferred policy in each policy unit is chosen before an economic appraisal is undertaken. The guidance on undertaking an economic appraisal of SMP policies states that economic assessments only provide a check on the viability of the selected preferred policies and review of their robustness in economic terms, and a full economic assessment is not required in the form of a CBA. Economic evidence does not drive the selection of the preferred policy.

It is recommended that future reviews of SMPs use economic appraisal and evidence more consistently and rigorously to inform decisions of preferred policies. There is a need to better assess the economic costs and benefits of coastal adaptation via SMPs in order to better understand and manage their impacts to communities and the environment. This is particularly important in light of the potential gap in funding to deliver SMPs, and coastal adaptation more generally. A more robust economic evidence base of the impacts of SMPs can aid in the prioritisation of funding across different FCERM projects, including grant-in-aid funding.

CBA results

Across each dimension of the CBA (at the SMP, policy unit, regional or national level), the costs and benefits of SMP policies are estimated based on the best available data and the methods these allow. While the estimates provide an indication of the order of magnitude of the impacts of the implementation of SMPs, they are subject to varying levels of uncertainty. These results should be interpreted with caution given the inherent uncertainties of the estimated costs of SMPs and the different scales at which the benefits are calculated. Key findings from the CBA include:

- **Cost of SMP policies:** Within each Epoch, the cost of SMP policies is less than £5 million in present value terms for the majority of policy units (over a 100-year timescale). The costs are highest in Epoch 2 followed by Epoch 1 and Epoch 3 respectively. The policy of HTL is the most costly across all Epochs, accounting for 80% - 90% of the total cost per Epoch. This is followed by MR which accounts for 6% - 15% of the total cost per Epoch. Across Epochs, the present value cost of HTL is between five and fourteen times the cost of MR.

- **Funding to deliver SMPs:** The present value cost of implementing SMPs in Epoch 1 is nearly £3 billion in 2011 prices. The magnitude of these costs raises the question of the extent of recent funding available to implement SMPs. Total expenditure on flood and coastal erosion risk management (FCERM) for the period 2005 – 2017 is estimated to be around £8 billion in 2011 prices. Expenditure on FCERM goes toward multiple sources including managing coastal, fluvial, surface water and groundwater sources of flood risk. This would suggest a likely gap in the funding available to implement SMPs within Epoch 1.

- **Benefits of SMP policies:** As with the costs, the benefits of avoided damages from flooding within each Epoch are less than £5 million in present value terms for the majority of policy units. The benefits of SMP policies are highest in Epoch 1 followed by Epoch 2 and Epoch 3 respectively. The policy of HTL has the highest benefits across all Epochs. This result is fundamentally influenced by the scope of the CBA which does not include environmental benefits e.g. from habitat creation under managed realignment (MR).

Alongside the benefits of avoided damages from flooding, the study also assesses the benefits of delayed damages from erosion. These are the benefits to properties better protected from the risk of erosion due to the implementation of policies in SMPs. The benefits of delayed erosion are estimated to be over £900 million in Epoch 1 in present value terms. The benefits more than double in Epoch 2 to £2 billion in present value terms and fall to around £1 billion in Epoch 3. In general, the proportion of benefits due to delayed damages of erosion increases over time from 26% of total benefits in Epoch 1 to around 55% in Epoch 2 and Epoch 3 respectively. This is due to the rising number of properties at risk of erosion over the next century.

- **Comparison of costs and benefits**: At the national level, the benefits of implementing SMP policies outweigh the costs, with a net benefit of nearly £2 billion over 100 years.

Key sensitivity of the CBA results

The following findings emerge from sensitivity analysis of the CBA results:

- **Impact of climate change on costs:** In general, exploring the likely impact of climate change on the costs of implementing SMPs establishes a range for the costs and their comparison to the benefits of SMPs. The impact reflects the effect of lower or higher sea level rise on the cost of SMP policies due to the need to strengthen and widen existing defences. SMPs with a net cost are unlikely to switch to having a net benefit under alternative assumptions regarding the impact of climate change on their costs. SMPs with a borderline BCR are however sensitive to these alternative assumptions. At the national level, the costs of SMPs outweigh the benefits in a high climate change scenario. It is recommended that the method for adjusting the costs of SMPs is refined and updated to use upcoming UK Climate Projections for 2018 (UKCP18) in future SMP reviews.

- **Impacts of erosion:** For SMPs or policy units where the CBA results are considered to be borderline and sensitive to the scope of the CBA, the sensitivity analysis demonstrates that different assumptions regarding the probability of occurrence of erosion can sway the results for certain SMPs. However, at the national level, there is a net benefit from implementing SMP policies regardless of the assumptions for the probability of erosion.

- **Environmental impacts:** It is important to assess the environmental impacts of SMP policies. For sites where MR is a proposed policy and the CBA results are not favourable (costs outweigh the benefits), it is worth investigating the potential for habitat creation to justify the costs of MR. However, not all MR schemes will lead to habitat creation and that new habitat may not necessarily always result in a net positive change in the benefit e.g. where one valuable habitat is replacing another.

ES.4.5 Case studies of coastal adaptation pathways

The study developed a series of six case studies for locations with coastal adaptation challenges. In contrast to SMPs which consider fixed/static policies, the case studies develop dynamic adaptation pathways based on levels of risks and triggers to decision-making. The key findings from the development of these case studies are:

- Coastal adaptation is a very complex and challenging issue to address and it is important to emphasise the requirement for a joined-up approach across multiple organisations (public and private sector) working with communities to develop and implement any approach. The lead-in time for implementing any such measures will also be lengthy, and this can be reflected in the adaptation pathways by the relative length of the uncertainty zones shown on the pathway diagrams within each case study which are also a much better, visual way of conveying different options to stakeholders compared to the tabular approach taken in developing the current SMPs.

- The application of adaptation pathways focused on the management approach (which can be aligned to SMP policy type) and use of monitoring key thresholds to trigger future management decisions, has benefits over sticking to rigid setting of policy type within defined time-bound epochs as is the case with SMPs. This provides a more flexible and pragmatic way of both appraising options to address long-term risks in dynamic coastal environments that provide inherent uncertainties, and identifying which options will or will not ‘lock-in’ certain pathways over-time.

  The current use of time-bound epochs in SMPs does not make this clear. Indeed, time-bound epochs cause problems in their own right when things do not happen in strict accordance with their timings, and so using adaptation pathways is likely to be something that can, with appropriate planning and investment in engagement, be used to communicate the drivers of future management decisions to communities. Use of the adaptation pathways approach supported by on-going monitoring in this way means that the ‘timing’ of future management decisions along the pathway can be influenced by both the occurrence of storm events at any point, as well as more gradual changes due to sea level rise.

- At present, the approach to adapting to coastal change involving relocation of assets away from areas of coastal flood and erosion risk is not occurring, in part due to there no national-level Outcome Measure or policy driver, nor funding mechanism(s) available to consider such relocation options in the context coastal flood and erosion risk management, as well as local social, environmental and political pressures to not to relocate but continue to defend (which is unsustainable in many areas).

  One of the main factors that could aid implementation of a more proactive approach to asset relocation would be if there were to be a change in government policy and associated funding prioritisation / outcome measures that enable coastal flood and erosion risk management to cost-effectively relocate at risk properties and assets (i.e. ‘remove the risk’). This would greatly facilitate the ability to plan and implement the management approaches identified for this area, and likely result in a much more proactive approach to community relocation such that communities have long-term security, whilst allowing restoration of natural processes at the coast as defences are removed.

  Such a change in government policy and associated funding prioritisation / outcome measures would also significantly change the discussion of the coastal flood and erosion risk management options typically being considered currently in different parts of the coast, from relocation being a ‘fall-back’ option if it becomes unviable to defend, to relocation possibly emerging as the preferred option to provide a long-term, sustainable solution that delivers a much higher level of protection against flood / erosion risk to those relocated out of the risk areas.

- In addition, at the time of developing the case studies, it is not apparent that any examples of relocating communities on a large scale exist with a full assessment of the complexities, including costs, of doing so. As such it is recommended that future research should consider detailed investigation using several anonymised case studies to explore this in more detail. This would develop some data that can be used to aid the assessment of relocation options in the future. In doing so, a range of community scales should be considered to assess whether there is a likely size of community above which relocation is likely to be prohibitive on cost or other grounds.

1. Introduction

1.1 Background

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1.1.1 Shoreline Management Plans (SMPs)

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In this way, SMPs aim to manage the risks of flooding and erosion in the long-term to built assets, while conserving those assets important to us along our coastlines such as our natural environment, amenity beaches and recreational areas. It is important to note that SMPs are non-statutory policy documents for coastal defence management planning which inform wider strategic planning.

In England and Wales, SMPs were first developed between 1994 and 1999. Following their completion, a number of reviews were undertaken. This led to the development of new procedural guidance for the review and update of the second generation of SMPs. This procedural guidance was published in 2006 by Defra with the intention of having the second generation of SMPs set out a vision for sustainable management of the shoreline in the future and to provide a route map to get there.

Following the guidance (Defra, 2006), 22 second generation of SMPs were developed between 2006 and 2011 around England and Wales.

Each SMP is broken down into smaller policy units (PUs) for which the procedural guidance requires one of the following four policies to be defined:

- Hold the line (HTL) – maintain or change the level of protection provided by existing coastal defences in their present location;
- Advance the line (ATL) – build new defences on the seaward side of the existing defence line to reclaim land;

- Managed realignment (MR) – allow the shoreline position to move backwards (or forwards) with management to control or limit movement; or
- No active intervention (NAI) – a decision not to invest in providing or maintaining defences.

One of these polices is defined for each PU over the following timescales:

- Epoch 1 in the short-term (2005 to 2025);
- Epoch 2 in the medium-term (2026 to 2055); and
- Epoch 3 in the long-term (2056 to 2105).

Policy scenarios are chosen based on technical, environmental, social, and economic factors as well as local characteristics.

1.2 Objectives

The project is split into three parts with the following objectives:

Part I – Summary statistics of coastal change

The first part of the study answers the following questions:

1. What is at risk in the short-, medium- and long-term (Epochs 1-3), in terms of households, other buildings, infrastructure, agricultural land, designated habitats, from:

    a. Damage by coastal flooding in terms of expected annual losses and in plausible extreme event scenarios?
    b. Loss to coastal erosion?

2. What projects and other activities are underway over the period 2015-2021 to manage these risks, and how are these being funded and delivered for:

    a. Coastal flood and erosion alleviation schemes?
    b. Other (non/low-engineering) approaches aiming to reduce the consequences of ongoing erosion and flooding?

3. How are SMPs reflected in Local Plans around the coast of England?

Part II - National economic assessment of coastal change management

The second part of the study answers the following questions:

4. What are the costs (capital and maintenance) of the following SMP policies in the short-, medium- and long-term:

    a. Hold-the-line?
    b. Managed realignment?
    c. No active intervention?
    d. Advance the line?

5. What share of the above costs might be available as grant-in-aid under current Partnership Funding arrangements?

6. What economic benefit or impact would result from the policies under (4)? What is the nature of any impacts e.g. loss of properties to erosion; flood risk to people?

7. For how much of the English coastline is:

    a. Hold-the-line not economically viable and on what timescale?
    b. Managed realignment not economically viable and on what timescale?

8. What the key sensitivities to (4) and (7) with respect to key uncertainties such as sea level rise, capital and maintenance costs, and appraisal benefits when assessed in full.

Part III - Case studies of coastal adaptation pathways

The third part of the study aims to:

9. Determine a method to identify ten locations in England with coastal adaptation challenges this century.

10. Develop potential adaptation pathways for six of the ten locations identified under (9).

1.3 Geographic and temporal scope of study

This study focuses on coastal change in England. Table 1.1 presents the SMPs and PUs covered by the study.

Table 1.1: List of Shoreline Management Plans considered in the study

Shoreline Management Plans		Region(s)	No. policy units	Length (km)
1	Scottish border to the River Tyne (Northumberland and North Tyneside)	North East	101	180
2	The Tyne to Flamborough Head (North East)	North East	98	197
3	Flamborough Head to Gibraltar Point	North East	16	201
4	Gibraltar Point to Hunstanton (The Wash)	Anglian	4	104
5	Hunstanton to Kelling Hard (North Norfolk)	Anglian	32	75
6	Kelling Hard to Lowestoft (Kelling to Lowestoft)	Anglian	24	80
7	Lowestoft to Felixstowe (Lowestoft Ness to Felixstowe Landguard)	Anglian	66	126
8	Essex and South Suffolk	Anglian	102	529
9	River Medway & Swale Estuary	Southern	30	187
10	Isle of Grain to South Foreland	Southern	27	112
11	South Foreland to Beachy Head	Southern	30	108
12	Beachy Head to Selsey Bill (South Downs)	Southern	27	47
13	Selsey Bill to Hurst Spit (North Solent)	Southern	62	367
14	Isle of Wight	Southern	61	157

Shoreline Management Plans		Region(s)	No. policy units	Length (km)
15	Hurst Spit to Durlston Head (Poole & Christchurch Bays)	South West Southern	57	129
16	Durlston Head to Rame Head	South West	194	716
17	Rame Head to Hartland Point (Cornwall & Isles of Scilly)	South West	261	455
18	Hartland Point to Anchor Head (North Devon & Somerset)	South West	91	311
19	Anchor Head to Lavernock Point (Severn Estuary)	Midlands South West	48	269
20	Lavernock Point to St Ann's Head (South Wales)	Out of scope		
21	St Ann's Head to Great Ormes Head (West of Wales)	Out of scope		
22	Great Ormes Head to Scotland (North West England and North Wales).	North West	202	639
Total (England)			1,533	4,991

Notes: *In some SMPs, policy units are broken down into smaller lengths of coast and considered separately, for example because they have different policy scenarios. The figures above consider each policy unit within an SMP once, regardless of any further breakdowns. This explains the differences compared to Table 2.10.

In assessing the impacts of coastal change, the study generally adopts a timescale of 100 years in line with other flood and coastal erosion risk management studies and assessments. This corresponds to the period from 2005 – 2105 considering the inception of SMPs was in 2005. The study also develops case studies which consider adaptation pathways beyond the 100-year timescale.

1.4 Report structure and other study outputs

This report presents the methodology and results from all three parts of the projects. Following this introduction:

- Section 2 focuses on Part I of the study and presents summary statistics of coastal change including the assets and land at risk, projects to manage these risks and an assessment of how SMPs are reflected in Local Plans;
- Section 3 focuses on Part II of the study and presents the assessment of the costs and benefits of implementing SMPs in a cost-benefit analysis framework;
- Section 4 focuses on Part III of the study and outlines the approach to selecting and developing adaptation pathways for six case study locations; and
- Section 5 concludes with key conclusions and recommendations for further research.

The content of the report is also supported by eight supplementary appendices. For Part I of the study, these include:

- A note outlining the approach to estimating the impact of erosion on complex cliffs (Appendix A);
- Detailed summary statistics on the impact of coastal flooding and erosion on assets and land (Appendix B).
- Maps illustrating planned projects to adapt to coastal change between 2015 and 2021 (Appendix C);
- A list of Local Planning Authorities and their Local Plans (Appendix D);

- Supporting information to inform the assessment of how SMPs are reflected in Local Plans (Appendix E); and

For Part II of the study, these include:

- Assumptions used in the national cost-benefit analysis of the measures set out in SMPs (Appendix F); and
- A series of maps which illustrate the types of SMP policies and their associated costs in England, across different Epochs (Appendix G).

For Part III, Appendix H provides an overview of the approach to dealing with uncertainty in adaptation decision-making.
Finally, this report is part of a suite of outputs from the study. The accompanying research outputs are:

- Outputs from spatial analysis developed as part of the project, in the form of shapefiles;
- A cost-benefit analysis tool which presents the comparison of costs and benefits of coastal change;
- Illustrative adaptation pathways for sites with coastal challenges; and
- An infographic which summarises the key messages from the study.

2. Part I - Summary statistics of coastal change

This section sets out the approach, analysis and findings for Part I of the study as follows:

- Section 2.1 focuses on the assets and land at risk of coastal change;
- Section 2.2 focuses on the coastal adaptation projects during the period 2015-2021; and
- Section 2.3 looks at the extent to which SMPs are reflected in Local Plans.

2.1 Assets and land at risk of coastal change

2.1.1 Data sources

The study made use of nationally available and consistent risk and receptor datasets that were made available under license from the Environment Agency and Open Data made available under the Open Government License. Table 2.1 lists the datasets used and summarises data source, version and license details.

Table 2.1: Summary of input data sources, versions and license conditions

Dataset	Source	Category	License Requirements	Data Version
Shoreline Management Plan 2 Mapping	Environment Agency	Reporting Unit	Open Government Licence	October 2015
National Coastal Erosion Risk Mapping (NCERM)	Environment Agency	Risk Areas - Coastal Erosion	Conditional Contractors Licence	September 2017
Flood Map for Planning (Rivers and Sea) - Flood Zone 2 & 3	Environment Agency	Risk Areas - Coastal Flooding	Open Government Licence	October 2017
Risk of Flooding from Rivers and Sea	Environment Agency	Risk Areas - Coastal Flooding	Conditional Contractors Licence	April 2017
National Receptor Database (NRD) 2014 Properties	Environment Agency	Receptor Data - Property	Conditional Contractors Licence	NRD 2014
MasterMap Building Outlines	Environment Agency	Receptor Data - Property	Conditional Contractors Licence	NRD 2014
Open Data - roads and rail	Ordnance Survey	Receptor Data - Transport	Open Government Licence	November 2017
Integrated Transport Network	Ordnance Survey	Receptor Data - Transport	Conditional Contractors Licence	November 2017
Agricultural Land Classification	Natural England	Receptor Data - Agriculture	Open Government Licence	Provisional and Post 1988 versions
Special Protection Areas	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017
Potential Special Protection Areas	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017
Special Areas of Conservation	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017
Possible Special Areas of Conservation	Natural England	Receptor Data – Environmental	Open Government Licence	June 2017
RAMSAR	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017

Dataset	Source	Category	License Requirements	Data Version
Proposed RAMSAR	Natural England	Receptor Data – Environmental	Open Government Licence	March 2016
Potential Marine Special Protection Areas	Natural England	Receptor Data – Environmental	Open Government Licence	January 2016
Sites of Special Scientific Interest	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017
National Nature Reserves	Natural England	Receptor Data – Environmental	Open Government Licence	September 2017
Marine Conservation Zones	Natural England	Receptor Data – Environmental	Open Government Licence	June 2017
Local Nature Reserves	Natural England	Receptor Data – Environmental	Open Government Licence	August 2017
Heritage Coast	Natural England	Receptor Data – Environmental	Open Government Licence	May 2015
Ancient Woodland	Historic England	Receptor Data – Environmental	Open Government Licence	July 2017
Priority Habitats Layer	Natural England	Receptor Data – Environmental	Open Government Licence	August 2017
Areas of Outstanding Natural Beauty	Natural England	Receptor Data – Environmental	Open Government Licence	May 2015
National Parks	Natural England	Receptor Data – Environmental	Open Government Licence	August 2016
Historic Landfill	Environment Agency	Receptor Data – Environmental	Open Government Licence	October 2017
World Heritage Sites	Historic England	Receptor Data – Environmental	Open Government Licence	May 2017
Scheduled Monuments	Historic England	Receptor Data – Environmental	Open Government Licence	May 2017
Listed Buildings	Historic England	Receptor Data – Environmental	Open Government Licence	April 2017
Battlefields	Historic England	Receptor Data – Environmental	Open Government Licence	April 2017
Protected Wrecks	Historic England	Receptor Data – Environmental	Open Government Licence	April 2017
Parks and Gardens	Historic England	Receptor Data – Environmental	Open Government Licence	April 2017

2.1.2 Data preparation

Before the GIS overlay analysis between receptors and risk datasets could be performed a number of data preparation tasks were needed. These are summarised in the following sections.

2.1.2.1 NCERM data

Coastal erosion risk areas were extracted from the NCERM database for the short-term (SMP Epoch 1), medium-term (SMP Epoch 2) and long-term (SMP Epoch 3) periods for the No Active Intervention scenario, as this represents the scenario that no SMP policies are enacted and any existing defences are not maintained and so fail into the future, returning the coast back to a more natural state (and thus illustrates the benefits of intervening where it is viable to do so).

As NCERM only provides data for simple-cliff types and not complex cliff types that are subject to less frequent landslide events, a desktop review of complex cliff locations was carried out and added to the NCERM data to fill in the gaps around the coast where coastal erosion/landsliding is an issue but is not mapped by NCERM. In doing so, and reflecting the uncertainty about predicting coastal change in complex cliff areas, only a 100-year risk zone assuming the No Active Intervention scenario was defined for these areas. As such, the erosion numbers presented in subsequent sections of this report are for the No Active Intervention scenario **excluding** the additional risk from complex cliffs risks. The additional risk from complex cliffs is reported separately to highlight the additional erosion losses that could occur at any time. The approach to how complex cliff areas were defined is set out in 0.

2.1.2.2 Property data

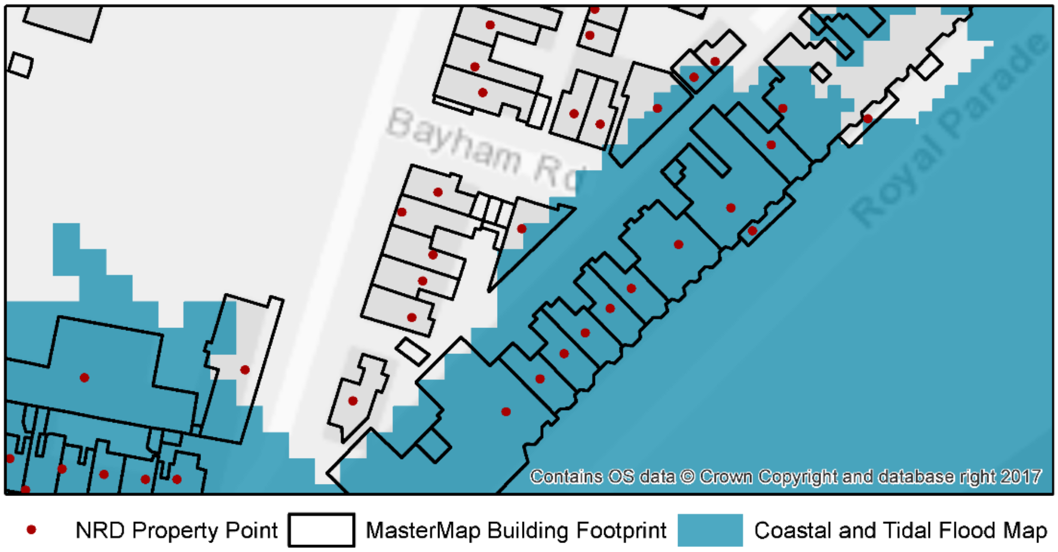
NRD 2014 is a property point dataset. To improve on the identification of properties at risk from coastal erosion or flood risk, the NRD property points were associated with their building footprints from the Ordnance Survey MasterMap Topography dataset. This association was completed in two steps:

- A table join using the OS MasterMap Topography layer ‘TOID’ attribute
- A spatial join on NRD records where no ‘TOID’ association was made.

The building footprints were then used for the risk analysis processing rather than the property point location. k outlines.

Figure 2.1 provides an example of the relationship between NRD property points locations and OS MasterMap building footprints, relative to the coastal flood risk outlines.

Figure 2.1: NRD property points locations and OS MasterMap building footprints relative to flood risk outlines



2.1.2.3 Flood map for planning data

The Environment Agency's Flood Map for Planning includes a number of layers. The data used for this study were:

Flood Zone 3 – The Environment Agency's best estimate of the areas of land at risk of flooding, when the presence of flood defences is ignored and covers land with a 1 in 100 (1%) or greater chance of flooding each year from Rivers; or with a 1 in 200 (0.5%) or greater chance of flooding each year from the Sea.

Flood Zone 2 – The Environment Agency's best estimate of the areas of land at risk of flooding, when the presence of flood defences is ignored and covers land between Zone 3 and the extent of the flooding from rivers or the sea with a 1 in 1000 (0.1%) chance of flooding each year. This dataset also includes those areas defined in Flood Zone 3.

As this study was looking at coastal flood risk only, coastal and tidal flood risk areas were identified using the 'Type' attribution that defines the type of source data for each flood polygon (e.g. Fluvial / Tidal Models, and/or Fluvial / Tidal / Coastal Models). Note, these are present day flood risks and do not reflect impacts of climate change. The coastal flood risk may also not include impacts of waves. There is no national assessment of how climate change will alter flood risk around the coast in the same, consistent level of detail as the present-day risk is modelled and mapped. That said, it is reasonable to assume that all flood risks (probability and extent) will increase in the future with climate change, so the estimates of assets at risk of flooding presented in this analysis are conservative estimates.

2.1.3 GIS analysis

All prepared risk and receptor datasets were imported into an ESRI Geodatabase and run through a sequence of spatial overlay processes (i.e. union, intersect and spatial join operations) to identify the features, lengths and areas of each receptor dataset that fell within each of the coastal flood and erosion risk extents.

To facilitate the reporting of risk data against each of the SMPs for England, the SMP frontages had to be interpreted into polygon 'domains' that covered the coastal erosion and flood risk extents. At unit boundaries, reporting domains were extrapolated from the SMP coastline inland through a desk based review that considered the underlying topography, tidal watercourses and Ordnance Survey base mapping.

2.1.3.1 Risk reporting

A Microsoft SQL database was used to summarise and report the risk analysis results. The outputs from the GIS analysis were uploaded to an SQL database, and SQL statements were developed to sum the numbers of properties, the lengths of road and rail, and the areas of the various agricultural and environmental datasets for each flood risk and erosion risk bands.

The Risk of Flooding from Rivers and Sea data was also used to estimate damages to property using the Multi-Coloured Manual (MCM) Weighted Average Annual Damages method (Penning-Roswell et al.,2017), deriving depth-damage estimates for properties only.

The summary reports were saved as MS Excel format workbooks. These outputs are collated in terms of flood risk impacts and erosion risk impacts in Appendix B, with discussion and analysis of the outputs being provided in the following section.

2.1.4 Findings

2.1.4.1 Key findings – risks of coastal flooding

The following findings are drawn from outputs presented in Appendix B.

<u>Property</u>

Using the Environment Agency's Flood Map for Planning (Rivers and Sea) - Flood Zone 2 and Flood Zone 3 data, which provides flood risk mapping assuming no defences are present (thus indicating the potential risk if flood defence assets are not maintained into the future), shows the following across all SMPs covering England:

- There is a total of 373,547 residential properties and 144,985 non-residential properties within Flood Zone 3, which represents the present day 1:200 (0.5%) year risk from coastal flooding - see Figure 2.2.
- These figures rise to 445,448 (up 19% or 71,901) for residential properties, and to 173,110 (up 19% or 28,125) under the more extreme Flood Zone 2 risk zone, which represents the present day 1:1,000 year risk from coastal flooding – see Figure 2.3. Note, Flood Zone 2 risk includes Flood Zone 3 risk, hence the increase of properties from Flood Zone 2 to Flood Zone 3.

This analysis counted all properties that the Environment Agency deem as 'reportable' for property impact analysis. For the monetary value of damages, there is a different flag that the Environment Agency have developed that excludes upper floor properties (amongst others) for the purpose of direct flood damage calculations.

Due to limitations of available data noted in Section 2.1.2.3, it is not possible to assess how the number of properties in these flood zones will change with climate change over the next century; however, it would be expected that the risks will increase over-time, as indicated in the work by Sayers et al (2017), which suggests that by the 2050s the impacts of climate change on increased residential property flood damages in England could be between about 22% and 97%; and by the 2080s, between about 43% and 130% (NB: these % increases include the impacts of climate change on all sources of flooding (fluvial, coastal and surface water), not specifically coastal flooding alone).

It is clear from Figure 2.2 and Figure 2.3 that the greatest number of properties at risk of flooding is in SMPs 3 and 4, which cover extensive low-lying areas of Lincolnshire and The Wash. The next with the highest number of properties are in SMPs 18, 19 and 22. In the case of SMPs 18 and 19, this area covers the Somerset Levels and Severn Estuary, whilst SMP 22 covers the north-west of England. Further details are presented in Appendix B.

Figure 2.2: Coastal flood risk to properties by SMP under Flood Zone 3 (present day, 1:200 year event)

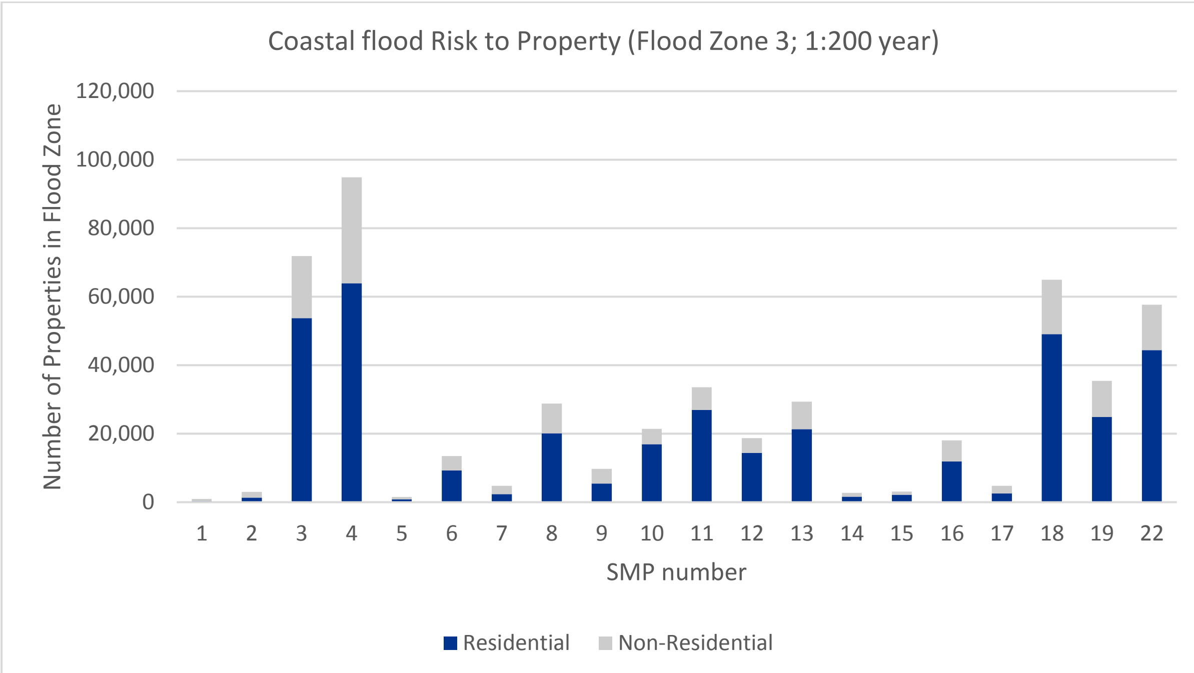
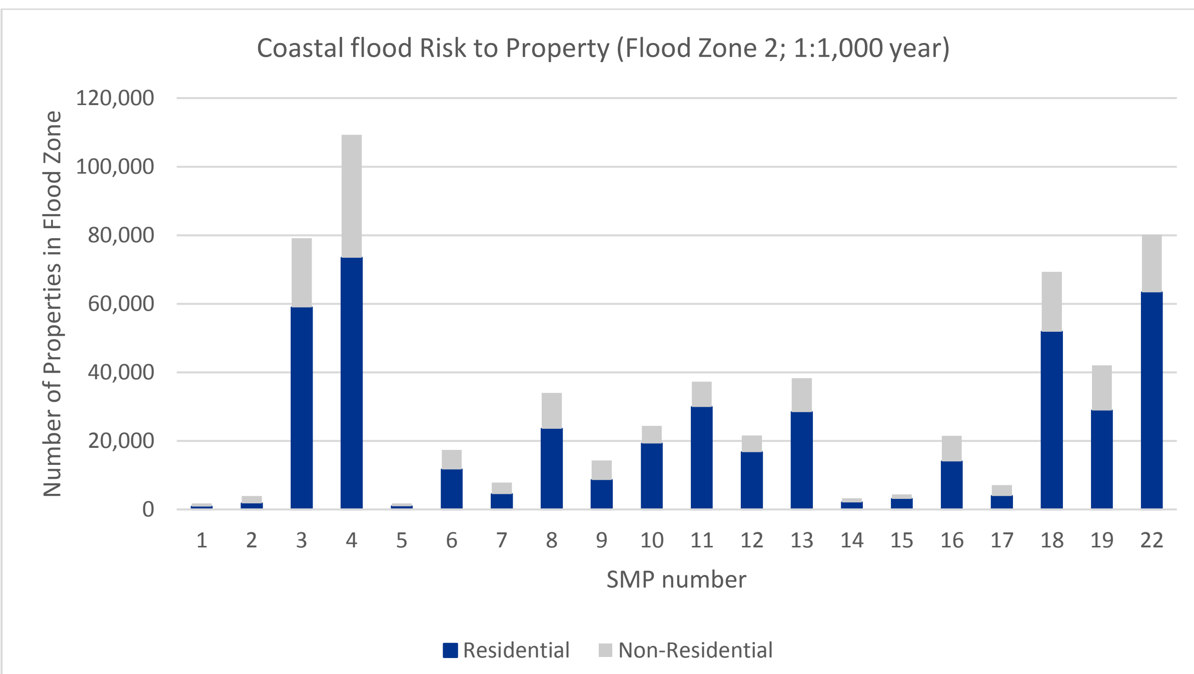


Figure 2.3: Coastal flood risk to properties by SMP under Flood Zone 2 (present day, 1:1,000 year event)

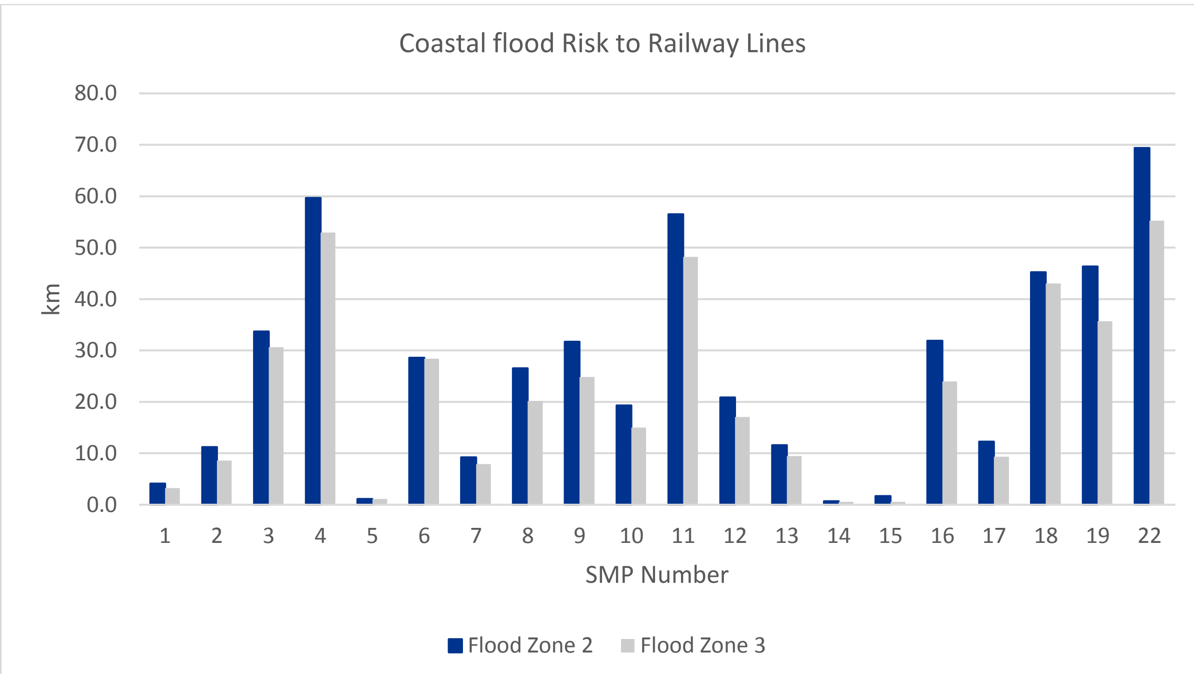


Infrastructure

Railways

Using the Environment Agency's Flood Map for Planning (Rivers and Sea) - Flood Zone 2 & 3 data, across all SMPs covering England, there is a total of 59 railway stations and 436km of railway line within Flood Zone 3, which represents the present day 1:200 (0.5%) year risk from coastal flooding. These figures rise to 77 railway stations (up 18) and 522km of railway line (up 86km) under the more extreme Flood Zone 2 risk zone, which represents the present day 1:1,000 year risk from coastal flooding. Figure 2.4 illustrates the total lengths of railway line at risk by SMP in England; this shows that the greatest risks lie within SMPs 4, 11, 18, 19 and 22. Further details are presented in Appendix B.

Figure 2.4: Coastal flood risk to railway lines by SMP



Roads

Figure 2.5 and Figure 2.6 show the present-day flood risk to various types of road infrastructure across all SMPs covering England using the Environment Agency's Flood Map for Planning (Rivers and Sea) - Flood Zone 2 & 3 data. Table 2.2 presents the total lengths of each road type in Flood Zone 2 and Flood Zone 3 across the SMPs covering England.

What can be seen from this data is that the largest road types at risk of flooding appear to be local and minor road-types, which would pose issues for local access in the main during flood events. Key road types (i.e. A- Road, B-Roads and Motorways) are at comparatively less risk in terms of total lengths affected. Further details are presented in Appendix B.

Figure 2.5: Coastal flood risk to road infrastructure by SMP under Flood Zone 3 (present day 1:200 year)

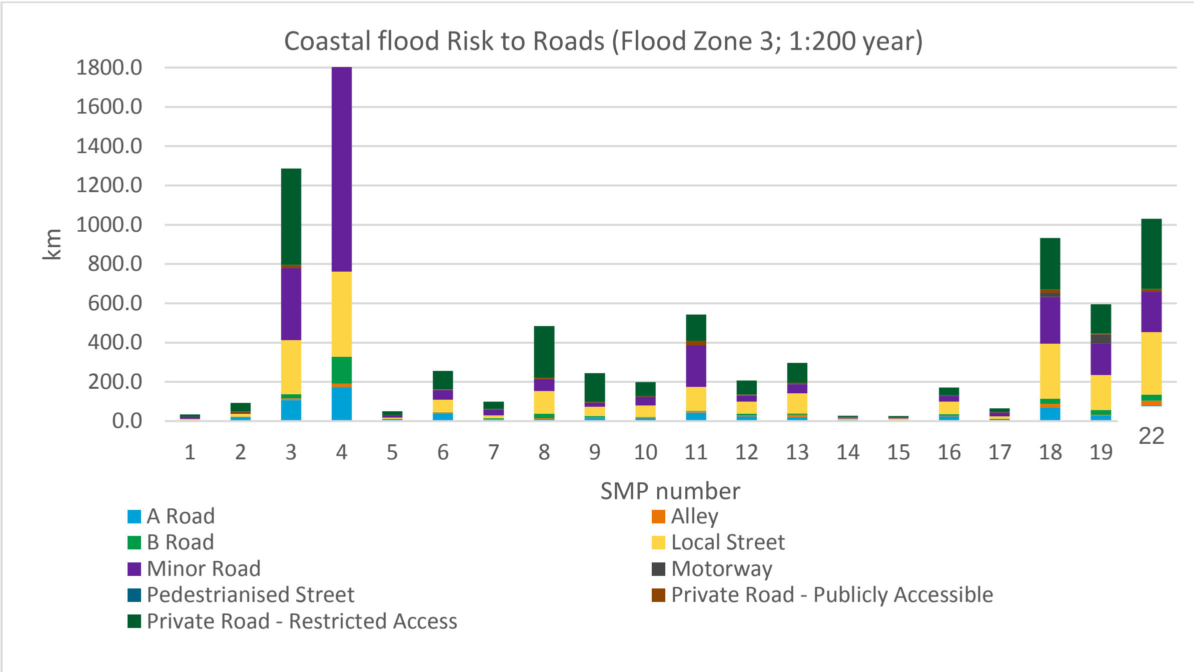


Figure 2.6: Coastal flood risk to road infrastructure by SMP under Flood Zone 2 (present day 1:1,000 year)

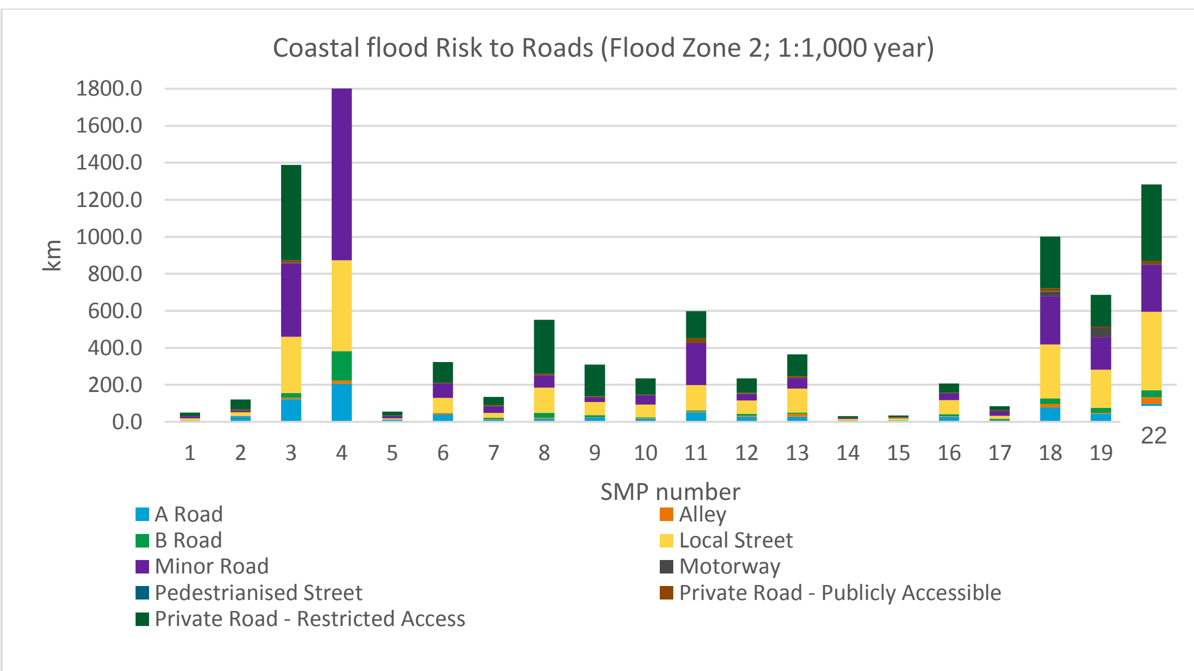


Table 2.2: Total length of road types in each coastal flood zone across all SMPs in England

Road Type	Total Length of Road Type (km) in each coastal Flood Zone	
	Flood Zone 2 (1:1,000 year)	Flood Zone 3 (1:200 year)
A Road	852	701
Alley	142	116
B Road	374	320
Local Street	2,590	2,193
Minor Road	3,349	2,969
Motorway	85	71
Pedestrianised Street	5	3
Private Road - Publicly Accessible	161	141
Private Road - Restricted Access	3,424	3,048

Agricultural land

Table 2.3 and Table 2.4 show the various agricultural land classifications at risk under Flood Zone 3 and Flood Zone 2 respectively using the Environment Agency's Flood Map for Planning (Rivers and Sea) - Flood Zone 2 & 3 data. What is evident is that the largest area of high-quality agricultural land (grades 1 to 3) at risk of flooding, by quite some way, is in SMP4 which covers the area surrounding The Wash. This SMP accounts for more than half the total Grade 1 and 2 land at risk of flooding across all the SMPs in England. Further details are provided in Appendix B.

Table 2.3: Agricultural land at risk of coastal flooding under Flood Zone 3 (1:200 year)

SMP	Agricultural Land Classification (Ha)							Total (ha)
	Grade 1	Grade 2	Grade 3	Grade 3a	Grade 3b	Grade 4	Grade 5	
1	0	323	1,413	0	12	67	110	**1,926**
2	0	5	599	0	0	153	768	**1,526**
3	2,949	10,117	29,995	56	175	355	0	**43,648**
4	64,458	63,664	6,247	135	60	2,502	0	**137,067**
5	0	99	1,369	0	0	995	0	**2,464**
6	755	1,059	12,791	0	0	369	0	**14,974**
7	1	209	5,386	0	19	3,745	0	**9,359**
8	661	3,221	14,231	4	53	4,865	989	**24,024**
9	549	185	401	4	6	6,841	424	**8,409**
10	387	1,216	3,773	17	77	1,502	254	**7,227**
11	5,562	10,439	4,636	14	76	2,742	0	**23,469**
12	50	315	3,516	18	491	2,170	0	**6,561**
13	304	688	967	23	17	723	296	**3,017**
14	0	0	228	0	0	608	21	**857**
15	0	0	70	0	0	788	592	**1,451**

SMP	Agricultural Land Classification (Ha)							Total (ha)
	Grade 1	Grade 2	Grade 3	Grade 3a	Grade 3b	Grade 4	Grade 5	
16	78	110	600	11	65	1,416	5	2,286
17	0	43	335	4	1	210	8	602
18	487	6,996	17,668	149	1,376	3,583	354	30,611
19	69	1,699	15,273	65	268	3,961	151	21,486
22	4,157	5,806	14,868	81	97	9,724	4,140	38,873
Total	80,467	106,193	134,368	581	2,794	47,318	8,114	379,836

Table 2.4: Agricultural land at risk of coastal flooding under Flood Zone 2 (1:1,000 year)

SMP	Agricultural Land Classification (Ha)							Total Ha
	Grade 1	Grade 2	Grade 3	Grade 3a	Grade 3b	Grade 4	Grade 5	
1	0	289	1,634	0	13	69	108	2,112
2	0	5	611	0	0	215	829	1,661
3	3,029	10,550	32,113	61	180	423	0	46,354
4	69,234	72,662	6,985	157	78	2,808	0	151,924
5	0	114	1,441	0	0	1,020	0	2,575
6	1,429	1,443	13,420	0	0	400	0	16,691
7	1	231	5,575	0	21	4,044	0	9,872
8	757	3,323	14,959	5	56	4,961	995	25,055
9	751	223	546	17	16	7,045	491	9,090
10	415	1,388	4,006	17	81	1,649	298	7,854
11	5,891	10,913	5,706	20	84	2,991	0	25,605
12	63	368	3,655	19	528	2,279	0	6,912
13	356	805	1,026	30	18	776	325	3,336
14	0	0	244	0	0	624	24	892
15	0	0	84	0	0	833	643	1,560
16	106	136	725	16	75	1,531	10	2,599
17	0	55	490	5	2	270	13	835
18	537	7,239	18,723	156	1,394	4,126	356	32,529
19	113	1,804	15,895	71	308	4,313	177	22,681
22	3,936	6,525	17,131	108	107	9,893	4,381	42,080
Total	86,615	118,070	144,969	681	2,961	50,271	8,648	412,216

<u>Designated environment</u>

Using the Environment Agency's Flood Map for Planning (Rivers and Sea) - Flood Zone 2 & 3 data, the risk of flooding under Flood Zone 3 and Flood Zone 2 has been identified for the following range of designated environmental features:

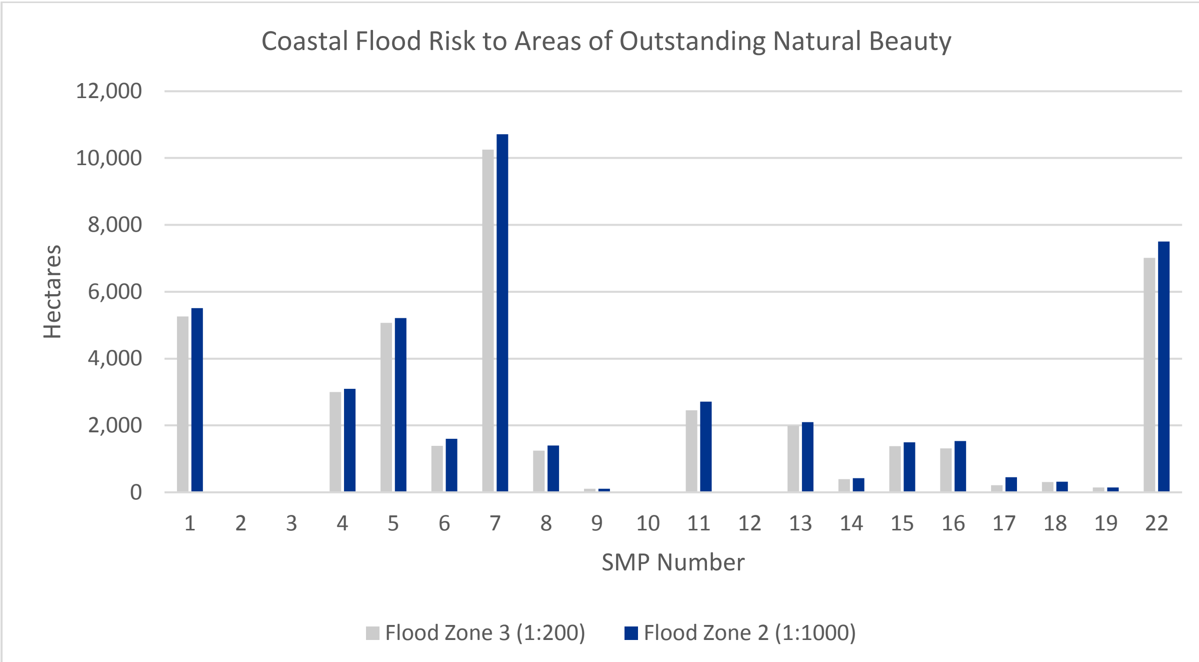
- Ancient Woodlands
- Area of Outstanding Natural Beauty
- Battlefields
- Heritage Coast
- Historic Landfill
- Listed Buildings
- Local Nature Reserve
- Marine Conservation Zone
- National Nature Reserve
- National Park
- Registered Park and Garden
- Possible Special Area of Conservation
- Potential Marine Special Protection Area
- Potential Special Protection Area
- Priority Habitats
- Proposed Ramsar
- Protected Wreck
- Ramsar
- Scheduled Monument
- Site of Special Scientific Interest
- Special Area of Conservation
- Special Protection Area
- SSSI Risk Impact Zones
- World Heritage Site.

Full details covering the nature of flood risk to each of the above features is provided in Appendix B. The following summarises only the flood risk impacts in relation to a number of the key features.

Area of Outstanding Natural Beauty

There are Areas of Outstanding Natural Beauty (AONBs) at risk of flooding across most SMPs in England, with the exception of SMPs 2, 3 and 12. The largest area of AONB at risk of flooding occurs in SMP 7. There is very little relative increase in risk between Flood Zone 3 (present day 1:200 year) and Flood Zone 2 (present day 1:1,000 year).

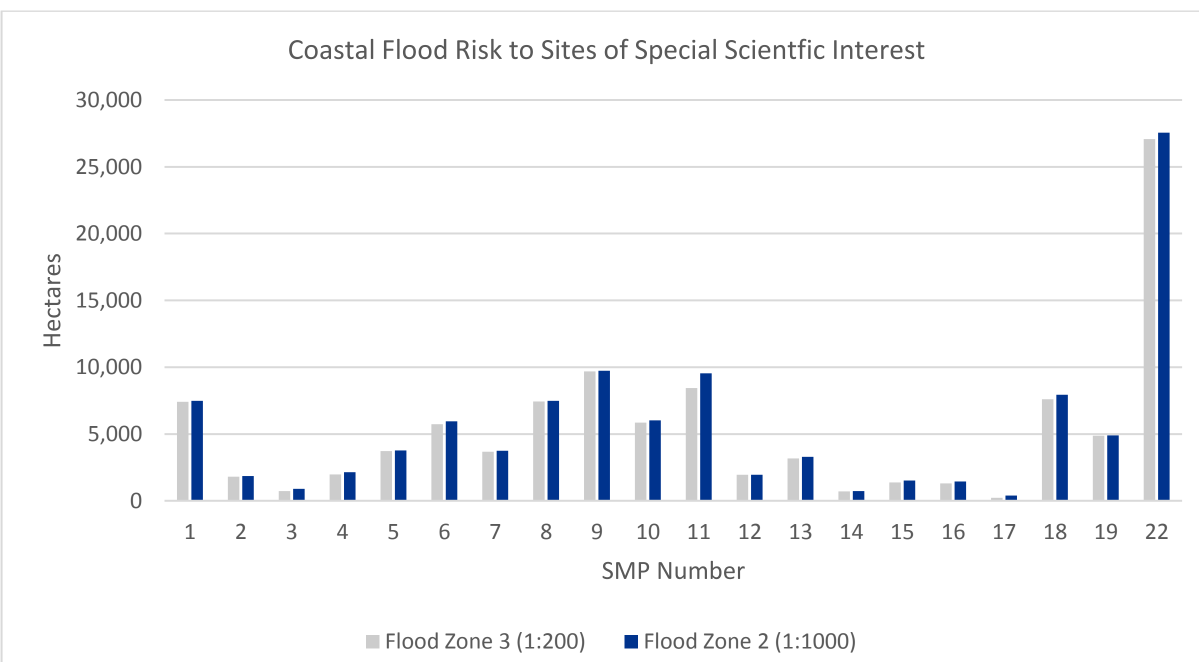
Figure 2.7: Coastal Flood Risk to Areas of Outstanding Natural Beauty by SMP



Site of Special Scientific Interest

Every SMP across England has some level of flood risk posed to Sites of Special Scientific Interest (SSSI). The largest area of SSSI at risk of flooding occurs in SMP 22. There is very little relative increase in risk between Flood Zone 3 (present day 1:200 year) and Flood Zone 2 (present day 1:1,000 year).

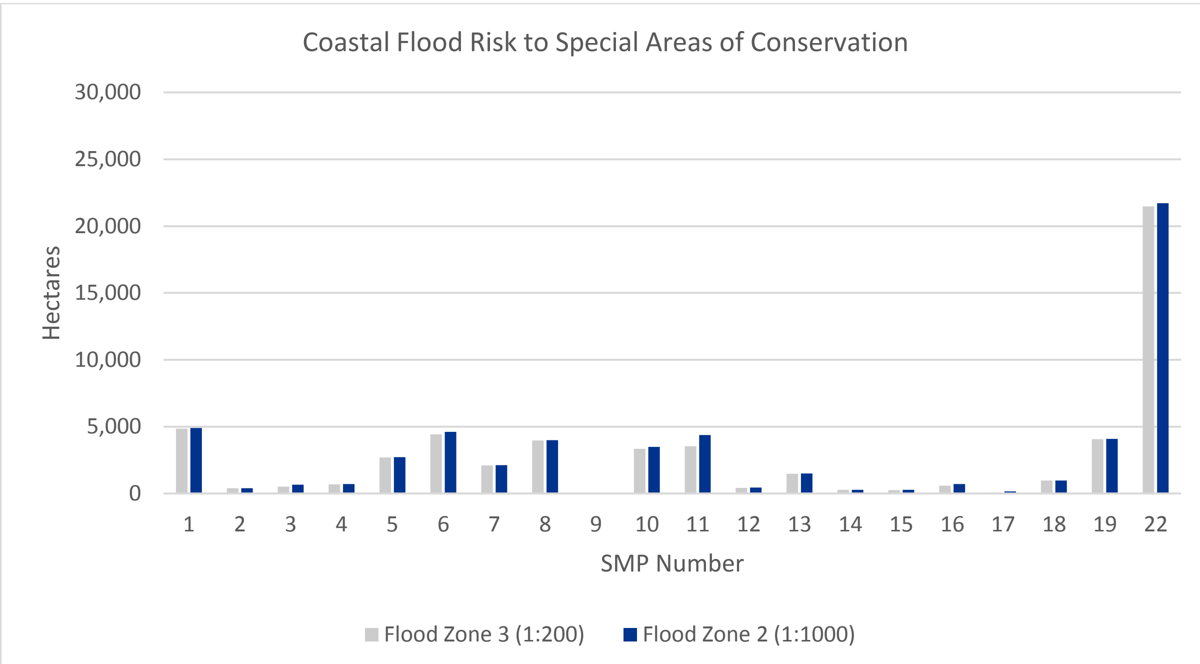
Figure 2.8: Coastal Flood Risk to Sites of Special Scientific Interest by SMP



Special Area of Conservation

All SMPs across England, with the exception of SMP 9, has some flood risk posed to Special Areas of Conservation (SAC) designations. The largest area of SAC at risk of flooding occurs in SMP 22. There is very little relative increase in risk between Flood Zone 3 (present day 1:200 year) and Flood Zone 2 (present day 1:1,000 year).

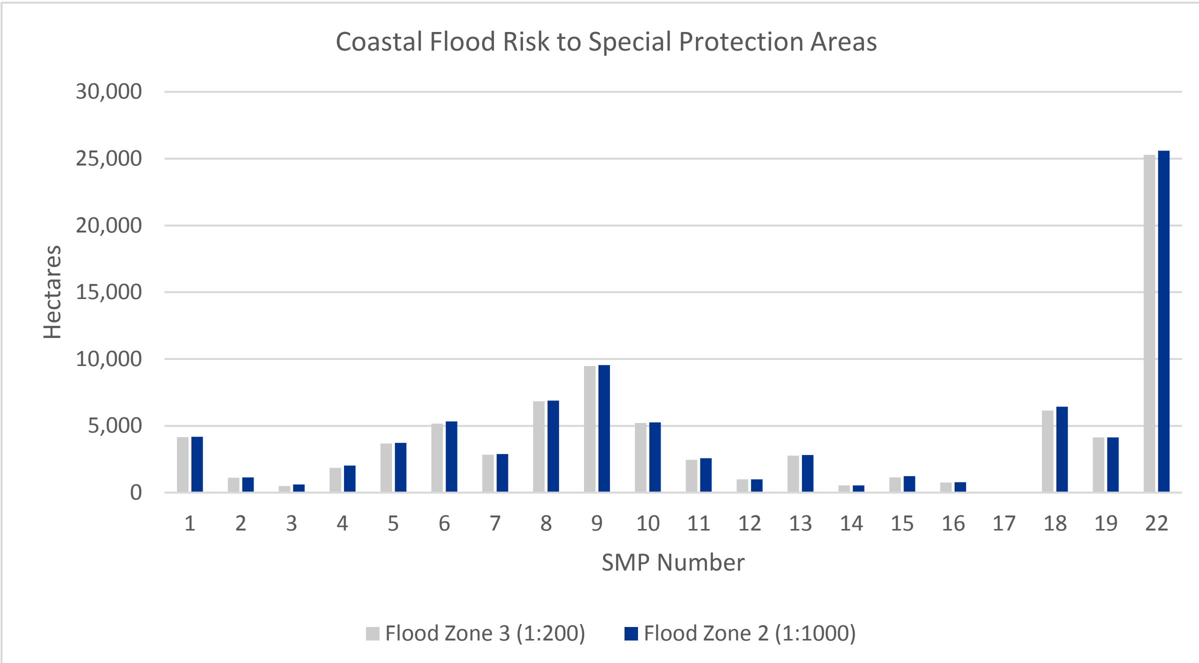
Figure 2.9: Coastal Flood Risk to Special Areas of Conservation by SMP



Special Protection Area

Every SMP across England has some flood risk posed to Special Protection Area (SPA) designations. The largest area of SPA at risk of flooding occurs in SMP 22. There is very little relative increase in risk between Flood Zone 3 (present day 1:200 year) and Flood Zone 2 (present day 1:1,000 year).

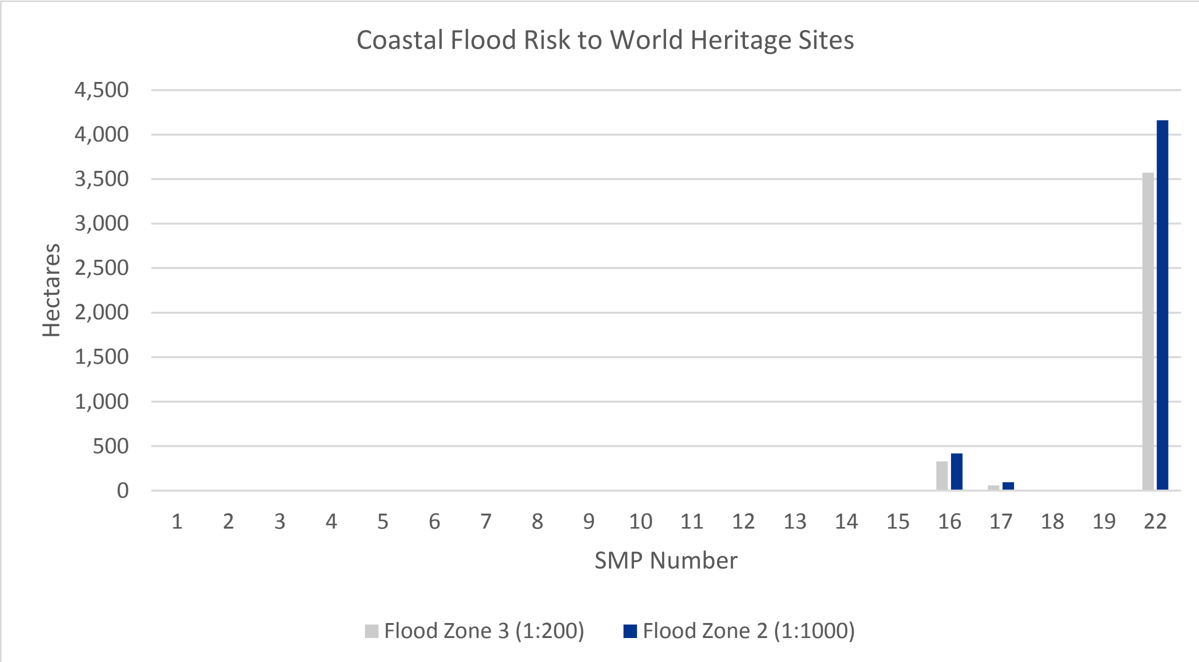
Figure 2.10: Coastal Flood Risk to Special Protection Areas by SMP



World Heritage Site

UNESCO World Heritage Sites are at risk of coastal flooding in five of the SMPs around the coast of England. The largest area of flood risk any of these world heritage sites is in SMP 22 covering the North West of England.

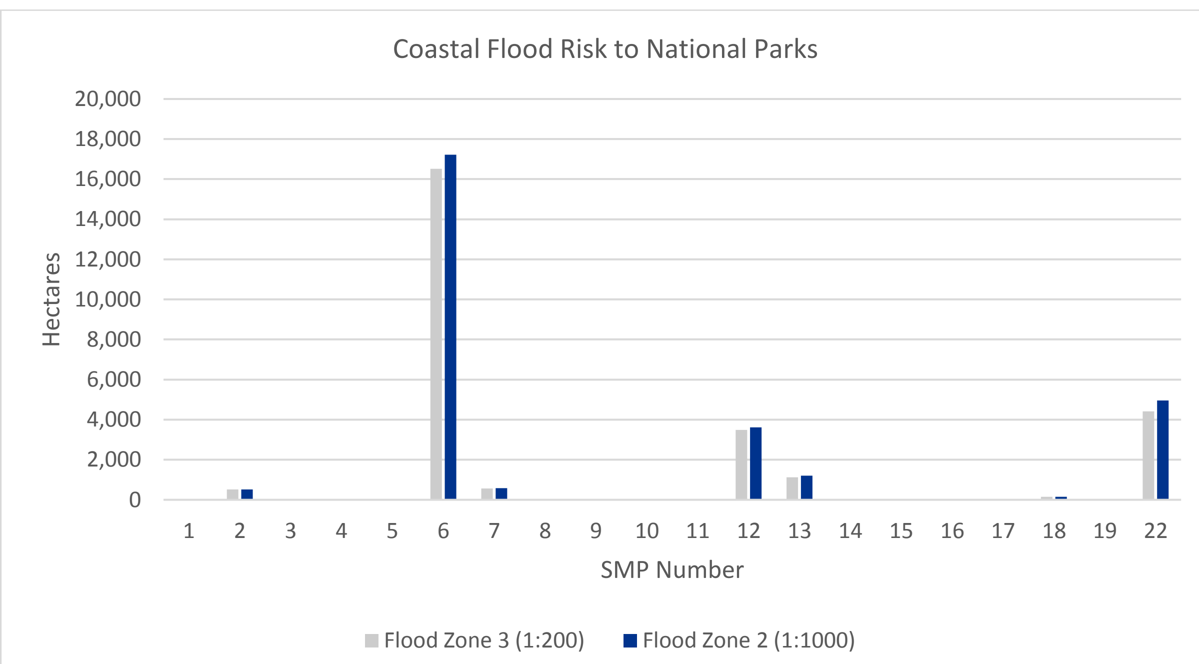
Figure 2.11: Coastal Flood Risk to UNESCO World Heritage Sites by SMP



National Park

National Parks are at risk of coastal flooding in eight of the SMPs around the coast of England. The largest area of flood risk to any of these SMPs is in SMP 6 (Kelling Hard to Lowestoft (Kelling to Lowestoft)).

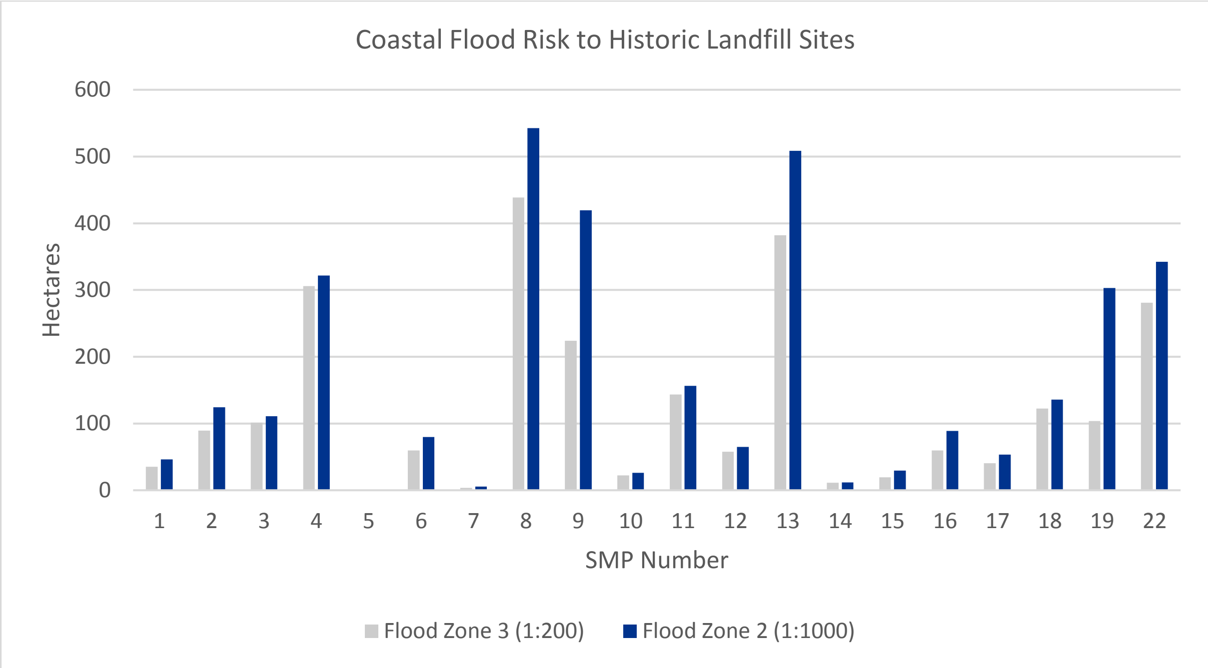
Figure 2.12: Coastal Flood Risk to National Parks by SMP



Historic Landfill

Although not a designated habitat, historic landfill sites pose a risk to the environment if they become flooded or eroded. Figure 2.13 shows that there are historic landfill sites at risk of flooding in all SMP areas, with the exception of SMP 5. Depending on the SMP, the relative increase in historic landfill area at risk from Flood Zone 3 (1:200) to Flood Zone 2 (1:1,000) is variable.

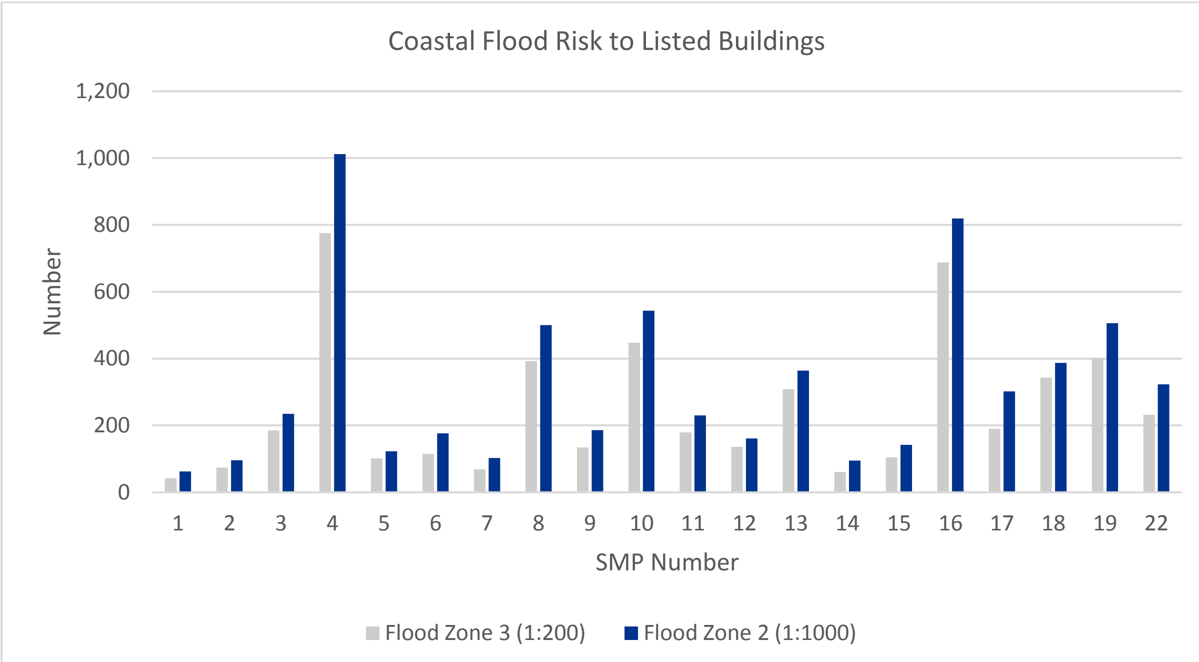
Figure 2.13: Coastal Flood Risk to Historic Landfill Sites by SMP



Listed Buildings

Listed Buildings are at risk of flooding in every SMP across England. The number of listed buildings at risk varies across SMP, but the largest numbers occur in SMP 4 and SMP 16. Depending on the SMP, the relative increase in the number of listed building at risk form Flood Zone 3 (1:200) to Flood Zone 2 (1:1,000) is variable.

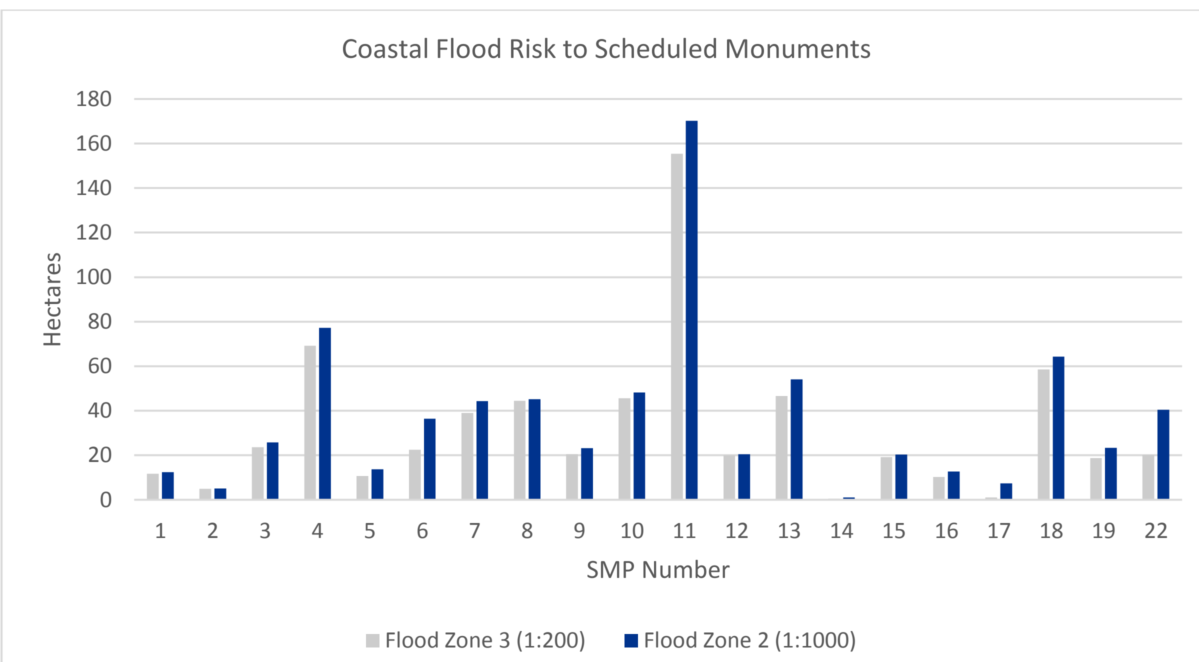
Figure 2.14: Coastal Flood Risk to Listed Buildings by SMP



Scheduled Monuments

Scheduled Monuments are at risk of flooding in each SMP across England. However, SMP 11 has the largest area of scheduled monuments at risk of flooding. There is very little relative increase in risk between Flood Zone 3 (present day 1:200 year) and Flood Zone 2 (present day 1:1,000 year).

Figure 2.15: Coastal Flood Risk to Scheduled Monuments by SMP



2.1.4.2 Key findings – risks of coastal erosion

The following findings are drawn from outputs presented in Appendix B and are based on the No Active Intervention scenario to demonstrate the extent of risk if no management were to be undertaken from now.

Property

Erosion Risk to residential and non-residential properties in each SMP under a scenario of No Active Intervention, and how this varies over time by Epoch is presented for in Table 2.5, Table 2.6 and Table 2.7 for three erosion probabilities:

- Upper Estimate (based on the 5%-ile probability of occurrence; this represents the worse-case scenario over the next 100 years) – see Table 2.5.
- Mid-Estimate (based on the 50%-ile probability of occurrence) – see Table 2.6.
- Lower Estimate (based on the 95%-ile probability of occurrence) – see Table 2.7.

What can be seen from this data is that there is a varying level of erosion risk in SMPs around England, with numbers of properties at risk ranging from a few hundred to a few thousand. The exceptions to this are SMPs 4, 5, 9 and 19 where the risks are significantly lower, as they are largely flood risk dominated areas.

It should be noted that these figures in Table 2.5, Table 2.6, and Table 2.7 do not include for the additional risk posed by complex cliffs. In reality, some of these complex cliff risks could occur in Epoch 1, Epoch 2 or Epoch 3, but the timing of such events is uncertain and so rather than include in Table 2.5 and Table 2.6, they are instead provided in Table 2.8 to illustrate the potential additional risk from complex cliffs. Irrespective of this, the trend over the next century is for an ever-increasing number of residential and non-residential properties to be at risk of erosion – see Figure 2.16 and Figure 2.17. Further details are provided in Appendix B.

The scale of the risk is, however, much smaller by comparison to the risk of coastal flooding, and of the order of the tens of thousands compared to hundreds of thousands.

Table 2.5: Changing erosion risk to property by Epoch and SMP (No Active Intervention scenario; Upper Estimate)

SMP	Residential Properties – Upper Estimate			Non-Residential Properties – Upper Estimate		
	Epoch 1	Epoch 2	Epoch 3	Epoch 1	Epoch 2	Epoch 3
1	58	334	1,119	76	221	582
2	167	1,481	4,036	178	571	1,184
3	186	1,493	3,781	115	560	1,277
4	0	0	211	2	7	26
5	0	0	2	2	6	23
6	217	1,480	4,670	141	680	1,618
7	200	1,485	4,245	250	855	1,675
8	34	769	3,468	708	2,167	2,611
9	2	47	158	36	57	109
10	54	394	1,541	35	162	387
11	1,068	5,936	13,857	347	1,446	2,810
12	1,665	7,500	19,006	328	1,308	3,566

SMP	Residential Properties – Upper Estimate			Non-Residential Properties – Upper Estimate		
	Epoch 1	Epoch 2	Epoch 3	Epoch 1	Epoch 2	Epoch 3
13	452	2,790	5,544	227	901	1,837
14	112	601	1,463	95	375	807
15	416	3,952	8,316	250	807	1,392
16	176	629	1,349	192	500	809
17	244	1,585	3,640	281	1,199	2,241
18	53	347	684	60	219	423
19	3	8	21	2	6	13
22	382	1,008	4,995	126	479	1,778
TOTALS	**5,489**	**31,839**	**82,106**	**3,451**	**12,526**	**25,168**

Table 2.6: Changing erosion risk to property by Epoch and SMP (No Active Intervention scenario; Mid-Estimate)

SMP	Residential Properties – Mid-Estimate			Non-Residential Properties – Mid-Estimate		
	Epoch 1	Epoch 2	Epoch 3	Epoch 1	Epoch 2	Epoch 3
1	22	235	692	62	182	408
2	46	1,087	2,671	84	423	945
3	104	978	2,811	75	400	986
4	0	0	125	1	7	15
5	0	0	1	1	4	16
6	153	876	3,394	88	464	1,238
7	41	1,029	3,090	49	658	1,350
8	6	359	2,163	311	2,004	2,366
9	2	23	115	33	49	80
10	23	250	875	19	118	260
11	934	3,947	10,056	254	1,048	2,165
12	1,106	4,931	13,899	247	940	2,617
13	223	2,258	4,363	116	676	1,419
14	47	447	996	58	274	603
15	193	2,735	6,244	183	642	1,151
16	151	397	979	141	394	642
17	88	1,087	2,672	147	884	1,718
18	42	258	501	48	160	327
19	3	5	17	2	5	10
22	351	739	3,104	99	403	1,141
Total	**3,535**	**21,641**	**58,768**	**2,018**	**9,735**	**19,457**

Table 2.7: Changing erosion risk to property by Epoch and SMP (No Active Intervention scenario; Lower Estimate)

SMP	Residential Properties – Lower Estimate			Non-Residential Properties – Lower Estimate		
	Epoch 1	Epoch 2	Epoch 3	Epoch 1	Epoch 2	Epoch 3
1	4	127	378	46	124	235
2	12	673	1,601	23	295	600
3	52	438	1,746	17	239	654
4	0	0	20	1	2	8
5	0	0	1	1	2	10
6	108	443	2,118	62	283	873
7	4	539	1,859	6	439	962
8	4	234	982	225	1,741	2,186
9	1	3	47	31	38	57
10	1	121	455	8	72	175
11	771	1,571	6,569	155	715	1,555
12	548	2,964	9,315	147	601	1,698
13	80	1,478	2,998	75	455	924
14	12	268	630	20	174	398
15	94	1,649	4,081	116	463	844
16	129	285	664	117	283	507
17	64	569	1,623	123	520	1,174
18	34	199	366	41	122	232
19	3	3	10	2	3	6
22	325	470	1,228	81	300	583
Total	**2,246**	**12,034**	**36,691**	**1,297**	**6,871**	**13,681**

Table 2.8: Changing erosion risk to property by Epoch and SMP (No Active Intervention scenario; Lower Estimate)

SMP	Residential Properties			Non-Residential Properties		
	Upper Estimate	Mid-Estimate	Lower Estimate	Upper Estimate	Mid-Estimate	Lower Estimate
1	0	0	0	0	0	0
2	7,228	642	72	2,005	342	98
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

SMP	Residential Properties			Non-Residential Properties		
	Upper Estimate	Mid-Estimate	Lower Estimate	Upper Estimate	Mid-Estimate	Lower Estimate
10	0	0	0	0	0	0
11	21,100	841	0	3,580	241	0
12	0	0	0	0	0	0
13	18	0	0	20	0	0
14	12,114	729	95	2,892	331	19
15	13,657	3,004	181	1,951	484	17
16	29,368	3,418	318	7,103	993	104
17	0	0	0	1	0	0
18	84	49	9	67	25	4
19	0	0	0	0	0	0
22	1,992	2	0	571	0	0
Total	**85,561**	**8,685**	**675**	**18,190**	**2,416**	**242**

Figure 2.16: Changing erosion risk to residential properties over the next century under No Active Intervention scenario (excluding impacts of complex cliffs)

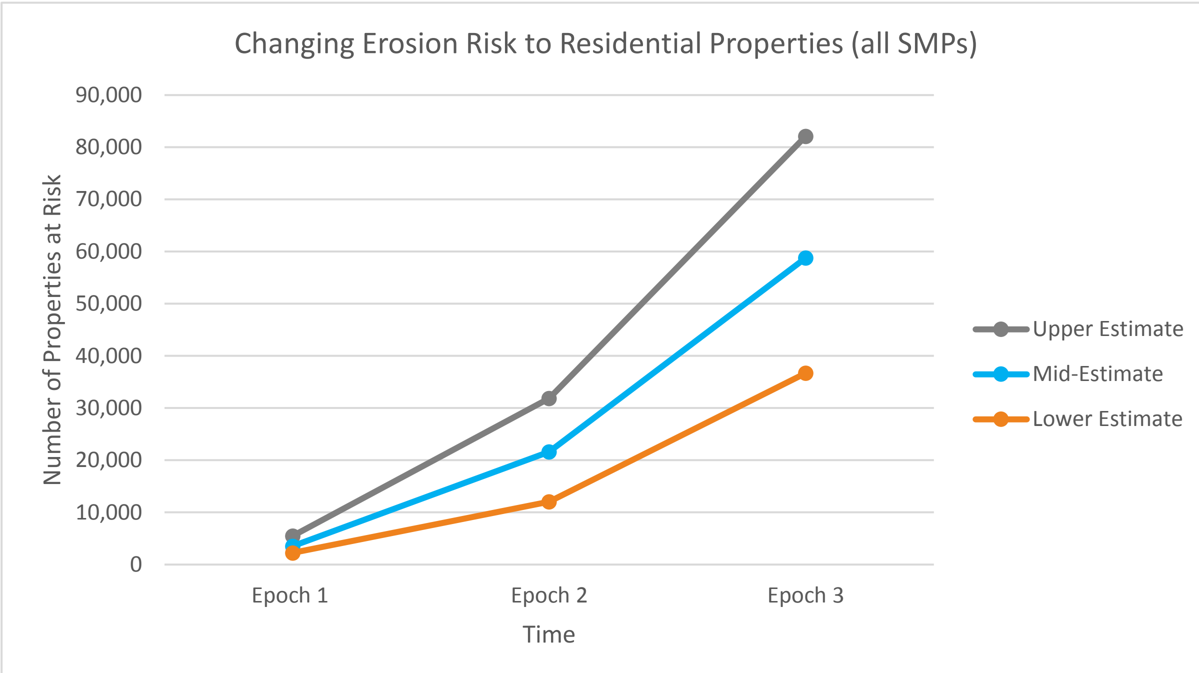
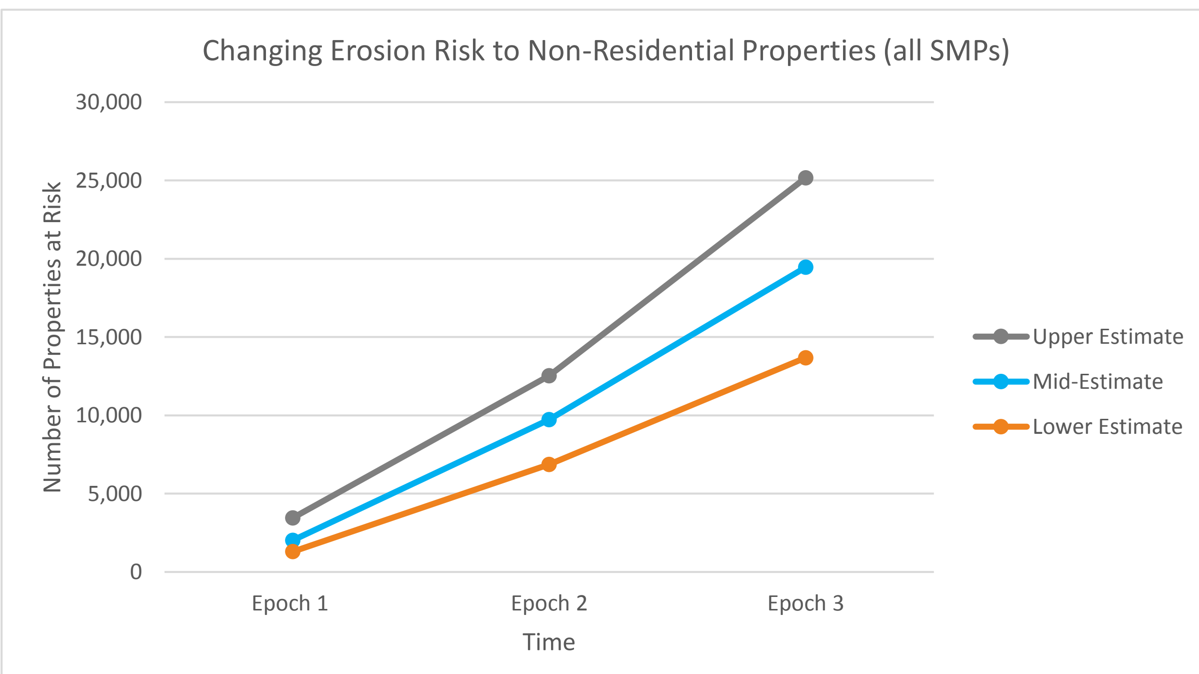


Figure 2.17: Changing erosion risk to non-residential properties over the next century under No Active Intervention scenario (excluding impacts of complex cliffs)



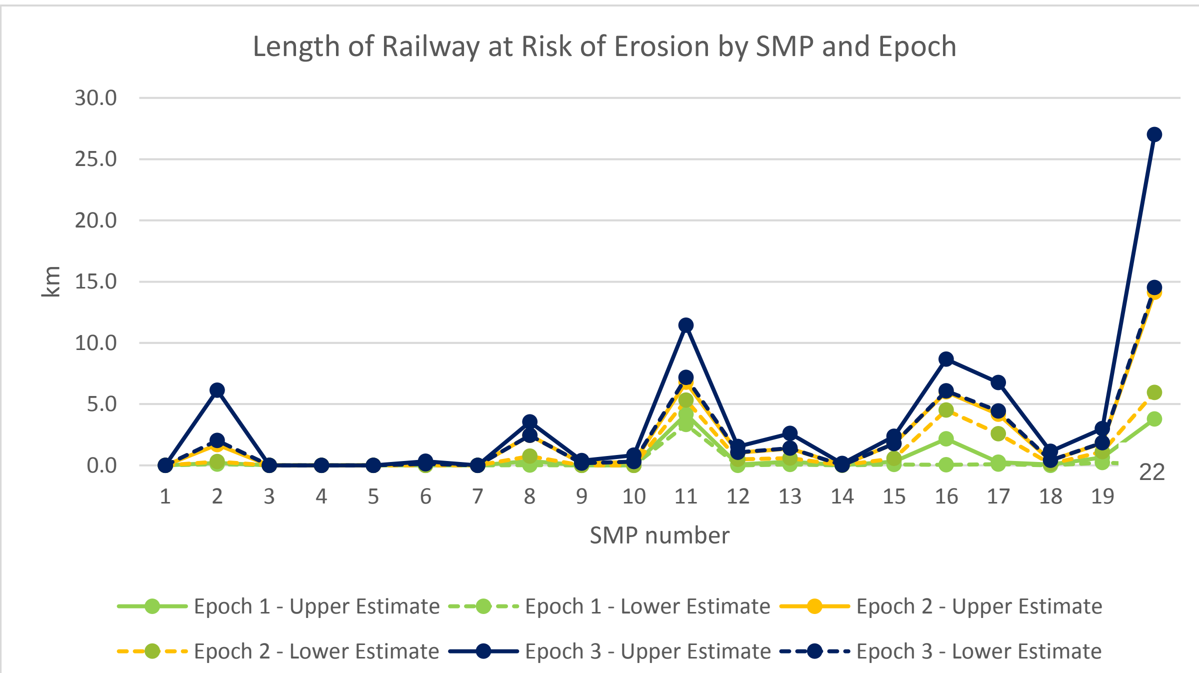
Infrastructure

Railways

With reference to Appendix B, there are no railway stations at risk of erosion in the short-term (Epoch 1) under the No Active Intervention scenario. This rises to up to 5 railway stations in Epoch 2, and 15 in Epoch 3. Those railway stations at risk are spread across SMPs 8, 11, 12, 13, 14, 15, 16 and 22.

The total length of railway line at risk of erosion under the No Active Intervention scenario also increases over-time with the greatest risks being in SMP 22, 11 and 16 (see Figure 2.18).

Figure 2.18: Envelope of erosion risk to railway lines by SMP and Epoch under No Active Intervention scenario (excluding impacts of complex cliffs)



Roads

The assessment of erosion risk to various road types by SMP and Epoch under the No Active Intervention scenario, excluding the impacts of complex cliffs, is presented in full in Appendix B. The following summarises key points about this data by road type:

- Motorway – there is only about 5km of motorway at possible risk of erosion over the next 100 years, and only in the upper estimate scenario. This is largely one section of motorway in SMP 13.
- A-Road – in Epoch 1 there is less than 6km of A-road at risk of erosion at most across all SMPs. This rises to about 40km and 90km in Epochs 2 and 3 respectively. The longest length at risk in Epoch 1 is within SMP 12. This changes to SMP 22 in Epoch 2 and Epoch 3.
- B-Road – in Epoch 1 there is less than 3km of B-road at risk of erosion across all SMPs. This rises to about 25km and 50km in Epochs 2 and 3 respectively. The longest length at risk in Epoch 1 is within SMP 2. This changes to SMP 15 in Epoch 2 and Epoch 3.
- Alley – these is very little classified as Alley at risk in Epoch 1 and Epoch 2, and only up to 20km in total across all SMPs in the upper estimate scenario by Epoch 3.

- Local Street – there is up to about 16km of Local Streets at risk across all SMPs in Epoch 1. This total length at risk rises to 109km by Epoch 2 and 310km in Epoch 3. SMP 12 has the longest total length of Local Streets at risk in all three epochs.
- Minor Road – there is up to about 25km of Minor Roads at risk across all SMPs in Epoch 1. This total length at risk rises to 97km by Epoch 2 and 190km in Epoch 3. SMP 11 has the longest total length of Minor Road in Epochs 1 and 2; this changes to SMP 22 in Epoch 3.
- Pedestrianised Street – there is very little pedestrianised street at risk of erosion over the next 100 years across all SMPs.
- Private Roads – there is up to about 44km of Private Roads at risk across all SMPs in Epoch 1. This total length at risk rises to about 177km by Epoch 2 and 366km in Epoch 3.

It is clear from the above that there is no significant risk to motorways, but there are significant risks to other key road assets (A- and B-roads) in the medium to long-term, with around 160km of asset at risk in the upper estimate by Epoch 3. There is a similar amount of minor roads that provide local access that is important for local community cohesion and tourism at risk over this time period, with over 190km of assets at risk in the upper estimate by Epoch 3. In some areas this number will be higher if the impacts of complex cliffs are considered.

Agricultural land

The largest risk from erosion in Epochs 1, 2 and 3 under the No Active Intervention scenario is to Grade 3 agricultural land, with around 760Ha at risk in Epoch 1, rising to around 4,300Ha in Epoch 3, excluding the impacts of complex cliff risks. The largest area at risk is in SMP 3. Details are presented in Appendix B.

Grade 4 land is next with up to around 1,000Ha at risk by Epoch 3. The risk to Grade 1, 2 and 5 agricultural land is much less, with less than 1,320Ha in total across these three grades at risk over the next 100 years.

Designated environment

A range of designated environment features have been analysed in terms of erosion risk by SMP, and how this varies by Epoch under the No Active Intervention scenario. Full details covering the nature of erosion risk (excluding any additional impacts from complex cliffs) to each of these features is provided in Appendix B. The following summarises the erosion risk impacts in relation to a number of the key features.

Area of Outstanding Natural Beauty

The total area of AONB at risk of erosion is of the order of 700Ha in Epoch 1, with risk of around 100Ha at most in any one SMP area. This risk increases up to 1,950Ha in Epoch 2 and 4,020Ha in Epoch 3 (when the impacts of complex cliff risks are included). The risk is quite well spread across SMPs, with any one SMP only having several hundred hectares at risk.

Site of Special Scientific Interest

The total area of SSSI at risk of erosion is of the order of 800Ha in Epoch 1, with typically risk of less than 100Ha in any one SMP area. This risk increases up to about 2,000Ha in Epoch 2 and 3,450Ha in Epoch 3. The risk is quite well spread across SMPs, with anyone SMP only having several hundred hectares at risk.

Special Area of Conservation

The total area of SAC at risk of erosion is of the order of 435Ha in Epoch 1, with typically risk of less than 50Ha in any one SMP area; the exception is in SMP 22 where there is more than 100Ha at risk. This risk increases up to about 1,050Ha in Epoch 2 and 1,950Ha in Epoch 3. The risk is quite well spread across SMPs, with any one SMP typically only having less than two hundred hectares at risk. SMP 22 has the largest area at risk in all three Epochs.

Special Protection Area

The total area of SPA at risk of erosion is of the order of 250Ha in Epoch 1, with typically risk of less than 50Ha in any one SMP area. This risk increases up to about 600Ha in Epoch 2 and 1,100Ha in Epoch 3. The risk is quite well spread across SMPs, with any one SMP typically only having less than two hundred hectares at risk.

World Heritage Site

Erosion risk to UNESCO World Heritage Sites is limited to SMPs 15, 16, 17 and 22. In total, there is at most 140Ha of World Heritage Site at risk of erosion over the next 100 years under the upper estimate.

To say this is all risk is also misleading, as in the case of SMP 15 and SMP 16, the reason for UNESCO World Heritage Designation is the natural erosion of the coastline. As such, only the impacts on SMP 17 and 22 would potentially adversely impact the designated features.

National Park

Erosion risk to National Parks around the coast of England is limited, with at most 525Ha of at risk of erosion nationally over the next 100 years under the upper estimate. The largest risk area is SMP 2, where up to around 200Ha of erosion could occur by Epoch 3.

Historic Landfill

Erosion risk to historic landfill sites around the coast of England is limited, with at most about 30Ha at risk in Epoch 1, rising to about 113Ha in Epoch 2 and 239Ha in Epoch 3. The largest areas at risk are in SMPs 2 and 13.

Although the total area of historic landfill sites at risk of erosion over the next century is relatively small by comparison to impacts on other designated features, the environmental impacts of erosion leading to landfill material entering the marine environment is much more significant.

Listed Buildings

There are up to 78 listed buildings at risk of erosion across all SMPs in England during Epoch 1, with the largest numbers at risk being in SMPs 2 and 17. This number increases to up to around 730 listed buildings by Epoch 2 and around 1,750 listed building by Epoch 3, with the largest numbers being in SMPs 2, 11 and 17 with about 300 listed buildings at risk of erosion in each.

Scheduled Monuments

There is very little scheduled monument at risk, with only up to about 30Ha at risk across all SMPs around England in Epoch 1, rising to up to about 85Ha in Epoch 2 and 167Ha in Epoch 3.

2.2 Coastal adaptation projects from 2015-2021

2.2.1 Data sources

Table 2.9 summarises the data sources used in order to assess the projects that are underway over the period 2015-2021.

Table 2.9: Data sources

Data / Source	Description
"Identifying Delivery Risks in Shoreline Management Plan Policies" (CH2M, 2017) and "The Cost of Implementing SMP Policies for Coastal Defence: Reviewing Coastal Defence Spending Commitments" (Halcrow, 2011) – *project reports and data sourced from CH2M's project archives.*	This project by CH2M for the Environment Agency provided a high level systematic analysis of the issues within the 20 Shoreline Management Plans (SMPs) across England and identified which Policy Units had the greatest delivery risks. As part of the research, information was collated on each SMP Policy Unit including the policy statement, defence types, benefit/costs and risks and has been used as the basis for analysis in this new research project.
Flood and Coastal Erosion Risk Management Investment Programme 2015 to 2021 – republished April 2017 (https://www.gov.uk/government/publications/programme-of-flood-and-coastal-erosion-risk-management-schemes)	This document provides information on the latest flood and coastal erosion risk management (FCERM) capital works programme for the period 2015 to 2021. It provides details of capital FCERM schemes planned or completed in this period.
Environment Agency Programme of flood and coastal erosion risk management planned schemes interactive map (https://www.google.com/maps/d/viewer?mid=1stOhiRoo8HQc2sk1aSit4lb3gHc&ll=52.86827844866016%2C-2.311162549999949&z=4).	The FCERM planned capital works programme for the period 2017/18 to 2021 is also available to view on an online interactive map.
Project Delivery Unit (PDU) prioritized programmes – *sourced from CH2M and Jacobs PDU leads in each of the 7 PDU areas.*	There are 7 Project Delivery Units (PDUs) around England tasked by the Environment Agency with delivering all capital projects between 2018 and 2021. The PDUs were established in mid-2017 and have each developed prioritized programmes of capital works to deliver.
Shoreline Management Plan websites for SMPs covering the coast of England only (i.e. SMPs 1 to 18 plus parts of SMP 19 and SMP 22) – accessed via https://www.gov.uk/government/publications/shoreline-management-plans-smps	Each SMP has its own website, on which any changes that have been made to any SMP policies are notified. Each SMP website was reviewed to capture this information, and this shows only 7 policy changes in SMPs around the coast of England.*

Notes:*SMPs in England are due to undergo a "light touch" review between 2018 and 2020 to take account of changed guidance and information since they were adopted, including: (a) new climate change guidance (UKCP18); (b) new partnership funding arrangements and outcome measures; and (c) more evidence from regional coastal monitoring programmes (Personal Communication (a)).

2.2.2 Analysis

Data from the sources listed above has been collated into a single spreadsheet to capture a range of information regarding:

- The SMP policies and the implementation expectations by Epoch as set out in each SMP policy statement for each policy unit
- The location of capital projects actually planned/completed in the period 2015-2021 to implement those policies around the coast of England alongside predicted costs of each project, funding split between FCERM Grant in Aid (GiA) and third-party contributions, and numbers of properties expected to be better protected against the risk of flooding or coastal erosion by 2021 as a result of the investment.

Table 2.10 summarises the data by SMP around the coast of England, and totals for a national perspective. Figure 2.19 and Figure 2.20 illustrate this data graphically. Table 2.11 illustrates the relative amount of funding contribution required for the identified schemes in each SMP area. Section 2.2.3 provides discussion on the findings of this research based on this data.

The data collected in the spreadsheet has also been used to create a GIS layer which allows the details of each project to be viewed in the context of where the project is located around the coast and in relation to SMP policy units via an interactive map. Maps based on this GIS data are also provided in Appendix C of this report.

2.2.2.1 Assumptions and limitations

In order to undertake this analysis, a number of assumptions have had to be made due to missing or incomplete data. These assumptions pose a number of limitations on the analysis and so findings presented in Section 2.2.3, and are as follows:

The FCERM capital works programme data for 2015-2021 (republished in April 2017) did not provide any location information in regard to “completed” projects “completed” since the start of the programme (1st April 2015), only for “planned projects”. Similarly, projects listed in data for each of the seven PDUs also lacked any coordinate data. Therefore, in order to identify where these projects are located, assumptions were made using limited information based on the project name and region/area/lead authority. Google Earth Pro was then used to derive latitude/longitude coordinates for each. Due to these approximations regarding location data, there may be errors where projects have been assigned to the wrong policy unit.

The project latitude/longitude coordinates provided on the online interactive map for “planned” projects to 2021 were indicative (within 1 km), requiring each stated project location shown on the interactive map to be cross checked with the policy unit information from each SMP. Despite this, some projects in the published data appear to have been assigned incorrect co-ordinates and so are shown in the wrong location; however, without any more information the stated coordinates have been assumed in this research.

Within the FCERM capital works programme data for 2015-2021 (republished in April 2017) there were also duplicates of projects which had both been counted as having been planned and completed. Both sets of the planned and completed project data were collected into the summary spreadsheet due to it not always being clear if the planned and completed projects were the same. As such, the numbers of projects stated may not be exact, but can provide a good estimate.

In addition to the above, it should be noted that only data relating to capital projects has been obtained for this analysis. Data on maintenance works and other non/low engineering activities in the period 2015-2021 is not available in a nationally consistent form.

Table 2.10: SMP Epoch 1 statistics summary

SMP	No. PUs*	No. of PUs with expected capital and/or maintenance work	No. PU's with capital works expected	No. PU's where unclear if works are capital or maintenance	No. of planned/ completed capital works	Total Project Costs (£k)	Total Grant in Aid (£k)	Total Contributions Required (£k)	No. Homes better protected against flooding and/or coastal erosion by scheme estimated completion
1 - Scottish Border to the Tyne	101	64	1	63	9	8,056	2,835	5,222	254
2 - The Tyne to Flamborough Head	98	58	1	57	14	57,871	39,317	18,554	2,316
3 - Flamborough Head to Gibraltar Point	30	14	0	14	9	48,164	41,177	6,987	24,466
4 - Gibraltar Point to Hunstanton	4	3	0	3	3	5,744	2,109	3,635	1,055
5 - Hunstanton to Kelling Hard	34	22	0	22	0	0	0	0	0
6 - Kelling Hard to Lowestoft Ness	24	23	1	22	11	89,482	57,229	32,253	3,629
7 - Lowestoft Ness to Felixstowe Landguard Point	66	55	4	51	1	22,491	4,651	17,840	415
8 - Felixstowe to Two Tree Island	103	94	1	93	6	86,599	38,404	48,195	2,811
9 - Medway and Swale	30	26	5	21	1	1,930	1,930	0	0
10 - Isle of Grain to South Foreland	27	22	4	18	18	23,895	21,968	1,927	13,019
11 - South Foreland to Beachy Head	30	22	2	20	23	111,401	85,307	26,094	67,364
12 - Beachy Head to Selsey Bill	27	24	1	23	17	218,535	130,103	88,432	6,898
13 - Selsey Bill to Hurst Spit	62	53	0	53	16	199,512	166,210	33,302	11,816
14 - Isle of Wight	61	34	0	34	4	14,527	13,616	912	715
15 - Hurst Spit to Durlston Head	57	45	1	44	11	36,812	31,141	5,671	2,675
16 - Durlston Head to Rame Head	194	110	5	105	31	131,513	76,404	55,109	13,020
17 - Rame Head to Hartland Point	262	130	0	130	16	17,084	5,047	12,037	488
18 - Hartland Point to Anchor Point	91	56	5	51	9	82,011	52,149	29,862	11,620
19 - Anchor Head to Welsh Border	50	32	0	32	8	84,107	16,604	67,503	12,181
22 - Northwest England	204	146	3	143	21	199,487	189,505	9,982	35,639
Total	**1,555**	**1,033**	**34**	**999**	**228**	**1,439,220**	**975,704**	**463,516**	**210,381**

Notes: *In some SMPs, policy units are broken down into smaller lengths of coast and considered separately. The figures above count these smaller lengths of coast within PUs. This explains the differences compared to Table 1.1.

Table 2.11: SMP Epoch 1 statistics – contribution required to deliver SMP schemes

SMP	No. of planned/ completed capital works in SMP area	Total Project Costs (£k)	Total Grant in Aid (£k)	Total Contributions Required (£k)	No. schemes with Contribution Required of <20% total cost		No. schemes with Contribution Required of 20%-50% total cost		No. schemes with Contribution Required of >50% total cost		No. Schemes with no cost data provided	
					No.	*As % of total no. schemes*	No.	*As % of total no. schemes*	No.	*As % of total no. schemes*	No.	*As % of total no. schemes*
1 - Scottish Border to the Tyne	9	8,056	2,835	5,222	1	*11%*	2	*22%*	5	*56%*	1	*11%*
2 - The Tyne to Flamborough Head	14	57,871	39,317	18,554	4	*29%*	5	*36%*	1	*7%*	4	*29%*
3 - Flamborough Head to Gibraltar Point	9	48,164	41,177	6,987	4	*44%*	2	*22%*	1	*11%*	2	*22%*
4 - Gibraltar Point to Hunstanton	3	5,744	2,109	3,635	0	*0%*	1	*33%*	1	*33%*	1	*33%*
5 - Hunstanton to Kelling Hard	0	0	0	0	0	*0%*	0	*0%*	0	*0%*	0	*0%*
6 - Kelling Hard to Lowestoft Ness	11	89,482	57,229	32,253	4	*36%*	1	*9%*	1	*9%*	5	*45%*
7 - Lowestoft Ness to Felixstowe Landguard Point	1	22,491	4,651	17,840	0	*0%*	0	*0%*	1	*100%*	0	*0%*
8 - Felixstowe to Two Tree Island	6	86,599	38,404	48,195	2	*33%*	1	*17%*	2	*33%*	1	*17%*
9 - Medway and Swale	1	1,930	1,930	0	1	*100%*	0	*0%*	0	*0%*	0	*0%*
10 - Isle of Grain to South Foreland	18	23,895	21,968	1,927	14	*78%*	0	*0%*	0	*0%*	4	*22%*
11 - South Foreland to Beachy Head	23	111,401	85,307	26,094	11	*48%*	3	*13%*	1	*4%*	8	*35%*
12 - Beachy Head to Selsey Bill	17	218,535	130,103	88,432	9	*53%*	3	*18%*	1	*6%*	4	*24%*
13 - Selsey Bill to Hurst Spit	16	199,512	166,210	33,302	12	*75%*	1	*6%*	2	*13%*	1	*6%*
14 - Isle of Wight	4	14,527	13,616	912	3	*75%*	0	*0%*	1	*25%*	0	*0%*
15 - Hurst Spit to Durlston Head	11	36,812	31,141	5,671	4	*36%*	4	*36%*	1	*9%*	2	*18%*
16 - Durlston Head to Rame Head	31	131,513	76,404	55,109	17	*55%*	5	*16%*	4	*13%*	5	*16%*
17 - Rame Head to Hartland Point	16	17,084	5,047	12,037	5	*31%*	4	*25%*	5	*31%*	2	*13%*
18 - Hartland Point to Anchor Point	9	82,011	52,149	29,862	4	*44%*	3	*33%*	1	*11%*	1	*11%*
19 - Anchor Head to Welsh Border	8	84,107	16,604	67,503	2	*25%*	4	*50%*	1	*13%*	1	*13%*
22 - Northwest England	21	199,487	189,505	9,982	12	*57%*	3	*14%*	1	*5%*	5	*24%*
Total	**228**	**1,439,220**	**975,704**	**463,516**	109	*48%*	42	*18%*	30	*13%*	47	*21%*

Figure 2.19: Total number of policy units in each SMP, number of those policy units where capital/maintenance work is expected in Epoch 1 based on stated SMP policy unit intent, and actual planned/completed work (2015-2021) in each SMP policy unit

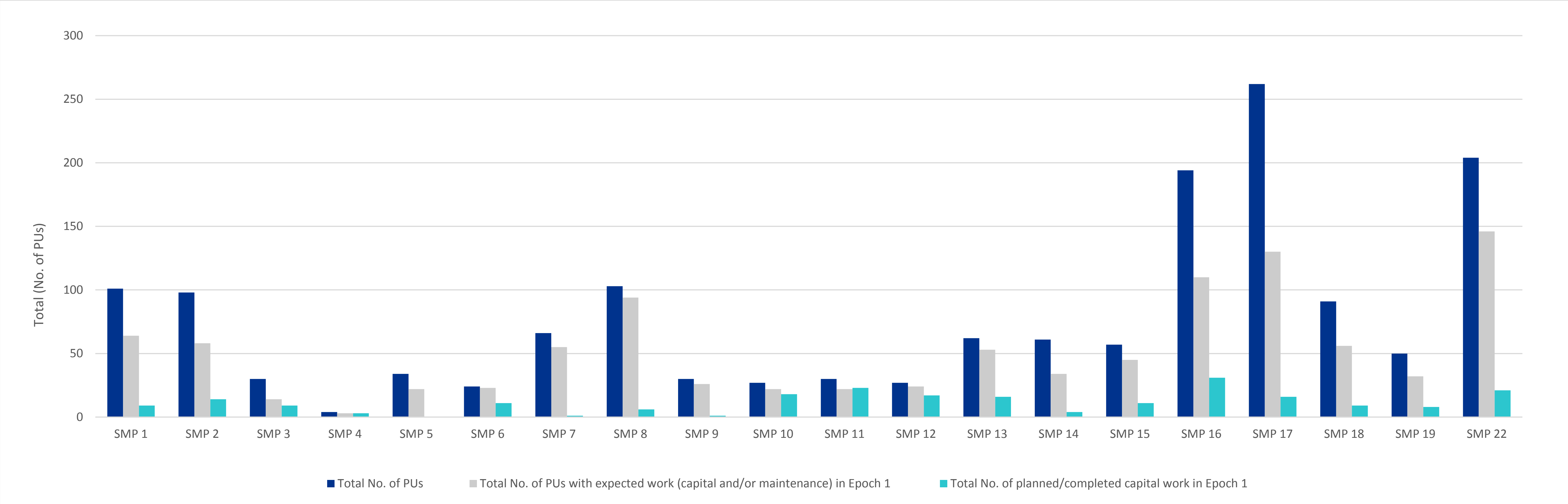
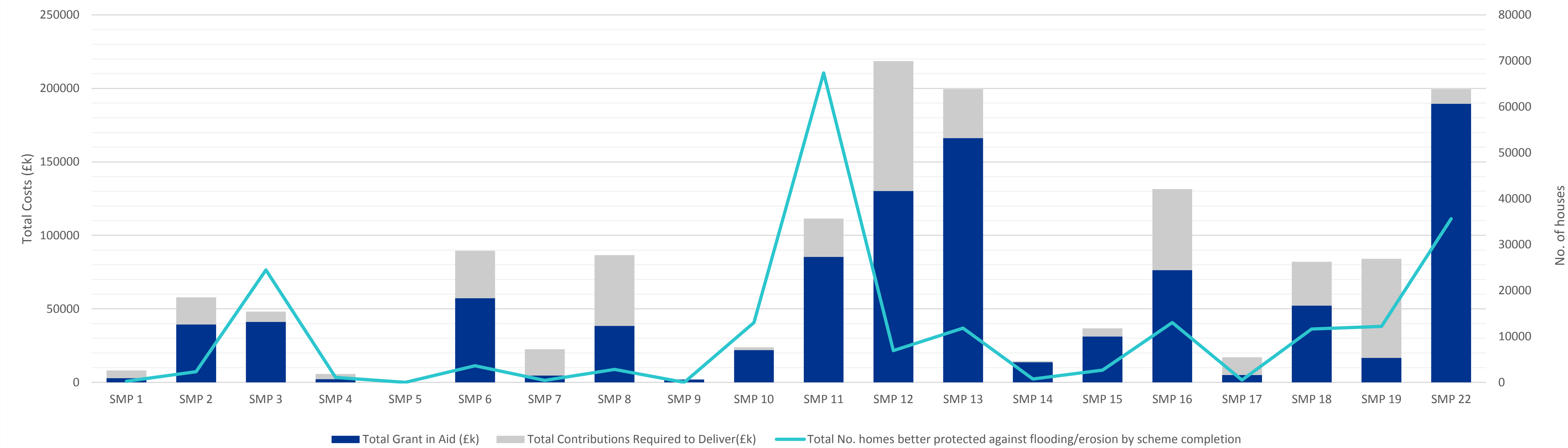


Figure 2.20: Total project costs in each SMP area, shown as relative proportions of grant in aid available and contributions required



2.2.3 Findings

The following presents the findings of the analysis undertaken to assess the activities that are underway over the period 2015-2021.

2.2.3.1 Funding and delivery of coastal flood and erosion alleviation schemes

As shown in Table 2.10 , in terms of what the SMPs expect to occur to implement policies around the coast of England in Epoch 1, the following can be said:

- In total, there are 1555 policy units covering the coast of England, spread across 20 SMPs.
- Of those, 1033 policy units expected capital and/or maintenance works to occur during Epoch 1; and of these, only 34 explicitly stated capital works as being expected, whilst the remaining 999 were less definitive (i.e. SMP policy statements suggest for each Epoch either: maintenance works only; capital works only; both maintenance and capital works; or are unclear as to what policy delivery expectations are).
- The 2015-2021 FCERM capital works programme data shows only 228 capital projects as being planned or completed in the period 2015-2021. This is possibly a lower figure than would be expected given >1000 policy units with some expectation of works in Epoch 1.
- However, as: (a) the SMP data is not explicitly clear on the number of capital only projects expected in Epoch 1 (see point above); and (b) that Epoch 1 in SMPs covers a greater time period (2005-2025) compared to the capital works programme, thus providing uncertainty over projects occurring prior to 2015 or planned post-2021; it remains unclear as to exactly how much progress is being made in implementing SMP policies.
- This is evidence that could be developed and improved as part of the planned “light touch” SMP reviews to be completed between 2018 and 2020 and should be recommended to the Environment Agency to form part of the scope of that work (Personal Communication (a)).
- The total of the project costs of all 228 capital projects planned/completed in the period 2015-2021 across all 20 SMPs is £1.4 billion. If averaged over the seven-year period, this gives an average capital expenditure of about £200 million per annum.
- Of this £1.4 billion total, approximately £976 million will come from FCERM GiA. The balance of approximately £464 million is required to come from third-party contributions as part of partnership funding arrangements. The published data does not include any details of where this other funding is expected to come from, and evidence from the PDUs (see points below) suggests there are significant challenges in achieving this level of third-party contribution to enable the full capital works programme to be delivered by 2021. To put this into some context, as part of granting the six-year funding for 2015-2021, HM Treasury required £600 million of third-party contributions to be raised in this period; as of September 2016, it was confirmed that £270 million of this target had been achieved (Priestley, 2017).
- Table 2.11 adds further clarity on the relative amount of third party contributions required to deliver the identified schemes in each SMP based on data contained in the FCERM capital works programme data, with 48% of schemes identified requiring less than 20% of contributions (making them potentially relatively more likely to be delivered), whilst 13% of schemes nationally require more than 50% contribution, making these schemes potentially relatively less likely to be delivered. In viewing these figures in Table 4.2, it is important to stress that these only relate to schemes in the FCERM capital works programme data for which cost data is provided; there are 21% of schemes for which no data on costs and contribution levels is provided.
- Up to 210,381 homes will be better protected once the expected works have been completed by 2021 as a result of the investment stated above across the 228 projects, assuming that all 228 projects are delivered. It is also notable that 127,469 of these better protected properties are in just three SMP areas (SMPs 3, 11 and 22) with a total stated cost to deliver of £359 million over the period to 2021; this represents 61% of better protected properties for the investment of 25% of the total costs across 228 projects nationally between 2015 and 2021.
- It should also be noted that, due to the uncertainties about third-party funding contributions noted above, there are significant challenges to be overcome in order to deliver better protection by 2021 to all 210,381 homes.

- Of the 228 capital projects around the coast of England identified as being planned or completed in the period 2015-2021, 102 of these are to be led by the Environment Agency (the remainder are led by Local Authorities). During 2017, delivery of these Environment Agency capital projects was given to seven Project Delivery Units (PDUs) in England. As part of establishing the PDUs, each PDU team has reviewed and developed the national (April 2017) capital programme to develop a prioritised list of capital projects to deliver by 2021.

  These prioritised PDU delivery programmes have been reviewed by this project and found the following:

  - Although the PDUs were established to deliver Environment Agency capital projects, the PDUs are able to be used by Local Authorities to deliver capital projects if they wish to, but thus far there has been limited uptake of this option nationally, and no uptake in terms of coastal flood and erosion risk management projects.
  - Of the 102 projects identified from the April 2017 capital projects programme as being led by the Environment Agency, only 18 of these appear to be currently listed in the PDU prioritised delivery programmes. It is understood from discussion with those leading the PDUs that this narrower focus on 18 or so priority coastal flood and erosion risk management projects is due to PDUs focussed on those that will provide largest outcome measures in terms of “numbers of homes better protected against flooding”. It is unclear what will become of the remaining 84 projects are not currently listed in the PDU delivery programmes.
  - Of the 18 projects listed in the PDU prioritised delivery programme, the majority (14; or 78%) are flagged as at risk of not being deliverable (Amber/Red). From discussion with PDU leads and review of data, it is understood that the greatest risk to delivery of these projects is the lack of ability to secure the necessary partnership funding contributions to unlock the proportion of the total costs that will be paid for by the FCERM GiA budget.
  - The PDU prioritised delivery programmes also include a small number (<10) projects that would appear to be coastal but which were not on the April 2017 programme. This is likely as a result of the capital programme review and refresh process that occurred after April 2017, the outputs of which are expected to be published in April 2018 (Personal Communication (b)).

With reference to Figure 2.19, which shows the total number of policy units along with the expected works and planned/completed works for each SMP, it can be seen that:

- Most of the SMPs have a high number of expected works with a small proportion of that work recorded as planned/completed.
- SMPs 10, 11 and 12 have the smallest differences between expected and planned/completed works.
- SMPs 5, 7 and 9 have only a small number of recorded projects planned/completed compared to those expected.
- SMPs 16, 17 and 22 have a large number of policy units and comparatively low number of expected and planned/completed works. This is, however, due to a large proportion of policy units having a “no active intervention” policy.

With reference to Figure 2.20, which shows a breakdown of the costs for each SMP alongside the number of homes predicted to be better protected after project completion, it can be seen that:

- Nearly all of the SMPs show that the majority of the total cost will be from grant in aid with the remaining cost made up by required contributions.
- SMPs 3, 9, 10, 14, 15 and 22 have nearly all the total cost made up of grant in aid whilst SMPs 7 and 19 require larger amounts of third party contributions compared to grant in aid.
- There is a clear disparity around the coast in terms of total costs and numbers of properties protected. For example, SMPs 12 and 13 have high costs and relatively smaller total number of properties better protected, whereas by comparison, SMP 11 protects the highest total number of properties for about half the total cost. The reason for this are not wholly clear, but it may be that SMP 11 contains a much larger number of properties within the coastal flood plain compared to SMPs 12 and 13 that can be protected by

smaller levels of investment in coastal flood and erosion risk management activities in the period 2015-2021.

2.2.3.2 Funding and delivery of low-engineering approaches

In regard to low-engineering approaches, these are taken here to mean maintenance activities to maintain existing coastal flood / erosion assets. Investigations undertaken for this research has identified that very little nationally consistent data is available to understand what maintenance activities area undertaken around the coast of England, or indeed are planned to occur, in the period 2015-2021. The SMPs generally identify that maintenance works are anticipated to occur in areas where the SMP policy in Epoch one is to intervene (i.e. policy is either HTL, MR or ATL).

It was the intention of this project to seek to obtain information on maintenance activities via survey of coastal local authorities to be issued through the coastal groups around England. In investigating how to approach such a survey, discussions were held with the chair of the coastal groups, Bryan Curtis (Personal Communication (c)). These discussions highlighted:

- Coastal groups have attempted to capture this information in recent years for other projects with little success, and what data has been obtained has been very limited and not provided a national picture.
- Maintenance work undertaken by Local Authorities will probably break down into 3 categories: reactive, routine and planned. The reactive element will be very low budget items and may include things such as litter removal/bench repairs. Routine items will be more substantial repairs. Planned items will be the higher value schemes which will often be capitalised and added to the six-year capital programme anyway (so likely captured in the data discussed in Section 2.2.3.1 above).
- Most Local Authorities will/have only undertaken the bare minimum of maintenance if any at all due to limited resources being available, as maintenance is funded via the Revenue Support Grants allocated to each Local Authority by central Government, but this is not ring-fenced specifically to deliver FCERM asset maintenance.

Given the above, it was concluded that a survey of coastal Local Authorities would be unlikely to yield useful results.

It is worth highlighting here also the findings of CH2M (2015) that directly relates to this issue of asset maintenance. In this regard, it was highlighted that although the purpose of SMP policies in some areas is to enable short-term maintenance of existing defences whilst adaptation is planned/implemented (which in itself implies a need for some ongoing investment in that maintenance in the short-term), there has been a general decline in FCERM funding since 2010 that has left about ¾ of flood defence assets not being maintained to their optimum needs in 2014/15. This means that assets that need to be maintained whilst adaptation plans are developed are likely not being maintained to an adequate standard; if this is the case then it only adds to the need to develop and implement adaptation measures sooner rather than later so that they are prepared for when the defences become life-expired sooner than perhaps they would have done had they been appropriately maintained.

2.2.3.3 Funding and delivery of non-engineering approaches

In regard to non-engineering activities, these are taken here to mean activities such as land use planning, flood proofing, etc. As with the low-engineering approaches, there is again very little nationally consistent data on what is occurring/is planned to occur in this regards in the period 2015-2021, even though most of the SMPs identify that some form of adaptation planning is needed in many areas during Epoch 1, particularly those where the SMP policy is expected to transition in the medium to long-term to a different policy.

To drive such adaptation planning, the National Planning Policy Framework (NPPF) (DCLG, 2012) recommends that Local Planning Authorities identify Coastal Change Management Areas (CCMAs) within Local Plans for areas “likely to be affected by coastal change (physical change to the shoreline through erosion, coastal landslip, permanent inundation or coastal accretion).” Defra subsequently funded East Riding of Yorkshire Council to lead development of “Coastal Change Adaptation Planning Guidance for England” (Halcrow, 2015) to provide good practice guidance to local planning authorities on how to develop and implement CCMAs. This guidance defines a 4-stage process for developing CCMAs based upon SMP policy, underpinned by a need for ongoing, long-term engagement with communities and stakeholders affected by coastal change.

Research undertaken for the National Trust Shifting Shores+10 project (CH2M, 2015) included analysis of the uptake of CCMAs around the coast of England by local planning authorities and found that (at the time of the research in 2015), “of the 94 coastal LPAs in England, around:

- 29 have CCMAs referred to in adopted or currently draft local plans.
- 35 of the 65 coastal LPAs that do not have CCMAs defined, do have something akin to CCMAs in adopted or draft/emerging local plans.
- 30 coastal LPAs still do not have either CCMAs, or something akin to CCMAs, in adopted or draft/emerging local plans.

The main barriers to CCMA development appear to relate to:

- The Local Plan had already been reviewed / adopted prior to CCMAs being required.
- CCMAs are included in draft/emerging plans but are not yet developed.
- Development of a CCMA is deferred pending further studies.
- They are not seen as a priority as they are not statutory.
- The coastal area is assessed as not being at significant risk of coastal change or the risk is relatively low.
- Where the risk is only from flooding.
- Where SMP policy is Hold the Line.
- Organisational arrangement, where there is ineffective integration across sectors within the local planning authority.
- The lack of communication and engagement with local communities.
- The lack of available funding for the development of CCMAs and implementation of adaptation measures.”

2.3 SMPs in Local Plans

2.3.1 Approach and data utilised

Around the coast of England, there are 94 coastal local authorities, each with statutory duties to prepare and implement national planning policies/guidelines at the local level, guided by a Local Plan. A Local Plan is the basis for the future development of homes, employment and business sites while protecting the countryside and coastline. Planning applications, whatever their size and proposed use, are assessed for approval against the policies contained within the Local Plan.

To assess how SMPs are reflected in local plans around the coast of England, the local plans for each area were sought from the website of each, and reviewed to identify and capture information relating to SMPs, including the following key information:

- The Local Plan status (Draft, Adopted, Submission).
- Date of Local Plan publication.
- Date Local Plan is active until.
- If the local plan indeed refers to Shoreline Management Plans within its policies, and how.

In undertaking this research, it should be noted that of the 94 coastal local planning authorities in England, there are six sets of two councils that have published, or are publishing, joint local plans. These areas are:

- Waveney District Council + Suffolk Coastal District Council
- Eastbourne Borough Council + Lewes District Council
- Adur District Council + Worthing Borough Council
- West Dorset District Council + Weymouth & Portland Borough Council
- South Hams District Council + Plymouth City Council
- Torridge District Council + North Devon District Council.
-

Appendix D identifies the Local Plans that have been identified and reviewed for this research. Appendix E provides the full data extracted from each, which is analysed in Section 0 below.

2.3.2 Analysis

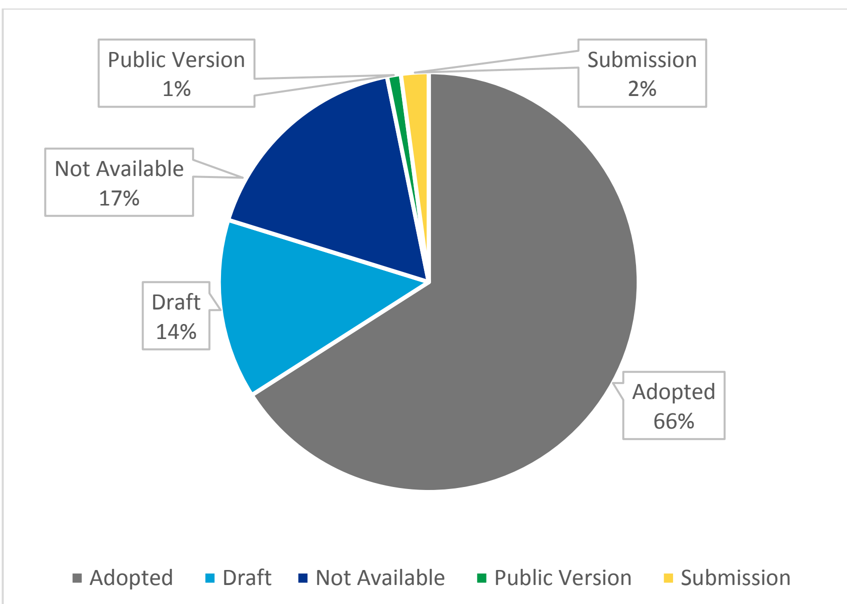
The Local Plans have been analysed to identify the number of plans that are in various stages of publication. Local plans are created in various stages, from initial evidence gathering, publication and submission, though to adoption. The status of each Local Plan reviewed for this research is shown in Table 2.12 and Figure 2.21. Two-thirds of Local Plans are currently approved (adopted), whilst the remainder are in some state of development or were not available to review for this research.

It should be noted that due to the length of time it takes to prepare, consult (including public examination) and gain approval to adopt a new Local Plan (several years), the technical substance of a local plan including how it references SMPs may have been determined prior to 2011 in some Local Plans; as such, although 66% of Local Plans reviewed were adopted after the SMP, there is a small amount of uncertainty about whether or not these Local Plans reflect the final defined SMP policies in all cases.

Table 2.12: Local Plan publication summary

Publication Status	Count	Percentage (%)
Adopted	62	65.96
Draft	13	13.83
Not Available	16	17.02
Publication Version	1	1.06
Submission	2	2.13
Total	**94**	**100**

Figure 2.21: Local Plan publication summary



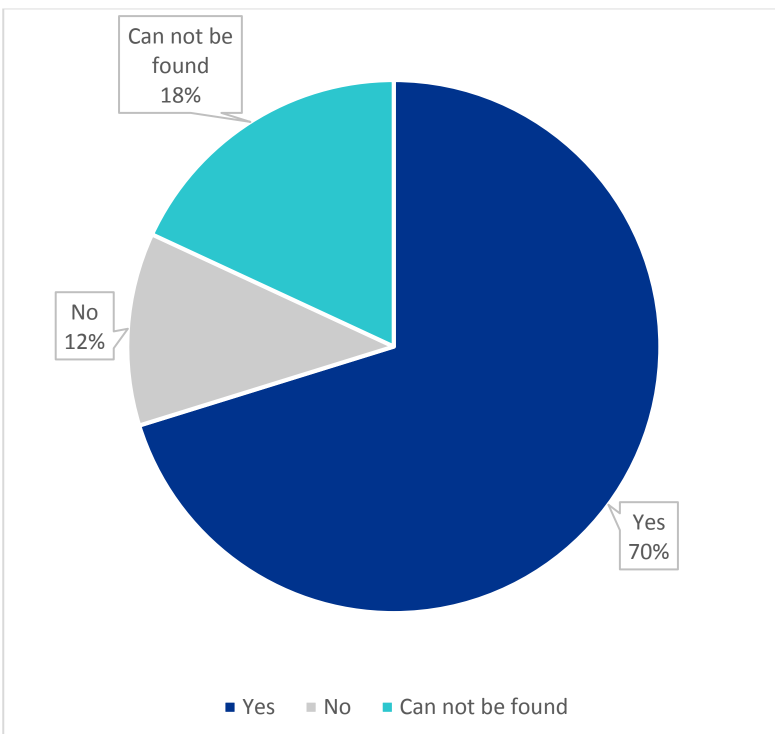
The publication dates for each Local Plan reviewed have also been analysed to identify if they coincide with the latest round of SMPs. This information is shown in Table 2.13 and Figure 2.22. This shows that nearly 70% of all Local Plans reviewed were published after the SMPs were all adopted in 2011 (i.e. 2012 to present).

It should be noted that Government guidance for Local Plans states “Most Local Plans are likely to require updating in whole or in part at least every 5 years. Reviews should be proportionate to the issues in hand. Local Plans may be found sound conditional upon a review in whole or in part within 5 years of the date of adoption” (GOV.UK). It could therefore be expected that all Local Plans should by 2018 be “post-2011 SMP adoption” and so reflect current SMP policy, which is not borne out by the numbers determined in this research. Indeed, the data suggests that around 30% of all local plans have not been updated in more than five years.

Table 2.13: Local Plan publication dates

Post 2011	Count	Percentage (%)
Yes	66	70
No	11	12
Not Available	17	18
Total	**94**	**100**

Figure 2.22: Local Plan publication dates post-2011 (“YES”) and pre-2011 (“No”)



Local Plans typically have planning horizon of 20 to 30 years, which is somewhat shorter than the 100-year planning horizon of SMPs. Of the Local Plans reviewed for this research, Table 2.14 and Figure 2.23 and Figure 2.24 show that the majority of Local Plans only cover up to a period between 2026 and 2033 (i.e. the end of the first SMP Epoch and into the second).

Table 2.14: Local Plan active dates summary

Dates Active to	Count	Percentage (%)
Not Found	16	17
2011	1	1
2016	1	1
2021	3	3
2022	1	1
2025	1	1
2026	11	12
2027	8	9
2028	5	5
2029	5	5
2030	8	9
2031	16	17
2032	8	9
2033	5	5
2034	2	2
2035	1	1
2036	2	2
Total	**94**	**100**

Figure 2.23: Local Plan active dates summary

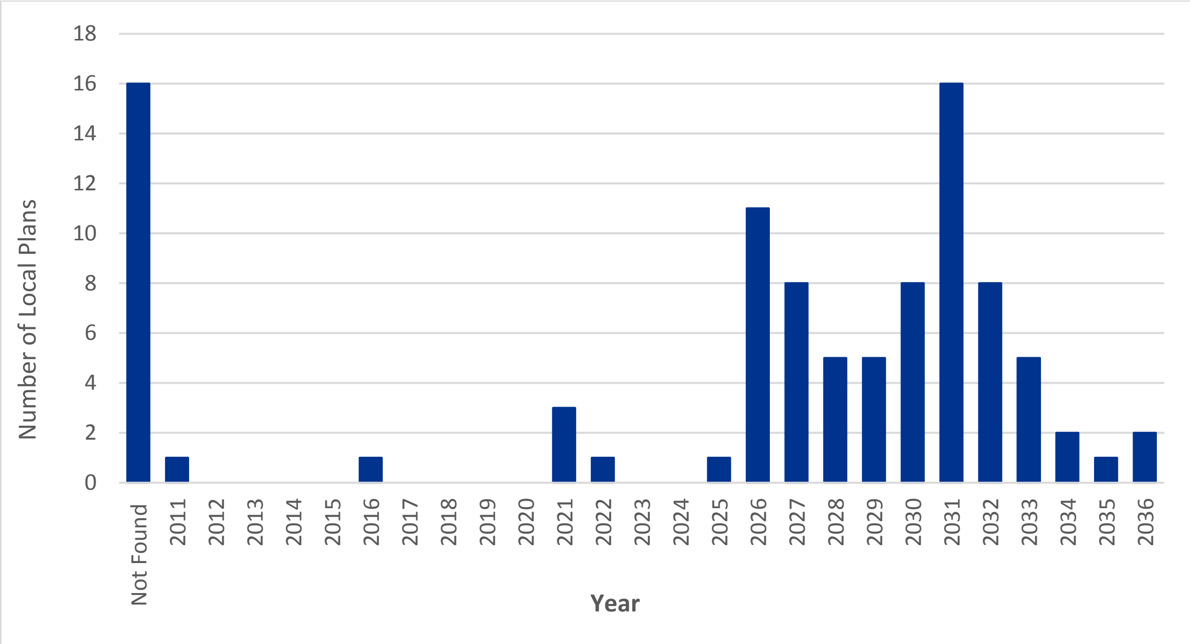
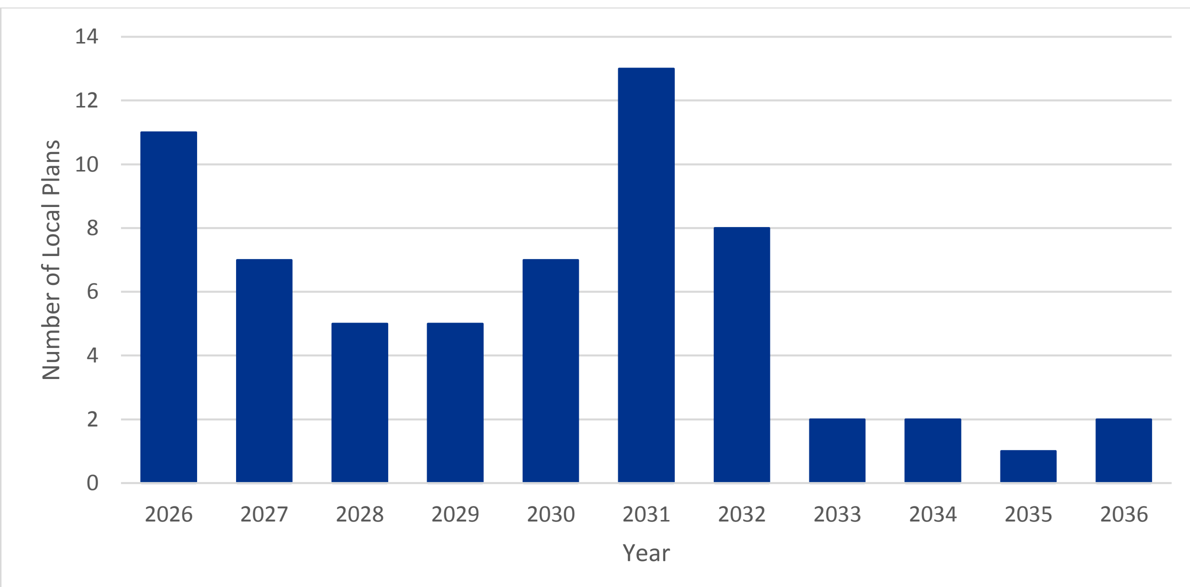


Figure 2.24: Local Plan active dates for the plans that have been adopted post-2011



Analysis of how the Local Plans reviewed for this research do (or do not) refer to SMPs is presented in the following Table 2.15 and Figure 2.25 and Figure 2.26. This shows that over three-quarters of Local Plans reviewed do make reference to SMPs (the figure falls to two-thirds when non-available Local Plans are factored in, for which it is uncertain how they do or do not refer to SMPs).

Table 2.15: Percentage of Local Plans that refer to Shoreline Management Plans

Do the local plans refer to SMP(s)?	Count	Percentage (%)
Not Found	16	17
No	17	18
Yes	61	65
Total	**94**	**100**

Figure 2.25: Percentage of all Local Plans that refer to Shoreline Management Plans

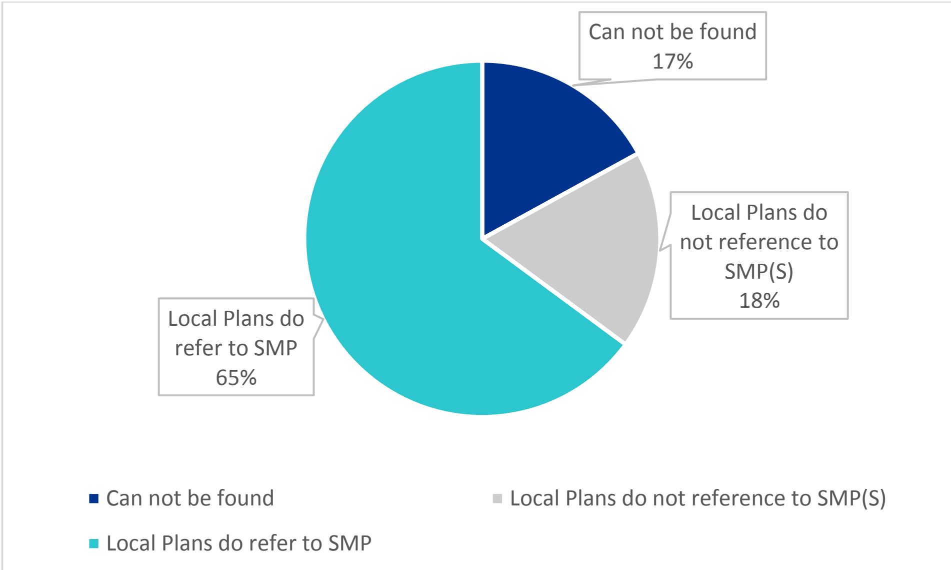
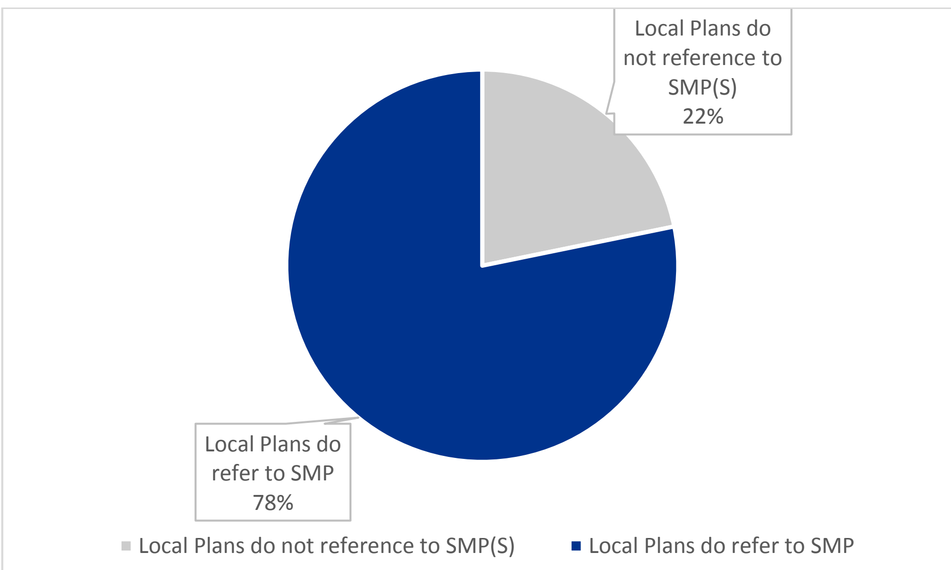


Figure 2.26: Percentage of Local Plans reviewed that refer to Shoreline Management Plans



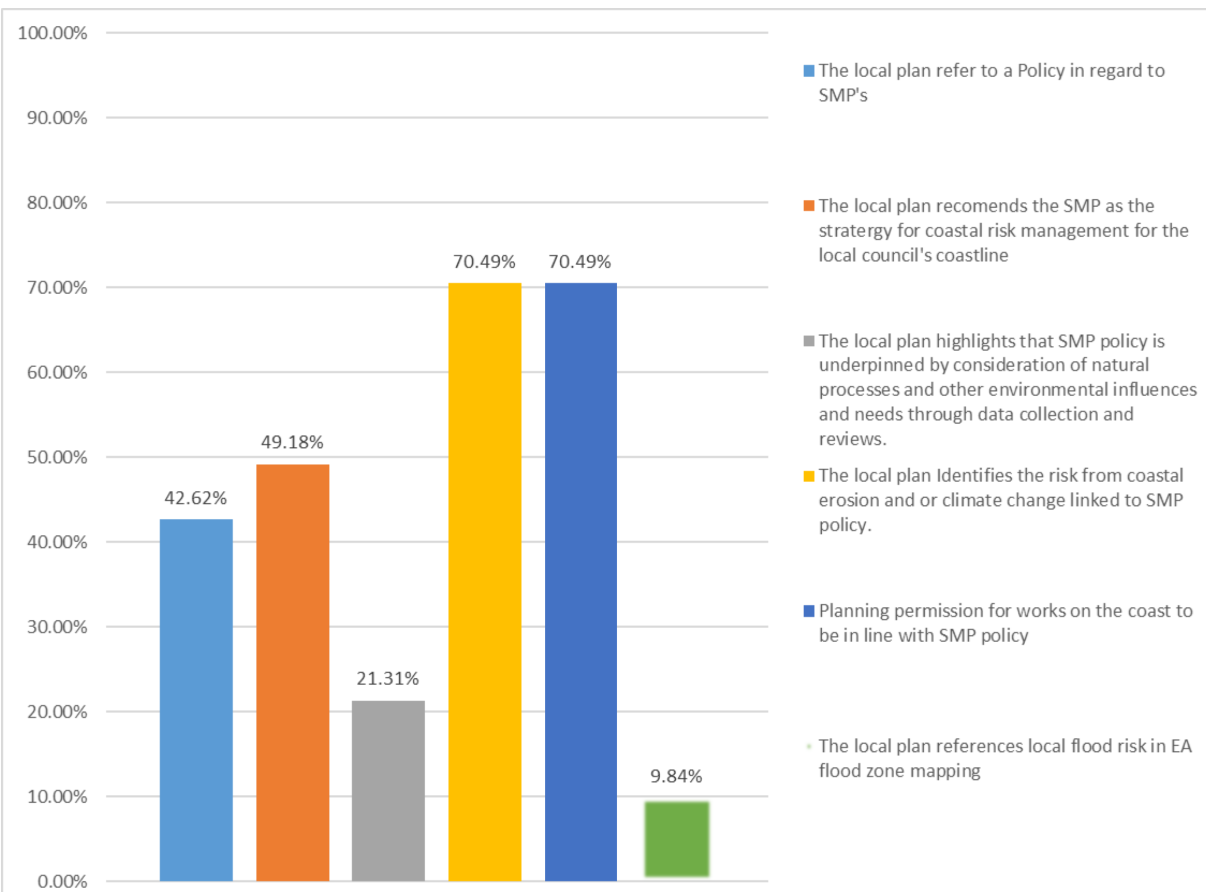
For the Local Plans that do refer to SMPs, from review of each it has been possible to identify a number of broad-themes that categorise how each Local Plan makes reference to SMPs. These are summarised in Table 2.16 and Figure 2.27 below.

Table 2.16: Summary of themes by which Local Plans refer to SMPs

Percentages (%) of all local plans (94) that fall within the below categories.			
Category	**% local plans referring to individual category**	**Category**	**% local plans referring to individual category**
The local plan refers to a Policy regarding SMP(s)	43	The local plan Identifies the risk from coastal	71

Percentages (%) of all local plans (94) that fall within the below categories.			
Category	**% local plans referring to individual category**	**Category**	**% local plans referring to individual category**
		erosion and/or climate change linked to SMP policy.	
The local plan recommends the SMP as the strategy for coastal risk management for the local council's coastline	49	The local plan states planning permission for works on the coast are to be in line with SMP policy	71
The local plan highlights that SMP policy is underpinned by consideration of natural processes and other environmental influences and needs, through data collection and reviews.	21	The local plan references local flood risk to EA flood zone mapping.	10

Figure 2.27: Summary of themes by which Local Plans refer to SMPs



2.3.3 Conclusions

As seen in Figure 2.21 the majority (66%) of England's local coastal planning authorities have a current adopted local plan. However, 17% of the local coastal planning authorities do not have an accessible local plan for review during the time of research. This is largely due to many of these 17% of local plans being in the process of being updated and the current adopted local plan not being available online to review as a result.

A total of 20 SMPs covering the coast of England were developed and adopted between 2006 and 2011. Therefore, for Local Plans to be referring to the latest SMPs they ought to have been written/adopted post-2011. As seen in Figure 2.22, 73% of current local plans (of the previous 83% of local plans that were found) have been adopted post-2011. This means that a small number of Local Plans cannot possibly refer to current SMP policy. However, it should be noted that all these plans did already have an SMP1 in place, so they could (should) still have made reference to the existing SMP. For the purposes of this analysis these Plans are excluded for the analysis below, but this remains an omission in coverage of coastal change issues.

Each Local Plan has a time stated that it will expire by. As illustrated in Figure 2.23, the majority of Local Plans only cover up to a period between 2026 and 2033. This only equates to the end of the first SMP Epoch and into the second, and reflects the difference in planning horizons taken by Local Plans (typically 20 to 30 years) compared to SMPs (100 years).

In terms of how the Local Plans that have been reviewed do or do not reference SMPs, it is shown in Figure 2.25 and Figure 2.26, that 78% of the Local Plans identified and reviewed for this research do indeed refer to SMPs within them. This leaves 22% of Local Plans that do not refer to SMPs; the reason for this is not clear.

Of the 78% of Local Plans that do reference SMPs, a number of themes have been identified in how SMPs are referred to/made use of in Local Plans, as summarised in Figure 2.27. Key findings from this analysis are:

Within the Local plans, the councils recognise the plans must strike a fine balance between providing for much needed regeneration and development activities, whilst minimising the amount of new development exposed to flood and erosion risk.

The majority of Local Plans referred to the NPPF (DCLG, 2012) as setting out the requirement to identify areas that are likely to be affected by physical coastal change, referred to as Coastal Change Management Areas (CCMAs), and within these, to clearly define what development will be appropriate within CCMAs and make provision for development and infrastructure that needs to be relocated away from CCMAs. Guidance on how to define CCMAs was published in 2015 and takes the SMP policies as the start point for this process (Halcrow, 2015). It should be noted, however, the CCMAs are only typically to be defined in areas where SMP policy is (or is expected to transition to) No Active Intervention or Managed Realignment; CCMAs are not intended to guide management of residual risks in areas where the policy is Hold the Line.

The majority of Local Plans also identified that coastal change is a significant issue to parts of their coastlines. With the risk to land from coastal erosion set to be a prominent issue, the local plans acknowledged the predicted 20, 50 and 100-year erosion risk zones presented in the updated Shoreline Management Plans.

For example, East Riding of Yorkshire identified that East Riding has one of the fastest eroding coasts in northwest Europe (average cliff losses of 1-1.5 m per year). East Riding's Local Plan has identified that the SMP has assessed the risk associated with coastal erosion and flooding in East Riding and that it has identified the projected position of the coastline in the years 2025, 2055 and 2105. The predicted shoreline position of the coastline in 2105, together with the most recent monitoring of erosion since the SMP, was published, has been used to define the extent of the CCMA for the Local Plan area.

Overall, while it is positive that a large number of coastal Local Plans make reference to the evidence and policies set out in the relevant SMPs, it is clear that there is a lot more that could be done to actively integrate the evidence base from SMPs and implement Coastal Change Management Areas to set a framework for guiding and driving future adaptation in areas at greatest risk of coastal change. In doing so, there also needs to be greater recognition of residual risks in areas that are expected to continue to be defended, in order to drive adaptation and improved resilience to increasing coastal hazards where communities are to remain. The proactive management of all coastal hazard areas to both prevent inappropriate future development (or redevelopment) and ensure the resilience of communities where they are expected to continue to be defended, is a critically important step to deliver long-term adaptation to coastal change at the coast.

3. Part II - National economic assessment of coastal change management

This section presents the approach and results from the national cost-benefit analysis (CBA) of the measures outlined in SMPs (Part II of the study). The following section discusses the approach to economic appraisal in SMPs. This is followed by setting out the CBA framework for the assessment, and the estimation of the costs and benefits.

It is important to note that the costs and benefits of implementing SMPs are estimated based on the best available data and the methods these allow. While the estimates provide an indication of the order of magnitude of the impacts of coastal adaptation, they are subject to varying levels of certainty which are teased out in the following sections. This section is supported by Annex F which sets out the assumptions underlying the CBA in detail.

3.1 Economic appraisal in SMPs

Policy scenarios in the second generation of SMPs were selected based on technical, environmental, social, and economic factors as well as local characteristics. The preferred policy scenario is intended to be the one that is the most sustainable i.e. avoids tying future generations into inflexible or expensive options for defence (Defra, 2006).

The guidance on undertaking an economic appraisal of SMP policies states that economic assessments only provide a check on the viability of the selected preferred policies and a review of their robustness in economic terms, and a full economic assessment is not required in the form of a CBA. The preferred policy in each policy unit (PU) in an SMP is therefore chosen before an economic appraisal is undertaken. Economic evidence does not drive the selection of the preferred policy, rather the guidance states that it provides an indication of whether the policy is:

- Clearly economically viable;
- Clearly not economically viable; or
- Potentially economically viable and therefore may require more detailed assessment at a later date.

Cost estimates in SMPs reflect the costs of measures to implement the policies of hold-the-line (HTL), advance the line (ATL) or managed realignment (MR). These are based on replacement costs for linear structures such as revetments and seawalls, which cover the capital cost associated with these measures. Maintenance costs for different measures are taken from the Defra National Appraisal of Defence Needs and Costs (NADNAC) study. In addition to this, cost rate information for other types of defence structures, such as flood walls within estuaries, are derived from the Environment Agency's Unit Cost Database (2007). From the perspective of coastal adaptation, the policy of no active intervention (NAI) does not include any relevant costs of coastal adaptation measures. However, there may be costs associated with de-commissioning certain assets under NAI.

Benefits estimates in SMPs are calculated based on avoided damages compared to a no active intervention scenario i.e. do nothing. Damages are calculated based on the damage done to residential and non-residential properties. SMPs tend to estimate avoided damages in terms of the write-off cost of the whole value of properties which overstates the value of benefits. Other benefits in terms of avoided damage to utilities, highways, and intangibles, such as recreation, and other impacts on the local economy or environment are generally not captured by SMPs. The exclusion of these factors is thought to robustly confirm the economic viability of a policy, as these would provide added benefits (Defra, 2006).

3.2 Cost-benefit analysis framework

In the context of the implementation of SMPs, CBA can be used to determine whether:

1. An action or policy is worth undertaking to adapt to coastal flooding or erosion; and
2. If so, which option or policy to undertake the action is best – i.e. which combination of measures should be implemented to ensure that coastal adaptation is underway.

The CBA focuses on (1) above, as the measures and policies for coastal adaptation have been taken from the SMP documents developed for the English coastline.

The CBA framework for this study can be described in six standard steps, outlined below.

Stef 1 - Defining the objective of the cost-benefit analysis

In the context of this study, the objective of the CBA is to compare the costs and benefits of coastal change management as set out in the SMPs at the national level.

Step 2 - Establishing the baseline and investment impacts which are being assessed

In principle, a CBA should set out the outcomes, in terms of costs and benefits, of an investment against the outcome that would occur in the baseline. This will be based on the baseline which occurs before measures in SMPs were implemented i.e. a scenario of no active intervention (NAI) where flood and coastal erosion defences are not introduced, maintained or enhanced.

The policy impact is measured by the difference between the baseline and the outcomes that arise in each Epoch from the measures set out in SMPs, as follows:

- Hold the line (HTL) – maintain or change the level of protection provided by existing coastal defences in their present location;
- Advance the line (ATL) – build new defences on the seaward side of the existing defence line to reclaim land; or
- Managed realignment (MR) – allow the shoreline position to move backwards (or forwards) with management to control or limit movement.

Conceptually, all impacts of these policies should be assessed against the baseline. However, in practice the extent to which all impacts are considered depends on the availability of data. The scope of the analysis presented here focuses on the costs of implementing HTL, ATL or MR and the benefits of these policies in terms of avoided damages to properties from flooding and erosion. In this sense, the national CBA is considered a 'market' CBA as it focuses on market impacts only. An appropriate account of wider non-market impacts requires an assessment that takes into account local site conditions and characteristics for the more than 1,500 policy units covered in this study. Non-market impacts such as environmental benefits are considered as appropriate in the case studies in Part III of the study (see Section 4) where local data is more readily available. In this way, the case studies provide an augmented view of the impacts of coastal adaptation captured in the national CBA.

Step 3 - Measuring the costs and benefits of impacts in monetary terms

After identifying the range of impacts associated with the policy scenarios above, the next step is to value these in monetary terms. In the national CBA, the costs of coastal adaptation are extracted from the 20 SMP documents covered by the study. The benefits of coastal adaptation are based on avoided damages to residential and non-residential properties at risk of flooding. Benefits estimates are available in SMP documents.

Given their methodological issues mentioned in Section 3.1[5], new revised benefits figures are derived as part of the study in terms of avoided damages from coastal flooding and delayed damages from coastal erosion.

Step 4 - Analysing the costs and benefits

This step of the CBA relates to the aggregation of costs and benefits. The analysis in this study adopts a 100-year timescale, in line with other FCERM assessments. Following standard practice, costs and benefits occurring in the future are discounted as per the HM Treasury Green Book (2018).

The CBA results are presented in terms of:

- Present value benefits (PVB): the benefit of implementing the policy scenario versus the baseline of no active intervention in terms of avoided damages to properties from flooding, discounted to present value;
- Present value costs: the cost of measures to implement the policy scenario for each Epoch, discounted to present value;
- Net present value (NPV): the absolute difference between present value benefits and present value costs; and
- Benefit-cost ratio (BCR): the ratio of benefits to costs which gives a relative comparison of benefits and costs.

The NPV and the BCR indicate whether an action or policy can be justified on cost-benefit comparison grounds. However, in practice this may not necessarily represent the threshold for the assessment of how to approach coastal adaptation which can also involve technical, social, political, and environmental considerations.

For example, the decision to implement a policy or scheme could depend on the funding available via Partnership Funding. This considers the extent of grant-in-aid (GiA) funding that may available for a policy or scheme based on funding already secured from other public or private sources as well as qualifying benefits such as environmental benefits and avoided damages from flooding and erosion. This is set out in the Environment Agency's Partnership Funding Calculator (Environment Agency, 2014b).

The process for applying for GiA funding for SMPs would require a detailed assessment of the economic impacts (costs and benefits) of schemes for individual policy units. The current economic evidence from SMP documents does not lend itself to the level of detail and rigour required for such an assessment. This is compounded by the fact that SMPs do not cover the extent of environmental impacts from preferred policies. For this reason, it is not possible to evaluate the extent of SMP costs which could be funded via GiA funding, based on existing evidence.

Step 5 - Conducting sensitivity analysis

Sensitivity testing helps determine the circumstances under which the benefits of a policy outweigh costs, or vice versa. This helps establish the validity of results in the presence of data gaps and uncertainty. In practice, this can include using ranges of values for key variables, expected values as well as threshold and switching values to establish instances which can cause the CBA decision criteria to change.

Step 6 - Considering distributional impacts

CBA is concerned with economic efficiency considerations in decision-making. However, it is also important to consider the distributional impacts of a policy, assessing how benefits and costs are spread geographically, across different socio-economic groups and generations. Explicit weighting of costs and/or benefits for the purposes of addressing distributional issues has not been undertaken in the analysis presented here. This

[5] Notably that economic evidence does not play a central role in the selection of preferred policies in SMPs, and that estimates tend to overstate the benefits of SMPs.

aspect may, however, be considered as part of coastal adaptation planning alongside other social and political considerations.

3.3 Costs of implementing SMPs

The costs of implementing SMPs are based on estimates provided in the SMP documents themselves and build on analysis from the study by Halcrow (2011). A combination of capital and maintenance costs are provided to reflect a range of measures such as defences, seawalls, groynes, revetments, embankments and beach management measures. Costs estimates are adjusted for optimism bias[6] and the impact of climate change in terms of sea level rise as per the guidance for producing SMPs (Defra, 2006). Appendix F provides more information on the factors applied.

Table 3.1 shows the breakdown of costs in present value terms (over 100 years) by Epoch, across different types of policies. Within each Epoch, the cost of implementing SMPs is less than £5 million in present value terms for the majority of PUs. There are two PUs with costs that exceed £100 million in present value terms over 100 years. They have with high capital and/or maintenance costs linked to investments in existing defences, as stated in their respective SMP documents. Across all three Epochs, the most common policy for PUs is HTL with 47% - 56% of PUs having this policy. This followed by MR with 11% - 16% of PU having this policy. This is reflected in Figure 3.1 which maps the costs of implementing policies for all policy units in Epoch 1. Similar maps are provided for Epoch 2 and Epoch 3 in Appendix G.

summarises the magnitude of costs for each SMP by Epoch. The costs are highest in Epoch 2 followed by Epoch 1 and Epoch 3 respectively. The present value cost of implementing SMPs in Epoch 1 is nearly £3 billion in 2011 prices. The magnitude of these costs raises the question of the extent of recent funding available to implement SMPs. Priestly (2017) and Defra (2017) estimate total expenditure on flood and coastal erosion risk management (FCERM) for the period 2005 – 2017 to be around £8 billion in 2011 prices. Expenditure on FCERM goes toward multiple sources including managing coastal, fluvial, surface water and groundwater sources of flood risk. This would suggest a likely gap in the funding available to implement SMPs within Epoch 1. Table 3.3 presents the magnitude of costs at the regional level by type of policy and Epoch. The policy of HTL is the most costly across all Epochs, accounting for 80% - 90% of the total cost in each Epoch. This is followed by MR which accounts for 6% - 15% of the total cost per Epoch. The results also indicate that across Epochs, the present value cost of HTL is between five and fourteen times the cost of MR.

The total cost of implementing the policies set out in SMPs across the full 100-year timescale is estimated to be nearly £8 billion in present value terms. This is considerably less than the estimated cash value of costs reported in Halcrow (2011) which amounts to nearly £21 billion for England. Both estimates use data from SMP documents as a starting point but differ in their assumptions. For example, this study discounts all costs to present value whereas the Halcrow study ‘un-discounts’ present value costs to present them as cash values using a different approach. This study considers the spread of costs over PUs and their split and profile over time in terms of annual maintenance and one-off capital costs. The Halcrow study focused on reporting an overall national average. Applying the assumptions from the Halcrow study here, would produce comparable results. Overall, the difference between the two estimates demonstrates the inherent uncertainty in the data in SMP documents and its sensitivity to different assumptions and applications.

[6] Optimism bias is the proven tendency for appraisers to be over-optimistic about key project parameters, including capital costs, operating costs, project duration and benefits delivery (Green Book, 2018)

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Table 3.1: Summary of distribution of costs of implementing SMPs (number of policy units)

Present value cost range (100 years)	Number of policy units														
	Epoch 1 (2005 – 2025)					Epoch 2 (2025 – 2055)					Epoch 3 (2055 – 2105)				
	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total
£0m - £5m	510	774	159	2	1,445	534	627	227	-	1,388	558	662	238	4	1,462
£6m - £20m	3	57	6	-	66	6	89	15	-	110	12	45	5	-	62
£21m - £50m	1	13	1	-	15	1	27	1	-	29	-	5	-	1	6
£51m - £100m	-	5	-	-	5	-	1	3	-	4	-	1	-	-	1
£101 - £370m	-	2	-	-	2	-	2	-	-	2	-	2	-	-	2
Total (England)	**514**	**851**	**166**	**2**	**1,533**	**541**	**746**	**246**	**-**	**1,533**	**570**	**715**	**243**	**5**	**1,533**

Table 3.2: Cost of implementing SMPs (£m, present value 100 years)

SMP	No. PUs	Length (km)	Epoch 1 (2005 – 2025)						Epoch 2 (2025 - 2050)						Epoch 3 (2055 - 2105)					
			Policy scenarios in SMP (% of policy units)					PVC (£m)	Policy scenarios in SMP (% of policy units)					PVC (£m)	Policy scenarios in SMP (% of policy units)					PVC (£m)
			NAI	HTL	MR	ATL	Total		NAI	HTL	MR	ATL	Total		NAI	HTL	MR	ATL	Total	
SMP 1 - Scottish Border to the Tyne	101	180	37%	46%	18%	-	100%	9	37%	46%	18%	-	100%	16	37%	41%	23%	-	100%	24
SMP 2 - The Tyne to Flamborough Head	98	197	41%	49%	10%	-	100%	217	41%	46%	13%	-	100%	25	43%	45%	12%	-	100%	14
SMP 3 - Flamborough Head to Gibraltar Point	16	201	38%	56%	6%	-	100%	121	38%	56%	6%	-	100%	354	38%	56%	6%	-	100%	503
SMP 4 - Gibraltar Point to Hunstanton	4	104	25%	75%	-	-	100%	21	25%	75%	0%	-	100%	66	0%	100%	-	-	100%	47
SMP 5 - Hunstanton to Kelling Hard	32	75	16%	69%	16%	-	100%	14	16%	63%	22%	-	100%	108	16%	66%	19%	-	100%	19
SMP 6 - Kelling Hard to Lowestoft	24	80	4%	58%	38%	-	100%	38	33%	42%	25%	-	100%	12	33%	25%	42%	-	100%	4
SMP 7 - Lowestoft Ness to Felixstowe	66	126	21%	58%	21%	-	100%	78	23%	52%	26%	-	100%	45	24%	50%	26%	-	100%	189
SMP 8 - Felixstowe to Two Tree Island	102	529	8%	78%	12%	2%	100%	39	8%	68%	25%	-	100%	544	10%	74%	17%	-	100%	88
SMP 9 - Medway & Swale	30	187	13%	70%	17%	-	100%	135	17%	63%	20%	-	100%	264	17%	63%	20%	-	100%	64
SMP 10 - Isle of Grain to South Foreland	27	112	19%	78%	4%	-	100%	35	19%	70%	11%	-	100%	203	19%	67%	15%	-	100%	114
SMP 11 - South Foreland to Beachy Head	30	108	27%	67%	7%	-	100%	159	27%	67%	7%	-	100%	79	27%	57%	17%	-	100%	55
SMP 12 - Beachy Head to Selsey Bill	27	47	11%	70%	19%	-	100%	39	15%	70%	15%	-	100%	90	15%	59%	26%	-	100%	41
SMP 13 - Selsey Bill to Hurst Spit	62	367	15%	81%	5%	-	100%	902	13%	84%	3%	-	100%	446	19%	79%	2%	-	100%	110
SMP 14 - Isle of Wight	61	157	44%	52%	3%	-	100%	16	49%	46%	5%	-	100%	38	52%	36%	11%	-	100%	72
SMP 15 - Hurst Spit to Durlston Head	57	129	21%	58%	21%	-	100%	53	23%	51%	26%	-	100%	65	23%	40%	28%	9%	100%	87
SMP 16 - Durlston Head to Rame Head	194	716	43%	51%	6%	-	100%	169	44%	46%	9%	-	100%	263	44%	47%	8%	-	100%	110
SMP 17 - Rame Head to Hartland Point	261	455	54%	37%	8%	-	100%	82	57%	25%	18%	-	100%	67	62%	22%	16%	-	100%	80
SMP 18 - Hartland Point to Anchor Head	91	311	36%	58%	5%	-	100%	162	42%	43%	15%	-	100%	81	43%	47%	10%	-	100%	57
SMP 19 - Anchor Head to Lavernock Point	48	269	33%	58%	8%	-	100%	45	33%	58%	8%	-	100%	29	33%	58%	8%	-	100%	2
SMP 22 - Northwest England	202	639	29%	58%	12%	-	100%	295	30%	50%	20%	-	100%	414	31%	49%	20%	-	100%	215
Total (England)	1,533	4,991	34%	56%	11%	0.1%	100%	2,630	35%	49%	16%	-	100%	3,208	37%	47%	16%	0.3%	100%	1,897

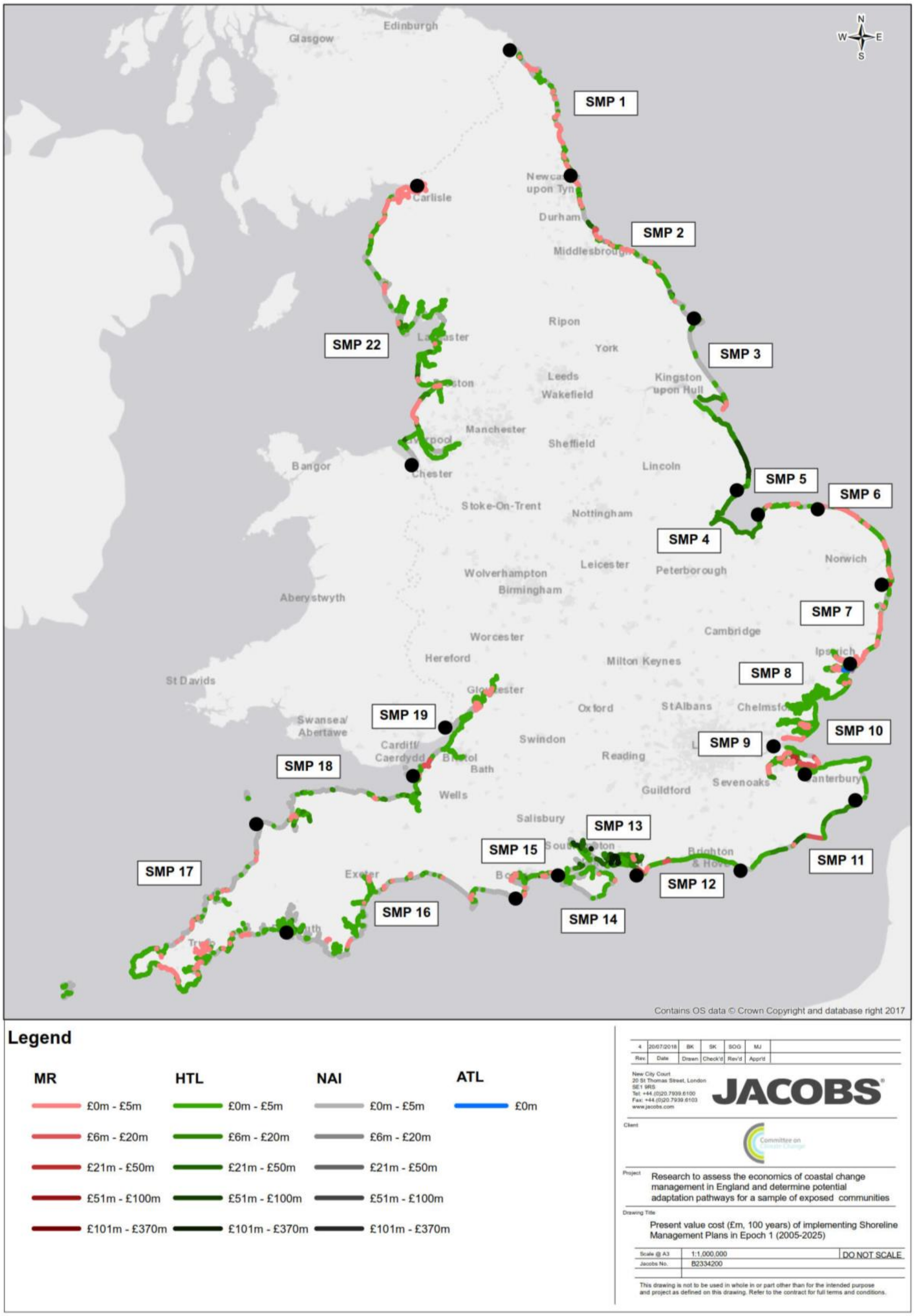
Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. PVC: present value cost.

Table 3.3: Regional summary of distribution of costs of implementing SMPs (£m, present value 100 years)

Region	Present value costs (£m, 100 years)														
	Epoch 1 (2005 – 2025)					Epoch 2 (2025 – 2055)					Epoch 3 (2055 – 2105)				
	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total
Anglian	6	177	7	-	190	5	486	284	-	775	24	292	30	-	347
Midlands	-	20	3	-	23	-	10	4	-	14	-	1	0.4	-	1
North East	35	307	4	-	346	26	361	7	-	394	31	508	3	-	541
North West	2	282	10	-	295	3	356	55	-	414	1	180	34	-	215
South West	57	398	26	-	481	93	328	68	-	488	90	179	28	34	331
Southern	18	1,163	114	-	1,295	29	1,040	54	-	1,123	51	368	42	-	461
Total (England)	**119**	**2,348**	**164**	**-**	**2,630**	**155**	**2,580**	**472**	**-**	**3,208**	**198**	**1,528**	**137**	**34**	**1,897**

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book.

Figure 3.1: Map of costs of implementing SMPs in Epoch 1 (£m, present value 100 years)



3.4 Benefits of implementing SMPs

The benefits of implementing SMPs are based on estimating the avoided damages to properties from flooding and delayed damages of the impact of erosion as follows:

1. **Avoided damages to properties from coastal flooding:** Weighted average annual damages (WAADs) to properties were derived for each of the 20 SMPs in scope, following the method outlined in Penning-Roswell et al. (2017) using:
   - The Environment Agency's National Receptor Dataset for 2014, a more recent version than the one used in SMPs;
   - The Environment Agency's flood zone maps to determine the number of properties in different flood zones (e.g. with a 1:200 or 1:1,000 risk of flooding); and
   - Average damage estimates from Penning-Roswell et al. (2017)

   WAADs are estimated at the SMP level and reflect the damages that would be incurred in the NAI scenario[7]. To use them in the CBA, they should be linked to policy scenarios (e.g. NAI, HTL, MR, ATL) which are specified at the PU level. Estimates are therefore scaled down to the PU level using the length of PUs that is flood prone as a proportion of the total length of the SMP in which they are located. The separation of the length of PUs that is flood prone versus at risk of erosion is achieved using data from the National Coastal Erosion Risk Mapping (NCERM)[8].

   The estimation of avoided damages using WAADs considers the sequence of policies over all Epochs for each PU rather than each policy in isolation. This takes into account of the possibility that the benefits of a policy that occurs in one Epoch could extend to future Epochs. For example, the sequence of policies for a PU can be HTL/HTL/MR, moving from Epoch 1 to Epoch 3. The benefits in this case are the difference between damages in the do-nothing scenario (WAAD for properties with a 1:1,000 risk of flooding) and the residual risk to properties in the policy scenario. In Epoch 1 and Epoch 2 there is a residual risk to properties with less than a 1:200 risk of flooding. In Epoch 3 there is a residual risk to properties with a 1:2 risk of flooding which will be damaged following managed realignment. These properties are written off at their market value. The treatment of MR assumes that properties with a less than 1:2 chance of flooding are left better protected by the creation of new habitat created which provides flood risk attenuation benefits.

   There are over 20 sequences of policies over the three Epoch for the PUs within the scope of this study. Appendix F details how the benefits of avoided damages from flooding are estimated for each sequence.

   In addition to direct damages, indirect damages are also accounted for by upscaling direct damages following the approach in Environment Agency (2014) and Sayers (2015). This accounts for:
   - An uplift to property damages estimated due to using WAADs instead of flood depths;
   - Risk to life (deaths and stress);
   - Temporary accommodation;
   - Impacts on vehicles;
   - Impacts on emergency services;
   - Impacts to local Government;
   - Impacts on agriculture;
   - Impacts on transport; and

[7] Estimating WAADs at the PU level is beyond the scope of the study as it would require defining over 1,500 PUs as polygons in GIS to ascribe properties at risk of flooding to each polygon without overlaps.

[8] Alternative approaches to scaling down WAADs, such as overlaying PUs with the Environment Agency flood zone maps or using population density, are beyond the scope of this study.

- Impacts on utilities.

2. **Delayed damages to properties from the impact coastal erosion:** This is based on estimating the asset value of properties in the NAI scenario versus a scenario with coastal protection (i.e. where the policies in SMPs are implemented). The number of properties at risk of erosion is estimated in Part I of the study and reported in Section 2. This consists of properties at risk of erosion in the NAI scenario and properties at risk when the net impact of implementing SMP policies is taken into account. The asset value of properties with and without coastal protection is estimated following the method outlined in Penning-Roswell et al. (2017). This requires assumptions about the lifetime of properties without coastal protection and the lifetime of coastal protection projects and policies, reported in Appendix F. Where using this approach generates benefits that exceed the market value of properties at risk of erosion, the benefits are capped to the market value of properties.

   The benefits of delayed damages from the impact of coastal erosion are presented at the SMP level. They are summed with the benefits of avoided damages from flooding, in (2) above, at the SMP level as this is their common unit of analysis. At the national level, properties which are at risk of flooding are generally not also at risk of erosion so summing the two benefits estimates does not constitute double-counting.

Table 3.4 shows the breakdown of benefits of avoided damages from flooding in present value terms (over 100 years) by Epoch, across different types of policies. As with the costs, the benefits of avoided damages from flooding as a result of implementing SMPs within each Epoch are less than £5 million in present value terms for the majority of policy units. Table 3.5 summarises the magnitude of the benefits of avoided damages from flooding at the SMP level and by Epoch. The benefits are highest in Epoch 1 followed by Epoch 2 and Epoch 3 respectively.

Table 3.6 summarises the magnitude of the benefits of avoided damages from flooding at the regional level by type of policy and Epoch. The results indicate that the proportion of benefits for HTL falls from 90% to 83% of total benefits in moving from Epoch 1 to Epoch 3. Conversely the benefits of MR increase from 9% to 16% of total benefits in moving from Epoch 1 to Epoch 3. However, the policy of HTL has the highest benefits across all Epochs. This result is fundamentally influenced by the scope of the CBA which does not include environmental benefits e.g. from habitat creation under managed realignment (MR). These benefits are discussed in three of the six case studies where habitat creation is possible in the case of managed realignment. The benefits of MR should be assessed on a case-by-case basis as not all polices lead to new habitat creation and therefore net environmental gain. In practice, this will depend on local conditions such as:

1. The shape of the existing landscape and coast;
2. The type of existing habitat(s);
3. How far the coast is realigned; and
4. The type of new habitat that could be created.

Alongside the benefits of avoided damages from flooding, the study also assesses the benefits of delayed damages from erosion. These are the benefits to properties better protected from the risk of erosion due to the implementation of policies in SMPs. In their most disaggregated form, the results can be presented at the SMP level as shown in Table 3.7. The benefits of delayed erosion are estimated to be over £900 million in Epoch 1 in present value terms. They more than double in Epoch 2 to £2 billion in present value terms and fall to around £1 billion in Epoch 3. In general, the proportion of benefits due to delayed damages of erosion increases over time from 26% of total benefits in Epoch 1 to around 55% in Epoch 2 and Epoch 3 respectively. This is due to the rising number of properties at risk of erosion over the next century, as reported in Section 2. The results also indicate that across all Epochs, SMP 11 and SMP 12 have the highest benefits of delayed erosion.

Table 3.4: Summary of distribution of benefits of avoided damages from flooding as a result of implementing SMPs (number of policy units)

Present value benefit range (100 years)	Number of policy units														
	Epoch 1 (2005 – 2025)					Epoch 2 (2025 – 2055)					Epoch 3 (2055 – 2105)				
	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total	NAI	HTL	MR	ATL	Total
£0m - £5m	514	781	157	2	1,454	540	681	233	-	1,454	568	652	229	5	1,454
£6m - £20m	-	61	6	-	67	1	57	9	-	67	2	55	10	-	67
£21m - £50m	-	7	3	-	10	-	6	4	-	10	-	6	4	-	10
£51m - £100m	-	1	-	-	1	-	1	-	-	1	-	1	-	-	1
£101 - £700m	-	1	-	-	1	-	1	-	-	1	-	1	-	-	1
Total (England)	**514**	**851**	**166**	**2**	**1,533**	**541**	**746**	**246**	**-**	**1,533**	**570**	**715**	**243**	**5**	**1,533**

Table 3.5: Benefits of avoided damages of flooding as a result of implementing SMPs (£m, present value 100 years)

SMP	No. PUs	Length (km)	Benefits of avoided damages from flooding (£m, PV 100 years)		
			Epoch 1 (2005-2025)	Epoch 2 (2025-2050)	Epoch 3 (2050-2105)
SMP 1 - Scottish Border to the Tyne	101	180	2	1	1
SMP 2 - The Tyne to Flamborough Head	98	197	6	5	2
SMP 3 - Flamborough Head to Gibraltar Point	16	201	148	99	54
SMP 4 - Gibraltar Point to Hunstanton	4	104	781	520	288
SMP 5 - Hunstanton to Kelling Hard	32	75	36	29	16
SMP 6 - Kelling Hard to Lowestoft	24	80	52	26	14
SMP 7 - Lowestoft Ness to Felixstowe	66	126	38	26	13
SMP 8 - Felixstowe to Two Tree Island	102	529	230	154	85
SMP 9 - Medway & Swale	30	187	302	206	113
SMP 10 - Isle of Grain to South Foreland	27	112	188	123	69
SMP 11 - South Foreland to Beachy Head	30	108	54	37	20
SMP 12 - Beachy Head to Selsey Bill	27	47	31	20	11

SMP	No. PUs	Length (km)	Benefits of avoided damages from flooding (£m, PV 100 years)		
			Epoch 1 (2005-2025)	Epoch 2 (2025-2050)	Epoch 3 (2050-2105)
SMP 13 - Selsey Bill to Hurst Spit	62	367	89	60	31
SMP 14 - Isle of Wight	61	157	9	6	3
SMP 15 - Hurst Spit to Durlston Head	57	129	26	17	10
SMP 16 - Durlston Head to Rame Head	194	716	51	35	19
SMP 17 - Rame Head to Hartland Point	261	455	1	1	1
SMP 18 - Hartland Point to Anchor Head	91	311	81	52	28
SMP 19 - Anchor Head to Lavernock Point	48	269	314	212	116
SMP 22 - Northwest England	202	639	186	123	65
Total (England)	1,533	4,991	2,625	1,750	958

Table 3.6: Regional summary of distribution of benefits of avoided damages of flooding as a result of implementing SMPs (£m, present value 100 years)

Region	Present value benefits (£m, 100 years)														
	Epoch 1 (2005 – 2025)					Epoch 2 (2025 – 2055)					Epoch 3 (2055 – 2105)				
	NAI	HTL	MR	ATL	Total	NAI*	HTL	MR	ATL	Total	NAI*	HTL	MR	ATL	Total
Anglian	-	1,083	48	6	1,136	1	704	50	-	755	1	382	34	-	417
Midlands	-	143	35	-	179	-	97	24	-	121	-	51	16	-	67
North East	-	147	9	-	156	-	98	7	-	104	-	53	4	-	57
North West	-	157	29	-	186	-	80	42	-	123	-	40	25	-	65
South West	-	253	39	-	292	-	158	37	-	194	-	86	18	2	106
Southern	-	587	89	-	676	1	353	98	-	453	1	186	61	-	248
Total (England)	**-**	**2,370**	**249**	**6**	**2,625**	**2**	**1,490**	**259**	**-**	**1,750**	**2**	**797**	**157**	**2**	**958**

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. *The benefits of NAI relate to policy units where the sequence of policies over Epochs is MR/MR/NAI. In this case, the residual damages in Epoch 3, where NAI is the policy, will be lower than if MR did not occur. The avoided damages will therefore be positive.

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Table 3.7: Benefits of delayed damages from the impact of erosion as a result of implementing SMPs (£m, present value 100 years)

SMP	No. PUs	Length (km)	Benefits of delayed damages from erosion (£m, PV 100 years)		
			Epoch 1 (2005 - 2025)	Epoch 2 (2025 - 2050)	Epoch 3 (2050 -2105)
SMP 1 - Scottish Border to the Tyne	101	180	20	25	18
SMP 2 - The Tyne to Flamborough Head	98	197	24	78	39
SMP 3 - Flamborough Head to Gibraltar Point	16	201	17	59	40
SMP 4 - Gibraltar Point to Hunstanton	4	104	0.4	-	3
SMP 5 - Hunstanton to Kelling Hard	32	75	-	0.3	1
SMP 6 - Kelling Hard to Lowestoft	24	80	1	57	53
SMP 7 - Lowestoft Ness to Felixstowe	66	126	21	151	72
SMP 8 - Felixstowe to Two Tree Island	102	529	93	293	60
SMP 9 - Medway & Swale	30	187	12	3	5
SMP 10 - Isle of Grain to South Foreland	27	112	9	28	17
SMP 11 - South Foreland to Beachy Head	30	108	211	322	202
SMP 12 - Beachy Head to Selsey Bill	27	47	235	356	291
SMP 13 - Selsey Bill to Hurst Spit	62	367	64	209	72
SMP 14 - Isle of Wight	61	157	15	48	14
SMP 15 - Hurst Spit to Durlston Head	57	129	60	208	93
SMP 16 - Durlston Head to Rame Head	194	716	26	40	19
SMP 17 - Rame Head to Hartland Point	261	455	43	148	66
SMP 18 - Hartland Point to Anchor Head	91	311	17	28	13
SMP 19 - Anchor Head to Lavernock Point	48	269	-	0.4	0.2
SMP 22 - Northwest England	202	639	57	55	69
Total (England)	**1,533**	**4,991**	**926**	**2,109**	**1,147**

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book.

3.5 Cost-benefit analysis results

The cost and benefits detailed above are compared to generate results for the national CBA of the policies set out in SMPs. The full set of results is available in the CBA tool for the study which is provided as a separate workbook. The following highlights some of the key results from the CBA. Note that a benefit-cost ratio and net present value are only reported for the full 100-year timescale, rather than for each Epoch, to account for the possibility of the benefits of one policy in an Epoch continuing into future Epochs.

Table 3.8 presents the CBA results broken down by the 21 different sequences of policy scenarios over PUs and Epochs. As mentioned above, most PUs have a policy of HTL across all three epochs at the national level. This is denoted by HTL/HTL/HTL in Table 3.8. It is useful to consider the top six policy sequences in Table 3.8 as they cover 92% of PUs and 95% of the length of the coast, and therefore drive the overall CBA results. At the national level and over the full 100-year timescale, the avoided damages of flooding per km of PUs with a policy sequence across Epochs of HTL/HTL/HTL and HTL/MR/MR are the highest. The costs per km are highest for HTL/HTL/HTL and HTL/MR/HTL.

Due to limitations mentioned above, it is not possible to present the benefits of delayed damages from erosion across the policy sequences in Table 3.8 in a way which is comparable to the benefits of avoided damages to flooding. It is useful to compare the cost of policies to the benefit of avoided damages of flooding. Excluding the benefits delayed damages from erosion, the benefits of avoided damages from flooding for PUs with a policy of MR/MR/MR outweigh the costs across all three Epochs. For HTL/HTL/HTL this only holds for Epoch 1. This result would change if the benefits of delayed damages from the impacts of erosion were included as they drive the overall benefits in Epoch 2 and 3.

Across all PUs, policies and Epochs, the benefits of implementing SMP policies outweigh the costs, with a net benefit of nearly £2 billion over 100 years. This result is maintained for most SMPs, as shown in Table 3.9. The total length of SMPs where intervention is not cost-effective is estimated to be 2,664 km which makes up around 53% of the total length of the coast.

In general, these results should be interpreted with caution given the inherent uncertainties of the estimated costs of SMPs and the different scales at which the benefits of avoided damages of flooding and delayed damages of erosion are estimated.

Table 3.8: CBA results by policy scenario sequence and Epoch (£m, present value 100 years)

Policy scenario sequence[1]	No. PUs	Length (km)	Epoch 1 (2005 – 2025)				Epoch 2 (2025 – 2055)				Epoch 3 (2055 – 2105)				Overall (2005 – 2105)					
			Present value 100 years (£m)				Present value 100 years (£m)				Present value 100 years (£m)				BCR	Present value 100 years (£m)				
			Avoided damages of flooding	Delayed damages of erosion[2]	Total PVB	PVC	Avoided damages of flooding	Delayed damages of erosion[2]	Total PVB	PVC	Avoided damages of flooding	Delayed damages of erosion[2]	Total PVB	PVC		NPV	Avoided damages of flooding	Delayed damages of erosion[2]	Total PVB	PVC
HTL/HTL/HTL	647	2,390	2,072	-	-	1,925	1,378	-	-	2,374	749	-	-	1,453	-	-	4,200	-	-	5,753
NAI/NAI/NAI	499	1,575	-	-	-	117	-	-	-	148	-	-	-	174	-	-	-	-	-	439
MR/MR/MR	108	315	170	-	-	125	137	-	-	71	75	-	-	45	-	-	382	-	-	240
HTL/HTL/MR	64	206	98	-	-	82	65	-	-	125	35	-	-	56	-	-	198	-	-	263
HTL/MR/MR	58	164	121	-	-	67	78	-	-	89	47	-	-	33	-	-	246	-	-	189
HTL/MR/HTL	40	111	54	-	-	44	32	-	-	299	21	-	-	62	-	-	106	-	-	405
HTL/NAI/NAI	20	18	6	-	-	5	-	-	-	6	-	-	-	13	-	-	6	-	-	24
MR/NAI/NAI	17	36	25	-	-	2	2	-	-	0.1	1	-	-	-	-	-	29	-	-	3
MR/HTL/HTL	16	63	47	-	-	33	35	-	-	39	19	-	-	5	-	-	101	-	-	78
MR/MR/NAI	17	19	3	-	-	-	3	-	-	1	0.2	-	-	1	-	-	6	-	-	2
HTL/HTL/ATL	5	13	4	-	-	30	3	-	-	24	2	-	-	34	-	-	9	-	-	88
HTL/HTL/NAI	9	15	4	-	-	189	3	-	-	12	-	-	-	4	-	-	7	-	-	206
HTL/MR/NAI	8	26	10	-	-	5	6	-	-	4	-	-	-	5	-	-	17	-	-	14
NAI/MR/MR	7	8	-	-	-	0.1	1	-	-	5	1	-	-	0.4	-	-	1	-	-	5
MR/MR/HTL	6	6	2	-	-	0.1	1	-	-	0.1	1	-	-	0.4	-	-	4	-	-	1
NAI/NAI/MR	4	6	-	-	-	1	-	-	-	1	0.5	-	-	1	-	-	0.5	-	-	4
ATL/HTL/HTL	2	11	6	-	-	-	4	-	-	3	2	-	-	1	-	-	11	-	-	4
MR/HTL/MR	2	4	2	-	-	3	1	-	-	3	1	-	-	2	-	-	4	-	-	8
NAI/MR/HTL	2	3	-	-	-	0.1	1	-	-	4	0.4	-	-	0.2	-	-	1	-	-	4
NAI/HTL/HTL	1	0.2	-	-	-	1	0.1	-	-	0.4	0.03	-	-	0.2	-	-	0.1	-	-	1
NAI/NAI/HTL	1	2	-	-	-	-	-	-	-	-	5	-	-	5	-	-	5	-	-	5
Total (England)	1,533	4,991	2,625	926	3,551	2,630	1,750	2,109	3,859	3,208	958	1,147	2,105	1,897	1.2	1,781	5,334	4,182	9,515	7,735

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. PVB: present value benefits. PVC: present value costs. BCR: benefit-cost ratio. NPV: net present value. [1]This denotes the sequence of policies across Epochs. For example, HTL/MR/MR denotes PUs where HTL is the policy in Epoch 1 followed by MR in Epoch 2 and Epoch 3. [2]The benefits of delayed damages to properties at risk of erosion are calculated at the SMP level and cannot be disaggregated in this table. This is why only a national estimate is presented for each Epoch and the overall timescale.

Table 3.9: CBA results by SMP and Epoch (£m, present value 100 years)

SMP	Epoch 1 (2005 – 2025)				Epoch 2 (2025 – 2055)				Epoch 3 (2055 – 2105)				Overall (2005 – 2105)					
	Present value 100 years (£m)				Present value 100 years (£m)				Present value 100 years (£m)				BCR	Present value 100 years (£m)				
	Avoided damages of flooding	Delayed damages of erosion	Avoided damages of flooding	PVC	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC		NPV	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC
SMP 1 - Scottish Border to the Tyne	2	20	22	9	1	25	26	16	1	18	18	24	1.4	18	4	62	67	49
SMP 2 - The Tyne to Flamborough Head	6	24	31	217	5	78	83	25	2	39	41	14	0.6	-101	13	141	155	256
SMP 3 - Flamborough Head to Gibraltar Point	148	17	164	121	99	59	158	354	54	40	94	503	0.4	-562	300	116	416	978
SMP 4 - Gibraltar Point to Hunstanton	781	0.4	782	21	520	-	520	66	288	2.7	290	47	11.8	1,457	1,588	3	1,592	134
SMP 5 - Hunstanton to Kelling Hard	36	-	36	14	29	0.3	29	108	16	1	17	19	0.6	-59	81	1	82	141
SMP 6 - Kelling Hard to Lowestoft	52	1	53	38	26	57	83	12	14	53	67	4	3.7	148	92	111	203	54
SMP 7 - Lowestoft Ness to Felixstowe	38	21	59	78	26	151	178	45	13	72	85	189	1.0	9	77	244	322	312
SMP 8 - Felixstowe to Two Tree Island	230	93	324	39	154	293	447	544	85	60	145	88	1.4	246	469	446	916	670
SMP 9 - Medway & Swale	302	12	314	135	206	3	209	264	113	5	117	64	1.4	177	621	20	641	463
SMP 10 - Isle of Grain to South Foreland	188	9	197	35	123	28	151	203	69	17	86	114	1.2	81	380	53	433	353
SMP 11 - South Foreland to Beachy Head	54	211	265	159	37	322	358	79	20	202	222	55	2.9	552	111	734	845	293
SMP 12 - Beachy Head to Selsey Bill	31	235	265	39	20	356	376	90	11	291	301	41	5.5	772	61	881	942	170
SMP 13 - Selsey Bill to Hurst Spit	89	64	153	902	60	209	268	446	31	72	104	110	0.4	-933	180	346	525	1,458
SMP 14 - Isle of Wight	9	15	24	16	6	48	54	38	3	14	17	72	0.8	-31	18	78	96	127
SMP 15 - Hurst Spit to Durlston Head	26	60	86	53	17	208	225	65	10	93	103	87	2.0	209	53	362	415	206
SMP 16 - Durlston Head to Rame Head	51	26	77	169	35	40	75	263	19	19	38	110	0.3	-353	105	84	189	542
SMP 17 - Rame Head to Hartland Point	1	43	45	82	1	148	149	67	1	66	67	80	1.1	32	3	258	261	229
SMP 18 - Hartland Point to Anchor Head	81	17	98	162	52	28	81	81	28	13	42	57	0.7	-81	162	58	220	301
SMP 19 - Anchor Head to Lavernock Point	314	-	314	45	212	0.4	213	29	116	0.2	116	2	8.5	568	643	1	643	76
SMP 22 - Northwest England	186	57	243	295	123	55	178	414	65	69	134	215	0.6	-370	373	181	554	924
Total (England)	2,625	926	3,551	2,630	1,750	2,109	3,859	3,208	958	1,147	2,105	1,897	1.2	1,781	5,334	4,182	9,515	7,735

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. PVB: present value benefits. PVC: present value costs. BCR: benefit-cost ratio. NPV: net present value.

3.6 Sensitivity testing

Sensitivity testing of the CBA results presented in Section 3.5 was completed in order to test three aspects of the analysis:

- The impact of climate change on the costs of implementing SMPs;
- The impact of upper and lower estimates of erosion; and
- Environmental benefits of habitat creation under managed realignment.

3.6.1 Impacts of climate change

As mentioned in Section 3.3, the capital and maintenance costs of SMP policies are uplifted to account for the impact of climate change on coastal adaptation measures, based on the guidance by Defra (2006). The factors used reflect the need to strengthen and widen existing defences due to changes in sea level rise (an average of 1-2 mm per year based on IPCC (2002)).

The sensitivity testing looks at the impact of lower or higher factors on the costs of SMPs, as shown in Table 3.10. The base case reflects the factors cited in the SMP guidance (Defra, 2006) based on the Defra National Appraisal of Defence Needs and Costs (NADNAC) study. The low and high scenario factors are based on sensitivity testing of the factors in the NADNAC study.

Table 3.10: Uplift factors applied to adjust cost of SMPs for sea level rise

Epoch	Low climate change scenario	Base case (adopted in SMPs)	High climate change scenario
Epoch 1 (2005 – 2025)	x 1.0	x 1.0	x 1.0
Epoch 2 (2025 – 2055)	x 1.3	x 1.5	x 2.0
Epoch 3 (2055 -2105)	x 1.5	x 2.0	x 3.0

Table 3.11 provides a breakdown of the CBA results by SMP across all three Epochs (2005 – 2105) in the low and high climate change scenarios i.e. where costs are uplifted by less than and more than the base case of the CBA respectively. This results in a range from £7 billion to £10 billion for the overall costs of coastal adaptation. As expected, at the national level, this sensitivity test produces a higher net benefit in the low climate change scenario and conversely a net cost in the high climate change scenario. In the base case of the CBA (Table 3.9), eight SMPs present a net cost (NPV < 0) based on the comparison of the benefits to the cost of implementing their policies. In the low climate change scenario, those SMPs still present a net cost despite lower cost estimates. In the high scenario, three SMPs (7, 10 and 17) switch to having a net cost associated with their implementation, in addition to the eight SMPs in the base case. Based on the low and high climate change scenarios, the total length of SMPs where intervention is not cost-effective is estimated to be between 2,664 km and 3,358 km which makes up between 53% and 67% of the total length of the coast.

Overall, the sensitivity test illustrates the fact that SMPs with a net cost in the base case are unlikely to switch to having a net benefit under alternative assumptions regarding the impact of climate change on their costs. SMPs with a borderline BCR are however sensitive to these alternative assumptions. At the national level, the costs of SMPs outweigh the benefits in a high climate change scenario. It is recommended that the method for adjusting the costs of SMPs is refined and updated to use upcoming UK Climate Projections for 2018 (UKCP18) in future SMP reviews.

Table 3.11: CBA results by SMP in low and high climate change scenarios (100-year time horizon)*

SMP	Low climate change scenario (2005 – 2105)						High climate change scenario (2005 – 2105)					
		Present value 100 years (£m)						Present value 100 years (£m)				
	BCR	NPV	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC	BCR	NPV	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC
SMP 1 - Scottish Border to the Tyne	1.6	26	4	62	67	40	1.01	1	4	62	67	66
SMP 2 - The Tyne to Flamborough Head	0.6	-94	13	141	155	249	0.6	-116	13	141	155	271
SMP 3 - Flamborough Head to Gibraltar Point	0.5	-389	300	116	416	805	0.3	-931	300	116	416	1,347
SMP 4 - Gibraltar Point to Hunstanton	14.0	1,478	1,588	3	1,592	114	8.8	1,412	1,588	3	1,592	180
SMP 5 - Hunstanton to Kelling Hard	0.7	-40	81	1	82	121	0.4	-105	81	1	82	186
SMP 6 - Kelling Hard to Lowestoft	3.9	151	92	111	203	52	3.3	142	92	111	203	61
SMP 7 - Lowestoft Ness to Felixstowe	1.2	63	77	244	322	259	0.8	-100	77	244	322	422
SMP 8 - Felixstowe to Two Tree Island	1.6	340	469	446	916	576	1.02	21	469	446	916	895
SMP 9 - Medway & Swale	1.6	229	621	20	641	412	1.1	57	621	20	641	584
SMP 10 - Isle of Grain to South Foreland	1.5	136	380	53	433	297	0.9	-44	380	53	433	477
SMP 11 - South Foreland to Beachy Head	3.1	576	111	734	845	269	2.4	498	111	734	845	347
SMP 12 - Beachy Head to Selsey Bill	6.4	795	61	881	942	148	4.3	722	61	881	942	220
SMP 13 - Selsey Bill to Hurst Spit	0.4	-846	180	346	525	1,372	0.3	-1,135	180	346	525	1,661
SMP 14 - Isle of Wight	0.9	-8	18	78	96	103	0.5	-80	18	78	96	175
SMP 15 - Hurst Spit to Durlston Head	2.4	240	53	362	415	175	1.5	144	53	362	415	271
SMP 16 - Durlston Head to Rame Head	0.4	-290	105	84	189	480	0.3	-495	105	84	189	685
SMP 17 - Rame Head to Hartland Point	1.3	61	3	258	261	200	0.9	-30	3	258	261	291
SMP 18 - Hartland Point to Anchor Head	0.8	-56	162	58	220	276	0.6	-136	162	58	220	356
SMP 19 - Anchor Head to Lavernock Point	9.0	572	643	1	643	71	7.4	557	643	1	643	87
SMP 22 - Northwest England	0.7	-273	373	181	554	827	0.5	-588	373	181	554	1,142
Total (England)	1.4	2,670	5,334	4,182	9,515	6,845	0.98	-208	5,334	4,182	9,515	9,724

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. PVB: present value benefits. PVC: present value costs. BCR: benefit-cost ratio. NPV: net present value.

3.6.2 Impacts of erosion

The CBA assesses the delayed damages from erosion using a mid-estimate for erosion. This section explores the impact of upper and lower estimates of erosion as follows:

- Upper estimate (based on the 5%-ile probability of occurrence; this represents the worse-case scenario over the next 100 years); and
- Lower estimate (based on the 95%-ile probability of occurrence; this represents the most-likely-case scenario over the next 100 years).

Table 3.12 presents the results by SMP and shows the benefits of delayed damages from erosion over 100 years range between £3 billion and £6 billion depending on the assumed probability of occurrence of erosion. This results in a range from £8 billion to £11 billion for the overall benefits of coastal adaptation including the avoided damages of flooding. In the base case of the CBA (Table 3.9), eight SMPs present a net cost based on the comparison of the benefits to the cost of implementing their policies. In the low erosion scenario where the benefits are lower (due to fewer properties being at risk of erosion), three additional SMPs (1, 7 and 17) present a net cost alongside those eight SMPs in the base case. In the high erosion scenario where the benefits are higher (due to more properties being at risk of erosion), SMP 14 switches to having net benefit compared to the base case where it had a net cost. Based on the upper and lower erosion scenarios, the total length of SMPs where intervention is not cost-effective is estimated to be between 2,507 km and 3,426 km which makes up between 50% and 69% of the total length of the coast.

Overall, the sensitivity test illustrates the fact that the comparison of costs and benefits for individual SMPs can be sensitive to assumptions regarding the probability of occurrence of erosion. This is particularly the case for SMPs 7 and 17 which also switch their CBA position in the sensitivity test for the impact of climate change on SMP costs above. However, at the national level, there is a net benefit from implementing SMP policies regardless of the assumptions for the probability of erosion.

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Table 3.12: CBA results by SMP with lower and upper erosion estimates (100-year time horizon)*

SMP	Lower estimate of properties at risk of erosion (2005 – 2105)						Upper estimate of properties at risk of erosion (2005 – 2105)					
	BCR	Present value 100 years (£m)					BCR	Present value 100 years (£m)				
		NPV	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC		NPV	Avoided damages of flooding	Delayed damages of erosion	Total PVB	PVC
SMP 1 - Scottish Border to the Tyne	0.9	-6	4	38	42	49	1.8	41	4	85	89	49
SMP 2 - The Tyne to Flamborough Head	0.4	-160	13	83	96	256	0.9	-33	13	209	222	256
SMP 3 - Flamborough Head to Gibraltar Point	0.4	-616	300	62	362	978	0.5	-515	300	163	463	978
SMP 4 - Gibraltar Point to Hunstanton	11.8	1,455	1,588	1	1,590	134	11.9	1,459	1,588	5	1,594	134
SMP 5 - Hunstanton to Kelling Hard	0.6	-60	81	0.4	81	141	0.6	-58	81	2	82	141
SMP 6 - Kelling Hard to Lowestoft	2.7	90	92	52	145	54	5.4	240	92	202	294	54
SMP 7 - Lowestoft Ness to Felixstowe	0.7	-85	77	150	227	312	1.5	145	77	380	458	312
SMP 8 - Felixstowe to Two Tree Island	1.2	167	469	368	837	670	1.6	407	469	608	1,077	670
SMP 9 - Medway & Swale	1.4	173	621	15	636	463	1.4	182	621	24	645	463
SMP 10 - Isle of Grain to South Foreland	1.2	57	380	30	410	353	1.3	114	380	87	467	353
SMP 11 - South Foreland to Beachy Head	1.9	275	111	457	568	293	3.8	822	111	1,005	1,115	293
SMP 12 - Beachy Head to Selsey Bill	3.6	438	61	548	608	170	7.7	1,143	61	1,252	1,313	170
SMP 13 - Selsey Bill to Hurst Spit	0.3	-1,058	180	220	400	1,458	0.4	-804	180	474	654	1,458
SMP 14 - Isle of Wight	0.5	-61	18	48	66	127	1.03	4	18	112	130	127
SMP 15 - Hurst Spit to Durlston Head	1.3	71	53	224	277	206	2.7	358	53	511	564	206
SMP 16 - Durlston Head to Rame Head	0.3	-376	105	61	166	542	0.4	-316	105	121	226	542
SMP 17 - Rame Head to Hartland Point	0.7	-66	3	160	163	229	1.6	142	3	368	371	229
SMP 18 - Hartland Point to Anchor Head	0.7	-95	162	44	206	301	0.8	-61	162	78	240	301
SMP 19 - Anchor Head to Lavernock Point	8.5	567	643	0.3	643	76	8.5	568	643	1	644	76
SMP 22 - Northwest England	0.5	-437	373	114	487	924	0.7	-300	373	251	624	924
Total (England)	1.04	274	5,334	2,676	8,009	7,735	1.5	3,537	5,334	5,938	11,272	7,735

Notes: All monetary values are expressed in 2011 prices and discounted to present value over a 100-year time horizon using a discount rate in accordance with the HM Treasury Green Book. PUs: policy units. BCR: benefit-cost ratio. NPV: net present value. PVB: present value benefits. PVC: present value costs

3.6.3 Environmental benefits

The consideration of environmental benefits is not included in the national CBA. The is because a robust assessment of net environmental benefits, as a result of interventions such as SMP policies, requires information of local data and characteristics. Given the scale of the national scope of the CBA, an assessment of these benefits has not been carried out.

In order to support the discussion of the role of environmental benefit in SMP policy decisions, they are investigated in three of the six case studies (see Section 4) where managed realignment could lead to habitat creation. These are as follows:

1. Location A: The combined potential inter-tidal habitat area that could be created is approximately 80 hectares (40 ha in each compartment). In addition to the environmental benefits of new mudflat creation, this would result in the loss of built assets and agricultural land, with associated costs. Economic evidence from the Environment Agency's Economic Valuation of Environmental Effects (EVEE) Handbook is used to value the total annual potential benefits at over £110,000 per year as a result of improved water quality, access to recreation, aesthetic value and biodiversity provided by the new habitat. In practice, it would take time for the habitat to establish itself and for the full annual benefits of £110,000 per year to be realised. It is uncertain what the net impact of managed realignment would be in cost-benefit terms, as this would also need to reflect any potential losses resulting from the loss of built assets and agricultural land.

2. Location B: It is assumed that realignment of defences along the length of SMP policy unit to create new habitat would occur between the present defence line and the railway line, excluding the area around the settlement itself. This would provide approximately 430 ha of inter-tidal habitat potentially. This would replace agricultural land with inter-tidal marsh, with associated costs. The total annual potential benefits are estimated at over £600,000 per year as a result of improved water quality, access to recreation, aesthetic value and biodiversity provided by the new habitat. In practice, it would take time for the habitat to establish itself and for the full annual benefits of £600,000 per year to be realised. It is uncertain what the net impact of managed realignment would be in cost-benefit terms given the potential scale of the costs of managed realignment.

- Location C: Managed realignment would require a breach in the boundary of a Nature Reserve and result in freshwater / brackish reedbed habitat changing into more inter-tidal marsh habitat. The maximum area of habitat achievable in this area would be under 50 Hectares. If this full extent is achievable, then further detailed investigation would be required to fully understand the direct and indirect effects of this change. Specifically, greater assessment of, the implications of realignment for surface water drainage; the flood risk to areas inland that drain into the landward areas of the Nature Reserve and discharges through the current defence line via outfalls.

  The existing freshwater/brackish reedbed already produces environmental benefits. Managed realignment would result in the replacement of existing habitat with inter-tidal marsh; which itself would produce benefits. Economic evidence suggests that the value per ha of freshwater wetland (inland marsh) creation is around £1,400 per ha in 2011 prices and is not materially different from the value of inter-tidal marsh. Therefore, habitat creation from managed realignment is not expected to yield a material net environmental benefit at this location. The net impact is expected to be an increase in costs at this location in Epoch 3.

Further information on these and other case studies is provided in Section 4.

These examples demonstrate that environmental impacts, particularly due to environmental improvements, are important impacts of the policies set out in SMPs, in particular where MR is the policy. For sites where MR is a proposed policy and the CBA results are not favourable (costs outweigh the benefits), it is worth investigating the potential for habitat creation to justify the costs of MR. It is important to note however that not all MR schemes will lead to habitat creation and that new habitat will not necessarily always result in a net positive change in the benefits, as shown in the example for Location C.

4. Part III - Case studies of coastal adaptation pathways

This section provides an overview of the approach to select and develop the case studies for areas with coastal challenges. It also provides a summary of the key conclusions and lessons learnt from the case studies overall.

4.1 Case study selection

Part III of the study aims to develop potential adaptation pathways for a selection of exposed coastal communities in England. The approach first establishes criteria to identify ten locations in England with coastal adaptation challenges this century, and then develops potential adaptation pathways for six of the ten locations identified.

To this end, an initial long-list of approximately 40 potential case study sites were identified from a range of readily available sources, namely:

- Case studies used in previous related work, including:
  - Coastal Change Adaptation Planning Guide for England (Halcrow, 2015).
  - National Trust Shifting Shores + 10 years (CH2M, 2015).
  - Defra Coastal Change Pathfinders (Defra, 2012).
- Direct experience and knowledge from the project team in consultation with the CCC and its Adaptation Sub-Committee.

In order to reduce the initial long-list of potential case study sites to a short-list of ten, a range of criteria were then considered. These are presented as follows under eight broad categories within which key parameters have been defined:

- **Level of knowledge of site**
  - Is there lots of information available?
  - Is there limited information available?
  - Do we know key knowledgeable stakeholders?
- **Shoreline type**
  - Undeveloped (natural)
  - Partly developed (rural)
  - Well developed (urban)
- **Shoreline setting**
  - Open coast
  - Estuary
  - Sand dunes
  - Soft cliffs
  - Hard cliffs
  - Lagoon
  - Sand beach
  - Shingle beach

- Barrier beach
- Intertidal mudflats
- Salt marsh

- **FCERM policy situation**
  - SMP #
  - SMP Policy Unit(s)
  - SMP Policy - epoch 1
  - SMP Policy - epoch 2
  - SMP Policy - epoch 3
  - Will SMP policies change with time (e.g. could 'hold the line' give way to 'managed retreat' when a threshold or tipping point is reached)?
  - Are SMP policies influenced by the situation in adjacent policy units?
  - Are alternative current or near-term risk management measures being considered?
  - Have future (longer-term) risk management actions been identified (in response to different scenarios)?
  - Are there uncertainties about the SMP policy being deliverable?
  - Has (an outline) adaptation strategy been developed?
  - Have barriers to adaptation been identified and actions to reduce barriers been considered?
  - Have future 'tipping points' under a changing climate been identified?
- **Current risk management provision**
  - Breakwater
  - Seawall
  - Flood wall
  - Rock revetment
  - Groynes
  - Gabions
  - Earth embankment
  - Beach recycling
  - Beach recharge
  - Sand dune management
  - Land use planning / development control
  - Undefended
- **Coastal challenge**
  - Flooding
  - Erosion
  - Flooding and Erosion

- Landslide
- Habitat loss
- Accretion
- Unaffordable (BCR>1 but lack partnership funding contributions)
- Uneconomic (BCR<1)
- Are coastal change processes well understood, including the effects of climate change on rates of change and dynamic interactions between different coastline components and SMP policy units?

- **Designations at risk**
  - Areas of Outstanding Natural Beauty
  - National Nature Reserve
  - Site of Special Scientific Interest
  - Special Protection Area
  - Special Area of Conservation
  - World Heritage Site
  - Ramsar
  - Marine Conservation Zone
  - Listed Building(s)
  - Scheduled Monument(s)
  - National Park
- **Assets at risk**
  - Highway
  - Railway
  - Power station
  - Services/ utilities
  - Commercial properties
  - Residential properties
  - Risk to human health
  - Risk to ecosystem health
  - Other (state).

The long-list of possible case study sites were each reviewed against the criteria set out above within a matrix to enable ready comparison between sites. The assessment matrix was reviewed by the project team and the CCC's Adaptation Sub-Committee to select a short-list of ten representative case study sites. To achieve this, the matrix was first filtered based on the 'level of knowledge' criterion. Given the tight time-scale of the project it is important at this stage to have confidence that a good amount of information is known to be readily available, and that key stakeholders that hold knowledge of the area are known. The setting of each location, the nature of the coastal challenges and the assets at risk were then examined to ensure a mix of coastal and estuarine settings and challenges over the short, medium and long-term.

From the short-list of ten case study locations identified, six where then selected to be assessed in more detail for the development of illustrative adaptation pathways, based on:

- The location of sites around England to provide a reasonable geographical spread; and
- Similarities / differences between each potential location to ensure case studies would be distinctly different and could provide a range of adaptation pathway examples and lessons learnt.

4.2 Case study development

In order to develop adaptation pathways for the six sites selected, for each area the coastal change challenges were considered by the project team to first identify a number of possibly viable options for the sites to adapt to future challenges.

These options were developed into adaptation pathways in a way that embeds risk-based decision-making within the pathways. This reflects the significant uncertainty inherent in the decision-making process and is achieved by:

- Defining triggers, thresholds and decision points that drive change in approach;
- Considering the influence of prevailing levels of risk at each site; and
- Considering how these two elements affect the timing of the point at which decisions are made.

Figure 4.1 provides an example adaptation pathway as developed in this research. Appendix H provides further details on the principles of how the adaptation pathways were developed and how uncertainty is considered in the approach.

For each of the six case studies, a core assessment was developed to consider the technical, environmental and economic implications of each pathway, assuming sea level rise of around 1m over the next century. Sensitivity tests were then carried out to qualitatively assess the possible implications of the core assessment to the following “what if” scenarios:

a) What if sea level rise were to rise by 2m over 100 years?

b) What if an extreme event were to cause significant damage in short to medium term?

c) What if government priorities were to change policy selection criteria?

d) What if government were to introduce policy and tools/incentives to enable “removal” of assets at risk as a policy option?

e) What if there were to be reduced environmental regulation?

f) What if there were to be an increased priority to protect agricultural land?

g) What if available funding were to increase / decrease?

Finally, the initial assessment for each of the six sites was discussed with a knowledgeable key stakeholder in each location to provide local input and a ‘reality check’ on the assessment. This helped refine the pathways and highlighted further concerns or opportunities that different pathways could pose socially, politically, economically and environmentally.

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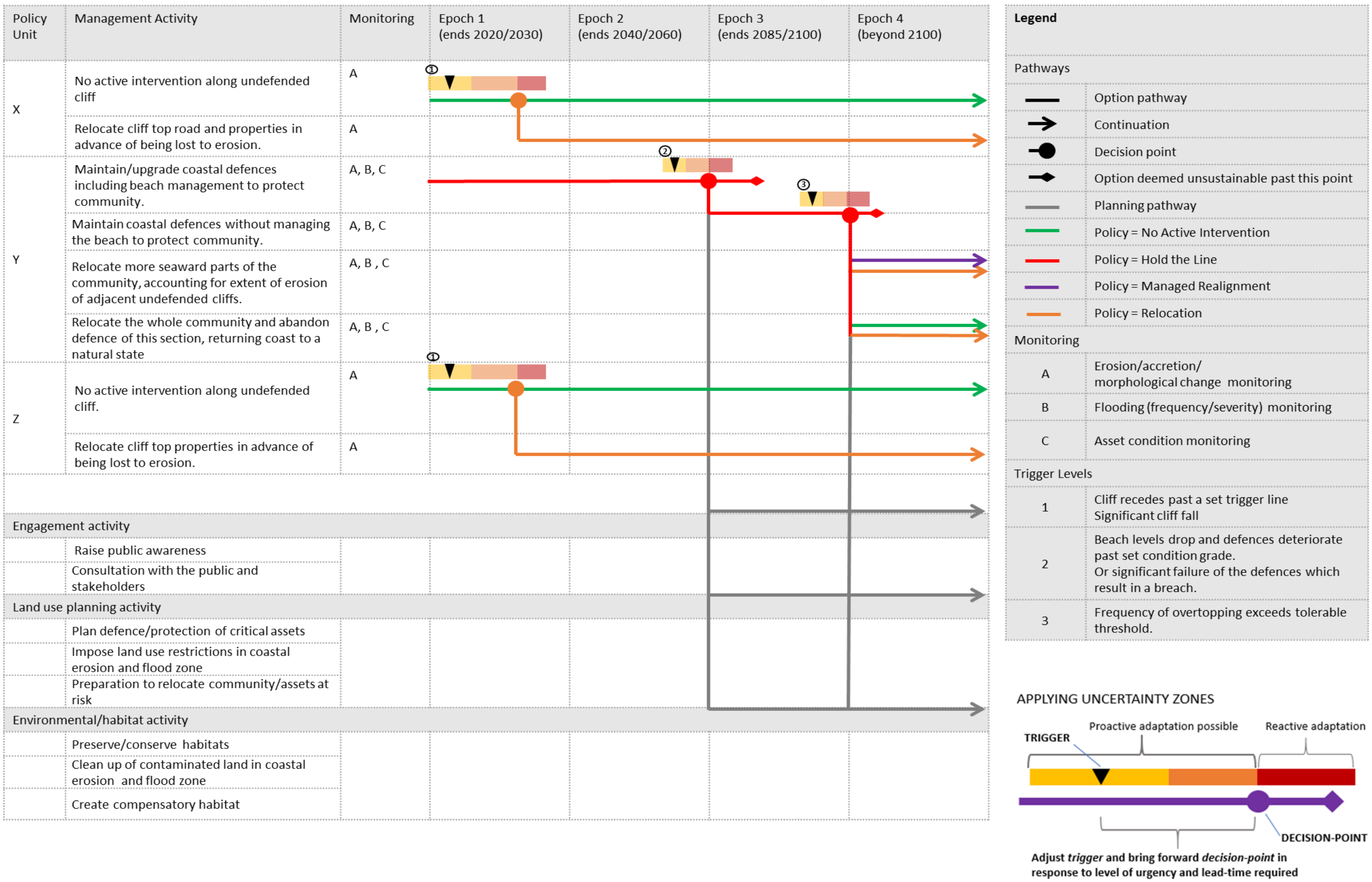
Figure 4.1: Example adaptation pathway for a hypothetical community that is currently defended but bounded by natural eroding cliffs



4.3 Conclusions and lessons learnt

The application of adaptation pathways focused on the management approach (which can be aligned to SMP policy scenarios) and monitoring key thresholds to trigger future management decisions, has benefits over sticking to rigid policy decisions within defined time-bound epochs as is the case with SMPs. This provides a more flexible and pragmatic way of both appraising options to address long-term risks in dynamic coastal environments that provide inherent uncertainties, and identifying which options will or will not 'lock-in' certain pathways over time.

The current use of time-bound epochs in SMPs does not make this clear. Indeed, time-bound epochs cause problems in their own right when things do not happen in strict accordance with their timings, and so using adaptation pathways is likely to be something that can, with appropriate planning and investment in engagement, be used to communicate the drivers of future management decisions to communities. Use of the adaptation pathways approach supported by on-going monitoring in this way means that the 'timing' of future management decisions along the pathway can be influenced by both the occurrence of storm events at any point, as well as more gradual changes due to sea level rise.

In addition, this approach of monitoring the coast and making decisions to adapt in parts of it based on regular review of monitoring data in relation to triggers/thresholds defined on an adaptation pathway is also an important point to note for continued justification of the national coastal monitoring programme in England.

Use of adaptation pathway diagrams developed in these case studies is a far more visual way of conveying different scenarios to stakeholders than is typically conveyed in SMP policy epoch tables, and can therefore better convey information to stakeholders when engaging them in decision-making.

Coastal adaptation is a very complex and challenging issue to address and it is important to emphasise that it requires a joined-up approach across multiple organisations (public and private sector) working with communities to develop and implement any approach. The lead-in time for implementing any such measures will also be lengthy, and this can be reflected in the adaptation pathways by the relative length of the uncertainty zones bar shown on the pathway diagram.

Adaptation pathways were explored that would involve relocating assets at risk of coastal flooding or erosion away from the risk zones to provide a long-term sustainable risk management approach. This has highlighted that:

Relocation of assets away from areas of coastal flood and erosion risk provides opportunities for "at risk" communities to have long-term security, whilst allowing restoration of natural processes at the coast as defences are removed. However, currently there is no national-level Outcome Measure or policy driver, nor funding mechanism(s) available to consider such relocation options in the context coastal flood and erosion risk management.

When considering relocation of communities, it is uncertain if there is a certain size of community where it becomes less viable to consider large-scale relocation, which may be appropriate especially in coastal flood risk or landslide areas.

The costs involved in relocating assets, and the social and political consequences of doing so, may be too large to overcome without significant changes to Government policy and provision of new resources / tools, and so the outcome may be greater armouring and defence of the community where it lies.

Indeed, one of the main factors that could aid implementation of a more proactive approach to asset relocation would be if there were to be a change in government policy and associated funding prioritisation / outcome measures that enable coastal flood and erosion risk management to cost-effectively relocate at risk properties and assets (i.e. 'remove the risk'). This would greatly facilitate the ability to plan and implement the management approaches identified for this area, and likely result in a much more proactive approach to community relocation such that communities have long-term security, whilst allowing restoration of natural processes at the coast as defences are removed.

Such a change in government policy and associated funding prioritisation / outcome measures would also significantly change the discussion of the coastal flood and erosion risk management options typically being considered in different parts of the coast, from relocation being a 'fall-back' option if it becomes unviable to defend, to relocation possibly emerging as the preferred option to provide a long-term, sustainable solution that delivers a much higher level of protection against flood / erosion risk to those relocated out of the risk areas.

It may be more viable to implement such an approach as a rolling-process of relocating assets as they become at risk, rather than relocating an entire community in one go, though this may be more appropriate in areas of gradual coastal erosion rather than large areas at risk of sudden coastal flooding or landsliding.

Such a rolling programme of asset relocation will provide a more manageable cost spread over a period of time compared to large, up-front costs of whole-scale community relocation. This in turn would provide a more reasonable level of costs to compare relocation options against the costs to continue to provide some level of defence. A rolling programme of relocation would also enable management of available land-areas to relocate assets to over a longer-period of time, particularly if areas to be relocated to also have their own various constraints to overcome.

In areas subject to landslides, there is significant uncertainty around when the next landslide event will occur that results in cliff-top recession. All that is certain in these areas is that such events will occur and so the proactive approach in these areas should be to engage with communities to plan and implement adaptation measures as soon as possible. This is particularly important where landslide events could cause loss of access to otherwise unaffected interests of the area.

Relocation of communities also needs to give consideration to a range of socio-environmental factors, including:

- Property owners may not accept relocation to a different area that does not offer the same valued aspects as the current location.
- Environmental and other planning constraints in the proposed ‘receiving area’ for relocated communities area may mean it is not possible to relocate assets in the same area.

It is therefore vital to understand both (i) what will property owners accept (both in terms of offered relocation and risk of property being lost), and (ii) what will the planning system allow. This further emphasises the importance of engagement over a period of time with all stakeholders to develop and plan coastal adaptation measures that will be deliverable.

- Adaptation pathways that explored managed realignment approaches highlighted that these approaches in some areas can provide for new habitat, or at least space into which habitat (e.g. sand dunes) can evolve into as sea levels rise, providing natural coastal defence assets.

  In some areas, managed realignment may mean a change in habitat type (e.g. from freshwater to saline) which could have implications for designated sites. In such areas, the ecological interests would likely remain but be of a different form. The amenity and recreation use of such sites may also alter, particularly in the way in which people access the coast these areas as car parks/foot paths may need to be relocated as a result of managed realignment. Amenity and recreation use of such sites is unlikely to be removed by managed realignment, but merely altered by it.

  However, the degree of actual management of any realignment will be variable, depending on the amount of funding that can be achieved. In some areas, only limited intervention to provide shorter lengths of more sustainable defence to provide protection to key features will be viable based on current funding criteria, meaning less control over where, when and what habitat is achieved compared to taking a more proactive approach to managed realignment.

  If adaptation is not possible in some areas, and continued defence is to continue and can be funded, the adaptation pathways that explore this show that there is a possibility that communities may have to accept continued defence but with a lower standard of service being provided, meaning that communities should expect more frequent coastal flooding in particular as a result. As a result, it is important to emphasise that continued defence does not mean there is no need to adapt to coastal change, rather communities must accept more frequent inundation and become resilient to it by measures such as property level protection and expecting to have road access cut-off regularly.

5. Summary and conclusions

The key findings and conclusions from the study are presented in the following sections.

5.1 Assets and land at risk of coastal change

The study estimated the different types of assets and land at risk of coastal flooding and erosion. Notable results include:

- Along England's coastline, there are over 500,000 properties (residential and non-residential) with a 1:200 risk of flooding and potentially up to around 9,000 properties at risk of erosion.
- The number of properties at risk of erosion is forecast to increase to more than 107,000 at risk properties within the next century excluding the impacts of complex cliffs in some areas. In addition to this, there are potentially around a further 100,000 properties at risk of recession of complex cliffs that could occur at any time in the next century, although the timing and magnitude of recession in complex cliff areas is uncertain. Irrespective of this, the trend over the next century is for an ever-increasing number of residential and non-residential properties at risk of erosion.
- The scale of risk of erosion is however much smaller by comparison to the risk of coastal flooding, in general.
- There are nearly 190,000 ha of Grade 1 and Grade 2 agricultural land at risk of flooding (1:200 risk) which represents nearly 9% of such land in England[9].
- There are significant areas of designated land at risk of flooding (1:200 risk) for example:
  - 163,000 ha of Priority Habitats which represent 7% of Priority Habitats in England[10];
  - 105,000 ha of Sites of Special Scientific Interest (SSSIs) which represents nearly 10% of SSSIs in England[11]; and
  - 42,000 ha of Areas of Outstanding National Beauty (AONBs) which represents around 2% of AONBs in England[12].

  These types of designations include rich ecosystems and productive natural capital assets which in turn provide valuable benefits to the rest of society in terms of biodiversity, recreation, climate regulation, etc.
- Currently available data does not allow future flood risks in Epoch 2 and Epoch 3 to be estimated for the assets and land mentioned here. Further research is required to fill this important gap.

5.2 Coastal adaptation projects from 2015 - 2021

The study also assessed the extent of capital projects planned or underway during the period 2015 – 2021 to manage the risks identified above. It is important to note that although the 2015 – 2021 capital works take place within Epoch 1, they are not necessarily attributable to or driven by specific SMP policies given that SMPs are not statutory. The key findings from the assessment are:

[9] Based on data from Natural England on Provisional Agricultural Land Classification (ALC). See Natural England (2018c).
[10] Based on data from Natural England on the Priority Habitat Inventory. See Natural England (2018b).
[11] Based on data from Natural England on Sites of Special Scientific Interest (England). See Natural England (2018d).
[12] Based on data from Natural England on Areas of Outstanding Natural Beauty (England). See Natural England (2018a).

- The 2015-2021 FCERM capital works programme shows only 228 capital projects are planned or have been completed in the period 2015-2021 across SMP areas. This is possibly a lower figure than would be expected given that more than 1,000 policy units require such projects in Epoch 1.
- More than 200,000 homes will be better protected once the expected works have been completed by 2021 assuming that all 228 projects are delivered. More than 127,000 of these homes are located in just three of the 20 SMPs in England, namely:
  - SMP 3 - Flamborough Head to Gibraltar Point;
  - SMP 11 - South Foreland to Beachy Head; and
  - SMP 22 - Great Ormes Head to Scotland (North West England only).
- The total cost of all 228 capital projects planned/completed in the period 2015-2021 across all 20 SMPs is £1.4 billion.
- Of this total cost, approximately £976 million will come from FCERM grant-in-aid (GiA) funding. The balance of approximately £464 million is required to come from third-party contributions as part of partnership funding arrangements. The published data does not include any details of where this additional funding is expected to come from. Evidence from the PDUs suggests there are significant challenges in achieving this level of third-party contribution to enable the full capital works programme to be delivered by 2021. To put this into some context, as part of granting the six-year funding for 2015-2021, HM Treasury required £600 million pounds of third-party contributions to be raised in this period; as of September 2016, it was confirmed that £270 million of this target had been achieved (Priestley, 2017).
- There is a disparity around the coast in terms of total costs and numbers of properties protected. For example, some SMPs have high costs and a relatively small number of properties better protected.

5.3 SMPs in Local Plans

In investigating the extent to which Local Plans reflect SMPs, the study found that 78% of the Local Plans identified and reviewed refer to SMPs. This leaves 22% of Local Plans that do not refer to SMPs for unspecified reasons.

Overall, while it is positive that a large number of coastal Local Plans make reference to the evidence and policies set out in the relevant SMPs, further work is needed to integrate the evidence base from SMPs and implement Coastal Change Management Areas to set a framework for guiding and driving future adaptation in areas at greatest risk of coastal change. In doing so, there is a need for greater recognition of residual risks in areas that are expected to continue to be defended. This can help drive adaptation and improve resilience to the increase in coastal hazards to remaining communities.

5.4 Cost-benefit analysis of SMP policies

The study undertook a CBA of the polices set out in SMPs. The costs included in the CBA reflect the cost of measures in SMP documents. The benefits included in the CBA reflect avoided damage to properties from flooding and the benefits of the delayed damages of erosion. Environmental impacts are not included in the CBA. The limited scope of the CBA is the result of the lack of available data to assess these impacts at the national level.

Economic appraisal in SMPs

In SMP documents, the preferred policy in each policy unit is chosen before an economic appraisal is undertaken. The guidance on undertaking an economic appraisal of SMP policies states that economic assessments only provide a check on the viability of the selected preferred policies and review of their robustness in economic terms, and a full economic assessment is not required in the form of a CBA. Economic evidence does not drive the selection of the preferred policy.

It is recommended that future reviews of SMPs use economic appraisal and evidence more consistently and rigorously to inform decisions of preferred policies. There is a need to better assess the economic costs and benefits of coastal adaptation via SMPs in order to better understand and manage their impacts to communities and the environment. This is particularly important in light of the potential gap in funding to deliver SMPs, and coastal adaptation more generally. A more robust economic evidence base of the impacts of SMPs can aid in the prioritisation of funding across different FCERM projects, including grant-in-aid funding.

CBA results

Across each dimension of the CBA (at the SMP, policy unit, regional or national level), the costs and benefits of SMP policies are estimated based on the best available data and the methods these allow. While the estimates provide an indication of the order of magnitude of the impacts of the implementation of SMPs, they are subject to varying levels of uncertainty. These results should be interpreted with caution given the inherent uncertainties of the estimated costs of SMPs and the different scales at which the benefits are calculated. Key findings from the CBA include:

- **Cost of SMP policies:** Within each Epoch, the cost of SMP policies is less than £5 million in present value terms for the majority of policy units (over a 100-year timescale). The costs are highest in Epoch 2 followed by Epoch 1 and Epoch 3 respectively. The policy of HTL is the most costly across all Epochs, accounting for 80% - 90% of the total cost per Epoch. This is followed by MR which accounts for 6% - 15% of the total cost per Epoch. Across Epochs, the present value cost of HTL is between five and fourteen times the cost of MR.

- **Funding to deliver SMPs:** The present value cost of implementing SMPs in Epoch 1 is nearly £3 billion in 2011 prices. The magnitude of these costs raises the question of the extent of recent funding available to implement SMPs. Total expenditure on flood and coastal erosion risk management (FCERM) for the period 2005 – 2017 is estimated to be around £8 billion in 2011 prices. Expenditure on FCERM goes toward multiple sources including managing coastal, fluvial, surface water and groundwater sources of flood risk. This would suggest a likely gap in the funding available to implement SMPs within Epoch 1.

- **Benefits of SMP policies:** As with the costs, the benefits of avoided damages from flooding within each Epoch are less than £5 million in present value terms for the majority of policy units. The benefits of SMP policies are highest in Epoch 1 followed by Epoch 2 and Epoch 3 respectively. The policy of HTL has the highest benefits across all Epochs. This result is fundamentally influenced by the scope of the CBA which does not include environmental benefits e.g. from habitat creation under managed realignment (MR).

  Alongside the benefits of avoided damages from flooding, the study also assesses the benefits of delayed damages from erosion. These are the benefits to properties better protected from the risk of erosion due to the implementation of policies in SMPs. The benefits of delayed erosion are estimated to be over £900 million in Epoch 1 in present value terms. The benefits more than double in Epoch 2 to £2 billion in present value terms and fall to around £1 billion in Epoch 3. In general, the proportion of benefits due to delayed damages of erosion increases over time from 26% of total benefits in Epoch 1 to around 55% in Epoch 2 and Epoch 3 respectively. This is due to the rising number of properties at risk of erosion over the next century.

- **Comparison of costs and benefits**: At the national level, the benefits of implementing SMP policies outweigh the costs, with a net benefit of nearly £2 billion over 100 years.

Key sensitivity of the CBA results

The following findings emerge from sensitivity analysis of the CBA results:

- **Impact of climate change on costs:** In general, exploring the likely impact of climate change on the costs of implementing SMPs establishes a range for the costs and their comparison to the benefits of SMPs. The impact reflects the effect of lower or higher sea level rise on the cost of SMP policies due to the need to strengthen and widen existing defences. SMPs with a net cost are unlikely to switch to having a net benefit under alternative assumptions regarding the impact of climate change on their costs. SMPs with a borderline BCR are however sensitive to these alternative assumptions. At the national level, the costs of SMPs outweigh the benefits in a high climate change scenario. It is recommended that the method for adjusting the costs of SMPs is refined and updated to use upcoming UK Climate Projections for 2018 (UKCP18) in future SMP reviews.

- **Impacts of erosion:** For SMPs or policy units where the CBA results are considered to be borderline and sensitive to the scope of the CBA, the sensitivity analysis demonstrates that different assumptions regarding the probability of occurrence of erosion can sway the results for certain SMPs. However, at the national level, there is a net benefit from implementing SMP policies regardless of the assumptions for the probability of erosion.

- **Environmental impacts:** It is important to assess the environmental impacts of SMP policies. For sites where MR is a proposed policy and the CBA results are not favourable (costs outweigh the benefits), it is worth investigating the potential for habitat creation to justify the costs of MR. However, not all MR schemes will lead to habitat creation and that new habitat may not necessarily always result in a net positive change in the benefit e.g. where one valuable habitat is replacing another.

5.5 Case studies of coastal adaptation pathways

The study developed a series of six case studies for locations with coastal adaptation challenges. In contrast to SMPs which consider fixed/static policies, the case studies develop dynamic adaptation pathways based on levels of risks and triggers to decision-making. The key findings from the development of these case studies are:

- Coastal adaptation is a very complex and challenging issue to address and it is important to emphasise the requirement for a joined-up approach across multiple organisations (public and private sector) working with communities to develop and implement any approach. The lead-in time for implementing any such measures will also be lengthy, and this can be reflected in the adaptation pathways by the relative length of the uncertainty zones shown on the pathway diagrams within each case study which are also a much better, visual way of conveying different options to stakeholders compared to the tabular approach taken in developing the current SMPs.

- The application of adaptation pathways focused on the management approach (which can be aligned to SMP policy type) and use of monitoring key thresholds to trigger future management decisions, has benefits over sticking to rigid setting of policy type within defined time-bound epochs as is the case with SMPs. This provides a more flexible and pragmatic way of both appraising options to address long-term risks in dynamic coastal environments that provide inherent uncertainties, and identifying which options will or will not ‘lock-in’ certain pathways over-time.

  The current use of time-bound epochs in SMPs does not make this clear. Indeed, time-bound epochs cause problems in their own right when things do not happen in strict accordance with their timings, and so using adaptation pathways is likely to be something that can, with appropriate planning and investment in engagement, be used to communicate the drivers of future management decisions to communities. Use of the adaptation pathways approach supported by on-going monitoring in this way means that the ‘timing’ of future management decisions along the pathway can be influenced by both the occurrence of storm events at any point, as well as more gradual changes due to sea level rise.

- At present, the approach to adapting to coastal change involving relocation of assets away from areas of coastal flood and erosion risk is not occurring, in part due to there no national-level Outcome Measure or policy driver, nor funding mechanism(s) available to consider such relocation options in the context coastal flood and erosion risk management, as well as local social, environmental and political pressures to not to relocate but continue to defend (which is unsustainable in many areas).

  One of the main factors that could aid implementation of a more proactive approach to asset relocation would be if there were to be a change in government policy and associated funding prioritisation / outcome measures that enable coastal flood and erosion risk management to cost-effectively relocate at risk properties and assets (i.e. ‘remove the risk’). This would greatly facilitate the ability to plan and implement the management approaches identified for this area, and likely result in a much more proactive approach to community relocation such that communities have long-term security, whilst allowing restoration of natural processes at the coast as defences are removed.

  Such a change in government policy and associated funding prioritisation / outcome measures would also significantly change the discussion of the coastal flood and erosion risk management options typically being considered currently in different parts of the coast, from relocation being a ‘fall-back’ option if it becomes unviable to defend, to relocation possibly emerging as the preferred option to provide a long-term, sustainable solution that delivers a much higher level of protection against flood / erosion risk to those relocated out of the risk areas.

- In addition, at the time of developing the case studies, it is not apparent that any examples of relocating communities on a large scale exist with a full assessment of the complexities, including costs, of doing so. As such it is recommended that future research should consider detailed investigation using several anonymised case studies to explore this in more detail. This would develop some data that can be used to aid the assessment of relocation options in the future. In doing so, a range of community scales should be considered to assess whether there is a likely size of community above which relocation is likely to be prohibitive on cost or other grounds.

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Appendix A - Methodology for estimating erosion for complex cliffs

This analysis in Section 2.1 requires the compilation of existing data to generate summary statistics of coastal change risks. The National Coastal Erosion Risk Mapping (NCERM) database informs part of this analysis, however gaps exist within the dataset pertaining to projected erosion zones for Complex Cliffs. Many cliffs are classified as Simple Cliffs, where there is a straightforward relationship by toe erosion and cliff top retreat, and an annual erosion rate can be used as a basis for projection. In contrast, Complex Cliff behaviour is determined not only by toe erosion, but also groundwater level etc., which control the frequency and magnitude of deep-seated landsliding. As landslides occur infrequently, and potentially only once in a hundred years or less, it is necessary to understand frequency and magnitude relationships before making projections of cliff top retreat; use of a simple annual recession rate is not appropriate as a basis for projection.

This appendix outlines the approach to defining complex cliff erosion projections based on judgement-based frequency and magnitude data on cliff recession events, in order to complete the research dataset.

A.1 Introduction

The NCERM Project was undertaken by Halcrow for the Environment Agency and uses coastal erosion concepts first developed for the Defra funded “Futurecoast” project also led by Halcrow (Halcrow, 2002). Its aim was to publish robust and consistently-derived projections of coastal erosion. The methodology combines projections of historical coastal recession rates to determine future erosion losses over three Epochs of 20, 50 and 100 years. It provides two scenarios:

1. Adoption of coastal management policies as defined in the shoreline management plans, and
2. A scenario of no active intervention to simulate natural behaviour of undefended cliffs.

Projections are provided for stretches of coast that are sub-divided into a series of cliff behaviour units mapped using the methodology described by Lee and Clark (2002). The outputs for each time period are presented to show 5%, 50% and 95% probability losses from erosion, which account for uncertainty associated with cliff recession processes and impacts of climate change and sea level rise. Cliff recession data was taken from the Futurecoast project (Halcrow, 2002) and historical data held in current shoreline management plans (SMP). These were updated where necessary following a review by local authorities.

NCERM recognises three types of coastline:

- **Erodible Coasts** that have simple cliffs, simple landslides and composite cliffs that behave predictably with an annual erosion rate, which NCERM has assessed.
- **Complex Cliffs** that behave non-linearly, and feature multi-tiered landslides that are difficult to predict through simple extrapolation of historical recession rates. Complex and relict cliffs are not covered by NCERM, and require site-specific expert review of cliff behaviour.
- **Floodable Coasts** identified by the Environment Agency flood maps. These are not covered by NCERM.

For erodible coasts, which include simple cliffs, simple landslides (e.g. mudslides) and composite cliffs (typically weak over strong materials), a simplified assumption is made that future cliff recession will be driven by toe erosion. These cliff types are characterised by various rates of cliff toe erosion which is generally in balance and equal to the rate of cliff top recession (Lee and Clark 2002). The feedback mechanism between toe erosion and cliff top recession is usually subject to a time-lag. However, the frequency of erosion and/or landslide events is high (typically 1:1 to 1:10 years) and can be measured using an assessment of long term historical erosion data from comparison of early Ordnance Survey data (~1850s to present) and/or aerial photography (~1940s to present). Therefore, for these coasts, the erosion rate can be averaged to a historical annual cliff recession rate which provides a basis for future prediction for any number of years.

In contrast, complex cliff systems operate by an interrelated series of events, including erosion of the cliff toe and landsliding, that are not solely related to coastal processes and – importantly – that operate over a frequency of 1:100 to 1:10,000 years. This complexity means that potential future behaviour may not be fully represented in the historical record and it is not appropriate to use an average annual recession rate as a basis for long-term projection. Site-specific ground conditions have a dominant control over complex cliff behaviour. For example, elevated groundwater levels due to sustained high rainfall can trigger major events that transform system behaviour (i.e. deep-seated landslide movement). The annual erosion rate cannot be used alone for future projection as this may lead to a significant under-prediction of future recession where change is mainly driven by episodic large-scale landslide events that are distributed randomly over time. Conversely, applying both annual erosion and episodic landslide events may result in over-prediction. Therefore, the behaviour of complex cliffs can be summarised in terms of magnitude and frequency of landsliding, i.e. how much retreat occurs in a single event and how often do these events occur (Moore et al. 2010).

An important feature of complex cliff systems is the presence of a rear scarp that may be 1 km or more inland of the sea-cliff or landslide toe. Recession of the rear scarp is potentially influenced by erosion at the landslide toe and adverse ground conditions. Therefore, it is important to consider the full extent of the complex cliffs when mapping and undertaking such assessments. The wide distance between headscarp and sea cliff, and infrequent ground movement, means that developments are widespread on complex cliffs. For example, the towns of Ventnor (Isle of Wight) and Lyme Regis (Dorset) are built upon unstable ground associated with complex cliff and this needs to be considered when assessing the economic implications of coastal erosion and landsliding.

A.2 Approach

For the majority of the complex cliff sites along the coast, site-specific data on historical behaviour are unavailable or limited. In order to generate estimates of the future behaviour of complex cliffs, existing expert judgement-based data from the Futurecoast Cliffs Database has been utilised.

The Futurecoast Cliffs Database (Halcrow, 2002) provides a systematic assessment of the coastal cliffs of England and Wales in accordance with the cliff behaviour unit classification advanced by Lee and Clark (2002) and subsequently used by NCERM. Futurecoast was a regional-scale study of the coast of England and Wales to inform the 2nd round Shoreline Management Plans developed between 2006 and 2011. Futurecoast provides a robust geomorphological framework for conceptualising coastal evolution. The cliffs database includes factual information on cliff materials, failure mechanisms, presence of cliff engineering and coastal defences and expert judgement-based assessments of activity status, recession potential, magnitude and frequency, sediment supply potential, sensitivity to climate change and uncertainty in the assessment. Used carefully, these data provide a valuable resource for cliff behaviour assessments and recession prediction studies.

In this study, coastal erosion risk zones were generated for complex cliff behavioural units identified within the NCERM dataset based on a no active intervention scenario (i.e. natural cliff recession). Projections were estimated for a 100-year timescale using the Futurecoast data on probable magnitude and frequency of landslide events. As the frequency of landslide events may exceed 1:100 years, it was determined that provision of erosion projections for less than 100 years was not viable, and therefore projections are made for 100 years only.

The approach is as follows:

1. Data held in Futurecoast on the expected range of magnitude and frequency of recession events were extracted for all complex cliffs identified by NCERM.
2. Magnitude and frequency of landslide event classes from the Futurecoast database were utilised (Table 1; Table 2).
3. For each magnitude class, the lower, middle and upper range were defined in relation to the probability of losses from erosion quoted in the Futurecoast cliffs database, as follows:
    - Best case (5%) is the lowest magnitude for the given class.
    - Most likely case (50%) is the approximate mean magnitude for the given class.
    - Worst case (95%) is the greatest magnitude for the given class.

4. For each frequency class, the lower, middle and upper range were defined in relation to the probability of losses from erosion quoted in the Futurecoast cliffs, as follows:
   - Best case (5%) is the lowest frequency for the given class.
   - Most likely case (50%) is the approximate mean frequency for the given class.
   - Worst case (95%) is the greatest frequency for the given class.

   The frequencies were expressed in terms of an annual probability of occurrence. For example, an event frequency of 1:5 years has an annual probability of 0.2 (i.e. 1:5); an event frequency of 1: 1,000 years has an annual probability of 0.001 (i.e. 1:1,000).

   The 100-year recession project was calculated for each probability class (5%, 50% and 95%), by multiplying the magnitude of each event by its frequency, and multiplying this by 100.
5. In certain cases, particularly where landslide frequency was considered to be high, the 100 recession projections were unrealistically high. Upper bound values for recession frequency and magnitude were then refined based on judgement and empirical data to produce more realistic projections.
6. The results are appended to an ArcGIS shapefile allowing 5, 50 and 95% erosion distances to be created by buffering from the contemporary cliffline.

Table A. 1: Recession magnitude classes

Recession magnitude (single landslide event)		5%	50%	95%
6	High >50m (>1ha)	40	50	55
7	Medium 10-50m (0.2-1ha)	10	25	40
8	Low <10m (<0.2ha)	1	2.5	5

Table A. 2: Recession frequency classes

Recession (event) frequency		5%	50%	95%
1	<1 year (erosion)	1	1.5	2
2	1-10 years	0.1	0.2	0.8
3	10-100 years	0.01	0.02	0.08
4	100-250 years	0.004	0.005714	0.008
5	250-1000+ years	0.001	0.001538	0.004

A.3 Results and discussion

The results were compared against Futurecoast validation undertaken by Moore et al. (2010), where projections were based on detailed assessments of a number of complex cliff frontages using historical maps and aerial photos, landslide ground models and understanding of the relationships between toe erosion and groundwater levels on cliff recession. The sites comprised:

- Barton-on-Sea to Naish (Hampshire). Complex cliff comprising a series of translational failures.
- Fairlight Cove (East Sussex). Complex cliff comprising translation failures and mudslides.
- Binnel Bay, St Catherine's Point, Blackgang and Chale (Isle of Wight). Complex range of translational and rotational landslides on the Ventnor Undercliff.
- Charmouth (Dorset). Complex cliff comprising translation failures and mudslides.

The projected recession distances compared well (Table 3), with all projected distances falling within the probability of losses from erosion (distances were not significantly over- or under-estimated).

It is important to recognise the inherent uncertainty within the source data used to validate projections. Records of past behaviour are patchy and source data may include error.

In order to accurately project cliff top recession for complex cliffs, a site-by-site assessment should be undertaken, making best use of all available geological records and monitoring data.

Table A. 3: Comparison of validated projection data by Futurecoast and projections in this study

Site	100-year recession projection (m)				Futurecoast source
	Predicted in this study			Validated by Futurecoast	
	5%	50%	95%		
Fairlight Cove, East Sussex	100	500	3,200	175	Georeferenced photos, 1995-2003
Barton-on-Sea to Naish, Hampshire	10	50	400	30	Orthophotos, 1940-2001
Binnel Bay, Isle of Wight	40	100	440	79	Georeferenced photos, 1986-2000
St Catherine's Point, Isle of Wight	4	8	22	73	Georeferenced photos, 1986-2000
Blackgang Undercliff, Isle of Wight	10	50	320	95	Georeferenced photos, 1986-2000
Chale, Isle of Wight	100	500	3,200	380	Georeferenced photos, 1986-2000
Charmouth, Dorset	40	100	440	184	Orthophotos, 1976-1995

Appendix B - Summary statistics of coastal change

See separate files:

- <Appendix B1 Flood Risk Impacts Data_220718.xlsx>
- <Appendix B2 Erosion Risk Impacts Data_220718.xlsx>

Appendix C – Maps of 2015-2021 projects

See separate file:

- <Appendix C Maps of 2015-2021 projects_220718.pdf>

Appendix D - Local planning authorities and their Local Plans

The table below presents Local Planning Authorities around the coast of England and their respective Local Plans reviewed for the research in Section 2.3. Note that joint local plans are highlighted in grey.

	Local Coastal Planning authority	Local Plan Name
1	Northumberland Council	Northumberland Local Plan Sustainability Appraisal Scoping Report
2	North Tyneside Metropolitan Borough Council	North Tyneside Local Plan
3	South Tyneside Council	South Tyneside Local Development Framework Core strategy.
4	Sunderland City Council	Core Strategy and Development Plan 2015-203
5	County Durham Council	Not Available
6	Hartlepool Borough Council	Hartlepool Local Plan
7	Stockton-On-Tees Borough Council	Not Available
8	Redcar & Cleveland Council	Not Available
9	Scarborough Borough Council	Scarborough Borough Local Plan
10	East Riding of Yorkshire Council	East Riding Local Plan (2012-2029)
11	City of Kingston upon Hull Council	Not Available
12	North Lincolnshire Council	North Lincolnshire Local Development Framework Core Strategy
13	North East Lincolnshire Council	North East Lincolnshire Pre- submission Draft Local Plan 2016
14	East Lindsey District Council	East Lindsey Core Strategy
15	Boston Borough Council	Not Available
16	South Holland District Council	South Holland Local plan
17	King's Lynn and West Norfolk Borough Council	Kings Lynn & West Norfolk Borough Council - Local Development Framework - Core Strategy

	Local Coastal Planning authority	Local Plan Name
18	North Norfolk District Council	North Norfolk Local Development Framework
19	Great Yarmouth Borough Council	Great Yarmouth Local Plan - Core Strategy 2013 - 2030
20	Waveney District Council	Suffolk Coastal District Council Core Strategy
21	Suffolk Coastal District Council	Suffolk Coastal District Council Core Strategy
22	Ipswich Borough Council	Core Strategy and Policies Development Plan Document Review
23	Bamberg District Council	Local Plan 2011 - 2031 Core Strategy & Policies
24	Tendring District Council	Tendring District Local Plan 2013-2033 and Beyond Publication Draft
25	Colchester Borough Council	Colchester Local Plan the Publication Draft stage of the Colchester Borough Local Plan 2017 – 2033
26	Maldon District Council	Maldon District Approved Local Development Plan 2014-2029
27	Rochford District Council	Rochford District Council – Local Development Scheme 2017-2021
28	Southend-on-Sea Borough Council	Not Available
29	Castle Point Borough Council	New Local Plan Castle Point
30	Thurrock Borough Council	Not Available
31	Dartford Borough Council	Dartford Borough Council Core Strategy Proposed Adoption Document
32	Gravesham Borough Council	Gravesham Local Plan Core Strategy Adopted September 2014
33	Medway Council	Medway Council Local Plan 2012 - 2035. Development Options Regulation 18 consultation report.
34	Swale Borough Council	Bearing Fruits 2031: The Swale Borough Local Plan, Full Council Item
35	Canterbury City Council	Canterbury District Local Plan
36	Thanet District Council	Draft Thanet Local Plan to 2031 Preferred Options Consultation
37	Dover District Council	Not Available
38	Shepway District Council	Shepway Core Strategy Local Plan

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	Local Coastal Planning authority	Local Plan Name
39	Rother District Council	Rother Local Plan - Core Strategy.
40	Hastings Borough Council	Shaping Hastings - Hastings Local Plan - Planning strategy 2011 - 2028
41	Wealden District Council	Not Available
42	Eastbourne Borough Council	Lewes District Local Plan Joint core strategy
43	Lewes District Council	Lewes District Local Plan Joint core strategy
44	Brighton & Hove City Council	Brighton and Hove Local Plan 2005
45	Adur District Council	Adur Local Plan
46	Worthing Borough Council	Adur Local Plan
47	Arun District Council	Arun Local Plan
48	Chichester District Council	Chichester Local Plan Key Policies 2014 - 2029
49	Havant Borough Council	Draft Havant Borough Local Plan 2036
50	Portsmouth City Council	The Portsmouth Plan - Portsmouth Core Strategy
51	Gosport Borough Council	Gosport Borough Local Plan 2011-2029
52	Fareham Borough Council	Fareham Local Development Framework - Shaping Fareham's Future - Core strategy
53	Eastleigh Borough Council	Eastleigh Borough Local Plan review (2001-2011)
54	Southampton City Council	Local Development Framework Core Strategy Development Plan Document
55	Isle of Wight Council	Island Plan Isle of Wight core strategy (including waste and minerals) and development management development plan document March 2012
56	New Forest District Council	New Forrest District Council local development framework Core Strategy
57	Christchurch Borough Council	Christchurch and East Dorset Local Plan - Part 1 Core Strategy
58	Bournemouth Borough Council	Bournemouth Local Plan Core Strategy
59	Poole Borough Council	Poole Local Plan Pre- Submission draft

	Local Coastal Planning authority	Local Plan Name
60	Purbeck District Council	Planning Purbeck's Future - Purbeck Local Plan Part 1.
61	West Dorset District Council	West Dorset, Weymouth & Portland Local Plan
62	Weymouth & Portland Borough Council	West Dorset, Weymouth & Portland Local Plan
63	East Devon District Council	East Devon Local Plan 2013 to 2031
64	Exeter City Council	Exeter City Council Core strategy
65	Teignbridge District Council	Teignbridge Local Plan 2013 - 2033
66	Torbay Council	Torbay Local Plan a Landscape for success The Plan for Torbay: 2012 to 2030
67	South Hams District Council	Plymouth and South west Devon joint local plan 2014 -2034
68	Plymouth City Council	Plymouth and South west Devon joint local plan 2014 -2034
69	Cornwall Council	Cornwall Local Plan Strategic Policies 2010 - 2030
70	Torridge District Council	North Devon and Torridge Local plan
71	North Devon District Council	North Devon and Torridge Local plan
72	West Somerset District Council	Adopted West Somerset Local Plan to 2032
73	Sedgemoor District Council	Local Plan Consultation Proposed Submission Local Plan
74	North Somerset Council	North Somerset Council Core Strategy
75	City of Bristol Council	Bristol Development Framework Core Strategy
76	South Gloucestershire Council	South Gloucestershire Local Plan Core Strategy 2006 - 2027
77	Stroud District Council	Your district Your future - Stroud District Local Plan
78	Forest of Dean District Council	Forest of Dean District Council Core Strategy Adopted Version
79	Wirral Borough Council	Not Available
80	Cheshire West and Chester Council	Not Available

	Local Coastal Planning authority	Local Plan Name
81	Halton Borough Council	Not Available
82	Liverpool City Council	Not Available
83	Sefton Council	A local plan for Sefton
84	West Lancashire Borough Council	West Lancashire Local Plan 2012 - 2027
85	South Ribble Borough Council	South Ribble Borough council forward with South Ribble
86	Fylde Borough Council	Plan for Fylde - Plan for the future Fylde Council Local Plan to 2032
87	Blackpool Borough Council	Blackpool Local Plan Part 1: Core Strategy 2012-2027
88	Wyre Council	Wyre Council Publication Draft Wyre Local Plan
89	Lancaster City Council	Not Available
90	South Lakeland District Council	South Lakeland Local Development Framework Core Strategy
91	Barrow-in-Furness Borough Council	Barrow Borough Local Plan 2016 -2031
92	Copeland Borough Council	Copeland Local Plan 2013-2028 Core strategy and Development Management Policies DPD
93	Allerdale Borough Council	Allerdale Borough Council
94	Carlisle City Council	Carlisle District Local Plan

Appendix E - Local Plans and SMPs data capture

See separate file:

- < Appendix E Local Plans and SMPs data capture_220718.xlsx>

Appendix F – Assumptions to estimate costs and benefits of coastal adaptation in the national CBA

F.1 Introduction

This note summarises the key assumptions used to undertake the cost-benefits analysis (CBA) presented in Section 3.

The purpose of the CBA is to compare the costs and benefits of implementing Shoreline Management Plans (SMPs). The CBA results are presented in Section 3.

F.2 Policy scenarios

Each policy unit (PU) should have a unique policy scenario to be used in the analysis. In practice, this is not always the case. The following assumptions have been applied to assign a unique policy scenario to each PU:

- Where more than one policy scenario is listed for a PU within one Epoch, this is cross-referenced against the type of measure outlined (e.g. defences, beach management) and the type of cost incurred/expected (capital and/or maintenance);
- If hold the line (HTL) is one of the policies outlined within an Epoch (e.g. alongside no active intervention (NAI) or managed realignment (MR)) and the type of measure is a sea defence or wall, it is assumed the overriding policy is HTL;
- If MR is one of the policies outlined within an Epoch (e.g. alongside HTL or NAI) and the type of measure is beach management, it is assumed the overriding policy is MR;
- Where one policy unit has multiple measures, which could reflect different policies, the overriding policy is selected based on the majority of the measures;
- Where one of the policies within an Epoch is NAI (e.g. alongside MR or HTL) and no measures are outlined and the costs are equal to zero, the overriding policy is assumed to be NAI. If the costs are greater than 0, the other policy is assumed to be the overriding policy.

F.3 Cost of SMPs

If a cost estimate is not broken down into capital and maintenance costs, around 74% of the cost is assumed to be a capital cost and the remaining 26% is assumed to be a maintenance cost. The proportions are determined based on the average proportions for SMPs where this split is specified.

Where there is a need to apportion costs over time (e.g. by Epoch to discount costs to present value) the spread of costs is assumed to equally distributed over time, in the absence of alternative information. For example, to disaggregate a cost estimate for the full 100 years across the three Epochs, it is assumed:

- 20% of costs accrue in Epoch 1 which is 20 years long;
- 30% of costs accrue in Epoch 2 which is 30 years long; and
- 50% of costs accrue in Epoch 3 which is 50 years long.

This is a conservative assumption in the absence of further information about the profile of costs over time.

The costs of SMPs in the CBA are based on the reported costs in SMP documents. These costs are not provided on an annual basis and some are discounted to present values while other are not. The costs also include the cost of replacing private defences. These costs are to be capital costs which occur in Epoch 2 and 3.

For costs that are already discounted, it is assumed the guidance on preparing SMPs (which refers to HM Treasury's Green Book) is followed and a 3.5% declining discount rate is used. For costs that are not discounted, it is assumed that capital costs occur in the first year of an Epoch and maintenance costs occur from the second year onwards. This is a standard assumption which implies that capital costs are on-off costs while maintenance costs are incurred annually as a type of operating cost. This allows annual costs to be estimated and discounted following the guidance mentioned above.

Some SMPs provide costs over the full 100-year timescales which are incurred in addition to the costs within each Epoch. Since they are not associated with a particular Epoch, they cannot be attributed to a particular policy (since a policy is defined for each Epoch). Where these costs are not discounted, they are assumed to be equally distributed over 100 years (in the absence of further information) and discounted to present value. Where these costs are already discounted, it is not possible to apply further adjustments to disaggregate them over time are attribute them to Epochs or policies. These costs are excluded from the reporting as their timing and nature are not clear and adding them would introduce uncertainty to the interpretation of overall cost of implementing SMPs. This applies to the following seven policy units:

SMP	Policy unit	Omitted present value cost (£m, 100 yrs)
SMP 15 - Hurst Spit to Durlston Head	CHB.F.2	69
SMP 17 - Rame Head to Hartland Point	5.2	8
SMP 2 - The Tyne to Flamborough Head	22.3	2
SMP 3 - Flamborough Head to Gibraltar Point	I - undefended	59
SMP 3 - Flamborough Head to Gibraltar Point	L	94
SMP 7 - Lowestoft Ness to Felixstowe	9.1	68
Total		301

F.4 Benefits of SMPs

The benefits of implementing SMPs are based on estimating the avoided damages to properties from flooding and delayed damages of the impact of erosion.

F.4.1 Weighted average annual damages (WAADs)

Weighted average annual damages (WAADs) to properties were derived for each of the 20 SMPs in scope, following the method outlined in Penning-Roswell et al. (2017) using:

- The Environment Agency's National Receptor Dataset for 2014, a more recent version than the one used in SMPs;
- The Environment Agency's flood zone maps to determine the number of properties in different flood zones (e.g. with a 1:200 or 1:1,000 risk of flooding); and
- Average damage estimates from Penning-Roswell et al. (2017)

WAADs are estimated at the SMP level and reflect the damages that would be incurred in the NAI scenario[13]. To use them in the CBA, they should be linked to policy scenarios (e.g. NAI, HTL, MR, ATL) which are specified at the PU level. Estimates are therefore scaled down to the PU level using the length of PUs that is flood prone as a proportion of the total length of the SMP in which they are located. The separation of the length of PUs that is flood prone versus at risk of erosion is achieved using data from the National Coastal Erosion Risk Mapping (NCERM) as shown in the table below.

SMP	Length of coast at risk of flooding (%)	Length of coast at risk of erosion* (%)	Total (%)
SMP 1 - Scottish Border to the Tyne	16%	84%	100%

[13] Estimating WAADs at the PU level is beyond the scope of the study as it would require defining over 1,500 PUs as polygons in GIS to ascribe properties at risk of flooding to each polygon without overlaps.

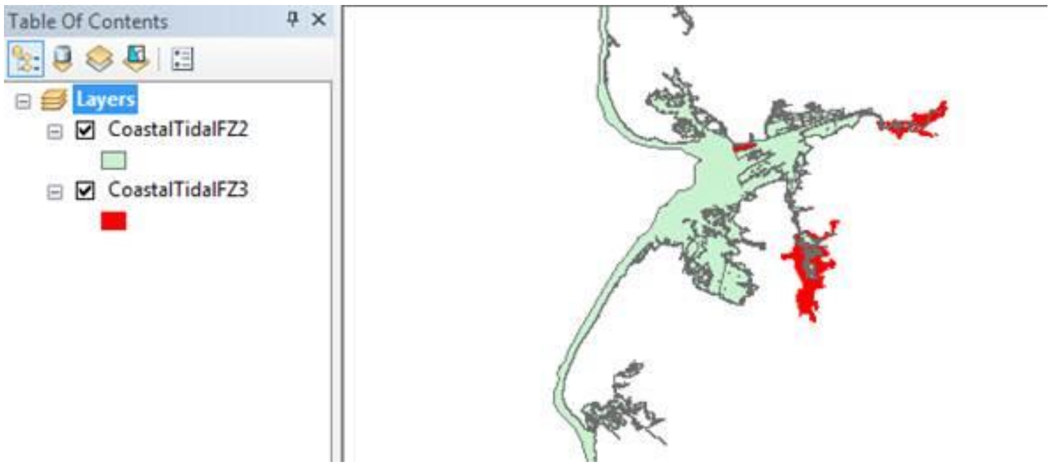
SMP	Length of coast at risk of flooding (%)	Length of coast at risk of erosion* (%)	Total (%)
SMP 2 - The Tyne to Flamborough Head	17%	83%	100%
SMP 3 - Flamborough Head to Gibraltar Point	59%	41%	100%
SMP 4 - Gibraltar Point to Hunstanton	98%	2%	100%
SMP 5 - Hunstanton to Kelling Hard	69%	31%	100%
SMP 6 - Kelling Hard to Lowestoft	25%	75%	100%
SMP 7 - Lowestoft Ness to Felixstowe	59%	41%	100%
SMP 8 - Felixstowe to Two Tree Island	85%	15%	100%
SMP 9 - Medway & Swale	90%	10%	100%
SMP 10 - Isle of Grain to South Foreland	49%	51%	100%
SMP 11 - South Foreland to Beachy Head	19%	81%	100%
SMP 12 - Beachy Head to Selsey Bill	24%	76%	100%
SMP 13 - Selsey Bill to Hurst Spit	41%	59%	100%
SMP 14 - Isle of Wight	34%	66%	100%
SMP 15 - Hurst Spit to Durlston Head	55%	45%	100%
SMP 16 - Durlston Head to Rame Head	26%	74%	100%
SMP 17 - Rame Head to Hartland Point	6%	94%	100%
SMP 18 - Hartland Point to Anchor Head	42%	59%	100%
SMP 19 - Anchor Head to Lavernock Point	68%	32%	100%
SMP 22 - Northwest England	50%	50%	100%

Notes: *Excludes erosion to complex cliffs.

The length of PUs is not available for PUs in the table below. For the purposes of the analysis, their length is assumed to be equal to the average length of PUs at the national level which is around 3.4 km.

SMP	Policy unit
SMP 17 - Rame Head to Hartland Point	14.8
SMP 17 - Rame Head to Hartland Point	20.3
SMP 17 - Rame Head to Hartland Point	26.3
SMP 22 - Northwest England	11c8.6

Note that for SMP 22, modelling provides a WAAD for non-residential properties with a 1:200 risk of flooding which is higher than for non-residential properties with a 1:1,000 risk of flooding. This does not accord with prior expectations and is a result of limitations in the national Flood Map for Planning data whereby the tidally tagged flood extents for the lower level of flood risk (FZ3) is greater than the flood extent given by the greater (more extreme) layer. The screen shot below shows an example of this by the red extents. The WAAD for properties with a 1:200 risk of flooding is therefore assumed to be equal to that properties with a 1:1,000 event.



The estimation of avoided damages using WAADs considers the sequence of policies over all Epochs for each PU rather than each policy in isolation. This takes into account the possibility that the benefits of a policy that occurs in one Epoch could extend to future Epochs. For example, the sequence of policies for a PU can be HTL/HTL/MR, moving from Epoch 1 to Epoch 3. The benefits in this case are the difference between damages in the do-nothing scenario (WAAD for properties with a 1:1,000 risk of flooding) and the residual risk to properties in the policy scenario. In Epoch 1 and Epoch 2 there is a residual risk to properties with less than a 1:200 risk of flooding. In Epoch 3 there is a residual risk to properties with a 1:2 risk of flooding which will be damaged following managed realignment. These properties are written off at their market value. The treatment of MR assumes that properties with a less than 1:2 chance of flooding are left better protected by the creation of new habitat created which provides flood risk attenuation benefits.

There are over 20 sequences of policies over the three Epoch for the PUs within the scope of this study. The table below details how the benefits of avoided damages from flooding are estimated for each sequence.

Policy scenario sequence	Avoided damages	Residual damages
HTL/HTL/HTL	• Avoided damages are WAAD for 1:200 throughout the whole appraisal period. between both • This assumes HTL does not protect properties with less than 1:1,000 risk of flooding. This is a conservative approach to avoid overstating the avoided damages of HTL as there would be different standards of protection across different SMPs.	• Residual damages are difference between WAAD for 1:1,000 and 1:200 event over 100 years
NAI/NAI/NAI	• Avoided damages are nil	• Residual damages are WAAD for 1:1,000 event
MR/MR/MR	• Avoided damages are difference between WAAD for 1:1,000 and 1:2 event • This assumes MR provides a greater level of protection to the properties that remain due to new habitat creation which delivers flood protection benefits • Properties with a 1:2 risk of flooding are written off at their market value using the regional average market price (10-year average) multiplied by number of properties with 1:2 risk of flooding • Land values have not been explicitly accounted for. Ideally if land in the 1:2 risk of flooding zone would not be damaged, the value of that land would be stripped out from the damage costs associated with MR. However, it is assumed that the land would be sufficiently damaged and/or be used for flood storage so there is no other alternative use of that land. The benefits of protecting properties against flooding will be captured in WAADs on the benefits side of the CBA. Thus, the value of land in terms of the flood storage it provides is intrinsically included in the CBA	• Write-off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • The cost of writing off properties is factored into the CBA in the first Epoch in which MR occurs • The market value for residential properties is sourced from the Land Registry's UK House Price Index • The market value for non-residential properties is estimated using the total capital value of properties (£) in the UK from the IPF[14] divided by the total flood space of properties (m^2) from the Penning-Roswell et al. (2017). This gives a value in £/m^2. This is multiplied by the average floor space per property (m^2/property) weighted by property type using the proportion of businesses per type from the ONS[15]. This gives a value in £/property terms. This is then multiplied by the number of non-residential properties with a 1:2 change of flooding. This is done in the absence of alternative publicly available information.
HTL/HTL/MR	• Epoch 1 avoided damages are WAAD for 1:200 event • Epoch 2 avoided damages are WAAD for 1:200 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 3 write off cost of properties with 1:2 risk of flooding
HTL/MR/MR	• Epoch 1 avoided damages are WAAD for 1:200 • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 write off cost of properties with 1:2 risk of flooding

[14] See: Investment Property Forum (IPF) (2017) The Size and Structure of the UK Property Market: End-2016 Update. http://www.ipf.org.uk/resourceLibrary/the-size-and-structure-of-the-uk-property-market---year-end-2016-update-july-2017-full-report.html [Accessed June 2018].

[15] See: Office for National Statistics (ONS) (2017) UK Business; Activity, Size and Location: 2017. https://www.ons.gov.uk/businessindustryandtrade/business/activitysizeandlocation/bulletins/ukbusinessactivitysizeandlocation/2017 [Accessed June 2018].

Policy scenario sequence	Avoided damages	Residual damages
	• Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 3 residual damages are nil because properties with 1:2 risk of flooding are written off in the first Epoch where MR occurs
HTL/MR/HTL	• Epoch 1 avoided damages are WAAD for 1:200 • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 write off cost of properties with 1:2 risk of flooding • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment
HTL/NAI/NAI	• Epoch 1 avoided damages are WAAD for 1:200 • Epoch 2 avoided damages are nil • Epoch 3 avoided damages are nil • This assumes HTL was for a defence reaching the end of its life and the benefits of HTL end abruptly after the end of the epoch	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 residual damages are WAAD for 1:1,000 event • Epoch 3 residual damages are WAAD for 1:1,000 event
MR/NAI/NAI	• Epoch 1 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs) • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs) • This assumes when MR is followed by NAI, properties which were better protected under MR will be at risk again. Properties with a 1:200 event are assumed to be at risk (excluding 1:2 event) to be consistent with the residual risk assumed for HTL.	• Epoch 1 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 2 residual damages are WAAD for 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs) • Epoch 3 residual damages are WAAD for 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs)
MR/HTL/HTL	• Epoch 1 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • This assumes when MR is followed by HTL, the investment in MR is upheld and the policy is to hold the new line	• Epoch 1 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 2 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment
MR/MR/NAI	• Epoch 1 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event Epoch 3 avoided damages are difference between WAAD	• Epoch 1 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 2 residual damages are nil because properties with 1:2 risk of flooding are written off in the first Epoch where MR occurs

Policy scenario sequence	Avoided damages	Residual damages
	for 1:1,000 and 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs) • This assumes when MR is followed by NAI, properties which were better protected under MR will be at risk again	• Epoch 3 residual damages are WAAD for 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs)
HTL/HTL/ATL	• Epoch 1 avoided damages are WAAD for 1:200 event • Epoch 2 avoided damages are WAAD for 1:200 event • Epoch 3 avoided damages are WAAD for 1:1,000 event	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 3 residual damages are nil because new defences are built on the seaward side of the existing defence line to reclaim land • Residual damages are nil because new defences are built on the seaward side of the existing defence line to reclaim land and better protect inland properties.
HTL/HTL/NAI	• Epoch 1 avoided damages are WAAD for 1:200 event • Epoch 2 avoided damages are WAAD for 1:200 event • Epoch 3 avoided damages are nil • This assumes HTL was for a defence reaching the end of its life and the benefits of HTL end abruptly after the end of the epoch	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 3 residual damages are WAAD for 1:1,000 event
HTL/MR/NAI	• Epoch 1 avoided damages are WAAD for 1:200 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:200 (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs)	• Epoch 1 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 write off cost of properties with 1:2 risk of flooding • Epoch 3 residual damages are WAAD for 1:200 event (less WAAD for 1:2 event for which properties are written off in the Epoch when MR first occurs)
NAI/MR/MR	• Epoch 1 avoided damages are nil • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 1 residual damages are WAAD for 1:1,000 event • Epoch 2 write off cost of properties with 1:2 risk of flooding • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding are written off in the first Epoch where MR occurs
MR/MR/HTL	• Epoch 1 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • This assumes when MR is followed by HTL, the investment in MR is upheld and the policy is to hold the new line	• Epoch 1 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 2 residual damages are nil because properties with 1:2 risk of flooding are written off in the first Epoch where MR occurs • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment
NAI/NAI/MR	• Epoch 1 avoided damages are nil • Epoch 2 avoided damages are nil	• Epoch 1 residual damages are WAAD for 1:1,000 event • Epoch 2 residual damages are WAAD for 1:1,000 event

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Policy scenario sequence	Avoided damages	Residual damages
	• Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event	• Epoch 3 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs
ATL/HTL/HTL	• Epoch 1 avoided damages are WAAD for 1:1,000 event • Epoch 2 avoided damages are WAAD for 1:1,000 event • Epoch 3 avoided damages are WAAD for 1:1,000 event	• Residual damages are nil because new defences are built on the seaward side of the existing defence line to reclaim land and better protect inland properties.
MR/HTL/MR	• Epoch 1 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • This assumes when MR is followed by HTL, the investment in MR is upheld and the policy is to hold the new line	• Epoch 1 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 2 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment
NAI/MR/HTL	• Epoch 1 avoided damages are nil • Epoch 2 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • Epoch 3 avoided damages are difference between WAAD for 1:1,000 and 1:2 event • This assumes when MR is followed by HTL, the investment in MR is upheld and the policy is to hold the new line	• Epoch 1 residual damages are WAAD for 1:1,000 event • Epoch 2 write off cost of properties with 1:2 risk of flooding in first epoch when MR occurs • Epoch 3 residual damages are nil because properties with 1:2 risk of flooding have been written off and the policy is to hold the new line following managed realignment
NAI/HTL/HTL	• Epoch 1 avoided damages are nil • Epoch 2 avoided damages are WAAD for 1:200 event • Epoch 3 avoided damages are WAAD for 1:200 event	• Epoch 1 residual damages are WAAD for 1:1,000 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event
NAI/NAI/HTL	• Epoch 1 avoided damages are nil • Epoch 2 avoided damages are nil • Epoch 3 avoided damages are WAAD for 1:200 event	• Epoch 1 residual damages are WAAD for 1:1,000 event • Epoch 2 residual damages are difference between WAAD for 1:1,000 and 1:200 event • Epoch 3 residual damages are difference between WAAD for 1:1,000 and 1:200 event

In addition to direct damages, indirect damages are also accounted for by upscaling direct damages following the approach in Environment Agency (2014) and Sayers (2015). This accounts for:

Factor	Estimates from LTIS2014 (**)
P: Uplift Property damages estimated by using WAAD instead of flood depths.	18% (9% - 28%)
RTL: Risk to life (deaths and stress)	16%
TA: Temporary Accommodation	5%
V: Vehicles	5%
ES: Emergency Services	5%
LG: Local Government	8%
A: Agriculture	3%
T: Transport	13%
U: Utilities	18%

This equates to multiplying residual damages by a factor of around 2. This is the same approach used the Sayers (2015) but with the inclusion of an uplift when using WAADs to account for flood depth (P in the table above).

F.4.2 Delayed damages from erosion

The estimation of delayed damages to properties from the impact coastal erosion is based on estimating the asset value of properties in the NAI scenario versus a scenario with coastal protection (i.e. where the policies in SMPs are implemented). The number of properties at risk of erosion is estimated in Part I of the study and reported in Section 2. This consists of properties at risk of erosion in the NAI scenario and properties at risk when the net impact of implementing SMP policies is taken into account, as follows:

- If the SMP policy is HTL in Epoch 1, 2 and/or 3, no erosion is calculated;
- If the SMP policy is MR in Epoch 1, 2 and/or 3, any erosion is manually defined. In some cases, the distance inland of managed realignment is known so defined in that way. In other places, MR is the same as NAI, so MR distances were manually adjusted to match NAI scenario distances. There are some cases where the future extent of MR is uncertain so a nominal (0.1m of recession or similar) is assigned; and
- If the SMP policy is NAI, then erosion is calculated. If an area has a policy of HTL in Epoch 1 or 2 but NAI or MR in epoch 2 or 3, erosion is 'delayed' until the Epoch where NAI or MR occurs.

The asset value of properties with and without coastal protection is estimated following the method outlined in Penning-Roswell et al. (2017). The benefits of delayed damages from erosion per properties are estimated by the difference between the two following equations:

$$Present\ value\ without\ coastal\ protection = MV \times \left(1 - \frac{1}{(1+r)^{p}}\right)$$

$$Present\ value\ with\ coastal\ protection = MV \times \left(1 - \frac{1}{(1+r)^{(p+s)}}\right)$$

Where:

- MV is the market value of a property;
- r is the discount rate;
- p is the lifetime of a property at risk of erosion without coastal protection; and
- s is the lifetime of the coastal protection project.

The lifetime of the coastal protection project is assumed to last for the full appraisal period (s = 100 years). It is assumed that without protection, properties at risk of erosion will be destroyed halfway into the Epoch within which they are at risk. This is shown in the following table.

Epoch	Length of Epoch	Lifetime of property without coastal protection (p)
Epoch 1 (2005 -2025)	20 years	p = 10 years = half length of Epoch 1
Epoch 2 (2025 – 2055)	30 years	p = 35 years = length of Epoch 1 + half of length of Epoch 2
Epoch 3 (2055 – 2105)	50 years	p = 75 years = length of Epoch 1 + length of Epoch 2 + half length of Epoch 3

Where the equations above generate benefits that exceed the market value of properties at risk of erosion, the benefits are capped to the market value of properties.

The benefits of delayed damages from the impact of coastal erosion are presented at the SMP level. They are summed with the benefits of avoided damages from flooding, in (2) above, at the SMP level as this is their common unit of analysis. At the national level, properties which are at risk of flooding are generally not also at risk of erosion so summing the two benefits estimates does not constitute double-counting.

F.5 Sensitivity testing

Sensitivity testing is undertaken for low and high climate change scenarios. This considers alternative factors for adjusting the costs of SMPs to account for asset deterioration. This follows the guidance for preparing SMPs.

The following uplift factors are used:

Epoch	Low climate change scenario	Base case (adopted in SMPs)	High climate change scenario
Epoch 1 (2005 – 2025)	x 1.0	x 1.0	x 1.0
Epoch 2 (2025 – 2055)	x 1.3	x 1.5	x 2.0
Epoch 3 (2055 -2105)	x 1.5	x 2.0	x 3.0

Note that the factors above are driven by the impact of sea level rise (an average of 1-2 mm per year based on IPCC (2002)) on assets (e.g. sea walls) and the need to strengthen them. The factors therefore reinforce preferred policies in SMPs rather than exploring the possibility of alternative policies due to the impacts of climate change e.g. relocation.

Further sensitivity testing is undertaken using upper and lower estimates of erosion and is reported in Section 3.6.

Appendix G – Maps of costs of SMPs by Epoch

See separate file:

- <Appendix G Maps of SMP costs_210718.pdf>

Appendix H – Approach to dealing with uncertainty in adaptation decision-making

H.1 Introduction

This appendix explains the conceptual issues of climate change projections and inherent uncertainty in the impacts of climate change at coastal sites that need to be considered when developing coastal change adaptation pathways. It concludes with discussion of how these issues and uncertainties have been taken into account in developing risk-based decision-making within the adaptation pathways that we have developed for each of the six case study sites assessed for this research project, drawing on experience of developing adaptation pathways in the UK and internationally.

H.1.1 The implications of climate change on coastal sites

The UK Foresight Flood and Coastal Defence Project considered the implications of climate change on coastal processes including the interrelated hazards of coastal flooding and erosion. It estimated that damage due to both hazards was set to rise significantly due to the potential implications of climate change over the course of this century (Evans et al, 2004).

The effects of climate change in coastal areas are driven by a series of physical variables including: mean sea level; surges and extreme water levels; and waves. Projected values for these variables are given in UKCP09 (Lowe et al., 2009). The UKCP09 projections indicate a gradual increase in mean sea level, accompanied by possible slight increases in surges, extreme water levels and waves.

UKCP09 considers sources of uncertainty affecting these projections and evaluates extent of uncertainty around the projected values. This allows the implications of uncertainty to be taken into account in any analysis of climate change impacts and in decision-making on how best to respond to the future implications of climate change.

Coastal erosion and flooding are significant threats to populations and assets in coastal areas. The impacts of climate change on coastal erosion, via the mechanism of sea-level rise, have been considered by Masselink and Russell (2013). They argue that a rise in sea levels typically leads to erosion of the lower part of the nearshore profile and deposition on the upper part of the profile, causing coastal systems to migrate landward, suggesting that “in the absence of a clear understanding of the coastal-change processes … the default position is to assume that present-day coastal change will persist; however, it is very likely that currently eroding stretches of coast will experience increased erosion rates due to sea-level rise”.

They also note that erosion in some areas of coastline will lead to accretion in at other coastal sites: “managed realignment is likely to increase in the future as a key management strategy and although this will result in increased local erosion rates, the enhanced erosion may benefit other sections of coast by reducing erosion or even causing accretion” and point out that adaptation is “emerging as the key coastal management paradigm to cope with coastal erosion”.

In considering the implications of climate change at the case study sites selected, the response of coastal processes to sea-level rise and other effects of climate change is likely to be strongly determined by site-specific factors such as the topography, natural landforms and geomorphological systems within the coastal zone, as well as land use, the presence of communities, critical infrastructure and existing coastal management FCERM interventions.

The Climate Change Risk Assessment (CCRA) Evidence Report (2016) concluded that more action is needed to address future flooding and coastal change risks to communities, businesses and infrastructure in coastal areas. The report identified a series of different types of risk and opportunity that could affect coastal areas, which we have considered in identifying our case-study sites, as indicated in the following table.

Table H. 1: Coastal zones risks and opportunities

Climate-change induced drivers	Coastal zone risks and opportunities identified in CCRA Evidence Report (2016)	Particularly relevant to the following case study areas
Sea-level rise, leading to flooding and coastal erosion	Will increase the threat to existing infrastructure networks (including flood and coastal erosion risk management infrastructure). Can lead to loss of coastal business locations and the infrastructure they rely on, that, for example, provide access, power and communications. May affect activities dependent on the cultural value of these locations, such as tourism.	All the case study sites
Sea level rise	Will threaten coastal ecosystems, many of which are important for buffering flooding and coastal erosion	North Fambridge Sefton (Formby Point)
Extreme water levels	Will accelerate rates of coastal erosion and put increasing lengths of the UK rail network at risk, as well as sea walls that protect coastal settlements	Dawlish East Riding of Yorkshire coast Great Yarmouth Preston Beach
All the above	The residual risk of flooding and erosion could remain high since improved flood defences will not be possible or affordable in every area. Coastal communities already vulnerable to coastal erosion and sea level rise face increasing levels of risk, especially in areas where formal flood defences are unlikely and long-term viability is at risk; and with climate change, a greater disparity in risk between protected and non-protected areas may emerge. But, warmer temperatures may encourage an increased number of visitors to the UK's national parks, beaches and open spaces.	All the case study sites

By identifying and trying to understand the root-causes of climate change induced risks and opportunities at each site, the timescales over which they could evolve and their potential severity we can determine the types of intervention and their timing that need to be considered to deal with the implications of climate change.

H.1.2 Dealing with uncertainty in assessing the implications of climate change

Decisions on how and when to adapt to changing coastal flooding and erosion needs to take account of the inherent uncertainty bound up in the causes of climate change and in estimating the potential effects of climate change. The principal sources of uncertainty lie in:

- the future levels of Green-House Gas (GHG) emissions;
- converting levels of GHG emissions to climate change projections via modelling;
- assessing the responses of natural and man-made systems and the environment to projected changes in the climate.

These three sources of uncertainty are dealt with in the following ways:

h) **Different GHG emissions scenarios** – the UKCP09 projections are based the three GHG emissions scenarios ('High', 'Medium' and 'Low' emissions). Consideration is also given to the H++ scenario[16]. The uncertainty associated with each scenario is reported. In general, the higher the rate of emissions the more rapid the rate of change in the projected parameter. This is illustrated in Figure H.1 from UKCP09 (Lowe *et al*., June 2009).

i) **The inherent uncertainty in the projections for each scenario developed through climate change modelling** – this is also reported by UKCP09. The higher the associated uncertainty, the higher the potential for variability in the future rate of change in the projected parameter as illustrated in Figure H. 1 (a reproduction of Figure 3.4 in UKCP09, 2009).

[16] There are some uncertainties involved in making projections of sea level into the future which are currently not very well constrained. For this reason, a High-plus plus (H++) scenario is also developed for vulnerability testing. The top end of this scenario range is currently believed to be very unlikely to occur during the 21st century, but cannot be completely ruled out.

Figure H. 1: The inherent uncertainty in projections for sea-level rise *(from UKCP09, 2009)*

	5th Percentile	Central estimate	95th Percentile
High emissions	15.4	45.6	75.8
Medium emissions	13.1	36.9	60.7
Low emissions	11.6	29.8	48.0

Table 3.3: UK absolute time mean sea level change (cm) over the 21st century (representing average in region shown in Figure 3.3), including ice melt, under three different scenarios, with 5th to 95th percentile confidence intervals. The changes are given for the period 1980–1999 to 2090–2099.

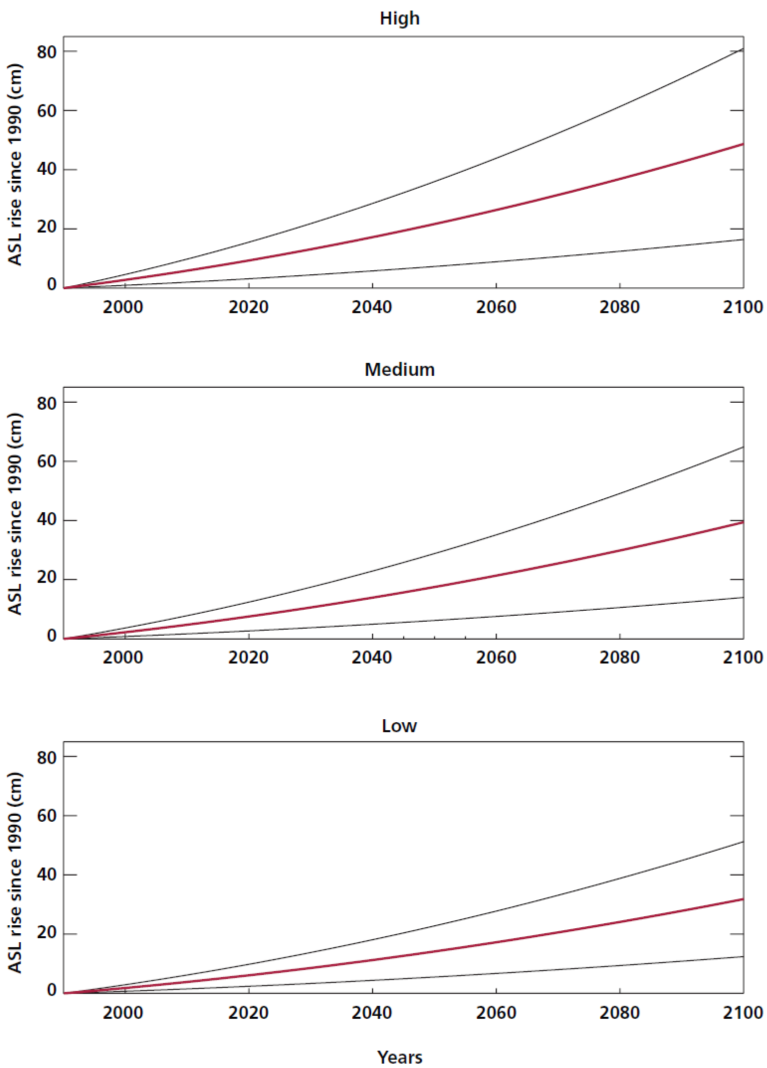


Figure 3.4: Estimated UK absolute sea level (ASL) rise time series for the 21st century (representing the average for masked region shown in Figure 3.3). Central estimates (thick lines) for each of three scenarios (low, medium and high emissions) shown together with range given by 5th and 95th percentiles (thin lines).

j) The third source of uncertainty is **the degree of variability in the actual impacts of climate change** on marine and coastal processes. This variability is in part, inherent natural variability. It is also due to the propagation of uncertainty (associated with climate change projections) through the dynamics of coastal zone processes (e.g. those determining flooding, erosion and deposition) and the interactions between different marine and coastal processes (e.g. the interaction between sea level rise and extreme sea levels); remembering also that these are, in turn, modified by human interventions in many areas. This highly <u>uncertain</u> future variability could manifest itself through unexpectedly extreme events at coastal sites where a combination of high tides and storm surges could trigger sudden and catastrophic erosion and flooding; the frequency of such extreme severe storm events are also predicted to increase as the climate changes[17].

H.2 Dealing with uncertainty in developing adaptation pathways

The first two (scenario-based) sources of uncertainty can be dealt with by adjusting the timeline for adaptation. This is based on the (approximate) assumption that a more rapid change in climate change parameters could have the practical implication of bringing forward decisions and increasing the required rate of adaptation. An example from Haasnoot et al. (2013) is provided in Figure H. 2 to illustrate the use of this approach through alternative time-bars and the implications of two scenarios ('Warm' and 'Crowd') on adaptation timescales.

Figure H. 2: An example of using alterative time-bars to indicate alternative scenarios influencing adaptation *(from Haasnoot et al., 2013)*

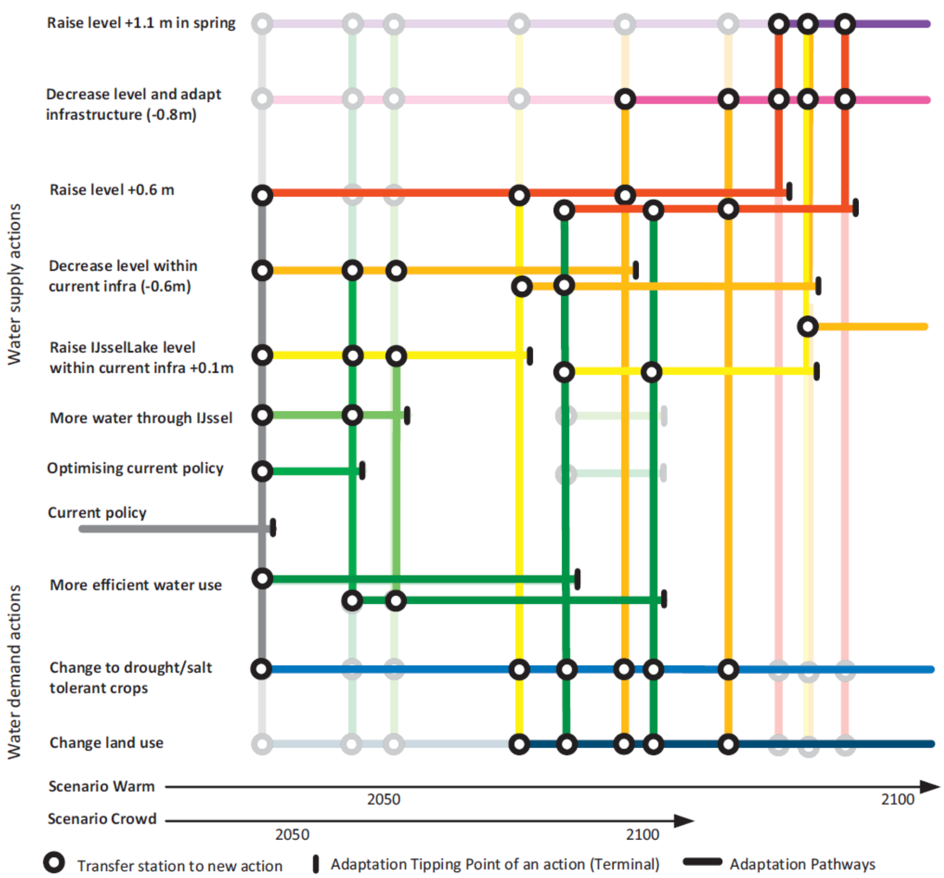


Fig. 6. Adaptation pathways map for fresh water supply from the IJsselmeer area.

Examining Figure H. 1, (Figure 3.4 from UKCP09, 2009), indicates that the central estimate sea-level rise of about 19 cm is projected for 2055 (the end of Epoch 2 as used in developing SMPs) under the 'Medium' emissions scenario. The same rise is projected to occur at around 2040 under the 'High' emissions scenario and at around 2060 for the 'Low' emissions scenario. The results of applying a similar interpretation for the ends of Epoch 1 (2025) and Epoch 3 (2105) are summarised in Table H. 2. In reviewing this table, it should be noted that the values relate to application of current sea level rise guidance, which was published after SMP2s were

[17] "Coastal Change Engagement Toolkit: A step by step guide". Living with a Changing Coast (LiCCo) project report (2015).

produced. SMP2s used the previous Defra guidance on sea level rise from 2006 which assumed an annual linear rate of increase of between 4 and 6mm per year.

Table H. 2: End of Epoch dates inferred from projections for sea-level rise under different emissions scenarios *(values taken from UKCP09, 2009)*

Epochs used in developing SMP's	End of epoch dates across the central estimates of average SLR		
	'Medium'	'High'	'Low'
Epoch 1	2025	2020	2030
Epoch 2	2055	2040	2060
Epoch 3	2105	2085	210?*

Notes- *Question mark reflects uncertainty.

If the SMP2s were to have been completed using the current sea level rise guidance based on UKCP09, the results in Table H.2 indicate, for example, that a 'High' emissions scenario would imply approximate end of SMP epochs in the year 2020 in Epoch 1, 2040 in Epoch 2, and 2085 in Epoch 3. This is in contrast to end of epoch dates of 2025 in Epoch 1, 2055 in Epoch 2, and 2105 in Epoch 3 for the 'Medium' emissions scenario based on projected central estimates of average sea-level rise.

Based on <u>central estimates</u> of average sea-level rise projections for each emissions scenario:

- SMP Epoch 1 could end between 2020 and 2030;
- SMP Epoch 2 could end between 2040 and 2060; and
- SMP Epoch 3 could end between 2085 and 210?

This inherent uncertainty means that the SMP epoch boundaries should not be considered as "fixed boundaries" at specific points in time. In developing SMP's, they were considered as approximate timings of policy / management approach implementation over time. Epochs were implicitly driven by the notion of trigger levels being reached at some point in the future (but not necessarily at an SMP epoch boundary), and informed by ongoing monitoring of physical processes and asset condition.

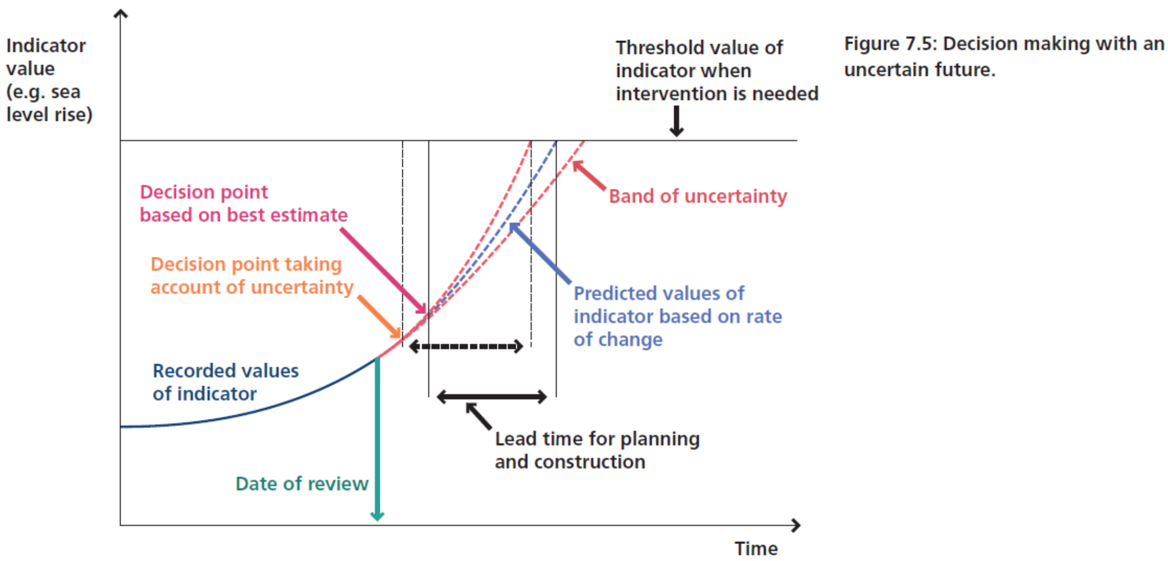
In developing the adaptation pathways for the six case study areas, the broad timelines on each pathway are indicated in terms of SMP epochs to make the link to the SMP for each area. However, decision points within the adaptation pathways would in practice respond to triggers being hit and thresholds being reached irrespective of SMP epoch within which these could occur.

If the inherent uncertainty in the projections for each scenario, as shown in Figure 3.4 in UKCP09 (2009) is taken into account in addition to the central estimates for each scenario, then the ranges indicated in the Epoch boundaries will increase beyond those listed above.

The third source of uncertainty also influences the timing of the adaptation decision-making process. This combination of uncertainty and variability indicates the need for embedding precaution within the decision-making process by taking a decision on adaptation before the climate change projection crosses a threshold – see Figure H. 3 based on Figure 7.5 from Chapter 7 of UKCP09 (2009). This advice on precautionary decision-making is endorsed by Defra and the UK Treasury guidance[18].

[18] UK Treasury & Defra. *Accounting for the Effects of Climate Change - Supplementary Green Book Guidance*. June 2009

Figure H. 3: The conceptual basis of precautionary decision-making *(from UKCP09, 2009)*



Clearly, the decision on when to adapt needs to be taken before a threshold is reached, but how early? The above figure shows caution in the face of uncertainty and the possible lead-time for planning and construction of adpatation schemes (which was an important consideration in developing the Thames Estuary 2100 flood risk adpatation strategy, from which this diagram has been taken).

A third consideration in when to make a decision is the level of consequence of crossing a threshold in terms of loss and/or damage. The higher the potential consequences, the more urgent the need to trigger an early decision to select and implement a reponse. The decision would be influenced by the nature of the risk; for example, if the risk is from coastal erosion then the consequence is likely to be a total loss of assets, whereas if the risk is from coastal flooding the consequence could be more frequent inundation (causing periods of damage and disruption) rather than a total loss of assets.

H.3 Approach adopted for this study

We have adopted the following approach in embedding (risk-based) decision-making within the adaptation pathways that we have developed for each case study site:

- we have defined what we mean by *triggers*, *thresholds* and *decision points*;
- we have considered the influence of prevailing levels of risk at each site; and
- we have then considered how the above affect the timing of the decision point.

H.3.1 Defining triggers, thresholds and decision points

We have based the following definitions of ' *triggers*, *thresholds* and *decision points* on Australian guidance by CSIRO (2016)[19]:

[19] Siebentritt, M.A. and Stafford Smith, M. (2016). *A User's Guide to Applied Adaptation Pathways Version 1*. Seed Consulting Services and CSIRO

- A *trigger* occurs when a condition (e.g. sea-level rise, erosion, etc) reaches a point where existing policies and responses should be reviewed
- A *decision point* occurs when a choice needs to be made between alternative future responses to avoid conditions reaching a threshold
- A *threshold* is a limit that, once crossed, could result in fundamental change in the level or extent of coastal flooding and coastal erosion – because of this threat of fundamental change, a threshold is sometimes referred to as a 'tipping-point'.

H.3.2 Determining the timing of triggers and thresholds

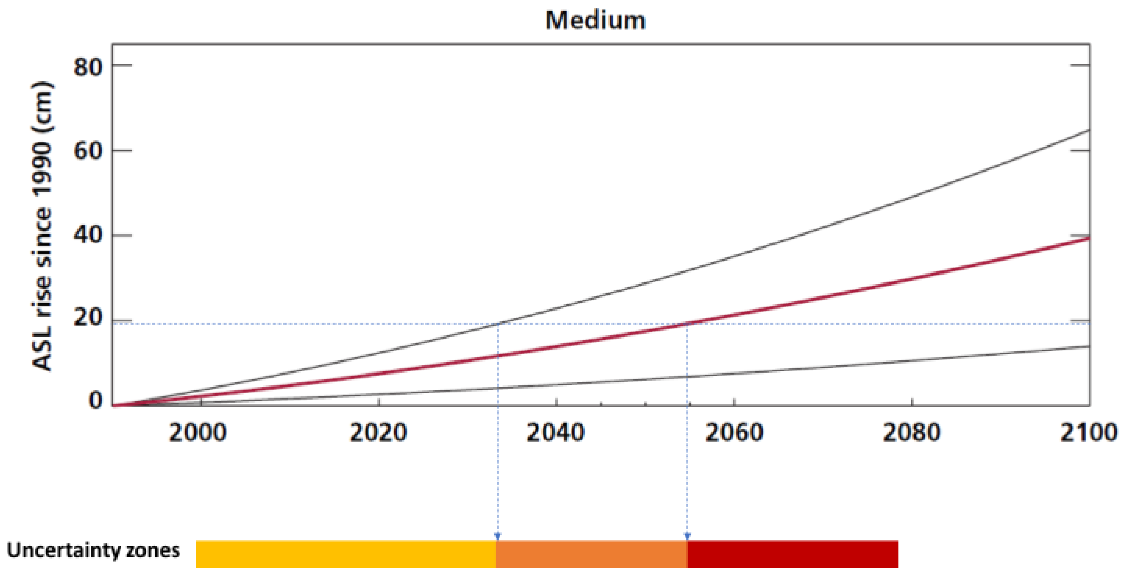
Forecasting the most likely time for conditions to reach *triggers* and then to cross *thresholds* is made difficult by uncertainty. *Thresholds* are typically associated with physical limits to what can be managed in terms of, say, erosion control, or contained in terms of flooding.

We propose three zones of uncertainty associated with determining when a threat associated with climate change could cross a *threshold*:

- **'Yellow' zone** – here the level of threat is heading in the direction of a *threshold* and may be approaching the 'freeboard' or buffer zone around the threshold. Although it is unlikely that threshold will be crossed in the short term, there will be an emerging concern about how best to prevent the threat crossing the threshold (e.g. by raising the threshold) or by modifying the threat. The temporal extent of the Yellow zone reflects the uncertainty around not being able to forecast the actual rate at which the level of threat will increase towards the threshold. The actual rate of change of the threat will depend on underlying directions and rates of change *onto which directions and rates of change due to climate change will be superimposed*. The 'Yellow' zone signals a need to monitor rates of change against latest available climate change projections and to identify and evaluate future adaptation options.
- **'Orange' zone** – here the level of threat will have entered the 'freeboard' or buffer zone (against uncertainty) around the *threshold*. It is now a possibility that an extreme event could cross the threshold as underlying conditions approach it. There will now be serious concern; a decision needs to be taken on what is the best adaptation action and implementing it. As in the case of the 'Yellow' zone, its projected timing is uncertain as this depends on underlying directions and rates of change onto which directions and rates of change due to climate change are superimposed.
- **'Red' zone** – here the level of threat is at the *threshold*, and could cross it, either in the form of an extreme event or through underlying change. Ideally, a decision on the best form of response needs will have been taken during the 'Orange' zone and a preferred adaptation response implemented (proactively) before the Red zone is entered. The extent of the 'Red' zone depends on the influence of uncertainty and extends to a point in time by which the threshold is very likely to have been crossed.

The conceptual basis for the three uncertainty zones is illustrated in Figure H. 4. This figure has been developed by taking, as an example, projected sea-level rise (based on UKCP09 data) and identifying, from the graph, uncertainty zones that could apply in 2055 (the end of Epoch 2 in the SMP's).

Figure H. 4: Estimating the timing of uncertainty zones using projected Absolute Sea Level (ALS) rise for the UKCP09 Medium emissions scenario



Issues such as those summarised in Table H. 3, characterise each of the three uncertainty zones, applied to the processes of *coastal erosion*, *coastal flooding* and the *deterioration of coastal FCERM assets*.

Table H. 3: Typical characteristics associated with each uncertainty zone

Key threats	Yellow	Orange	Red
Gradual or sudden increase in erosion due to climate change (interacting with changes in underlying processes of coastal geomorphology)	- Emerging concern: erosion rates are at the lower limit of what is considered acceptable in terms of erosion	- Concern over increasing erosion rates - Threshold being approached	- Serious concern over high erosion rates - Threshold will be crossed if no action taken
Gradual or sudden increase in flooding (due to climate change impacts and underlying processes of coastal geomorphology on extreme peak sea-levels)	- Emerging concern: frequency of extreme peak water levels reaching lower limit of 'freeboard' allowance on flood defences	- Frequency of extreme peak water levels exceeding design limit of flood defences is increasing	- Serious concern over flood threat - Peak extreme water will exceed design limit of flood defences
FCERM asset failure condition and potential failure modes (which could be progressive or sudden)	- Asset condition starting to deteriorate, which could initiate progressive failure	- Asset condition deteriorating - Progressive failure starting in places but still time to repair	- Serious concern over asset condition - Progressive failure occurring and may exceed

Key threats	Yellow	Orange	Red
	- Low likelihood of sudden failure	- Medium likelihood of sudden failure	capacity to repair - High likelihood of sudden failure

H.3.3 Responding to threats

Having identified when thresholds could be crossed, we need to establish a set of *triggers* appropriate to each of the processes affecting the coastal site. *Triggers* are different in concept to *thresholds*; they indicate a situation that triggers the need to start developing adaptation responses to climate change threats. Setting a trigger needs to reflect the lead-time needed to implement potential future actions as well as the sense of urgency in needing to act taking site-specific conditions into account.

Typical adaptation activities associated with each uncertainty zone are indicated in Table H. 4.

Table H. 4: Typical adaptation activities associated with each uncertainty zone

	Yellow	Orange	Red
Adaptation activities within each uncertainty zone	- Identify and appraise potential adaptive responses - Assess lead times for future options, and start preparatory work if potential response(s) has/have a long lead-time - Check if enough time to implement a proactive adaptation response that would avoid a 'threshold' being crossed **The *trigger* that initiates the process of developing and evaluating adaptation responses is likely to have to be set within the 'Yellow' zone** **A decision may also need to be taken during the 'Yellow' zone if one or more options have a long lead time.**	- Check if still time to implement a proactive adaptation response that would avoid a 'threshold' being crossed - Start preparatory work (if preferred response has a short lead-time) - Start implementing preferred response (if long lead-time required) **A proactive decision will need to have been implemented by the end of 'Orange' zone at the latest.**	- Preferred response completed and operational - Alert emergency response providers as probably insufficient time to implement a proactive adaptation response (if preferred response not operational). **Only reactive decisions can take place as the threshold is likely to be crossed within the 'Red' zone.**

As indicated above, **triggers** typically need to be set within the 'Yellow' zone so that decisions to adapt can be taken and implemented within the 'Orange' zone prior to **thresholds** being crossed in the 'Red' zone. This suggests the following time-line for adaptation activities:

a) Pre-trigger: start the adaptation process, draw up adaptation pathways, assess the potential impacts of climate change threats on public safety and loss (noting the implications of this in assessing the urgency with which to adapt as summarized in Table H. 5 below) and allow sufficient lead-time in setting a decision point;

b) Between a trigger and a decision point: evaluate adaptation options and decide on a preferred option;

c) At a decision point: start to implement the preferred option and ensure timely implementation;

d) Pre–threshold: ideally implement (proactive) adaptation responses since only reactive responses will be possible post-threshold.

Table H. 5: Modifying the timing of decision-making by taking the level of threat into account

Level of threat		Level of uncertainty		
		Yellow	**Orange**	**Red**
Impact on public safety and likely level of loss/damage	**Low**	Planning	Act during zone	Act by start of zone
	Medium	Planning	Act early in zone	Act by start of zone
	High	Act by end of zone	Act at start of zone	Act by start of zone

Based on the above we have applied the following convention when drawing up the adaptation pathways:

a) Show the *trigger* mid-way during the 'Yellow' zone; and

b) Show the *decision point* at the end of the 'Orange' zone – this is a <u>default</u> position. In writing up each case we draw attention to responses with long-lead time and/or concerns over the impact on public safety of not deciding in time that might require an <u>earlier</u> decision to be made.