Climate Change Risk Assessment 2017

Projections of future flood risk in the UK

Project A: Report prepared for the Committee on Climate Change, UK

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ABSTRACT

The Government is required under the 2008 Climate Change Act to publish a climate change risk assessment (CCRA) every five years. The first assessment was published in 2012 and the next is due in 2017. The second CCRA will feed in to the development of the next National Adaptation Programme (for England) due in 2018, as well as the national adaptation programmes of Scotland, Wales and Northern Ireland. This report presents the analysis for future flood risks in support of these assessments.

The assessment of future flood risk presented considers three climate change scenarios (a 2^{o}C and 4^{o}C change in Global Mean Temperature by the 2080s and a H++ scenario) and, three population growth projections (low, high and no growth). For the first time the analysis presented covers the whole of the UK (England, Wales, Scotland and Northern Ireland) and the risks associated with coastal, fluvial, surface water and groundwater flooding. Eight individual Adaptation Measures (including, for example, spatial planning, flood defences, catchment storage) are used to construct five Adaptation Scenarios (including enhanced and reduced levels of adaptation ambition in comparison to present day). Future flood risks for a range of climate, population and adaptation combinations are assessed using the UK Future Flood Explorer and the results presented.

Keywords: flood, risk, climate change, risk assessment, adaptation

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SUMMARY

Background

Under the 2008 Climate Change Act the Government is required to publish a Climate Change Risk Assessment (CCRA) every five years. The first assessment was published in 2012. The second CCRA is due in 2017 and will feed into the development of the next National Adaptation Programme (NAP) for England due in 2018, as well as the national adaptation programmes of Scotland, Wales and Northern Ireland. This report focuses on the assessment of future flood risks and forms part of these activities.

Approach

The first CCRA in 2012 focused on river and coastal flooding (with quantified analysis primarily restricted to England and Wales). Little consideration was given to the assessment of other sources of flooding (surface water and groundwater flooding), primarily due to the lack of available data at the time. The analysis undertaken here (as part of the second CCRA) provides a broader assessment of future flood risks across the whole of the UK and takes account of four sources of flooding (coastal, fluvial, surface water and groundwater).

Two climate change projections (based upon a 2°C and 4°C change in Global Mean Temperature (GMT) by the 2080s from the 1990s baseline), a more severe H++ scenario and three population growth projections (low, high and no growth) are considered together with six Adaptation Scenarios (including assumed enhanced and reduced adaptation levels when compared to present day). Each Adaptation Scenario reflects a range of individual Adaptation Measures to manage the probability of flooding, manage exposure to floods and reduce the vulnerability of those exposed. Future flood risks are projected for the 2020s, 2050s and 2080s.

The UK Future Flood Explorer (FFE) is used to complete the analysis. The UK FFE uses nationally recognized source, pathway and receptor data from across the UK to construct an emulation of the present day flood risk system and to explore the future change in flood risk (taking account of climate change, population growth and adaptation). The flexibility of UK FFE enables multiple futures to be explored and compared, and for the first time, the impact of adaptation, climate change and population drivers to be disaggregated.

Uncertainties in the analysis

Significant effort has been directed towards confirming that the approach taken is fit for purpose. In common with any analysis of risk however the results are subject to uncertainty; this includes the information provided by the lead authorities that underpins the present day estimates of risk as well as estimates of future risk made here. Given these inherent uncertainties higher confidence should be placed in the relative change in risk and lower confidence in the absolute estimates of risk.

Key messages

How might risk change in the future if we continue to manage flood risk as present? If current levels of adaptation continue Expected Annual Damages (EAD) are projected to increase significantly by 2080s. The projected increases are 50% under the 2°C climate change projection, 150% under 4°C climate change projection, and six fold under the H++ scenario. When projections of population growth are included the risks increase further.

How might the spatial pattern of risk change? Proportional increases in risk at a UK scale are broadly reflected in increases for constituent countries. Within each country there are significant regional variations, with risk increases in some regions three times greater than in others.

What is the relative importance of climate change and population growth? Climate change is the main driver of increased risk. For example, the 2°C climate change projection results in a greater

increase in flood risk (in terms of Expected Annual Damages) than population growth alone, even assuming high growth.

Which flood sources are most important for risk today and in the future? The most significant source of flooding today (based analysis of the underlying data provided by the lead authorities in each country) is fluvial (river), contributing £560m (40%) of total UK EAD. Coastal flooding contributes £320m (24%), surface water £260m (20%) and groundwater £210m (16%). In the future all of these sources are projected to increase risk. At a UK scale the proportional increases for each source of flooding are similar under the 2°C and 4°C climate projections and therefore the percentage contribution from each source to risk in the future is similar to present day. Under the H++ scenario fluvial risk increases more than for the other sources.

Future change in groundwater flooding is dominated by flooding from permeable superficial deposits (PSD). PSD flooding responds to changes in the frequency of fluvial flooding and hence reflect changes in the frequency of fluvial flooding. Groundwater flooding from both chalk and non-chalk aquifers (so-called Clearwater flooding) makes a small contribution to present and future flood risk in England and Wales and no contribution in either Scotland and Northern Ireland (although there may be localised issues).

What are the implications of sea levels continuing to rise? Wave conditions around much of the UK coast are limited in size by the nearshore water depth. Because of this, relative Sea Level Rise (rSLR) has a dominant influence on coastal flooding,(increasing both wave driven overtopping, the chance of a breach probability and, in more extreme climate change projections, tidal overflow. A 0.5m sea level rise (approximately equivalent to a 4°C increase in GMT by the 2080s) would make some 200km of coastal defences (20% of the total length in England) highly vulnerable to failure. Significant additional investment would be required to sustain these defences in their current location. A 'what-if' analysis suggests that if these defences were lost, the inundated area during a 1:200 year return period coastal surge would significantly increase, resulting in an additional 310,000 properties being exposed to coastal flooding when compared to the same event occurring under current sea levels. A 1.5m rise in mean sea level would affect 300km of defences and potentially 540,000 properties.

What are the main impacts of future flooding? The number of residential properties exposed to flooding more frequently than 1:75 years (on average) increases significantly in all futures; increasing from 860,000 today to 1.2 million (a 40% increase) by the 2080s under a 2°C increase in GMT, and to 1.7 million (a 93% increase) under 4°C. Both of these estimates assume no population growth and adaptation continuing at current levels.

The area of Special Protection Areas, Special Areas of Conservation and Ramsar sites exposed to flooding more frequently than 1:75 (on average) increases by 25% and 44% for 2°C and 4°C respectively by the 2080s. The area of Best and Most Versatile (BMV) agricultural land at risk from flooding increases by 32% and 65% under these climate projections.

Impacts on social infrastructure are similar to those seen for residential property. By the 2080s the number of care homes located in the highest flood probability category increase by 48% and 140%; schools by 32% and 95%; emergency services sites by 36% and 100%; hospitals by 23% and 68%; and GPs surgeries by 46% and 140% for 2°C and 4°C respectively, assuming current levels of adaptation are continued and no population growth.

The increases in Expected Annual Damages are greater than increases in numbers of properties in areas mostly likely to be flooded. Present day Expected Annual Damages (based analysis of the underlying data provided by the lead authorities in each country) are estimated to be £1.1bn (for the UK as a whole, excluding groundwater); by the 2080s, these are projected to increase to £1.7bn (under 2°C climate change projection) and £2.8bn (under 4°C climate change projection), assuming no population growth and continuing adaptation at current levels. Under the high growth population projection, these figures increase to £1.8bn and £2.9bn for 2°C and 4°C respectively.

How the number of people at risk change, including in deprived communities? The total number of people living in properties exposed to flooding more frequently than 1:75 years (on average) increases from 1.8milllion in the present day to 2.5million (an increase of 41%) under 2°C climate change projection and 3.5million (an increase of 98%) under 4°C climate change projection by the 2080s, assuming current levels of adaptation are continued and no population growth. People living in properties located within the UK's most deprived communities face even higher increases in risk. The number of people in these areas exposed to flooding more frequently than 1:75 years (on average) increases by 48% and 110% under 2°C and 4°C respectively.

How might risk to national infrastructure change? Infrastructure assets will be subject to significant increases in risk; with the number of sites exposed to the highest chance of flooding (i.e. more frequently that 1:75 years on average) increasing by 30% (under 2^{o}C climate change projection) and 200% (4^{o}C climate change projection) by the 2080s. Local actions currently being taken to protect infrastructure assets (e.g. for electricity substations) to a 1:200 year return period standard are effective in reducing risk for the 2020s and 2050s; but protection to an even higher standard would be required to cope with climate changes anticipated for the 2080s.

Effects of climate change on transport infrastructure are also significant; the length of railway line located in areas exposed to flooding more frequently than 1:75 years (on average) increases in the 2080s by 53% and 160%; the length of major roads by 41% and 120%; the number of railway stations by 10% and 28% for 2°C and 4^{o}C respectively.

By how much can adaptation offset the projected increases in risk? Current levels of adaptation can offset a significant proportion of the projected increase in risk (30-50% of the EAD increase arising from climate change and population growth), but will not be sufficient to completely offset all of the projected increases under either a 2°C or 4°C climate change projection. Under more extreme climate change current levels of adaptation would do little to prevent a significant increase in risk.

Delivering enhanced levels of adaptation can offset all the increase in risk under the 2°C climate change and low population growth projection, and almost all the increase under a 2°C climate change and high population growth projection. Enhanced levels of adaptation can offset 70% of the increase in risk associated with the 4°C climate change and high growth projection. Achieving this level of adaptation is, however, ambitious and will require concerted action across all aspects of policy and implementation. It is also likely to require significant additional investment (both public and private), although the amount potentially required was not assessed as part of this report. . However, under a 4°C rise, even an enhanced level of adaptation will not be sufficient to completely offset the increase in flood risk from a combination of climate change and population growth.

What types of adaptation measures are most effective at reducing risk? The most effective Adaptation Measures (considered here) are those that act to reduce the probability of flooding. This includes improving defences, managed realignment on the coast, catchment management and urban runoff management through sustainable drainage systems (SUDS).

Spatial planning and building codes are already very effective at reducing the risk to new build properties within the coastal and fluvial floodplain (less so in areas prone to surface water or groundwater flooding) and remain an important component all future Adaptation Scenarios. The potential for perverse outcomes is highlighted where development is relocated away from one source of flooding (i.e. fluvial or coastal) into areas subject to either surface water or groundwater flooding.

Adaptations that focus solely on reducing exposure and vulnerability are less able to influence future risks than those providing a more comprehensive whole system adaptation response. This is because the estimated flood risk is dominated by the vulnerability of the existing stock of properties. Even under the highest level of adaptation considered here, take up of receptor level protection measures amongst existing residential and non-residential properties owners is limited (50% by 2080s in areas with a high chance of flooding).

What types of risks appear to be the hardest to manage? Properties that are currently located within the areas of the fluvial or coastal floodplain with a low standard of protection (i.e. less than 1:75 years) are projected to experience significant increases in risk. The assumption made here (in line with findings from the Environment Agency's Long Term Investment Scenarios, 2014) is that the national investment case for providing community scale defences to these areas is limited. The significant increase in risk appears under all Adaptation Scenarios, reflecting the difficulty of retrofitting property or community level protection.

Who will take the lead in adapting to future flood risks? The analysis highlights that the most significant contribution to reducing risk is achieved through a whole system approach to adaptation. Whole system adaptation requires action by a broad range of stakeholders, from national level down to individual households and businesses.

When is action needed? Significant increases in flood risk are projected to occur as early as the 2020s. For example, the number of residential properties exposed to flooding more frequently than 1:75 years (on average) is predicted to increase by 20% by the 2020s under the scenario which gives a 4°C rise in GMT by the 2080s; EAD is also predicted to increase by 30%. This reinforces evidence from recent climate attribution studies that suggest the influence of climate change on flooding, and hence flood risk, may already be detectable and should be anticipated. The need for early adaptation also reflects the long lead time required to implement policy change and the long lived nature of the decisions made today that influence future risk.

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LIST OF ABBREVIATIONS

AM	Adaptation Measure
AIMS	Asset Information Management System (used by the Environment Agency)
AS	Adaptation Scenario
ASC	Adaptation Sub-Committee
CCRA	Climate Change Risk Assessment
CG (rCg)	(Representative) Condition Grade of a flood defence asset. *Within this report Cg 3 is used to imply the asset is in 'fair' condition; 1 implies in as built condition and 5 implies poor condition.*
CLA	Current Level of Adaptation
CWF	Clear Water Flooding (i.e. groundwater flooding from chalk and limestone aquifers)
DA	Devolved Administration (Wales, Scotland and Northern Ireland)
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EAD	Expected Annual Damages
EFA	Exposure Focused Adaptation
EWS	Enhanced Whole System adaptation
FCERM	Flood and Coastal Erosion Risk Management
FFE	Future Flood Explorer (the analysis model used here)
FRM	Flood Risk Management
GCM	Global Circulation Model
GMT	Global Mean Temperature
ICT	Information and Communications Technology
LTIS	Long Term Investment Scenarios (as undertaken by the Environment Agency)
LUA	Local Unitary Authority
NAP	National Adaptation Programme
NaFRA	National Flood Risk Assessment (undertaken by the Environment Agency)
NAAR	National Assets at Risk (two studies completed by Defra in the late 1990s and early 2000s)
NFM	Natural Flood Management
NFRA	National Flood Risk Assessment (undertaken by SEPA)
NRD	National Receptor Database (England and Wales only)
NRW	Natural Resources Wales
MSfW	Making Space for Water
PFA	Probability Focused Adaptation
PSD	Permeable Superficial Deposits
RANI	Rivers Agency, Northern Ireland
RASP	Risk Assessment for Strategic Planning (method of risk analysis underpinning NaFRA and LTIS)
RBD	River Basin District
ReFH	Revitalised Flood Hydrology
RLP	Receptor Level Protection (including resistance measures – to prevent flood water entering a property – and resilient measures – to reduce the damage if flood water does enter a property)
RWS	Reduced Whole System adaptation
rSLR	Relative Sea Level Rise
SEPA	Scottish Environment Protection Agency
SOP (rSOP)	(Representative) Standard of Protection provided by a flood defence asset. *Used in this report to express the frequency – expressed as a return period in years – that a given defence is likely would be overwhelmed by a storm event; this includes significant wave overtopping, river overflow or surcharging.*
uFMfSW	Updated Flood Map for Surface Water
VFA	Vulnerability Focused Adaptation
WAAD	Weighted Annual Average Damage
WPD	Work Package D (of the CCRA focused on describing a H++ scenario)

GLOSSARY OF TERMS

Adaptation	The adjustment of behaviour to moderate harm, or exploit beneficial opportunities, arising from future change.
Adaptation Measure	An individual adaptation action taken to reduce risk. In the context of this report, this means managing the probability of flooding as well as the exposure and/or vulnerability of receptors.
Adaptation Scenario	The implementation of a particular combination of Adaptation Measures.
Coastal flooding	Flooding from the sea when tidal surge, wave action or a combination of tidal surge and waves overtop or overflow the shoreline boundary.
Climate Projection	A plausible climate future. Three climate changes projections are considered, namely a 2°C and 4°C change in GMT by 2080s (from the 1990 baseline) and a so-called H++ scenario that is not associated with a particular change in GMT.
Endogenous change	Changes to the flooding system that are either directly controlled or strongly influenced by flood risk management policy.
Exogenous change	Changes to the flooding system that are outside of the control of flood risk management policy.
Emulation	An interpolation and extrapolation of existing data to estimate future risks. The Future Flood Explorer, the model used here to estimate risk, uses an emulation based approach.
Flood risk system	The combination of sources, pathways and receptors that influence flood risk.
Fluvial flooding	Flooding from a watercourse when water from an established river or drainage channel spills onto the floodplain (also called river flooding).
Futures	A particular combination of climate change, population growth and adaptation.
Groundwater flooding	Flooding from the ground caused by high groundwater levels in aquifers.
Mitigation	Actions taken to reduce the causes of anthropogenic climate change (e.g. through the reduction of greenhouse gas emissions)
Relative Sea Level Rise	The increase in mean sea levels relative to the land. Relative Sea level rise is therefore a combination of the change in sea level and/or a change in land level.
Return period	The expected (mean) time (expressed in this report in years) between the exceedence of a particular extreme threshold (peak flow, inundation etc.). Various options are available to express the frequency of occurrence of an event or its annual exceedance probability. Return period is adopted in this report.
Surface water flooding	Flooding directly from a rainfall event prior to the generated run-off reaching an established river or drainage channel (also called pluvial flooding).

1.0 INTRODUCTION

1.1 Background

The Government is required under the 2008 Climate Change Act to publish a climate change risk assessment every five years. The first assessment was published in 2012 and the next is due in 2017. The Adaptation Sub-Committee (ASC) of the Committee on Climate Change provides independent evidence-based analysis and advice to Government on preparing for climate change. The ASC has statutory roles to advise Government on the UK Climate Change Risk Assessment (CCRA) and report to Parliament on the implementation of the National Adaptation Programme (NAP).

The Department for Environment, Food and Rural Affairs (Defra) has on behalf of the Government asked the ASC to prepare an independent evidence report to inform the next risk assessment by July 2016. The Government will then lay before Parliament its summary of the CCRA by January 2017. Both the ASC and Government reports will feed in to the development of the next UK National Adaptation Programme due in 2018, as well as the National Adaptation Programmes in Wales, Scotland and Northern Ireland.

The evidence report will cover all countries of the UK (England, Northern Ireland, Scotland and Wales) and will be used to inform future priorities for adaptation policy. It will not cover the Crown Dependencies or Overseas Territories.

For many sectors the evidence provided will be based on literature review and expert narrative. For four areas new evidence will be gathered, including:

- **Project A** (Sayers): Updated projections of future flood risk in the UK (**this report**)
- **Project B** (HR Wallingford): Updated projections of water availability for the UK
- **Project C** (AECOM): Aggregate assessment of climate change impacts on the goods and benefits provided by the UK's natural assets
- **Project D** (Met Office): Development of high-end scenarios for a number of climate impacts beyond sea level rise/storm surge

1.2 Aims and objectives

The aim of Project A is to assess the impact of climate change and population growth on future flood risk (to the 2080s) and the opportunity to manage these risks through adaptation. In doing so, the supporting analysis must:

- Be credible at the chosen scales of aggregation (UK wide, national and regional).
- Use data that are recognisable to lead authorities.
- Be consistently applied across the whole of the UK.
- Assess all sources of flood risk (fluvial, coastal, surface water and groundwater).
- Define a range of future adaptation scenarios and assess their ability to manage future flood risk.
- Consider combined scenarios of climate change, population growth and adaptation to enable a meaningful comparison between risks now and in the future.

Note:
Adaptation costs are out of scope. No attempt is made to identify those adaptations that present the best value for money or offer the most efficient course of action. The analysis presented here considers the benefits of adaptation benefits but not costs and is therefore distinct from studies such as the Long Term Investment Scenarios (LTIS), published by the Environment Agency (Environment Agency, 2014a), that explores how much should be spent to reduce risk (in England) based on optimising the Nett Present Value of the alternative investment choices.

Coastal and river erosion risks are out of scope.

1.3 Target audience

The primary audience for this report are the lead authors of the CCRA Evidence Report due to be published in July 2016. Given the expertise of this audience a reasonably high level of prior knowledge regarding the assessment of flood risk and the associated policy options is assumed.

Effort is made throughout the report to highlight the assumptions made as well as the confidence in the underlying data used and the results presented.

1.4 Report structure

Following this introductory chapter the report is structured as follows:

- **Chapter 2: Context of the assessment**: Sets out the time and spatial scales of the analysis together with the sources of flooding, the drivers of future change and risk metrics considered.
- **Chapter 3: Exogenous change: Climate and population projections**: Sets out the population and climate change projections used.
- **Chapter 4: Endogenous change: Adaptation Measures and Scenarios:** Sets out the individual Adaptation Measures (influencing probability, exposure and vulnerability) together with how individual Adaptation Measures have been brought together into Adaptation Scenarios.
- **Chapter 5: Overview of the Future Flood Explorer**: Summarizes the limitations and assumptions of the analysis method used as well as the key uncertainties and how these have been addressed.
- **Chapter 6: Future flood risk: Analysis results:** Provides an overview of the analysis runs undertaken and presents the headline results in table, map and chart form.
- **Chapter 7: The impact of sea level rise in England: A what if analysis:** Presents the results from a parallel analysis focusing on the potential impact of sea level rise in England.
- **Chapter 8: Discussion of results: Provides a discussion of the results and findings of the analysis.**
- **Chapter 9: Recommended future developments of the CCRA approach:** Provides a short summary of areas that could be developed to improve future risk assessments.
- **Chapter 10: References**

More detail on specific aspects is provided through a series of Appendices:

- Appendix A: Supporting datasets
- Appendix B: Population growth projections
- Appendix C: Climate change projections
- Appendix D: Groundwater analysis approach
- Appendix E: Individual adaptation measures
- Appendix F: The Future Flood Explorer: Overview
- Appendix G: Exploring the validity of present day risk estimates and verifying the FFE.
- Appendix H: Additional supporting tables and figures (in support of those presented in the Main Report)
- Appendix I: Independent Review: Comments and Responses

Note: Shaded 'Note' are used through the Main Report and Appendices to highlight assumptions made and known limitations within the data and analysis.

2.0 CONTEXT OF THE ASSESSMENT

2.1 Flood hazards

Four sources of flooding are considered:

- **River**: Flooding from a watercourse when water from an established river or drainage channel spills onto the floodplain (referred to here as **fluvial** flooding).
- **Coastal**: Flooding from the sea when tidal surge, wave action or a combination of tidal surge and waves overtop or overflow the shoreline boundary.
- **Surface water:** Flooding directly from a rainfall event prior to the generated run-off reaching an established river or drainage channel (also called pluvial flooding).
- **Groundwater:** Flooding from the ground caused by high groundwater levels in aquifers.

Top left: Fluvial flooding: *Tewksbury, UK July 2007 (Taken by: Environment Agency)*

Top centre Bristol road, Birmingham, 2000 (Taken by: John Blanskby)

Bottom centre: West Bay, Dorset, October 2004 (Taken by*: West Dorset District Council*)

Right: Groundwater flooding in Berkshire, March 2014 (Taken by: A McKenzie)

Figure 2-1 Fluvial, coastal, surface water and groundwater flooding

Note:

Credibility of the underlying data provided: All of the data provided by stakeholders (as set out in Appendix A) are assumed to be representative of the present day system and reliable. In reality this is not always the case. However, the data upon which this assessment is based are the best publically available sources, often obtained from years of data acquisition and research and development programmes. The UK is well served by flood risk analysis in the public and private domains. Thus, whilst inevitably imperfect the information upon which this assessment is based is considered fit-for-purpose.

Fluvial and coastal flooding are assumed to be mutually exclusive: Floodplains are defined here as either are exclusively subject to coastal (including tidal) flooding or fluvial flooding, but not to both. It has been necessary to make this simplifying assumption due to the absence of readily available summary statistics on the correlation between coastal and fluvial flooding around the UK, and because hazard data provided either makes no distinction between coastal and fluvial sources (as for England and Wales) or fluvial and coastal hazards are provided separately (as of Scotland and Northern Ireland). It is difficult to estimate the impact of this assumption however figures provided by NRW indicate ~10% of properties are at risk of both coastal and fluvial flooding. This would indicate that by using a single source of flooding for these properties risk could be underestimated around 5%.

Surface water flooding is assumed to be uncorrelated to coastal or fluvial flooding: It is assumed that surface water flooding occurs separately to fluvial or coastal flooding and therefore the damages associated with surface water flooding are in addition to fluvial or coastal flood damages.

Groundwater flooding associated with permeable surface deposits (PSD) is assumed to be fully correlated with fluvial and surface water flooding: PSD are assumed to be hydraulically connected to the river network and therefore fluvial flooding necessarily leads to groundwater flooding in areas containing such deposits. In these areas is assumed that groundwater extends the duration of the flood and increases damage. Coastal flooding is assumed **not** to be a significant driver of PSD groundwater flooding.

Groundwater flooding not associated with PSD is assumed to be uncorrelated with all other sources: It is assumed that Clearwater flooding (as non-PSD groundwater flooding is known) occurs separately to all other sources of flooding and therefore the damages associated with Clearwater flooding are in addition to other damages.

All of the above assumptions are considered reasonable given the UK wide focus of this study.

2.2 Future changes in drivers of risk

2.2.1 Exogenous change: Population and climate change projections

Exogenous change refers to those changes outside of the influence of flood risk management policy. Two drivers of exogenous change are considered; population growth and climate change. Population projections and present day property occupancy rates are used to estimate the number of people and residential property that may be exposed to flooding in the future. The three population growth scenarios are used. The first two (a low growth projection, representing a 20% increase in population of the UK by 2080s and high population growth projection, representing a 53% increase in population of the UK by 2080s) are taken from the Office of National Statistics (ONS) projections as interpreted by the ASC for use in CCRA2. A third 'no growth' projection is also used. Two climate change projections are considered. This reflect the standard approach set out by the ASC to ensure consistently in the climate change projections adopted in CCRA2 and include a 2^{o}C and 4^{o}C rise in Global Mean Temperature by 2080s (from the 1961-90 baseline as used in UKCP09). A High++ (H++) scenario is also used. The H++ scenario is not related to a particular change in GMT but adopted as a credible, but high-end, change scenario.

Further detail on both the climate change and population growth projections is provided later in Chapter 3.

Note:

Household occupancy rates: Present day occupancy rates (i.e. 2.38 in England and Wales, 2.22 in Scotland and 2.56 in Northern Ireland as derived from 2011 Census) are assumed to be constant into the future. The number of residential properties is directly proportional to population growth. This assumption may lead to an underestimate in future property numbers if the trend for lower occupancy rates continues (for example the average household size in Scotland is projected to decrease to 2.03 people in 2037[1]). It is unclear how this change would manifest itself locally and was excluded from the supporting population analysis provided presented in Appendix B. It has therefore been excluded from the analysis presented here.

Non-residential properties or infrastructure: The analysis provided by the ASC in support of the population projections does not consider the associated growth in non-residential properties or infrastructure. Although no doubt an important consideration for understanding future changes in risk and adaptation it has not been possible to incorporate credible estimates of such change here.

Wealth or demography profile: Changes in wealth may act to both increase the absolute damages incurred during a flood (due to an increase in high value items within a house) but also act to reduce the 'relative pain' of the damage in terms of its proportion of the household income. Demographic changes will, particularly at local scale, modify flood vulnerability. This complexity is beyond the scope of this study. Instead a relative simple description of future change based solely upon population growth is used.

[1] http://www.nrscotland.gov.uk/files//statistics/household-projections/2012-based/html/household-projections-2012-main-points.html Accessed 28 July 2015

2.2.2 Endogenous change: Purposeful adaptations

Endogenous change refers to changes to the flooding system that are either directly controlled or strongly influenced through policies and actions that modify flood risk. In this context a broad range of individual Adaptations Measures (AMs) are considered including those that:

- **Manage the probability of flooding**: By improving traditional flood defences, managing flood flows (such as rural and urban storage and run-off management) or realigning the coast to improve the Standard of Protection (SoP) afforded by a defence.
- **Manage exposure to flooding:** By limiting the impact of new development on flood risk.
- **Manage the vulnerability of those exposed to flooding:** By encouraging individuals and organisations to improve the flood resistance and resilience of their properties/assets or improving forecasting and warning to enable more effective action to be taken.

Further detail on the Adaptation Measures (and how multiple measures are combined to form Adaptation Scenarios) is presented in Chapter 4.

Note:

Responsibility for adapting to future flood risks: Society as a whole has a role in adapting to climate change and managing flood risk. This includes individual homeowners, land owners, communities, organisations and governments. It is unlikely that adaptation will be successful without these collective actions. The adaptations explored within this report embed a consideration of actions by all of these stakeholders. No attempt however is made to attribute specific roles or responsibilities.

Insurance and experience: Flood insurance and the experience of people and organizations that have been affected by flooding can, in the right circumstances, be powerful vehicles that alert people to risks that they face (although often insurance does not give this signal as flood premiums are “bundled” with others perils, such as fire and burglary, in a single policy covering ‘all risks’). No attempt is made to quantify the impact of these drivers on risk. This is considered appropriate given insurance is primarily a means of ‘risk transfer’ and the limited understanding of how the levers of insurance and experience impact on behaviour make it difficult to quantify any reduction in risk in a meaningful way. A discussion of the possible effect on flood risk is included in the discussion (Chapter 9).

2.3 Risk metrics

A series of individual risk metrics (Table 2-1) are used to represent the future risks in five key areas of society, namely:

- **Property:** Both residential and non-residential properties are considered (with risks presented both as property counts and economic damages). Deprived Areas are included in the headline estimates and reported separately.
- **People**: Property counts are used together with the spatial variation in occupancy rates to present flood risk to people. The primary metric is a count of the number of people exposed to flooding. Deprived Areas are included in the headline estimates and reported separately.
- **Natural capital:** The area of land exposed to flooding within Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar sites is used as a proxy for the impact on natural capital. This use of a simplified metric reflects the difficulty in linking flooding to impact and although considered appropriate for inclusion, the results must be viewed in the context of the significant caveats noted below.
- **Agriculture**: The area of Best and Most Versatile Land (BMV) exposed to flooding is used as indicator of the impact on agriculture.
- **Infrastructure (Category A):** Energy and water sector assets are defined here as Category A infrastructure. This categorisation is used later to distinguish the level of adaptation in these sectors compared to others. No attempt is made to quantify the flood related economic damages in these sectors, instead asset counts are used.
- **Infrastructure (Category B):** Transport, social/emergency and waste (landfill) assets are defined here as Category B infrastructure. Under this heading assets counts are used to express risk, although it should be noted that some of these infrastructures are also included as non-residential properties (above).

The input datasets used to support the evaluation of these risks are described in Appendix A.

Note:

Direct and in-direct damages: Direct damages are estimated using the Weighted Annual Average Damage (WAAD) method (Penning-Rowsell *et al.*, 2013). This reflects direct economic losses to the UK Plc and includes, for example, damage to buildings and economic assets. For simplicity in-direct damages are assumed to be a function of direct damages (based on a multiplier of 1.7) and reflect the disruption of economic networks and related activities consequent upon flooding. Although these can be highly site specific the multiplier used here reflects the typical overall effect. Indirect damages should not be confused with 'intangible' losses (i.e. trauma; ill-health; loss of treasured possessions in floods; loss of pets as friends; etc.) that are excluded from the analysis presented here.

Non-residential damages: The assessment of non-residential damages includes consideration of businesses, police stations, schools, hospitals and all other building assets defined as non-residential within the supporting datasets. Damage is estimated using the non-residential sector average WAAD that includes direct damages only.

***Natural capital*:** Natural capital is an important but complex concept and there is some uncertainty as to how flooding impacts on the natural capital stocks and flows. Expressing this complexity in terms of the area exposed is recognized as a significant simplification as it fails to differentiate the likely impact of a flood on sites of contrasting size and habitat type – the loss of natural capital in a small species-rich wetland (such as the River Spey, Insh Marshes SPA) is likely to be proportionately higher than that arising from remobilising a large area of sandbanks that provides habitat for the harbour seal (for example the Firth of Tay and Eden Estuary SAC). The omission of Sites of Special Scientific Interest (SSSIs) outside of the internationally designated areas also means that some protected sites (often with high natural capital) are excluded in the analysis. This means that the areas reported here will be an under-estimate of the natural capital in protected sites. The importance of this simplification is however difficult to quantify and more detailed analysis, beyond the scope of this project, would be needed to identify those SPAs/SACs and Ramsar sites that are vulnerable to coastal and fluvial flooding. Further discussion of the climate change impacts on natural capital (although not specifically flooding) can be found in Work Package C *'Aggregate assessment of climate change impacts on the goods and benefits provided by the UK's natural assets'.*

Landfill sites*:* Only operational landfill sites are considered. Attempts were made to include historical landfill sites, but this information was not readily available for the whole of the UK.

Information and Communication Technology (ICT): Attempts were made to identity ICT infrastructure sites at a UK national scale. Although various datasets are available it has not been possible to develop a coherent national dataset within the scope of this project.

Table 2-1 Risk metrics

Type	Sub-type	Risk Metric
Property	Residential (All)	Counts (by flood probability bands)
		Expected Annual Residential Properties flooded
		Expected Annual Damages (EAD) – Direct only
		Event damages (Direct damages assigned to probability bands)
	Residential (Deprived areas only)	Expected Annual Residential Properties flooded – Direct only
		Counts (by flood probability bands)
		Expected Annual Damages (EAD) – Direct only
	Non-residential (All)	Counts by flood probability bands
		Expected Annual non-Residential Properties flooded
		Expected Annual Damages (EAD) – Direct only
		Event damages (direct damages assigned to probability bands)
	Properties (All)	Expected Annual Damages (Direct and indirect damages)
People	People (All)	Counts (by flood probability bands)
		Expected Annual People experiencing flooding
	People (Deprived areas only)	Counts (by flood probability bands)
		Expected Annual People experiencing flooding
Natural capital	Habitats (SPA, SAC & Ramsar sites)	Area of habitats exposed (by flood probability band)
Agriculture	Best and Most Versatile (BMV) land	Area of BMV exposed (by flood probability band)
Category A: Infrastructure (Considered **likely** to take autonomous action to adapt)	Water	Counts of **water** and **wastewater treatment** sites (by flood probability band)
	Energy	Counts of **power stations** (generation) and **sub-stations** (transmission/distribution) (by flood probability band)
Category B: Infrastructure (Considered **unlikely** to take autonomous action to adapt)	Emergency Services	Counts of **Hospitals** (by flood probability bands)
		Counts of **police**, **ambulance**, **fire stations** (collectively) (by probability bands)
	Transport	Counts of **railway station** sites (by flood probability band)
		Km of **major roads** (A roads and motorways) (by probability band)
		Km of **railway** lines (by flood probability band)
	Social	Counts of **Care Homes** (by flood probability bands)
		Counts of **GP surgeries** in probability bands
		Counts of **Schools** by flood probability bands
	Waste	Counts of **operational** (and licenced) **landfill sites** by flood probability band

2.4 Reporting scales (temporal, spatial and probability)

2.4.1 Temporal scale

The three time horizons used to represent the three epochs are set out in Table 2-2.

Table 2-2 Time horizons and epochs of interest

Epoch	Representative period	Assumed year for purpose of analysis
2020s	2010-2039	2025
2050s	2040-2069	2055
2080s	2070-2099	2085

Note:

Base Date October 2014: The base date for the analysis is October 2014. The assumptions made in reconciling the analysis to this date are:

- ***All data provided on present day risks are representative of the flood risk system as of October 2014****: All of* the datasets provided for use in the analysis are all considered to represent the state of the flood risk system as of October 2014 (despite the individual data within these datasets being derived at various times).
- ***Climate change only influences estimates from October 2014 onwards:*** To determine a future climate (for example sea levels or rainfall in the 2050s) it is assumed that any climate change that has occurred between the base date of the climate analysis (for example from 1960-1990 baseline that underpins UKCP09) to 2014 has already been observed and is included within the data provided on the present day flood risk system.

2.4.2 Spatial scale

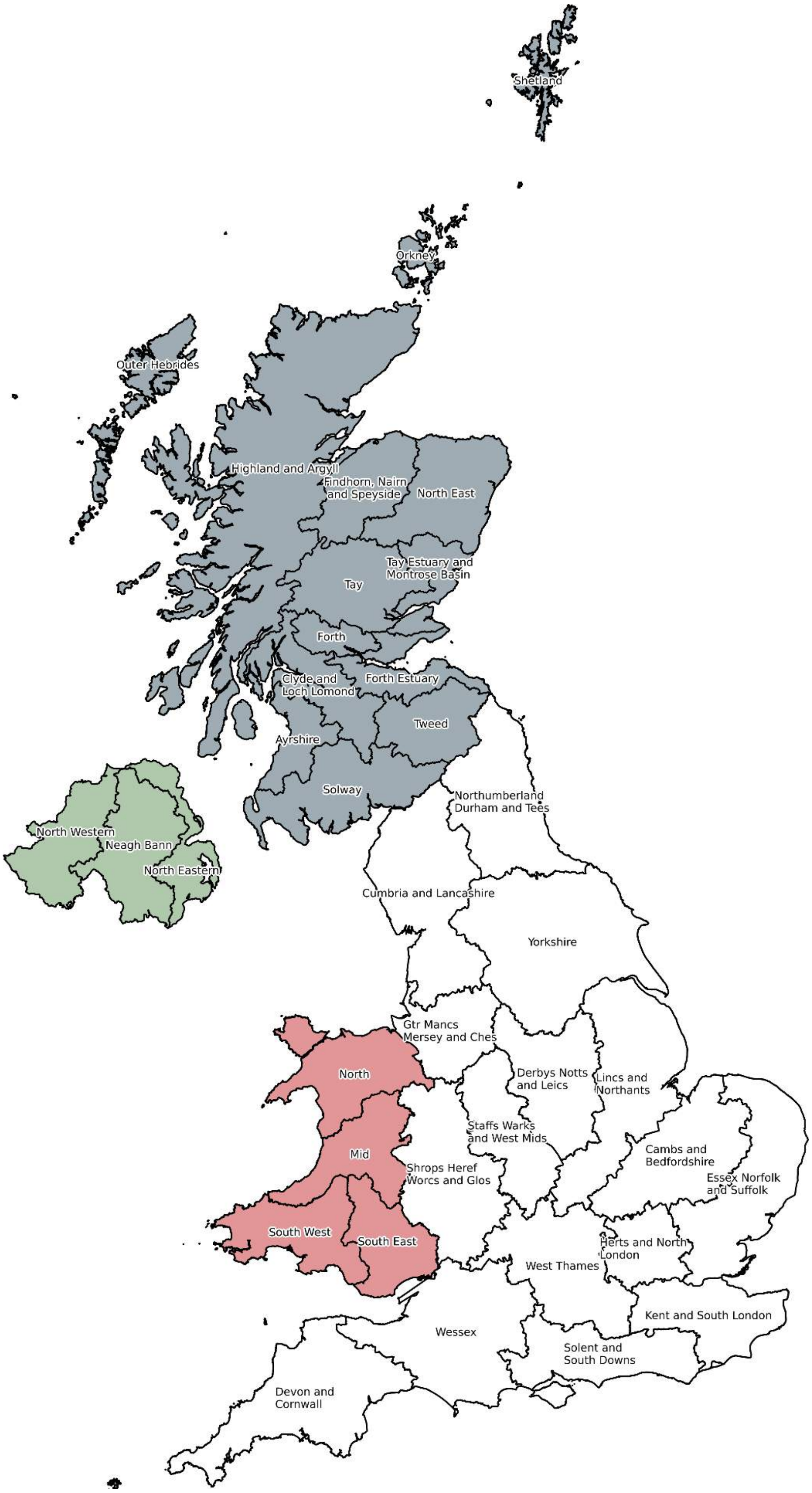
The analysis covers the UK with outputs reported at three spatial scales (Figure 2-2), namely:

- **UK** wide
- **National** (England, Wales, Scotland, Northern Ireland)
- **Regional** based upon: (i) England (Environment Agency Areas), (ii) Wales (Flood Risk Management Administrative Areas); (iii) Scotland (Local Flood Risk Management Plan Districts), and (iv) Northern Ireland (River Basin Districts).

Note:

Risk of false precision*.* Given the necessary simplifications to the underlying datasets and modelling approach the results presented here should not be used to inform local Flood Risk Management (FRM) Strategies. Local strategies should be supported by local analysis. It was therefore decided not to report at a finer spatial scale than those listed above as outputs would be subject to significant statistical noise (averaged out at larger scales).

Further discussion of the limitations and uncertainties is presented in Chapter 5.



Shading delineates England, Wales, Scotland and Northern Ireland

Figure 2-2 Spatial scales used for reporting results

2.4.3 Probability bands

The lead authorities in England, Wales, Scotland and Northern Ireland all assess flood risk using slightly different bands of probability. The chosen flood probability bands also vary according the source of flooding. For the purpose of this report these differences have been rationalized into a single banding (expressed in terms of a return period in years, as set out in Table 2-3). These bands are used to assess all flood sources across the UK. This has been done for purposes of simplicity and consistency in reporting.

Table 2-3 Flooding: Unifying the different probability bands used across the UK

<table>
<tr><th rowspan="2">Return Period (years) bands used</th><th rowspan="2">Annual Probability</th><th rowspan="2">Return Period (years)</th><th colspan="2">England[2,3]</th><th rowspan="2">Wales</th><th colspan="3">Scotland</th><th colspan="3">Northern Ireland</th><th>UK</th></tr>
<tr><th>Fluvial and coastal</th><th>Surface water</th><th>Fluvial</th><th>Coastal</th><th>Surface water</th><th>Fluvial</th><th>Coastal</th><th>Surface water</th><th>Ground-water[4]</th></tr>
<tr><td rowspan="7">More frequent than 1:75</td><td rowspan="3">>=0.1</td><td rowspan="3">=<10</td><td rowspan="3">GE1in10</td><td rowspan="5">High: More freq. than 1:30</td><td rowspan="10">As England</td><td rowspan="3">10</td><td rowspan="3">10</td><td rowspan="3">10</td><td>2</td><td rowspan="3">10</td><td rowspan="5">30</td><td rowspan="2">15-20</td></tr>
<tr><td>5</td></tr>
<tr><td>10</td><td>20-30</td></tr>
<tr><td>>0.05 and <0.1</td><td>10-20</td><td rowspan="2">LT1in10-GE1in30</td><td rowspan="2">30</td><td rowspan="5">200</td><td rowspan="5">200</td><td>25</td><td rowspan="2">50</td><td rowspan="7">30-50</td></tr>
<tr><td>>0.033 and <0.05</td><td>20-30</td><td>50</td></tr>
<tr><td>>0.0133 and <0.033</td><td>30-75</td><td>LT1in30-GE1in75</td><td rowspan="2">Med: 1:30 to 1:100</td><td>50</td><td>75</td><td>75</td><td rowspan="3">200</td></tr>
<tr><td rowspan="2">Between 1:75-200</td><td>>0.01 and <0.0133</td><td>75-100</td><td>LT1in75-GE1in100</td><td>100</td><td>100</td><td rowspan="2">200</td></tr>
<tr><td>>0.005 and <0.01</td><td>100-200</td><td>LT1in100-GE1in200</td><td rowspan="2">Low: 1:100 to 1:1000</td><td>200</td><td>200</td></tr>
<tr><td rowspan="2">Less frequent than 1:200 (to 1:1000)</td><td>>0.001 and <0.005</td><td>200-1000</td><td>LT1in200-GE1in1000</td><td rowspan="2">1000</td><td rowspan="2">1000</td><td rowspan="2">Not stated (200 year plus climate allowance)</td><td rowspan="2">1000</td><td rowspan="2">1000</td><td rowspan="2">1000</td></tr>
<tr><td>=<0.001</td><td>>=1000</td><td>LT1in1000</td><td>Very low: Less freq. than 1:1000</td></tr>
</table>

[2] The Long Term investment Scenario report used bands of High: 1-30; Medium: 1-30 to 1-in-100; Low: 1-in-100 to 1-in 1000; Very Low: >1 in 1000. These classes are also used in the published mapping products for fluvial and coastal sources.

[3] The Environment Agency, Flood Zones represented the undefended catchment. Flood Zone 1: there is less than a 0.1 per cent (1 in 1000) chance of flooding occurring each year; Flood Zone 2: there is up to a 0.1 per cent (1 in 1000) chance of occurring each year: Flood Zone 3: there is a 0.5 per cent (1 in 200) or greater chance of flooding from the sea or a 1 per cent (1 in 100) or greater chance of flooding from the river.

[4] Available groundwater mapping from BGS does not attitude the probability of flooding but refers to 'flood susceptibility' only. This has been interpreted for the purposes of this project as shown.

3.0 EXOGENOUS CHANGE: CLIMATE AND POPULATION PROJECTIONS

3.1 Population growth associated increases in residential property

3.1.1 Regional population growth

The Office for National Statistics (ONS) produce population projections for England, Wales, Scotland and Northern Ireland to 2100 with sub-national population projections to 2037. The ONS data have been extrapolated by the ASC to provide population projections to 2100 for Low, Principal and High growth variants at a local authority level (using the approach described in Appendix B). Only the Low and High variants together with a no population growth scenario are used here (Table 3-1 and Figure 3-1). These projections generally indicate a growth in population (particularly London and the south east of England). The only exceptions to this are in Northern Ireland (where, under the low growth variant, population decreases slightly by 2080s) and in Wales (where, under the low growth variant, population decreases slightly between the 2050s and 2080s).

Locally applicable property occupancy rates are used to translate the population projections to a demand for new residential properties. The location of these new properties within the floodplain varies according to the Spatial Planning Adaptation Measure (as discussed later in Chapter 4).

Table 3-1 Exogenous: Population growth

Region	Current population	Population growth						Occupancy rate
	As at 2012 (millions)	**Percentage change in population (from present day)** Note: Absolute vales in millions of people Residential property change: % change in residential properties is equal to these values. Non-residential properties: No change in non-residential properties is assumed						**Mean property occupancy rate** Note: Present day occupancy rates – from 2011 Census – are assumed to remain unchanged
		Low			**High**			
		2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	
UK	63.7m	68.4m +7%	74.2m +17%	76.5m +20%	70.1m +10%	83.0m +31%	97.2m +53%	2.4
England	53.5m	57.7m +8%	63.4m +18%	65.9m +23%	59.2m +11%	70.9m +33%	83.7m +56%	2.4
Wales	3.08m	3.21m +4%	3.25m +5%	3.18m +3%	3.29m +7%	3.63m +18%	4.07m +32%	
Scotland	5.31m	5.53m +4%	5.67m +7%	5.63m +7%	5.67m +7%	6.35m +20%	7.17m +36%	2.2
Northern Ireland	1.82m	1.92m +6%	1.93m +6%	1.77m -3%	1.97m +8%	2.16m +19%	2.30m +27%	2.6

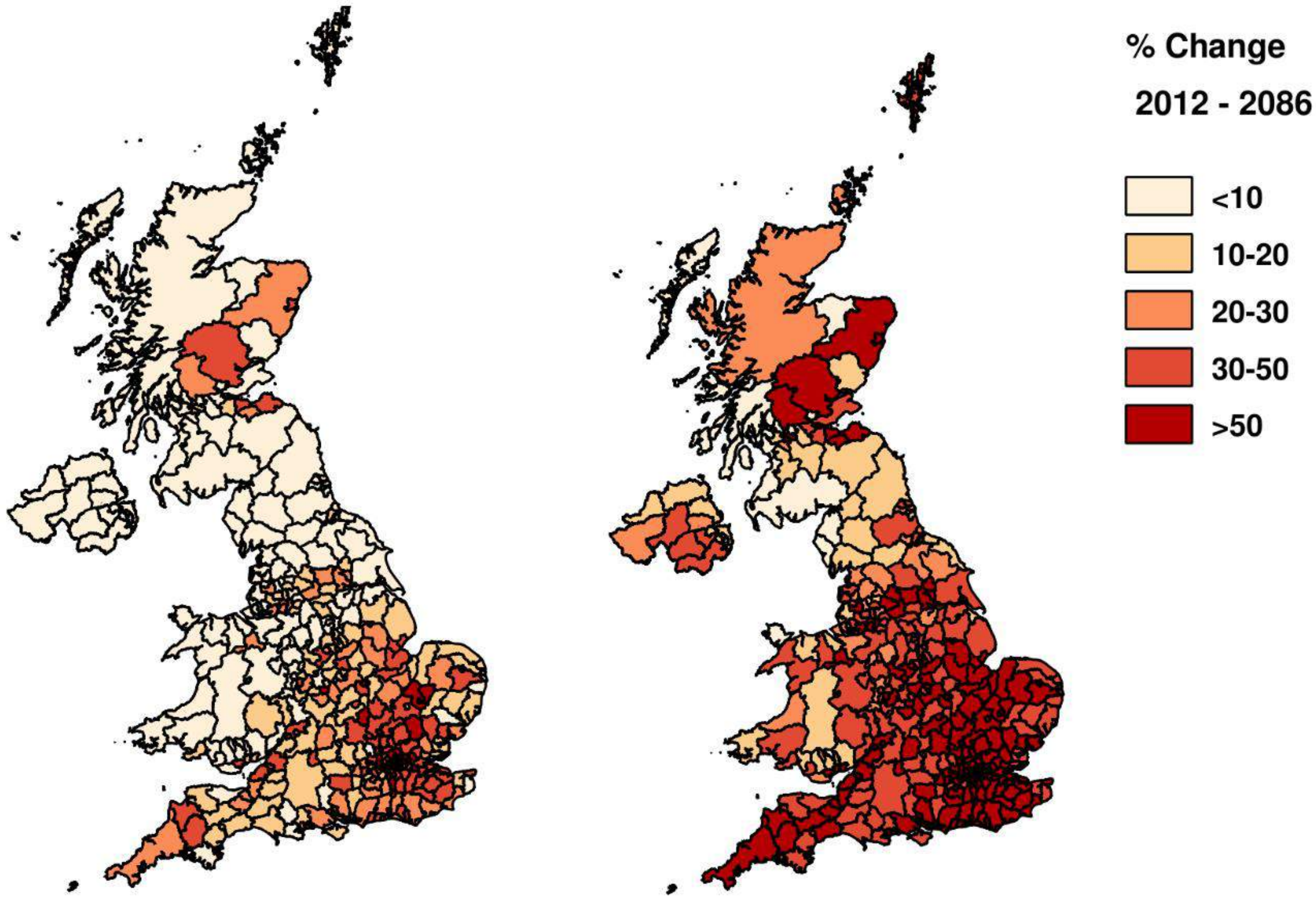


Figure 3-1 Projected population increases for low (left) and high (right) scenarios, by local authority area

3.2 Climate change

3.2.1 Coastal

Wave conditions around much of the UK coast are depth limited (Burgess & Townend, 2001). Because of this, relative Sea Level Rise (rSLR) has a dominant influence on coastal flooding (increasing both wave driven overtopping, the chance of a breach probability and tidal overflow) and is used as here as a proxy for all other climate related changes at coast.

The approach to the assessment of rSLR and its impact on the Standard of Protection (SoP) of coastal defences is summarized below (with more detail provided in Appendix C):

- ***Assessment of relative Sea Level Rise:*** The evidence used to estimate rSLR and the changes themselves are presented in Table 3-2 and Table 3-3 respectively.
- ***Assessment of the associated change in the Standard of Protection (SoP) of coastal defences:*** A relationship between rSLR and the change in the SoP afforded by a given coastal defence was established for five coastal response regions around the coast of England and Wales during the Foresight Future Flooding Study (Evans *et al.*, 2004a&b). These relationships have been extended by analogy to all regions of the UK (Figure 3-2) and applied to the updated rSLR projections. An example of this relationship is given Table 3-3 for the 2080s and highlights that the most severe reductions in SoP occur in the South-East of England and Mid-West Wales. This reflects the regional geomorphological conditions and the significant influence of sea level rise on depth limited wave conditions (see, for example, Deakin *et al*., 2001 and HR Wallingford, 2002 for further discussion).

Note:

Applicability of the Foresight Studies: The values developed within Foresight were in turn based upon the Coastal Defence Vulnerability 2075 (CDV2075) studies (HR Wallingford, 2002) and the National Assets at Risk Under Climate Change, 2001 (Halcrow, 2001; Deakin *et al*., 2001). Despite these studies being over 10 years old the underlying approach continued to be used until recently within LTIS (Environment Agency, 2014a). In the LTIS2014, however, changes in overtopping volume are used directly rather than the proxy of changes in SoP as used in Foresight and adopted here.

Exclusion of other important aspects of climate changes*:* Changes to storm sequence, surge, wave direction, wetting and drying of embankments and other changes in climate that may be important to the performance of coastal defences (Sayers *et al.*, 2015) are out of scope. This is considered reasonable in the context of this study and the accepted dominance of sea level rise.

Extrapolation to Scotland and Northern Ireland using analogues from England: To build the FFE for use across the whole of the UK it has, on occasion, been necessary to use analogues from England to infill data gaps elsewhere. For example, to estimate the impact of climate change on coastal defence standards it is assumed that the west coast of Scotland responds similarly to rSLR as the south west England. Although necessary, this assumption is recognized as a weakness. The west coast of Scotland is dominated by numerous fjords cut by Quaternary glaciers in highly resistant bedrock whereas coast of south west England is dominated by much shallower rias created by Holocene sea level rise in less resistant bedrock and will react differently to climate change. The significance of this assumption is difficult to gauge but adds additional uncertainty to the coastal results in Scotland and Northern Ireland.

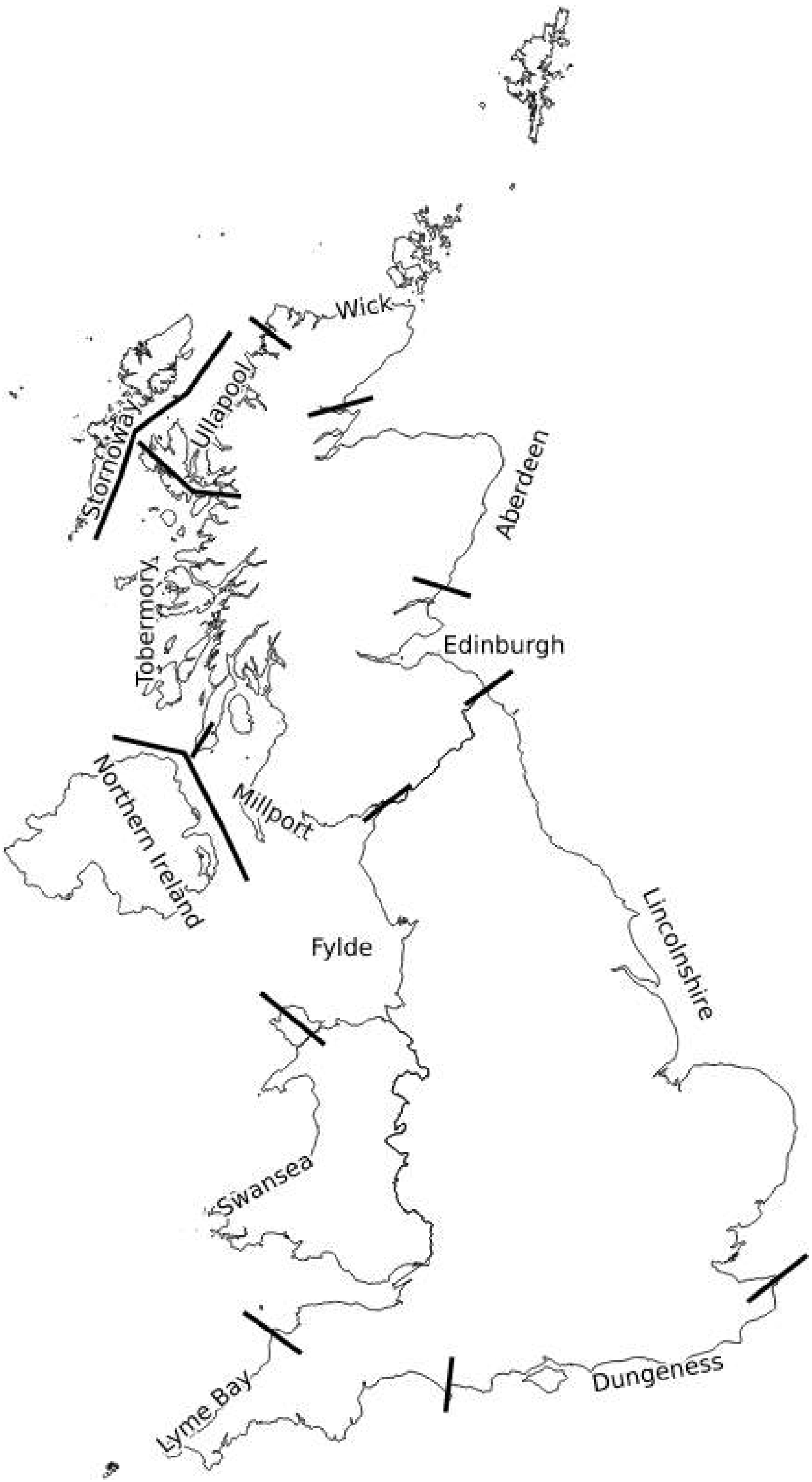


Figure 3-2 Coastal response regions

Table 3-2 Coastal flooding: Supporting evidence for relative Sea Level Rise

<table>
<tr><th>Climate change indicator</th><th>Means of quantification</th><th colspan="2">Supporting evidence used</th></tr>
<tr><td rowspan="3">Changes in mean sea level</td><td rowspan="3">mm/yr (relative to the land)</td><td>2°C</td><td>All UK: Taken from the UKCP09 interface (Low (B1) scenario (50%ile) directly.

B1 (50%ile) values are assumed here to be indicative of a 2°C rise by the 2080s. It should be noted that it is estimated as representing 2.6°C by 2080s (Table 4.8, UKCP09 Science Report) and as 1.8°C (a best estimate) (Table SPM.3. IPCC 4th Assessment Report[5]).</td></tr>
<tr><td>4°C</td><td>All UK: Based on an interpolation between the High (A1F1) scenario from UKCP09 plus an additional increase of 17/100cm per year (reflecting the approach used in Environment Agency, 2011 to allow of missing processes[6]) and the Medium (A1B) scenario (50%ile)

AIF1 (95%ile) values are assumed here to represent a 6°C increase in GMT by 2080s. It should be noted that it is estimated as representing 5.3°C (at a 90%ile level) in Table 4.8 UKCP09 Science report and 6.4°C (as upper end of the likely range) in Table SPM3: IPCC 4th Assessment Report.

A1B (50%ile) values are assumed here to represent a 2.8°C increase in GMT by 2080s. It should be noted that it is estimated as representing 3.4°C (at a 50%ile) level in Table 4.8 UKCP09 Science report and 2.8°C (as the best estimate value) in Table SPM3.</td></tr>
<tr><td>H++</td><td>All UK: Taken directly from Environment Agency, 2011 with extension to Scotland and Northern Ireland through analogy.</td></tr>
</table>

[5] https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html

[6] Based on personal communication with Bill Donovan – author of Environment Agency, 2011

Table 3-3 Coastal flooding: Relative Sea Level Rise projections (m)

	2 Degrees			4 Degrees			H++		
Region	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
England and Wales (based Deakin et al, 2001)									
Lincolnshire (East coast)	0.03	0.13	0.26	0.14	0.37	0.64	0.14	0.60	1.43
Dungeness (South-east coast)	0.03	0.14	0.26	0.14	0.37	0.64	0.14	0.60	1.43
Lyme Bay (South-west coast)	0.03	0.15	0.28	0.15	0.38	0.66	0.14	0.59	1.42
Swansea (Mid-West coast)	0.03	0.13	0.25	0.14	0.36	0.63	0.15	0.60	1.43
Flyde (North-west coast)	0.02	0.11	0.21	0.14	0.34	0.59	0.16	0.62	1.45
Scotland (locations based on CREW, 2012)									
Edinburgh	0.02	0.08	0.17	0.13	0.32	0.55	0.15	0.55	1.30
Aberdeen	0.02	0.09	0.18	0.13	0.32	0.56	0.14	0.55	1.30
Wick	0.02	0.11	0.21	0.14	0.34	0.59	0.13	0.54	1.28
Lerwick	0.04	0.16	0.30	0.15	0.39	0.67	0.10	0.51	1.26
Ullapool	0.02	0.09	0.18	0.13	0.32	0.56	0.14	0.55	1.30
Stornoway	0.02	0.11	0.22	0.14	0.34	0.59	0.13	0.54	1.28
Tobermory	0.02	0.08	0.16	0.13	0.31	0.54	0.15	0.56	1.30
Millport	0.02	0.08	0.16	0.13	0.31	0.54	0.15	0.56	1.30
Northern Ireland									
NI - All	0.02	0.09	0.17	0.13	0.32	0.55	0.13	0.52	1.23

Table 3-4 Changes in the SoP of coastal defences by 2080s: Assuming the 2°C climate change projection

	England and Wales					Scotland								Northern Ireland
Location	East Coast	South-east	South-west	Mid-west	North-west	Edinburgh	Aberdeen	Wick	Lerwick	Ullapool	Stornoway	Tobermory	Millport	All
Analogous region in England and Wales						East Coast	East Coast	East Coast	South West	South West	South West	South West	North West	North West
Present day SoP (return period, years)	**Future SoP** (return period, years)													
Coastal defence type: **Vertical Wall**														
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	3	4	3	3	3	4	4	3	3	5	4	5	4	4
20	4	4	8	3	5	6	6	5	4	7	6	8	6	6
50	13	4	23	3	16	20	19	16	15	24	20	27	21	20
100	20	8	61	5	32	30	29	24	22	36	30	40	32	39
200	53	20	153	17	48	80	77	63	58	95	80	108	86	59
Coastal defence type: **Embankment**														
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	4	4	3	3	3	6	6	5	4	7	6	8	6	4
20	7	4	5	5	5	10	10	8	7	12	10	13	11	6
50	13	4	23	9	16	20	19	16	15	24	20	27	21	20
100	33	6	61	17	32	50	48	40	36	59	50	67	54	39
200	93	10	123	26	96	141	134	111	102	166	140	189	150	117
Coastal defence type: **Shingle beach**														
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	3	4	3	3	3	4	4	3	3	5	4	5	4	4
10	4	4	3	3	3	6	6	5	4	7	6	8	6	4
20	7	4	5	5	5	10	10	8	7	12	10	13	11	6
50	13	4	23	9	16	20	19	16	15	24	20	27	21	20
100	40	6	61	26	32	60	57	48	44	71	60	81	64	39
200	106	10	123	34	80	161	153	127	116	189	160	200	172	98

Example: By the 208, the standard of protection afforded by a vertical wall in the North-West of England with a current SoP of 1:100 would reduce to 1:32 years assuming the 2°C climate change projection.

3.2.2 Fluvial

The influence of climate change on fluvial loads has been assessed as follows:

- ***Changes in peak flows:*** The changes in peak flows used here are based on a number of sources. The supporting evidence used to estimate the fluvial flow projections and the changes themselves are presented in Table 3-5 and Table 3-6
- ***Associated changes in the SoP of a defence:*** The relationship between a change in flow and a change in the probability of that flow being exceeded has been determined using the method first detailed in the National Assets at Risk Study (NAAR, Halcrow, 2001) and subsequently used in Foresight and the LTIS. The approach uses regional growth curves from Flood Studies Report (NERC, 1975) to translate a change in flow to a change in return period. This relationship is used to infer the change in the SoP that is independent of temperate and epoch (see Table 3-7 for an example).

More detail on this approach and the evidence used is provided in Appendix C.

Note:

H++ scenario: Not all areas within any given catchment will have the same sensitivity to climate change and in some locations the assumed H++ responses may be physically impossible. This local sensitivity has not been included here and the H++ results from Project D (mean values) are assumed to apply across the whole catchment whereas in reality this would not be the case. The change in risk under the H++ scenario is therefore likely to be overstated. The magnitude of the error introduced by this assumption is difficult to gauge without further analysis that is beyond the scope of this study.

Table 3-5 Fluvial flooding: Supporting evidence for the percentage change in peak flows

Climate change indicator	Means of quantification	Supporting evidence used	
Changes in **peak flows**	Change in the return period of a given flow (and by inference the water level in the river)	2°C	**England and Wales:** Based upon an interpolation of the Lower and Medium Change factors from Environment Agency, 2011 and Environment Agency Wales, 2011. Both of these reports are based on FD2020 (Reynard *et al.*, 2009). **Scotland:** Based upon the Low (B1) scenario (50%tile) for the 2080s from SEPA, 2011. These values are then interpolated to other epochs using factors derived from hydrologically similar areas in England. **Northern Ireland:** Based upon RPS report (RPS, 2009) climate change uplifts across catchments in NI are reasonably constant with little variation. A single uplift value for NI has therefore been adopted.
		4°C	As above with the following modifications: **England and Wales:** Based upon an interpolation of 'Upper Change Factor' from Environment Agency, 2011 (representative of approx. 6°C) and the 'Change Factor' (based on Medium (A1B) scenario (50%tile) representative of approx. 2.8C). **Scotland**: Based upon the High (A1Fi) scenario (50%tile) representative of 4°C for the 2080s from SEPA, 2011. **Northern Ireland:** As above based upon RPS report (RPS, 2014
		H++	**England and Wales:** Taken to be the mean value from the range published with CCRA Project D (adjusted to correct for an October 2014 base date). **Scotland:** Taken to be the mean value from the range published with CCRA Project D (adjusted to correct for an October 2014 base date). **Northern Ireland:** Taken to be the mean value from the range published with CCRA Project D (adjusted to correct for an October 2014 base date).

Table 3-6 Fluvial flooding: Percentage change in peak flows

Country	Region	2°C Projection			4°C Projection			H++ scenario		
		2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
England and Wales	Northumbria	5	8	13	16	21	31	54	90	178
	Humber	3	8	13	16	21	31	54	90	178
	Anglian	-3	3	10	18	24	42	56	93	170
	Thames	-3	3	10	18	24	42	56	93	185
	South East	-3	8	15	18	33	56	59	103	205
	South West	5	10	18	21	28	47	56	98	198
	Severn	0	8	13	16	28	42	56	95	190
	Dee	5	8	13	14	21	29	54	88	175
	North West	10	15	20	19	26	43	56	95	193
	Solway	10	18	18	19	26	40	56	95	193
	Tweed	8	13	23	19	26	32	54	90	183
	Western Wales	3	8	13	15	24	36	53	92	179
Scotland	Orkney and Shetland	11	19	27	16	22	33	59	100	200
	North Highland	7	13	18	14	19	29	56	93	185
	West Highland	12	21	30	22	30	45	59	105	208
	North East Scotland	5	9	13	8	11	17	51	85	173
	Argyll	12	21	30	22	30	45	59	105	208
	Tay	6	11	16	13	17	26	54	90	208
	Clyde	8	14	20	17	23	34	56	98	183
	Forth	7	12	17	14	19	28	56	95	195
	Solway	7	13	18	16	21	32	56	95	193
	Tweed	6	10	14	11	15	23	54	90	183
Northern Ireland		13	13	21	13	21	39	50	90	180

Table 3-7 Fluvial flooding: Relating percentage change sin peak flow to changes in return period (Northumbria)

Region 1	Northumbria										
	Current Return Period (years)										
% change in peak flow	2	2.3	5	10	25	50	100	500	1000	5000	10000
	Revised return period (years) given a change in peak flow										
-40	196	169	235	473	1330	2967	6648	43094	95943	607852	1339346
-20	6.8	7.9	19	43	123	268	582	3441	7345	42206	89230
-10	3.2	3.7	8.9	19	51	107	224	1229	2544	13687	28180
-5	2.4	2.8	6.5	13	35	72	147	772	1571	8157	16557
0	2.0	2.3	5.0	10	25	50	100	500	1000	5000	10000
+5	1.7	1.9	4.0	7.7	18	35	69	333	654	3147	6199
+10	1.5	1.7	3.3	6.1	13	26	50	227	439	2031	3940
+15	1.4	1.5	2.8	4.9	10	19	37	159	302	1343	2564
+20	1.3	1.4	2.4	4.1	8.6	15	28	114	212	908	1706
+25	1.2	1.3	2.1	3.5	7.0	12	21	84	153	627	1159
+40	1.1	1.1	1.6	2.4	4.2	6	11	37	64	232	408

Example: A 10% increase in peak flow (+10%) would reduce the return period of a particular flow from 1:100 to 1:50 years.

3.2.3 Surface water

The influence of climate change on surface water flooding is characterized through changes in surface water run-off. This is assessed by first considering the change the intensity of short duration rainfall and then translating this to a change in the return period of the run-off generated as follows:

- ***Changes in intense rainfall (sub-daily rainfall < 6 hours duration):*** Quantifying changes to surface water flooding requires an understanding of the changes in extreme (typically rarer than 1:30 year return period) short duration (1-6 hours) storms. Within this project the evidence from Defra (2006) and Environment Agency (2011) together with more recent information from the NERC funded CONVEX programme and research by UKWIR (UKWIR2015a&b) has been synthesized to provide an estimate of change factors for daily extreme rainfalls for all return periods and durations of 1-6 hours. A summary of the supporting evidence and the change factors used is presented in Table 3-8 and Table 3-9.
- ***Associated changes in the return period of a given run-off:*** The change in the chance of surface water flooding does not respond directly to changes in rainfall but also reflects the way runoff is produced. To reflect this, a nationally representative relationship has been developed (for England, Wales, Scotland and Northern Ireland), linking rainfall and runoff for urban and rural areas assuming a nationally representative depth-duration-frequency curve and a storm duration of 3 hours everywhere. Climate change uplifts for surface water flooding return periods are then calculated using this rainfall-runoff relationship to produce a runoff-frequency curve. The depth-frequency curve is uplifted by the climate change increase (e.g. +10%), and the rainfall-runoff relationship applied to produce a future runoff-frequency curve. The future runoff-frequency curve is then used to calculate the future probability of present day runoff values; these probabilities are then used to scale the impact curve. These runoff-frequency curves are not used for relating rainfall to impacts (this is already implicit in the hazard maps), but to assess the impact of climate change and adaptation. Example results are shown in Table 3-10.

More detail on this approach and the evidence used is provided in Appendix C.

Note:

The climate change factors for rainfall published by Environment Agency (Environment Agency, 2011) covering England and by Defra (Defra, 2006) covering the rest of the UK are not strictly applicable to sub-daily rainfall (despite being widely used as such by the water industry and others). Recent work for UKWIR (UKWIR, 2015a&b) has used a combination climate modelling (based on data from CONVEX) and observed data derived from areas around the world considered to provide an analogy of the UK's potential future climate, both approaches being based on recent research have been analyzed (Kendon *et al.*, 2012, Kendon *et al.*, 2014, Blenkinsop *et al.*, 2015). Although significant uncertainty exists in these numbers, and it is difficult to map the UKWIR results to changes in GMT used here, a clear conclusion is that the daily rainfall change allowances in the Environment Agency guidance are likely to underestimate the climate uplifts if applied to sub-daily rainfall, and that by the 2080s a 50% increase is a plausible prospect for rainfall duration of 1-hour to 6-hours (UKWIR, 2015a). The H++ values are taken directly from the work presented in Project D of the CCRA17 (undertaken by the Met Office).

The uplifts presented within the UKWIR report are assumed to be applied to present day climate (i.e. no baseline correction is needed). The uplifts are also assumed to apply to all of the UK, in line with the representative UK wide runoff model described above.

Table 3-8 Surface water flooding: Supporting evidence for changes in rainfall intensity for storms of less than six hours duration

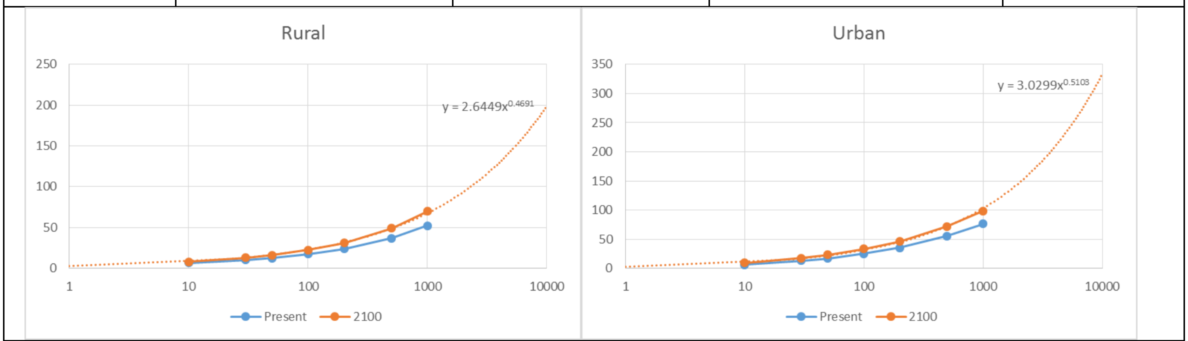
Climate change indicator	Means of quantification	Supporting evidence used	
Changes in **rainfall**	Change by **rainfall intensity for storms of < 6 hours duration**	2°C	Taken from UKWIR research into sub-daily rainfall and effects of climate change (UKWIR, 2015a&b)
		4°C	
		H++	

Table 3-9 Surface water flooding: Percentage changes in intense rainfall of < 6 hours duration

Climate change factor	Global Mean Temperature change (from 1990 baseline)	2020s	2050s	2080s
Lower	2°C	0	+10%	+20%
Medium	4°C	+10%	+20%	+50%
H++/WPD	n/a	+17%	+35%	+70%

Table 3-10 Example of present day runoff, and the return period of that runoff value in 2100 climate, assuming 20% uplift in intense rainfall ≤6 hours

Present Day Return period (years)	Rural		Urban	
	Present day runoff (mm)	Future Return Period (years)	Present day runoff (mm)	Future Return Period (years)
30	10	18	13	17
100	17	56	25	63
1000	52	580	76	560



**The example results are based on the runoff-frequency curves shown in the bottom row for rural and urban areas.*

3.2.4 Groundwater

Groundwater levels are governed by the amount and timing of groundwater recharge, which is in turn a function of rainfall and evapotranspiration. The relationship between rainfall and groundwater recharge is non-linear because soil moisture deficits need to be satisfied before recharge can take place, and the properties of soil and rock constrain the volume of water that can recharge in a given period. These relationships drive a seasonal groundwater response, with recharge typically greatest in the winter months when evapotranspiration is low. This complexity of response is one reason for the lack of published information on the impacts of climate change on groundwater flooding.

To overcome the lack of published data the existing classification of areas susceptibility to groundwater flooding (Macdonald *et al.*, 2008), observations of the frequency of groundwater flooding at a number of reference sites and the results of the BGS Groundwater Susceptibility Mapping undertaken as part of the Futureflows projects (Jackson *et al.*, 2011) are used assess the impacts on climate change on three forms of groundwater flooding including: (i) *Clearwater flooding* (from Chalk or Limestone aquifers); (ii) *Clearwater flooding* (from other aquifers), and (iii) flooding from *Permeable Superficial Deposits (PSD)* (where groundwater and fluvial systems are well linked). The areas susceptible to these different types of groundwater flooding are shown in Figure 3-3 to Figure 3-4.

The probability of groundwater flooding within an area of susceptibility (either Clearwater or PSD flooding) has not previously been defined because observational data on recurrence are limited, and the frequency of flooding will vary across a susceptible aquifer. New analysis undertaken for this report uses historical flood reports and hydrograph analysis to set present day Clearwater flood frequencies for ten distinct geographic areas within the Chalk and Jurassic aquifers in England. Outside these aquifers, where Clearwater flooding may occur in non-Chalk or limestone aquifers in England and Wales a baseline recurrence interval of 50 years is assumed. Groundwater flooding in areas of Permeable Superficial Deposits is assumed to be linked to fluvial flood frequency. The BGS Futureflows model is used to determine changes in these frequencies.

The evidence used to estimate the changes in groundwater flooding are summarized in Table 3-11. Change factors for Clearwater Flooding (from Chalk and Limestone aquifers) are given in Table 3-12. More detail on this approach and the evidence used is provided in Appendix D.

Note:

Variation in groundwater flood frequency not location: It is assumed that climate change will largely affect the frequency of flooding, rather than its spatial distribution at national level. This is reasonable because groundwater discharges are generally constrained by geological and hydrogeological factors, for instance the presence of fractures enhancing local permeability, or lithological variation constraining the location of a spring.

Future groundwater flood frequencies are unaffected by land use change: Groundwater recharge is significantly affected by land use and hence by changes in land use. In urban areas impermeable pavements and buildings reduce recharge, whereas sustainable urban drainage systems and utility leakage can increase recharge. In rural settings evapotranspiration can vary significantly between woodland, grassland and different crops. These may well be additional drivers of change. This interaction is excluded here.

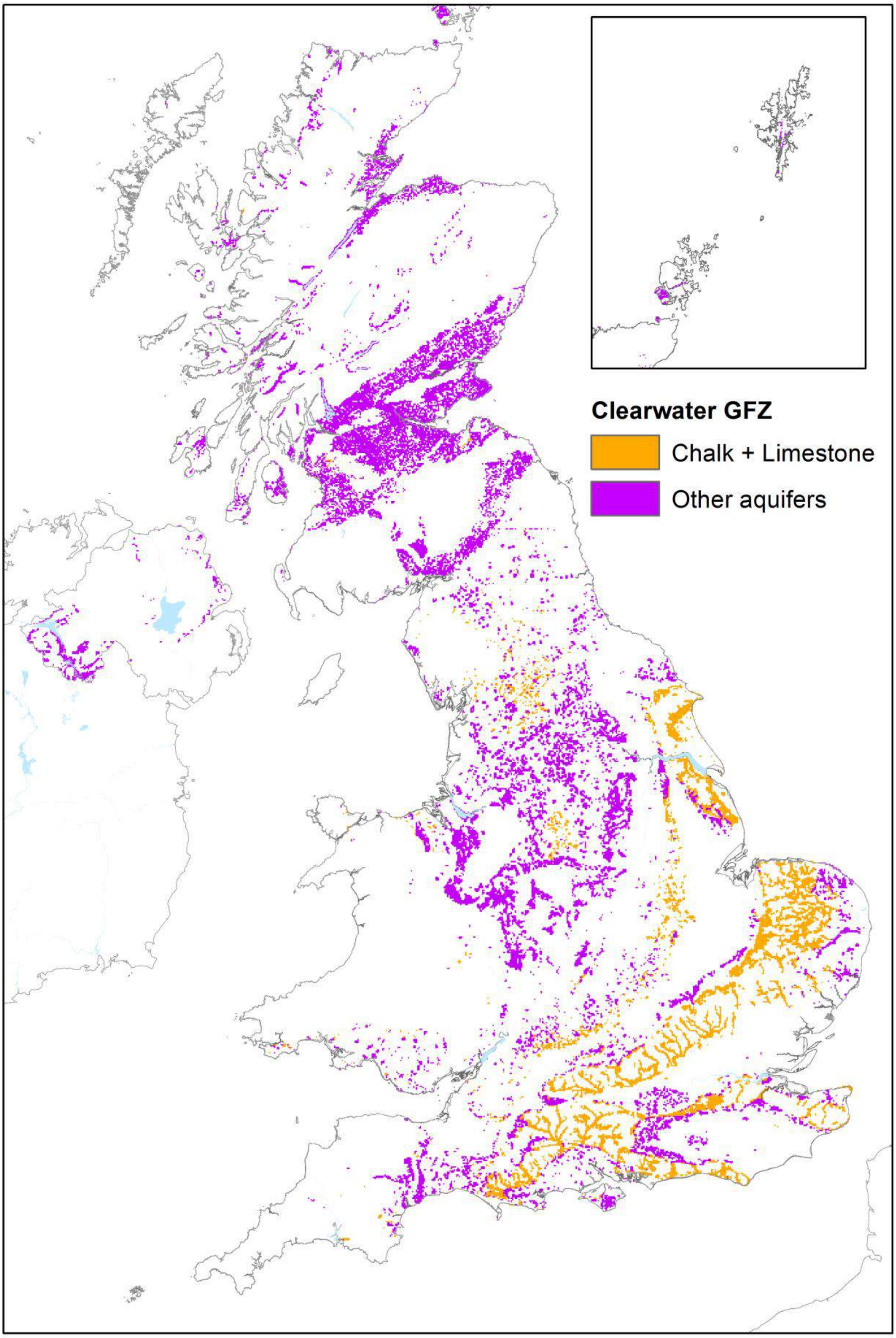


Figure 3-3 Groundwater Flood Zones: Clearwater

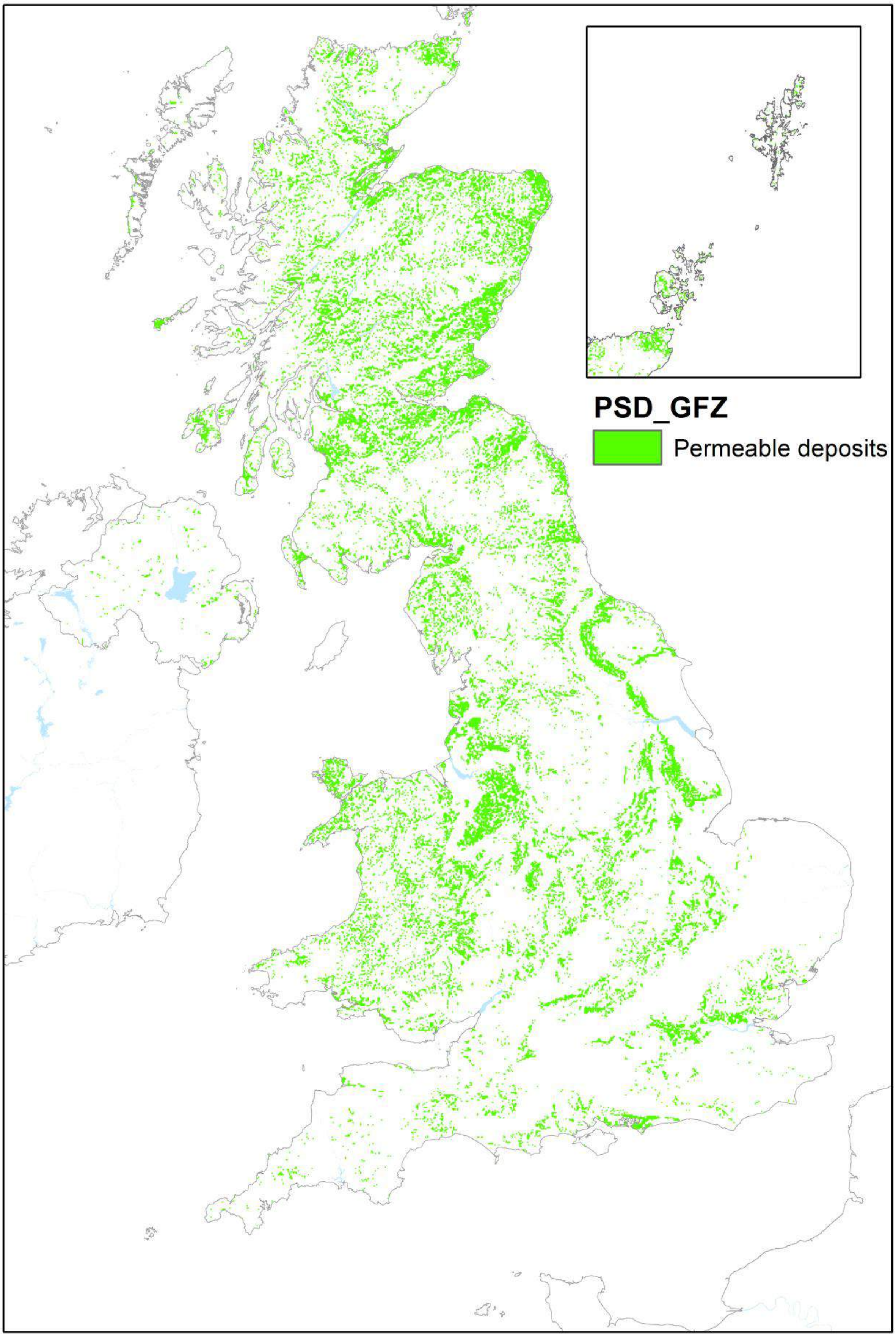


Figure 3-4 Groundwater Flood Zones: Permeable superficial deposits (PSD)

Table 3-11 Groundwater flooding: Supporting evidence

Climate change indicator	Means of quantification		Supporting evidence
Note: Although the groundwater models cover the UK, it is assumed here that Clearwater groundwater flooding is not applicable to Scotland or Northern Ireland.			
No single indicator as groundwater responses to combination of climate drivers	Percentage of time when groundwater exceeds 90th percentile level	**2°C**	**Clearwater flooding** (from Chalk or Limestone aquifers) **England, Wales, Scotland and Northern Ireland:** Results from Futureflows project using the HADRM3-PPEUK-afixa mode; which corresponds to a 2.58°C climate sensitivity. (Limestone in Northern Ireland was not separated from other aquifers). **Clearwater flooding** (from other aquifers) As Chalk aquifers **Permeable superficial deposit flooding** (where groundwater and fluvial systems are well linked). Responds to changes in fluvial flood frequency
		4°C	**Clearwater flooding** (from Chalk or Limestone aquifers) **England, Wales, Scotland and Northern Ireland:** Results from Futureflows project using HADRM3-PPEUK-afixk model; which corresponds to a 3.90°C climate sensitivity. (Limestone in Northern Ireland was not separated from other aquifers). **Clearwater flooding** (from other aquifers) As Chalk aquifers **Permeable superficial deposit flooding** (where groundwater and fluvial systems are well linked). Responds to changes in fluvial flood frequency
		H++	**Clearwater flooding** (from Chalk or Limestone aquifers) **England and Wales**: Results from Futureflows project using the HADRM3-PPEUK-afixq mode; which corresponds to a 7.11°C climate sensitivity. (Limestone in Northern Ireland was not separated from other aquifers). **Clearwater flooding** (from other aquifers) As Chalk aquifers **Permeable superficial deposit flooding** (where groundwater and fluvial systems are well linked). Responds to changes in fluvial flood frequency

Table 3-12 Groundwater flooding- Changes factors for Clearwater flood frequency in England

Region	Present day return period of GW flooding (years)	2020s			2050s			2080s		
		2°C	4 °C	H++	2 °C	4 °C	H++	2 °C	4 °C	H++
Chalk North Downs + Kent	30	1	1	0.7	1.2	0.3	0.7	1.3	0.5	0.5
Chalk South Downs	20	0.8	1.1	0.5	1.8	1	1.5	2	1.9	1.5
Chalk Wessex	15	1	1	1	1.5	0.9	1.3	1.6	1.5	1.6
Chalk Berks/Bucks	25	0.9	0.8	0.9	1.2	0.6	0.7	1.2	0.7	1.1
Chalk East Anglia	50	0.5	0.6	0.7	0.6	0.2	0.3	1.3	0.3	0.4
Jurassic Yorkshire	25	0.7	1	0.8	0.8	0.8	0.8	1	0.4	0.9
Jurassic South	25	0.7	0.7	1	1.2	1	1.2	1.5	1.1	1.2
Chalk Yorkshire	30	0.6	0.9	0.8	0.7	0.5	0.7	1	0.5	0.5
Chalk Lincolnshire	40	0.6	0.9	0.9	0.7	0.6	0.6	1.2	0.5	0.4
Chalk Hampshire	20	0.8	0.7	0.9	1.2	0.7	1.4	1.5	1.2	1.5
Not Chalk or Limestone Clearwater flooding	50	1.2	0.8	1.5	1.2	1	1.7	1.5	0.9	2

Note: Values show changes in frequency, where 1 represents current conditions, >1 indicates more frequent flooding (present frequency / divided by the factor) and vice versa for <1.

The geographic breakdown shown in Table 3-12 reflects the observed variations in aquifer response and groundwater flooding over the major Chalk and Jurassic Limestone aquifers of England (Figure 3-5**)**. Other English aquifers, and aquifers in Wales, Scotland and Northern Ireland are not subdivided.

The variability in change factors shown in Table 3-12 largely represents the complex interaction of changes in rainfall and evapotranspiration that contribute to groundwater recharge, and hence to the eventual emergence of groundwater flooding. Aquifer recharge is particularly sensitive to the length of the winter recharge season, the period when soil moisture deficits are absent, and to winter rainfall. An increase in precipitation during summer may have only a small effect on groundwater levels. Different aquifers response to rainfall and evapotranspiration is also moderated by the presence of superficial aquifers, by the depth of groundwater and by typical patterns of catchment land use.

The large variability observed in change factors, and the non-linearity of the response of groundwater flooding to climate change does reflect real uncertainties in aquifer response. Quite small changes in rainfall seasonality that may not be resolved by existing climate models may have substantial effects on groundwater if they shorten or extend the recharge season.

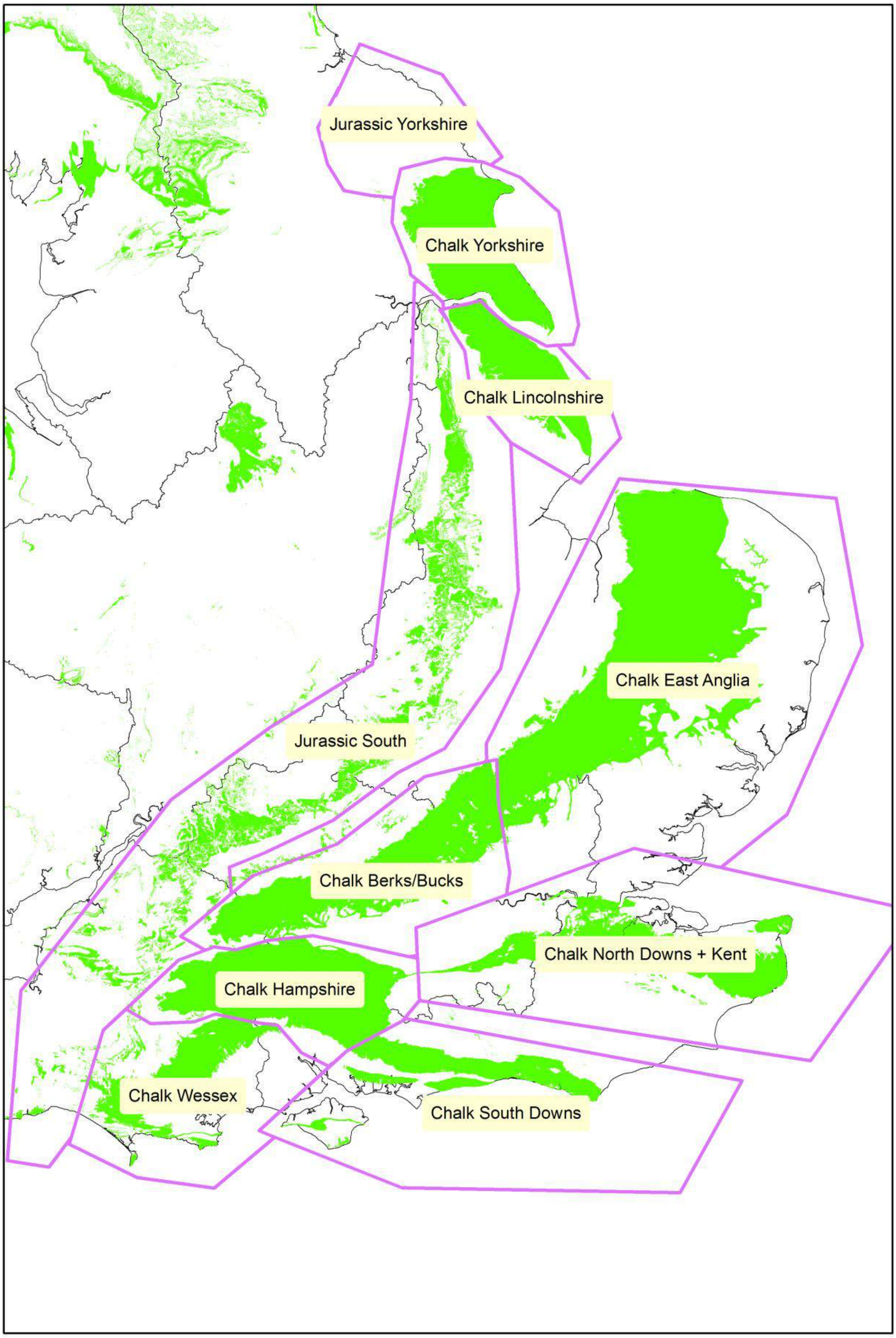


Figure 3-5 Subdivision of Chalk and Limestone aquifers in England

4.0 ENDOGENOUS CHANGE: ADAPTATION MEASURES AND SCENARIOS

4.1 Individual Adaptation Measures

Seven individual Adaptation Measures (AMs) are considered. These include action to manage the probability of flooding, the exposure to floods and the vulnerability of those exposed. The AMs reflects present day flood risk management policies that already encourage action to manage flood risk and adapt to future change. The degree of adaptation, however, crucially depends upon the interpretation and implementation of these policies rather than the policies themselves.

In recognition of this challenge of implementation, each Adaptation Measure has been considered in the context of three levels of adaptation:

- A continuation of **current levels of adaptation** (**CLA**): Flood risk management policies **continue** to be implemented as effectively as experienced in the recent past (i.e. achieving the same outcomes as in recent years).
- A **high(er) level of adaptation:** Flood risk management policies are **more** effectively implemented than in the recent past.
- A **low(er) level of adaptation:** Flood risk management policies are **less** effectively implemented than in the recent past.

Each Adaptation Measure, and its effectiveness under each level of adaptation, is summarized in Table 4-1 to 4-3. A more detailed description of each Adaptation Measure and the evidence used to interpret each level of adaptation is provided in Appendix E.

Note:

When considering the individual Adaptation Measures outlined above it is important to recognize:

Variation in national policies and implementation: The contrasting flood risk management legislation and the approaches adopted across England, Wales, Scotland and Northern Ireland means that the emphasis of past adaptations and the mix of future adaptation measures that may be used will differ (and perhaps markedly) across the UK. In developing the individual adaptation measures presented in this chapter it has been necessary to develop a single UK wide assessment of their effectiveness. In some instances achieving this single view is difficult. For example, Scotland has a stronger policy focus on natural flood management than currently is the case elsewhere in the UK. In England however take up of flood warning services is much more widespread. These, and many other differences (as set out in Appendix G), have been considered in developing a representative description of the effectiveness of each adaptation measure. In most cases a greater emphasis has been placed on polices that have the potential to influence risk the greatest. Any future development of the FFE could consider adaptation measures for each country (whilst continuing to analyse risk in a consistent way across the UK).

Local context in which Adaptation Measures are applied: The applicability and effectiveness of a given mix of adaptations will reflect the local context within which they are applied. This local context is in part embedded within the description of the individual Adaptation Measures. For example, the degree to which climate change reduces the standard of protection provided to an area reflects the present day standard in that area. This means that parts of the floodplain protected to a higher standard today continue to have more effort devoted to them in the future. The consideration of specific local constraints and opportunities that will determine the feasibility of specific adaptation measures at a local level is, however, out of scope.

***The role of flood insurance and experience*:** The availability and implementation of flood insurance is not considered here as a direct Adaptation Measure driving flood risk, or reducing risk where it is applied. This is mainly because flood insurance does not lessen risk necessarily by itself, but simply redistributes the effects of risk in terms of compensation to flood victims for the damage that they incur. This redistribution occurs as a result of the majority of policy owners not making claims at any one time, or indeed not making claims at all, resulting in a subsidy for those who do make claims.

Nevertheless flood insurance is not ignored. Under Flood-Re (Defra, 2013) it is expected that, in the longer term, insurance premiums will rise substantially for those at risk, and those at most risk will pay the much more than at present, as full actuarial pricing comes into being after 25 years (in the shorter term the proportion of people already paying a degree of risk-reflective pricing may see their premiums fall as price caps are imposed from April 2016). This could well have a substantial effect on the occupation of flood risk areas, thereby reducing risk as some people choose not to live in areas where premiums for flood insurance are as high as they need to be to cover the compensation claims that are made. Flood insurance can also provide a signal and thereby alert people to risks that they face, which in turn can encourage householders to take out receptor level protection measures. The changes in the behaviour of those at risk may also be triggered by flood insurance payments, and flood insurance may also provide a signal that people should remove valuable items from the threat of flooding (a discussion of the potential interactions between insurance and adaptation is discussed further in Chapter 9).

Table 4-1 Individual Adaptation Measures: Probability focused measures

Adaptation Measure (AM)	Description of the three levels of adaptation	
Manage the **probability** of flooding		
1 Construction and maintenance of river and coastal defences ***FFE measure:*** Change in the representative SoP (rSOP) and their associated condition (rCg).	CLA	In some areas where the benefit cost case is weakest the standard of protection provided reduces as investment fails to keep pace with climate change. Areas with the highest standards today (such as the Thames estuary) continue to be well protected and standards are maintained into the future. The majority of defences systems (i.e. those with an actual or target condition of rCg = 4 or higher) continue to be maintained at rCg = 4 or better. In areas protected by defences with rCg of 5, the case for continued maintenance or improvement is assumed weak and with time they deteriorate further.
	High(er)	Willingness to pay through initiatives such as partnership funding (in England) and innovative designs enable standards to be improved in highest consequence areas (i.e. those with a current rSOP> 1:500) and standards to be maintained for many others (i.e. those with a current rSOP>-1:75 and < 1:500). The condition of the most important assets is also improved (i.e. those with a current rCg> 3). Although less effort is devoted to lower standard systems (current SOP< 1:75), the reduction in standard is less than under the CLA.
	Low(er)	Effort is mainly directed towards the higher consequence areas and standards are maintained in these areas (i.e. rSOP>1:500). In lower risk areas, standards reduce in response to climate change. Defence condition continues to be appropriately managed (e.g. in England, as set by the EAs target condition grade).
2 Working with natural processes at the coast and in estuaries – Managed realignment ***FFE measure**:* Change in the rSoP provided to a Flood Area	CLA	The targets set out within the SMPs for England are met across the UK with 9% of the coastline realigned by the 2030s, 14% by 2060s and 16% by 2080s. This acts to reduce the impact of climate change on all coastal defences with an rSOP of less than 1:75 years. The rSOP of high standard defences is unaffected.
	High(er)	There is a greater emphasis on management realignment to reduce maintenance costs and provide compensatory habitat and the length of coast/estuary realigned increases to 15% by 2030, 25% by 2050 and 30% by 2080. This enables a great proportion of the climate change induced reduced in standard to be mitigated for coastal defences with an rSOP of less than 1:75 years.
	Low(er)	Managed realignment schemes reduce as targets fail to be met. This reflects increasing difficulty in implementing realignment schemes due to objections at a community level as a transition from a hold the line to a managed realignment policy is sought. A few schemes continue to go ahead where the environmental or cost case is greatest. This results in only 5% of the coast line being realigned by 2030 and 9% by 2050 (with no further change to 2080).
3 Natural flood management practices in rural catchments ***FFE measure:*** Change in return period of given **peak river flow**	CLA	Given the majority of management policies across the UK promote the role of Natural Flood Management (NFM) in some form the CLA scenario also has an element of such measures. The impact of NFM is however restricted reflected the limited level of take-up seen to date; achieving (up to) a 5% reduction on peak flows during more frequent events reducing to 2% during the more severe events (i.e. 1:100 year event) by the 2080s.
	High(er)	The multiple benefits of NFM is increasingly recognized resulting in wider up take. By 2080s NFM measures deliver up to a 20% reduction in peak flows during more frequent events and an 8% reduction during more extreme events (i.e. the 1:100 year return period event).
	Low(er)	The lack of scientific evidence and demonstrate continues to restrict take up and limited effort is devoted to NFM measures. As a result NFM measures have no significant impact peak flows during more frequent or more extreme flood events.
4 Urban flood management practices ***FFE measure:*** Change in return period of given **run-off volume**	CLA	Planning policies continue to strengthen and from 2020 onwards 25% of new developments implement Sustainable Urban Drainage (SUDS) - up from 15% today. Retrofitting to existing development continues to be limited (remaining around 10% by area). Broader efforts to manage surface water continue to have a limited impact on flood risk (reducing damages during events occurring more frequently than 1:30 years by 5% from 2020s onwards).
	High(er)	Planning policies continue to strengthen and by 2050 onwards 50% of all new developments implement SUDS. Retrofitting also increases, reaching 30% (by area) by the 2050s. A full range of surface water management measures are also increasingly implemented alongside SUDS (reducing damages during events occurring more frequently than 1:30 years by 50% by 2050s onwards).
	Low(er)	Continued uncertainty around roles and responsibility for SUDS restrict up take and implementation with new development remains around 15%. Retrofitting to existing developments stops. Wider surface water management measures also reduce and they have no significant impact on reducing flood damages.

Table 4-2 Individual Adaptation Measures: Exposure and vulnerability focused measures

Adaptation Measure (AM)	Description of the three levels of adaptation	
Manage the **exposure** to flooding		
5 Spatial planning *FFE measure:* Change in the location of new build residential properties in areas of flood risk	CLA	The percentage of new dwellings built within the fluvial and coastal floodplain continues as today (i.e. around 12%). Of these new dwellings, 20% are built in areas with a 1:75 or greater annual chance of flooding with the remaining properties equally split between low and moderate probability areas. It is assumed that this development is in line with planning policy, i.e. that it is has been made safe and resilient and without increasing flood risk elsewhere. The location and design of development outside of the fluvial and coastal floodplain is unaffected by flood risk considerations.
	High(er)	Consideration of flood risk takes a higher priority in the implementation of planning policy by local authorities and fewer new dwellings are built in the floodplain as a whole (reducing to 5% by 2050s), with a negligible number within areas with a 1: 75 or greater annual chance of flooding. Surface water hazard mapping is increasingly used to inform development decisions and planning controls are effective at preventing development in areas subject to a high chance of surface water flooding.
	Low(er)	Planning controls weaken resulting in a higher proportion of development being built in the fluvial and coastal floodplain (20% of all development) and a higher proportion of that in areas at a high chance of flooding (30% in areas with a 1:75 or greater annual chance of flooding). The location of development outside of the fluvial and coastal floodplain is unaffected by flood risk considerations.

Table 4-3 Individual Adaptation Measures: Vulnerability focused measures

<table>
<tr><th>Adaptation Measure (AM)</th><th colspan="2">Description of the three levels of adaptation</th></tr>
<tr><td colspan="3">Manage the vulnerability of those exposed to flooding</td></tr>
<tr><td rowspan="3">6a Receptor Level Protection Measures (Residential)

FFE measure: Change in the economic damage incurred at a given probability of flooding

Note: Across all levels of adaptation it is assumed that
• 80% of the RLP take-up is successful at reducing damage
• The reduction in damage is more significant during more frequent events.</td><td>CLA</td><td>Within the fluvial and coastal floodplain all new residential properties are built with appropriate flood resistance and resilience measures. Outside of the fluvial and coastal floodplain new properties continue to be built without any consideration of RLP measures. There is some limited take up (5-10%) of RLP measures by existing homeowners in areas at a high chance of either coastal or fluvial flooding.</td></tr>
<tr><td>High(er)</td><td>Within the fluvial and coastal floodplain all new residential properties are built with appropriate flood resistance and resilience measures. Grants and incentives support an increase in retrofitting (20-50%), particularly within areas at the highest chance of flooding. With an increased acceptance of the risk posed by flooding, and confidence in the performance of RLP measures there is some take-up in moderate and low probability areas. With access to improved surface water and groundwater flood maps and associated incentives from insurers there is also some uptake outside of the fluvial and coastal floodplain but is limited.</td></tr>
<tr><td>Low(er)</td><td>As confidence in flood maps reduce and the enforcement of planning policy weakens only 50% of new developments on the fluvial and coastal floodplain include RLP measures. The level of retrofitting is very limited, with only 3% of properties within areas at a high chance of flooding taking up RLP.</td></tr>
<tr><td rowspan="3">6b Receptor level protection measures (non-residential properties and infrastructure)

FFE measure: Change in the number of properties exposed and, for Category B non-residential properties only, the economic damage incurred when flooded.

Note: When implemented by Category A owners RLP achieves an SOP of >=1:200 years.</td><td>CLA</td><td>The example of widespread take up of RLP measures in the energy sector is mirrored by other Category A infrastructure providers, with 50% of all assets on the fluvial and coastal floodplain protected by the 2020s raising to 100% by the 2080s. Outside of the fluvial and coastal floodplain take up is less (20-50%). Take up by Category B providers is limited to 10% of assets within the highest risk areas of the fluvial and coastal floodplain by 2080s.
Damages for all non-residential properties (including infrastructure sites) are reduced in line with take up.</td></tr>
<tr><td>High(er)</td><td>Increasing awareness of flood risk support the wider take-up of by both Category A and B infrastructure providers, particularly within the areas exposed to a high probability of coastal or fluvial flooding (with a 100% of all Cat A and 50% of all Cat B assets protected). Outside of these areas take up increases, particularly amongst Cat A providers (reaching 50%) but remains stubbornly low amongst Cat B providers.</td></tr>
<tr><td>Low(er)</td><td>Take up by Category A infrastructure providers slows and fails to raise above 50%.Take up by Category B providers is negligible.</td></tr>
<tr><td rowspan="3">7 Forecasting, warning and community response

FFE Lever: Change in the economic damage incurred at a given probability of flooding</td><td>CLA</td><td>Flood forecasting and warning (FF&W) continues to be a significant component of the flood risk management effort and continues to improve (with up to 75% of residential properties in coastal areas acting on warnings and slightly less in fluvial areas and amongst non-residential properties by the 2080s). Effectiveness also improves, reflecting the ability to forecast more frequent events with long lead times and continued increases in awareness amongst those at risk. As a result direct damages associated with storm events occurring more frequently (on average) than 1:75 years are reduced by 5% by the 2080s.</td></tr>
<tr><td>High(er)</td><td>With the recognition that in lower consequences areas and in areas of high natural value traditional defences are unlikely to be affordable/desirable, significantly greater emphasis is placed upon FF&W (with up to 100% of residential properties in coastal areas acting on warnings and slightly less in fluvial areas and amongst non-residential properties). Coupled with science advances in radar and model technologies forecast accuracy improves and lead times extend. Warnings are widely believed and tailored to the specific needs of recipient and communities are better able to respond due to an improved understanding of risk they face. As a result direct damages associated with storm events occurring more frequently (on average) than 1:75 years are reduced by 15% by the 2080s.</td></tr>
<tr><td>Low(er)</td><td>Reduced investment in observational networks and awareness campaigns leads to a reduction in the accuracy of forecasts and an increase in the number of false warnings. This leads to an associated loss in confidence and hence effectiveness. Take-up reduces to 25%. For those signed up lead times and accuracy are poor and hence FF&W has no impact on damages.</td></tr>
</table>

4.2 Adaptation Scenarios

Many studies have confirmed that flood risk is best managed through a portfolio of measures implemented through a continuous processes of adjustment (Evans et al 2004a&b, Sayers *et al.*, 2014). This is reflected in much of the UK flood risk management policy (e.g. Treasury Green Book (2003); Making Space for Water (Defra 2005); Working with Natural Processes (Environment Agency, 2010, 2014b); Delivering Sustainable Flood Risk Management (Scottish Government, 2011)). The individual **Adaptation Measures** (described in the preceding section) have therefore been used to create five alternative **Adaptation Scenarios** and a **baseline scenario** with a varying level of ambition and focus (Figure 4-1).

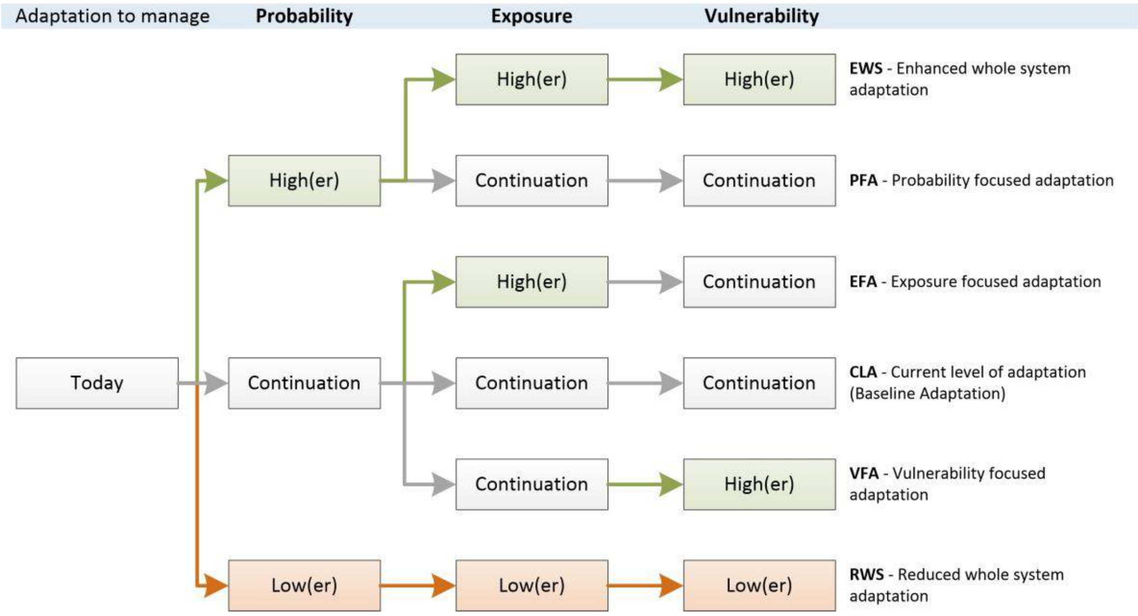


Figure 4-1 Alternative Adaptation Scenarios

The guiding philosophy behind each Adaptation Scenario is discussed below. A summary of the individual measures and their effectiveness under each Scenario is summarized in Table 4-4.

Note:

The CCRA Method statement (provided by the CCC) sets out three adaptation scenarios: "(i) ***No additional action.*** *No additional effort is taken to reduce risks or take advantage of opportunities compared to today, and there is no additional autonomous action. In many cases this will mean that no action is taken at all, while in some areas such as water resources planning and flood risk management it may mean that low levels of action continue at a defined level that is in line with the current level of ambition. This scenario is needed as much of the literature that provides future estimates of risks assumes no adaptation, either autonomous or planned. (ii)* ***Current objectives.*** *All actions that are currently planned in Government policies and programmes are implemented. This could include meeting certain policy goals. This scenario may also assumes that some autonomous adaptation takes place. (iii)* ***Current objectives+*** *This scenario goes beyond current policy and defines a higher level of adaptation. This could include all cost-beneficial adaptation or go further and consider transformational change or the potential limits of adaptation."*

The degree of adaptation to flooding however crucially depends upon the implementation of current policies rather than the policy objectives themselves. It would be inappropriate to interpret 'no additional action' as taking no further action to maintain or improve flood defences for example. Instead we have interpreted it as business as usual where flood risk management policies **continue** to be implemented as experienced in the recent past. The scenarios of *current objectives* and *current objective +* are also difficult to interpret in the context of flood risk management (given the reasonably comprehensive nature of the policies but challenges in implementation). For this reason five additional adaptation scenarios are considered that are more or less ambitious than the current level of adaptation.

4.2.1 Baseline adaptation: Continuation of Current Level of Adaptation (CLA)

Under the Baseline Adaptation (the CLA scenario) all individual Adaptation Measures continue to be implemented as experienced in recent years (i.e. in-line with the description provided under the **current level of adaptation** in Tables 4.1-3).

4.2.2 Enhanced 'whole system' adaptation (EWS)

Adaptation is **high(er)** than the current levels across all individual Adaptation Measures (including those to manage probability, exposure and vulnerability). Under the EWS Adaptation Scenario investment in flood defences increases and land use planning policy is more rigorous in restricting inappropriate development. Experience of flooding together with the increasing cost of flood insurance encourages the take-up of Receptor Level Protection at a greater rate than in recent years. Flood forecasting and warning systems develop with increased levels of sophistication, targeting those at risk more accurately than has been possible to date.

4.2.3 Probability focused adaptation (PFA)

Enhanced effort is directed towards the management of the probability of flooding, with **high(er)** levels of adaptation in both traditional flood defences as well as responses that work with natural processes to manage catchment flows, urban run-off and coastal realignment. Exposure and vulnerability focused measures such as Receptor Level Protection (RLP), land use planning and forecasting and warning continue to be implemented at the **current level of adaptation**.

4.2.4 Exposure focused adaptation (EFA)

Land use planning is strengthened and experiences a **high(er)** level of adaptation in comparison to present day. This reflects increased awareness of flooding and a concern to limit development in flood prone areas through more rigorous regulation of planning decisions. All other measures continue to be implemented at the **current level of adaptation**.

4.2.5 Vulnerability focused adaptation (VFA)

Reducing the vulnerability of the people and infrastructure exposed to flooding has an increased focus, with **high(er)** levels of adaptation in this regard. There is a greater emphasis on individuals, organisations and communities taking action to reduce their vulnerability through receptor level protection. There is also a greater demand for flood forecasting and warning arrangements and these improve. All other measures continue to be implemented at the **current level of adaptation**.

4.2.6 Reduced 'whole system' adaptation (RWS)

The adaptation effort as a whole reduces. All Adaptation Measures are implemented at a **low(er)** level than the current levels of adaptation. Investment in traditional defences reduces (reflecting a reduction in the willingness to pay for defences from national tax revenues as flooding is increasingly seen as less of a national risk and more of a local one, but local funding fails to replace centralized investments). There is little take up of innovative catchment-based or urban run-off measures occurs, spatial planning becomes less rigorous (resulting in new development on the floodplain than currently is the case), and flood forecasting and warning systems and receptor level protection see **low(er)** levels of effectiveness and performance.

Table 4-4 Summary of Adaptation Measures taken under each Adaptation Scenario

	Adaptation Scenario					
Individual Adaptation Measure or instrument	Baseline adaptation (CLA)	Enhanced 'whole system' adaptation (EWS)	Probability focused adaptation (PFA)	Exposure focused adaptation (EFA)	Vulnerability focused adaptation (VFA)	Reduced 'whole system' adaptation (RWS)
Managing the probability of flooding						
Changes to Standard of Protection due to climate change						
#1 Construction/maintenance of coastal and river flood defence infrastructure						
Reduction in standard avoided given a defence with a 1:50 year SoP today (express as a % of the change avoided)	75%	100%	100%	75%	75%	25%
Reduction in standard avoided given a defence with a 1:100 year SoP today (express as a % of the change avoided)	100%	150%	150%	100%	100%	50%
#2 Working with natural processes at the coast and in estuaries – Managed realignment						
Reduction in standard avoided given a defence with a 1:50 year SoP today (express as a % of the change avoided)	7.0%	12.5%	12.0%	7.0%	7.0%	4.5%
Reduction in standard avoided given a defence with a 1:100 year SoP today (express as a % of the change avoided)	0%	0%	0%	0%	0%	0%
Change in return period of given peak river flow						
#3 Natural flood management practices in rural catchments						
Frequent events (e.g. 10 year return period event)						
Reduction in the % increase in peak flow (assuming 100% non-BMV land)	2.0%	-10.0%	-10.0%	-2.0%	-2.0%	0.0%
Reduction in the % increase in peak flow (assuming 100% BMV land)	-1.0%	-2.0%	-2.0%	-1.0%	-1.0%	0.0%
Less frequent events (e.g. 100 year return period event)						
Reduction in the % increase in peak flow (assuming 100% non-BMV land)	-1.0%	-5.0%	-5.0%	-1.0%	-1.0%	0.0%
Reduction in the % increase in peak flow (assuming 100% BMV land)	-0.5%	-1.0%	-1.0%	-0.5%	-0.5%	0.0%
Change in return period of given run-off volume						
#4 Managing probability and damage: Urban flood management practices						
Reduction in the urban run-off due to the take up of SuDs (influencing flooding more frequent than 1:30 years only)						
New properties impact both the effective urban extent and the run-off characteristics of the area *Take up amongst new development*	25%	50%	50%	25%	25%	15%
Retroffing to existing properties impact only the effective urban extent *Take up amongst existing development*	10%	30%	30%	10%	10%	0%
Reduction in WAAD achieved through implementation of surface water management activities (other than SuDs)						
Properties flooded more frequently than 1:30 years (on average)	5%	50%	50%	5%	5%	0%
Properties flooded less frequently than 1:30 years (on average)	0%	0%	0%	0%	0%	0%
Managing exposure to flooding						
Change in the location of new build residential properties						
#5 Spatial planning						
In areas subject to flooding from the river and sea						
Proportion of new properties built in the floodplain: All areas	12%	5%	12%	5%	12%	20%
Proportion of those properties built in high probability areas (flooded more frequently than 1:75 years)	20%	0%	20%	0%	20%	30%
Areas subject to surface water flooding						
Proportion of new propoerties built in the floodplain: All areas	88%	95%	88%	95%	88%	80%
Proportion of those properties built in high probability areas (flooded more frequently than 1:75 years)	33%	0%	33%	0%	33%	33%
Areas subject to groundwater flooding						
Groundwater alone is considered to have no impact on planning decisions	na	na	na	na	na	na
Managing vulnerability of those exposed						
Change in the economic damage incurred at a given probability of flooding						
#6 Receptor Level Protection Measures						
Residential property take-up						
Off fluvial and coastal floodplain						
Take-up as a proportion of ***new*** *properties - All areas*	0%	50%	0%	0%	50%	0%
Take-up by ***existing*** *properties (% of exisitng properties) - All areas*	0%	10%	0%	0%	10%	0%
On fluvial and coastal floodplain						
Take-up as a proportion of ***new*** *properties - All areas*	100%	100%	100%	100%	100%	50%
Take-up by ***existing*** *properties (% of exisitng properties) - High probability areas*	7%	30%	7%	7%	30%	3%
Take-up by ***existing*** *properties (% of exisitng properties) - All other areas*	0%	5%	0%	0%	5%	0%
Effectiveness in reducing damages						
Where implemented % of receptor level protection successful in reducing damage	80%	80%	80%	80%	80%	80%
where successfully deployed % reduction in WAAD (1:10 year event)						
Coastal floodplain	40%	40%	40%	40%	40%	40%
Fluvial floodplains	100%	100%	100%	100%	100%	100%
Surface water	80%	80%	80%	80%	80%	80%
Groundwater	80%	80%	80%	80%	80%	80%
Non-residential property take-up						
Off fluvial and coastal floodplain						
Take up by ***Category A*** *(i.e. water and energy - all areas*	0%	30%	0%	0%	30%	0%
Take up by ***Category B*** *(transport, emergency services, social and watse) - all areas*	0%	5%	0%	0%	5%	0%
On fluvial and coatsal floodplain						
Take up by ***Category A*** *(i.e. water and energy - all areas*	75%	100%	75%	75%	100%	50%
Take up by ***Category B*** *(transport, emergency services, social and watse) - High probability areas*	5%	25%	5%	5%	25%	3%
Take up by ***Category B*** *(transport, emergency services, social and watse) - All other areas*	5%	15%	5%	5%	15%	0%
#7 Forecasting, warning and community response						
Residential property						
Take up in coastal floodplains	75%	100%	75%	75%	100%	50%
Take up in fluvial floodplains	50%	75%	50%	50%	75%	25%
Reduction in damages (given a 1:100 year event)	6%	10%	6%	6%	10%	0%
Non-Residential property						
Take up in coastal floodplains	50%	75%	50%	50%	75%	25%
Take up in fluvial floodplains	30%	50%	30%	30%	50%	25%
Reduction in damages (given a 1:100 year event)	6%	10%	6%	6%	10%	0%

Note:

Variations in current levels of adaptation across England, Scotland, Wales and Northern Ireland. Each country within the UK approaches flood risk management with a slightly different emphasis. Consequently some Adaptation Measures are more significant in some countries than others. For example in recent years take up of flood warning services is more widespread in England than it is in Scotland. To interpret the results correctly these differences need to be understood and are explained more fully in Appendix E.

More adaptation scenarios: Alternative adaptation scenarios are of course valid; however for reasons of simplicity and resource constraints, the limited set introduced above has been chosen.

Reduced 'whole system' adaptation: Under this scenario increased flooding is likely. It is assumed here that increased experience of flooding does not lead to **higher** levels of adaptation, perhaps because other threats are more dominant in the public mind than flooding. This is somewhat an extreme situation, but such extremes do represent a plausible retreat from major intervention by the state to counter flood risk even at current levels, and are important to consider in this analysis as they contextualize our scenarios with the **lower** levels of adaptation by presenting a "worst case" example.

***Exposure and vulnerability focused adaptations*:** Whilst reducing investment in managing the probability of flooding may be unlikely in the future, the direction of policy travel in the UK currently is towards greater devolution of responsibilities to local communities, and we judge that it is appropriate and sensible to seek to model these scenarios.

Adaptation Scenarios are not dynamic: The Adaptation Scenarios used here present a predefined view of future adaptation. The consideration of a more dynamic approach, changing policies as the reality of the future becomes know, although increasingly recognised as the reality of an adaptation it is not considered here. This reflects the scenario based approach across the CCRA studies and inherent complexities in developing and exploring dynamic adaptation pathways that is beyond the scope of this study.

5.0 OVERVIEW OF THE FUTURE FLOOD EXPLORER

The analysis presented in this report has been undertaken using the Future Flood Explorer (FFE). The FFE uses existing data to create an emulation of the flood risk system that is fast to run and capable of exploring the impact of future change on a range of risk metrics (set out in Table 2-1). The FFE relies upon nationally available datasets from each country and provides a **consistent UK wide view of changes in flood risk arising from all sources**. The quick run time of the FFE allows the alternative epochs, climate change futures and alternative Adaptation Scenarios to be assessed with limited runtime overhead.

The real world flood risk system is represented spatially within the FFE using *Calculation Areas* determined as follows:

- *Within river and coastal floodplains:* Calculation Areas are determined through consideration of the river network, boundaries of the floodplain and the coastline.
- *Outside of the fluvial or coastal floodplains*: Calculations Areas are created by sub-dividing the land surface into 1kmx1km squares.

A schematisation of the Calculation Areas for a small region is shown in Figure 5-1.

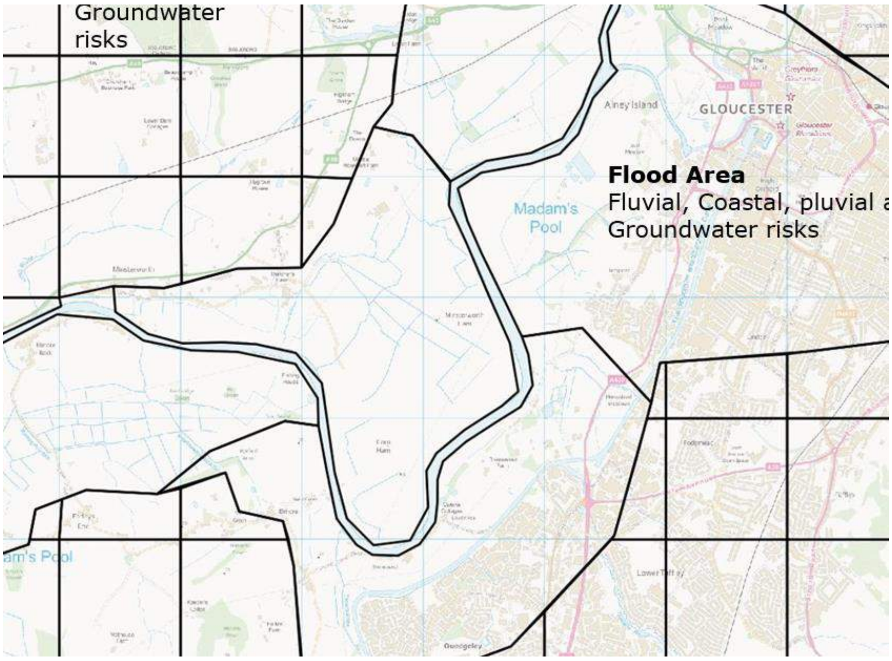


Figure 5-1 Calculation Areas aggregate nationally available flood information for use in the FFE

It is assumed that a given Calculation Area within the floodplain responds to either coastal or fluvial flood sources (but can still experience surface or groundwater flooding). To incorporate the effect of defences each Calculation Area is also associated with a representative SoP and Condition Grade.

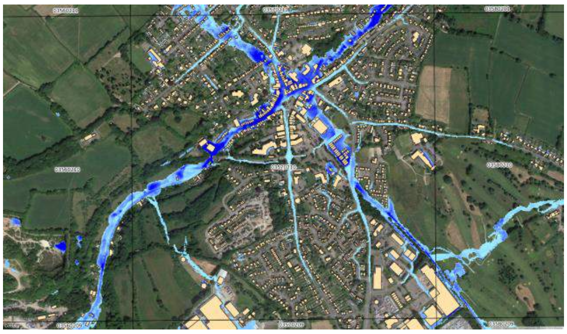
An *Impact Curve* (relating the return period of a flood event to the damage that would be incurred) is then generated for each Calculation Area (Figure 5-2) based upon the input datasets and results from the available flood modelling (as set out in Appendix A). The *Impact Curves* are then used to "look up" the impacts for any given return period and all risk metrics of interest (this is the essence of the emulation process). This process enables annual average damages to be assessed (by looking up damages associated with multiple return periods). It also enables the influence of climate and population change as well as adaptations to be assessed by making modifications to the Impact Curves (for example representing climate change by moving the impact curve along the return period axis).

1km square and receptors

1 in 30 year return period

1 in 100 year return period

1 in 1000 year return period



Impact Curve

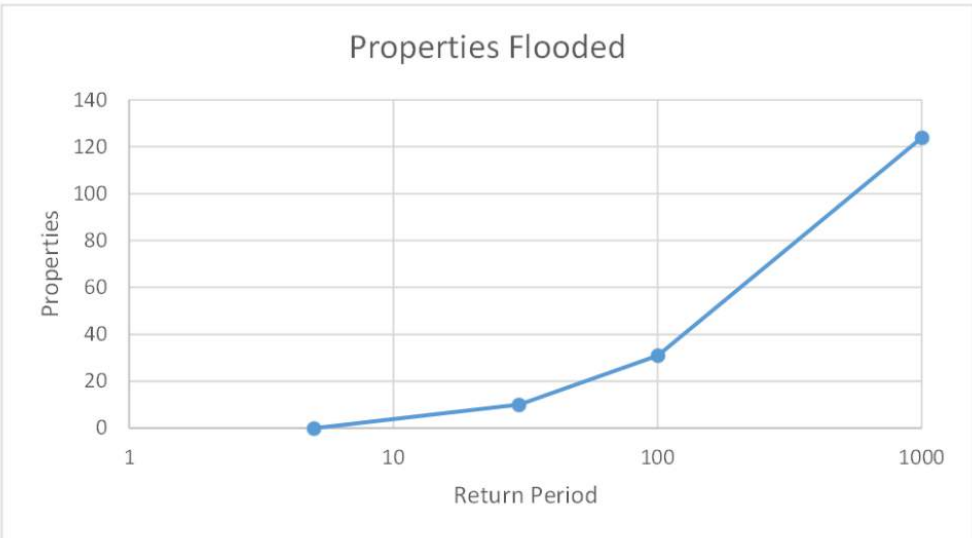


Figure 5-2 Developing an Impact Curve with the Future Flood Explorer: A hypothetical example for surface water

A detailed description of the FFE is provided in Appendix F.

Note:

Larger output scales are more useful and credible. As set out in Section 0 *t*he results from the FFE are aggregated to areas much larger than individual Calculation Areas. This is because the results from individual Calculation Areas are not necessarily meaningful for two primary reasons: (i) emulation process is subject to local noise, and (ii) assumptions underlying the climate, population and Adaptation Measures are not necessarily meaningful at a very local scale. Further discussion of the validity of the FFE is provided below and expanded in Appendix G.

5.1 Limitations and assumptions

Like all models the FFE and the associated analysis presented within this report is subject to number of assumptions and limitations. Many of these have already been introduced in earlier Chapters, the most important of the remaining assumptions and limitations are discussed below.

1 Input data are fit for purpose: The FFE relies upon the data provided by the national policy leads in England, Wales, Scotland and Northern Ireland. These data vary across the UK and are all uncertain to some degree (reflecting the underlying data and methods used to generate them). A review by the National Audit Office (NAO) of the data for England (National Audit Office, 2011) recognized this and called for greater effort to be directed towards communicating / understanding the confidence in National Flood Risk Assessment (NaFRA) analysis and validating the outputs. Similar statements are likely to be applicable to the approaches used in Scotland, Wales and Northern Ireland. Despite these uncertainties the assumption made here is that the information available from the Environment Agency, Scottish Environment Protection Agency Rivers Agency and Natural Resources Wales are fit for purpose. This is not to say that the data are locally accurate (all of the approaches have known limitations), but these data remain the most appropriate to use.

Note:

Although data are drawn from readily available sources at a national scale for the purposes of the analysis presented here, the results of more local studies could be incorporated in future updates if made available.

2 The FFE is an accurate emulator of the system: To provide credible results the FFE must be based upon data that are fit for purpose (point above) and capable of emulating these data accurately. The results from the FFE have been compared with results from national scale studies and confirm that it reproduces know results. This results of this analysis (discussed further in Section 5.2) confirm the FFE as fit of purpose.

3 Global Mean Temperature Changes (GMT) can be mapped to credible changes in flood relevant variables: In translating changes in GMT it is assumed that a given change in GMT will yield a credible estimate of the change in the flood relevant variable (i.e. change in peak flow, rSLR etc.) regardless of the emission scenario or interpolation between emission scenarios that generates a given change in GMT. This assumption allows the results from alternative emission scenarios and ‘Change Factors’ in published guidance documents from across the UK to be synthesized into the common set of climate change projections used here.

4 The extent of the floodplain does not change in response to climate change: The spatial extent of the floodplain does not change with climate change; only the frequency of flooding changes within the floodplain. For example, properties currently outside of fluvial and coastal floodplain are assumed to remain outside of the floodplain. This assumption impacts the results as follows:

- The ‘properties at risk’ metric estimates the number of properties exposed to flooding more frequently than 1:1000 years (on average). For England, Scotland and Wales the number of properties at risk does not change with climate change but will change with population growth. This is because the FFE approach assumes that the extent of the 1:1000 year floodplain does not change with climate change. Northern Ireland is an exception, as the hazard data provided includes a return period greater than 1000 years (actually the 1000 year plus climate change), which defines the floodplain extent. This means that properties at risk of flooding more frequently than 1:1000 can change with climate.
- Estimates of Expected Annual Damages within the FFE. The FFE integrates damages up to a return period of 1:1000 years (present day). Under climate change this will reduce, for example the 1:1000 year event may become the 1:200 year event). This introduces some additional uncertainty into future estimates of risk.

Note:

A separate analysis has been undertaken at the coast to explore the potential impact of SLR on the vulnerability of defences and the potential area of inundation should the most vulnerable defences be lost. This analysis takes place outside of the FFE and relaxes the assumption of a fixed floodplain extent. The results of this analysis are presented separately in Chapter 7.

5 Inflation is excluded: Monetary damages are reported at 2014 prices and inflation is excluded.

6 Future projections of population growth and climate change are independent considerations. Climate change and population are considered separately with no interdependences.

5.2 Uncertainty: Sources, model verification and validation of results

In common with all models the FFE is subject to uncertainty arising from a number of sources. Some of these can be controlled as part of this project (e.g. arising from the emulation process), and others are external and cannot be reduced (e.g. arising from uncertainties in input hazard data and future change). Table 5-1 summarizes both internal and external uncertainties and approach taken here to explore, and where possible quantify, their importance. The Table also provides a sign-post to the supporting studies (reported in Appendix G) undertaken to validate the underlying data provided by Environment Agency and verify the credibility of the FFE emulation.

Table 5-1 Sources of uncertainty

Uncertainty source	Likely magnitude	Affects	Approach to determining importance
External to this project			
Uncertainty in input data, for hazard, receptors and vulnerabilities.	Likely to be highly variable, ranging from highly credible data to data containing considerable uncertainty.	Understanding of present day and future risk	Various studies have questioned the credibility of the national flood risk estimates (e.g., Penning-Rowsell, 2015). The formal validation of risk is problematic and remains an active area of research. Despite these difficulties some effort has been made to compare the FFE results with real flood damages using the widespread flooding across England in 2007. This is reported in **Appendix G**.
Internal to this project			
Uncertainty introduced by the emulation process	The 'change' results – from one epoch to another and between adaptations – are likely to be more credible than the absolute estimates associated with a given future.	Present and future risks	The ability of the FFE to reproduce the input datasets has been explored through a series of verification tests. These tests show the FFE to be fit for purpose in the context of the CCRA. The results of these comparisons are presented in detail in **Appendix G**.
Climate change	Variable – and subject of this study	Future risk only	Uncertainty in climate change is explored through a scenario approach. Three scenarios are explored based on changes in GMT of 2^{o}C and 4^{o}C as well as the H++ scenario.
Population growth	Variable – and subject of this study	Future risk only	Uncertainty in population growth is explored through a scenario approach. Three scenarios are explored based on **no**, **low** and **high** growth scenarios.
Future adaptation	Variable – and subject of this study	Future risk only	Uncertainty in future adaptation is explored through a scenario approach. Six scenarios are considered, a baseline Adaptation Scenario (CLA) and five alternative scenarios.

6.0 FUTURE FLOOD RISKS: ANALYSIS RESULTS

6.1 Overview of analysis runs

The change in flood risk has been calculated using the FFE for each Adaptation Scenario (the baseline and the five alternatives) and seven combinations of climate change and population growth (Table 6-1). The H++ scenario is only considered in combination with the high population growth scenario; a combination designed to provide an extreme (high-end), but plausible, future.

Table 6-1 Core scenarios to be considered by the FFE

Exogenous scenarios		Change in Global Mean Temperature by 2080s from the 1990 baseline		H++ Scenario
		2°C	4°C	
Population growth scenario	No change	2 °C / No	4 °C/No	
	Low	2 °C/Low	4 °C/Low	
	High	2 °C/High	4 °C/High	H++/High

Note:

In viewing the tables and figures that follow it should be noted that:

Climate change projections: The 2°C and 4°C labels apply to the climate change projections; these do not imply, for example, a 4°C rise in GMT by the 2020s, but instead refer to the climate change projection that produces this temperature rise by the 2080s.

Percentage changes: Many of the results are shown as a percentage change. All percentage increases are relative to 2014 (not to the previous epoch). For example, a percentage increase of 100% implies that the future risk equals the present day risk plus 100% of the present risk (i.e. the future risk is twice the present day).

Only selected results are presented: Results for **all** metrics, sources, reporting areas, epochs, and adaptation scenarios are provided in an accompanying 'results spreadsheet'. This can be used to access the required metrics and climate, population and adaptation combinations.

6.2 Fluvial, coastal and surface water: Estimates of future flood risks

Selected results from the FFE are presented below together with a brief interpretation. The discussion of the results is provided later in Chapter 8 (following presentation of all of results).

6.2.1 Results: Tables and graphs

National headline risks: Baseline adaptation

Tables 6-2 to 6-6 present the headline changes in risk under the Baseline Adaptation scenario (CLA) for the UK, England, Scotland, Wales and Northern Ireland respectively for the 2080s. The Baseline Adaptation includes local protection of the majority of Category A infrastructure sites. As a result the number of Category A infrastructure assets exposed to frequent flooding (more often than 1:75 years on average) rapidly reduce.

National headline risks: The influence of alternative adaptations

Table 6-7 contrasts the changes in headline risks across the UK under the Baseline Adaptation (CLA) and the five alternative Adaptation Scenarios (assuming a 4°C climate change and a low population growth projection).

Table 6-8 summarizes the increases in Expected Annual Damages (EAD) due to climate change and population growth, and the extent to which these are offset by the CLA and EWS adaptation scenarios:

- By the 2080s, under the 2°C climate change projection, the CLA scenario offsets 28% (low population growth) and 38% (high population growth) of the increase in risk from climate and population; EWS does better in offsetting all of the increase and more (for low population, 110% of the increase is offset) or almost all the increase (for high population, 98% is offset).
- By the 2080s, under the 4°C scenario, the CLA scenario offsets 50% (low population) and 40% (high population) with the EWS scenario offsetting around 70% of the increase for both low and high population.
- By the 2080s, under the H++ scenario, CLA and EWS both offset around 70% (high population growth) of the increase.

In summary, under the 2°C and 4°C climate projections, CLA offsets 30-50% of increases due to climate change and population growth, EWS offsets more (70-100%).

Disaggregation of the drivers of future risk

Figure 6.1 provides an overall summary of the impact of the 2°C climate change projection and both high and low population growth on EAD by the 2080s. The contribution from each source of flooding (coastal, fluvial and surface water) makes to that risk and the effectiveness of each Adaptation Scenario in reducing the risk is also presented. Fluvial and coastal risk make approximately equal contributions to future risk, with less from surface water. The EWS, PFA and VFA scenarios are all capable of significantly offsetting climate change and population growth.

Figure 6-2 recasts the previous table in the context of the 4°C climate change projection. As expected, by the 2080s, the impact of climate change is more significant than under the 2°C scenario, and the climate influence on risk is more significant than the population increase under either of the two population scenarios. Fluvial risk makes a significantly bigger contribution than coastal and surface water. Again, adaptation measures offset a greater amount of the heightened risk under higher population growth scenarios.

Figure 6.3 focuses on the H++ scenario and high population growth only. As expected, by the 2080s the impact of climate change is significant and much larger than the increase due to population growth. The estimated EAD is dominated by fluvial flood risk. The adaptation measures make large reductions in risk (£2-3bn for all but EFA and RWS) and offset a significant proportion of the climate and population related increases (which total £3.6bn).

Spatial variation in risk

Table 6-9 presents the changes in risk by reporting area. This covers fluvial, coastal and surface water risks, under the 4°C climate projection by the 2080s. The values show a considerable variation in increases across reporting regions; some regions show decreases in numbers of properties and people in deprived areas at risk, due to decreases in population in these regions.

Table 6-2 UK: National headline risks under the Baseline Adaptation Scenario (i.e. assuming a continuation of current levels of adaptation)

		2020s			2050s			2080s		
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
No population growth										
Properties										
at risk										
No. residential	2,800,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. non-residential	1,100,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	860,000	5%	24%	54%	21%	53%	93%	40%	93%	120%
No. non-residential	420,000	3%	18%	43%	16%	42%	70%	30%	68%	86%
People (at risk of flooding more frequent than 1:75)										
No.	1,800,000	4%	23%	55%	20%	54%	98%	41%	98%	130%
No. in deprived areas	320,000	6%	28%	60%	26%	60%	110%	48%	110%	140%
Natural capital (at risk of flooding more frequent than 1:75)										
All designations (ha)	680,000	4%	12%	29%	15%	25%	55%	25%	44%	70%
Agriculture (at risk of flooding more frequent than 1:75)										
BMV land (ha)	570,000	1%	19%	36%	15%	39%	61%	32%	65%	83%
Infrastructure (at risk of flooding more frequent than 1:75)										
Water										
No. clean and wastewater sites	300	-61%	-54%	-37%	-33%	-12%	13%	-1%	33%	51%
Transport										
No. of rail stations	580	0%	5%	17%	4%	16%	32%	10%	28%	38%
Length of railway (km)	6,600	2%	13%	56%	13%	61%	130%	53%	160%	230%
Length of road (km)	2,400	1%	13%	46%	12%	49%	99%	41%	120%	170%
Energy										
No. Generation and transmission stations	1,300	-64%	-59%	-51%	-40%	-27%	-2%	-11%	10%	32%
Social										
No. Care homes	440	1%	16%	66%	13%	67%	130%	48%	140%	200%
No. Schools	1,100	1%	10%	41%	9%	42%	85%	32%	95%	130%
No. Emergency services	250	2%	16%	56%	13%	56%	110%	36%	100%	140%
No. Hospitals	94	1%	6%	28%	4%	29%	56%	23%	68%	94%
No. GP surgeies	560	2%	16%	65%	13%	64%	130%	46%	140%	190%
Waste										
No. landfill sites	400	0%	2%	5%	1%	6%	10%	5%	10%	14%
Expected Annual Damage (£)										
residential only (direct)	340,000,000	7%	35%	72%	26%	82%	280%	51%	170%	620%
Non-residential only (direct)	800,000,000	6%	31%	63%	26%	69%	220%	48%	140%	410%
Total (direct and in-direct)	1,900,000,000	6%	33%	66%	26%	73%	240%	49%	150%	470%
Low population growth										
Properties										
at risk										
No. residential	2,800,000	10%	9%	na	22%	23%	na	26%	26%	na
No. non-residential	1,100,000	0%	0%	na	0%	0%	na	0%	0%	na
at risk of flooding more frequent than 1:75										
No. residential	860,000	14%	35%	na	46%	86%	na	73%	140%	na
No. non-residential	420,000	3%	19%	na	16%	42%	na	31%	69%	na
Expected Annual Damage (£)										
residential only (direct)	340,000,000	14%	43%	na	40%	95%	na	65%	180%	na
High population growth										
Properties										
at risk										
No. residential	2,800,000	13%	13%	13%	43%	43%	44%	77%	78%	79%
No. non-residential	1,100,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	860,000	17%	39%	73%	71%	120%	170%	140%	230%	280%
No. non-residential	420,000	3%	19%	43%	17%	42%	71%	31%	70%	88%
Expected Annual Damage (£)										
residential only (direct)	340,000,000	16%	46%	83%	53%	100%	300%	78%	170%	470%

Table 6-3 England: Headline risks under the Baseline Adaptation Scenario (i.e. assuming a continuation of current levels of adaptation)

		2020s			2050s			2080s		
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
No Population growth										
Properties										
at risk										
No. residential	2,300,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. non-residential	960,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	690,000	5%	26%	58%	22%	57%	97%	43%	100%	130%
No. non-residential	360,000	3%	18%	44%	15%	42%	70%	30%	69%	87%
People (at risk of flooding more frequent than 1:75)										
No.	1,400,000	4%	25%	60%	21%	58%	100%	44%	110%	140%
No. in deprived areas	240,000	7%	31%	68%	29%	68%	110%	54%	120%	160%
Natural capital (at risk of flooding more frequent than 1:75)										
All designations (ha)	150,000	1%	10%	17%	8%	18%	28%	17%	35%	45%
Agriculture (at risk of flooding more frequent than 1:75)										
BMV land (ha)	480,000	0%	20%	37%	15%	41%	61%	34%	66%	81%
Infrastructure (at risk of flooding more frequent than 1:75)										
Water										
No. clean and wastewater sites	220	-60%	-53%	-35%	-32%	-9%	19%	2%	39%	60%
Transport										
No. of rail stations	430	0%	3%	15%	2%	14%	30%	8%	26%	37%
Length of railway (km)	3,900	1%	14%	70%	12%	81%	170%	70%	230%	310%
Length of road (km)	1,400	1%	15%	57%	11%	62%	120%	51%	150%	210%
Energy										
No. Generation and transmission stations	230	-49%	-38%	-13%	-11%	26%	65%	39%	98%	120%
Social										
No. Care homes	370	1%	16%	73%	13%	72%	140%	51%	160%	210%
No. Schools	760	1%	11%	52%	9%	53%	110%	40%	120%	170%
No. Emergency services	140	1%	14%	63%	11%	60%	120%	37%	120%	160%
No. Hospitals	89	1%	6%	27%	4%	27%	52%	23%	65%	90%
No. GP surgeies	510	1%	14%	66%	12%	64%	130%	46%	140%	190%
Waste										
No. landfill sites	380	0%	2%	5%	1%	6%	9%	5%	10%	14%
Expected Annual Damage (£)										
residential only (direct)	270,000,000	6%	33%	66%	22%	78%	270%	47%	160%	600%
Non-residential only (direct)	590,000,000	7%	33%	65%	26%	68%	220%	49%	130%	400%
Total (direct and in-direct)	1,500,000,000	7%	33%	65%	25%	71%	230%	48%	140%	470%
Low population growth										
Properties										
at risk										
No. residential	2,300,000	10%	10%	na	25%	25%	na	30%	30%	na
No. non-residential	960,000	0%	0%	na	0%	0%	na	0%	0%	na
at risk of flooding more frequent than 1:75										
No. residential	690,000	15%	38%	na	52%	96%	na	83%	160%	na
No. non-residential	360,000	3%	19%	na	16%	43%	na	31%	70%	na
Expected Annual Damage (£)										
residential only (direct)	270,000,000	14%	42%	na	41%	95%	na	67%	180%	na
High population growth										
Properties										
at risk										
No. residential	2,300,000	14%	13%	13%	46%	46%	47%	82%	83%	84%
No. non-residential	960,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	690,000	18%	42%	80%	78%	130%	190%	160%	250%	300%
No. non-residential	360,000	3%	19%	44%	16%	43%	71%	32%	71%	89%
Expected Annual Damage (£)										
residential only (direct)	270,000,000	17%	45%	79%	53%	100%	290%	77%	160%	440%

Table 6-4 Wales: Headline risks under the Baseline Adaptation Scenario (i.e. assuming a continuation of current levels of adaptation)

		2020s			2050s			2080s		
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
No population growth										
Properties										
at risk										
No. residential	160,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. non-residential	86,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	51,000	11%	30%	70%	27%	72%	110%	47%	110%	130%
No. non-residential	34,000	4%	22%	49%	19%	50%	78%	34%	73%	89%
People (at risk of flooding more frequent than 1:75)										
No.	95,000	8%	29%	74%	25%	75%	140%	49%	120%	160%
No. in deprived areas	20,000	4%	24%	52%	20%	56%	130%	40%	110%	150%
Natural capital (at risk of flooding more frequent than 1:75)										
All designations (ha)	22,000	1%	14%	24%	13%	26%	41%	24%	51%	68%
Agriculture (at risk of flooding more frequent than 1:75)										
BMV land (ha)	18,000	1%	17%	36%	15%	35%	54%	27%	59%	74%
Infrastructure (at risk of flooding more frequent than 1:75)										
Water										
No. clean and wastewater sites	53	-59%	-51%	-36%	-29%	-5%	12%	4%	37%	47%
Transport										
No. of rail stations	85	0%	5%	18%	4%	17%	29%	9%	23%	30%
Length of railway (km)	370	1%	12%	46%	10%	51%	95%	39%	120%	160%
Length of road (km)	180	1%	12%	43%	9%	47%	85%	35%	100%	130%
Energy										
No. Generation and transmission stations	47	-48%	-26%	-11%	4%	35%	56%	60%	98%	110%
Social										
No. Care homes	15	1%	34%	79%	24%	110%	190%	83%	190%	250%
No. Schools	20	2%	13%	39%	9%	40%	79%	29%	89%	120%
No. Emergency services	33	3%	25%	88%	19%	91%	170%	56%	150%	200%
No. Hospitals	5	4%	4%	53%	3%	52%	130%	24%	120%	160%
No. GP surgeies	21	1%	22%	70%	17%	80%	180%	49%	150%	210%
Waste										
No. landfill sites	18	0%	2%	5%	2%	11%	15%	9%	17%	23%
Expected Annual Damage (£)										
residential only (direct)	22,000,000	7%	45%	95%	35%	110%	390%	59%	220%	780%
Non-residential only (direct)	59,000,000	5%	36%	75%	29%	96%	300%	55%	200%	480%
Total (direct and in-direct)	140,000,000	6%	38%	80%	30%	99%	320%	56%	200%	560%
Low population growth										
Properties										
at risk										
No. residential	160,000	6%	6%	na	7%	7%	na	3%	4%	na
No. non-residential	86,000	0%	0%	na	0%	0%	na	0%	0%	na
at risk of flooding more frequent than 1:75										
No. residential	51,000	18%	38%	na	35%	82%	na	51%	110%	na
No. non-residential	34,000	4%	22%	na	19%	50%	na	34%	74%	na
Expected Annual Damage (£)										
residential only (direct)	22,000,000	12%	51%	na	40%	110%	na	60%	210%	
High population growth										
Properties										
at risk										
No. residential	160,000	9%	9%	9%	25%	26%	25%	48%	48%	47%
No. non-residential	86,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	51,000	21%	42%	85%	59%	110%	160%	110%	200%	230%
No. non-residential	34,000	4%	22%	49%	19%	51%	78%	35%	74%	90%
Expected Annual Damage (£)										
residential only (direct)	22,000,000	15%	54%	110%	56%	130%	420%	94%	250%	650%

Table 6-5 Scotland: Headline risks under the Baseline Adaptation Scenario (i.e. assuming a continuation of current levels of adaptation)

		2020s			2050s			2080s		
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
No population growth										
Properties										
at risk										
No. residential	180,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. non-residential	42,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	97,000	1%	10%	21%	10%	21%	58%	18%	43%	82%
No. non-residential	25,000	1%	9%	19%	9%	20%	50%	16%	36%	63%
People (at risk of flooding more frequent than 1:75)										
No.	200,000	1%	10%	21%	10%	21%	58%	18%	43%	82%
No. in deprived areas	40,000	2%	12%	21%	12%	23%	53%	20%	44%	76%
Natural capital (at risk of flooding more frequent than 1:75)										
All designations (ha)	490,000	4%	12%	33%	16%	27%	64%	27%	45%	77%
Agriculture (at risk of flooding more frequent than 1:75)										
BMV land (ha)	43,000	3%	10%	33%	12%	22%	70%	21%	43%	87%
Infrastructure (at risk of flooding more frequent than 1:75)										
Water										
No. clean and wastewater sites	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
Transport										
No. of rail stations	66	0%	14%	25%	14%	26%	52%	25%	44%	55%
Length of railway (km)	1,900	3%	12%	31%	14%	28%	70%	25%	60%	110%
Length of road (km)	750	2%	11%	27%	13%	26%	60%	23%	63%	120%
Energy										
No. Generation and transmission stations	980	-68%	-66%	-62%	-49%	-42%	-20%	-27%	-15%	7%
Social										
No. Care homes	41	2%	12%	20%	12%	23%	56%	20%	42%	73%
No. Schools	270	0%	7%	16%	7%	17%	41%	15%	34%	56%
No. Emergency services	64	2%	11%	24%	11%	28%	61%	21%	49%	76%
No. Hospitals	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. GP surgeies	7	-1%	7%	23%	7%	19%	92%	16%	50%	120%
Waste										
No. landfill sites	2	-1%	2%	3%	2%	4%	7%	4%	7%	7%
Expected Annual Damage (£)										
residential only (direct)	42,000,000	9%	46%	97%	43%	99%	320%	73%	190%	620%
Non-residential only (direct)	120,000,000	4%	22%	48%	19%	60%	200%	40%	120%	380%
Total (direct and in-direct)	280,000,000	5%	28%	60%	25%	69%	230%	49%	140%	440%
Low population growth										
Properties										
at risk										
No. residential	180,000	5%	5%	na	8%	8%	na	6%	6%	na
No. non-residential	42,000	0%	0%	na	0%	0%	na	0%	0%	na
at risk of flooding more frequent than 1:75										
No. residential	97,000	6%	14%	na	17%	28%	na	22%	47%	na
No. non-residential	25,000	1%	9%	na	9%	20%	na	17%	37%	na
Expected Annual Damage (£)										
residential only (direct)	42,000,000	11%	47%	na	41%	93%	na	60%	160%	na
High population growth										
Properties										
at risk										
No. residential	180,000	8%	8%	8%	27%	27%	26%	49%	49%	50%
No. non-residential	42,000	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75										
No. residential	97,000	9%	18%	29%	38%	52%	94%	73%	110%	160%
No. non-residential	25,000	1%	10%	19%	10%	21%	51%	17%	38%	64%
Expected Annual Damage (£)										
residential only (direct)	42,000,000	13%	50%	100%	53%	110%	300%	79%	190%	480%

Table 6-6 Northern Ireland: Headline risks under the Baseline Adaptation Scenario (i.e. assuming a continuation of current levels of adaptation

		2020s			2050s			2080s		
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
No population growth										
Properties										
at risk										
No. residential	56,000	0%	6%	9%	6%	10%	13%	10%	13%	13%
No. non-residential	15,000	1%	4%	6%	4%	6%	8%	6%	8%	8%
at risk of flooding more frequent than 1:75										
No. residential	23,000	7%	19%	36%	20%	37%	78%	31%	77%	100%
No. non-residential	6,600	24%	36%	54%	37%	58%	94%	45%	91%	110%
People (at risk of flooding more frequent than 1:75)										
No.	56,000	6%	18%	35%	20%	35%	75%	30%	75%	98%
No. in deprived areas	14,000	11%	23%	42%	26%	51%	96%	38%	93%	120%
Natural capital (at risk of flooding more frequent than 1:75)										
All designations (ha)	19,000	8%	21%	43%	22%	29%	69%	29%	77%	110%
Agriculture (at risk of flooding more frequent than 1:75)										
BMV land (ha)	28,000	2%	16%	29%	17%	27%	52%	27%	76%	110%
Infrastructure (at risk of flooding more frequent than 1:75)										
Water										
No. clean and wastewater sites	30	-70%	-68%	-60%	-50%	-46%	-24%	-29%	-13%	-1%
Transport										
No. of rail stations	3	22%	49%	53%	41%	49%	60%	50%	64%	71%
Length of railway (km)	400	3%	19%	37%	20%	33%	68%	32%	91%	140%
Length of road (km)	73	5%	19%	37%	21%	31%	68%	31%	85%	130%
Energy										
No. Generation and transmission stations	2	-73%	-73%	-73%	-60%	-60%	-19%	-46%	-17%	8%
Social										
No. Care homes	12	0%	6%	10%	6%	11%	36%	11%	34%	51%
No. Schools	65	2%	9%	16%	10%	14%	35%	15%	39%	55%
No. Emergency services	9	17%	38%	59%	42%	54%	98%	55%	94%	130%
No. Hospitals	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
No. GP surgeies	23	19%	42%	47%	42%	48%	71%	48%	70%	82%
Waste										
No. landfill sites	0	0%	0%	0%	0%	0%	0%	0%	0%	0%
Expected Annual Damage (£)										
residential only (direct)	8,100,000	8%	28%	74%	33%	62%	270%	60%	150%	640%
Non-residential only (direct)	19,000,000	11%	30%	74%	36%	62%	250%	63%	140%	500%
Total (direct and in-direct)	47,000,000	10%	29%	74%	35%	62%	250%	62%	150%	540%
Low population growth										
Properties										
at risk										
No. residential	56,000	5%	11%	na	6%	10%	na	-5%	-3%	na
No. non-residential	15,000	2%	4%	na	4%	6%	na	6%	8%	na
at risk of flooding more frequent than 1:75										
No. residential	23,000	12%	24%	na	21%	37%	na	12%	52%	na
No. non-residential	6,600	24%	37%	na	37%	58%	na	45%	90%	na
Expected Annual Damage (£)										
residential only (direct)	8,100,000	11%	32%	na	33%	62%	na	43%	120%	na
High population growth										
Properties										
at risk										
No. residential	56,000	8%	14%	17%	26%	32%	33%	39%	41%	41%
No. non-residential	15,000	2%	4%	6%	5%	7%	8%	7%	8%	8%
at risk of flooding more frequent than 1:75										
No. residential	23,000	15%	28%	46%	44%	63%	110%	66%	120%	150%
No. non-residential	6,600	24%	37%	54%	38%	59%	95%	46%	92%	110%
Expected Annual Damage (£)										
residential only (direct)	8,100,000	13%	35%	83%	48%	80%	290%	84%	200%	680%

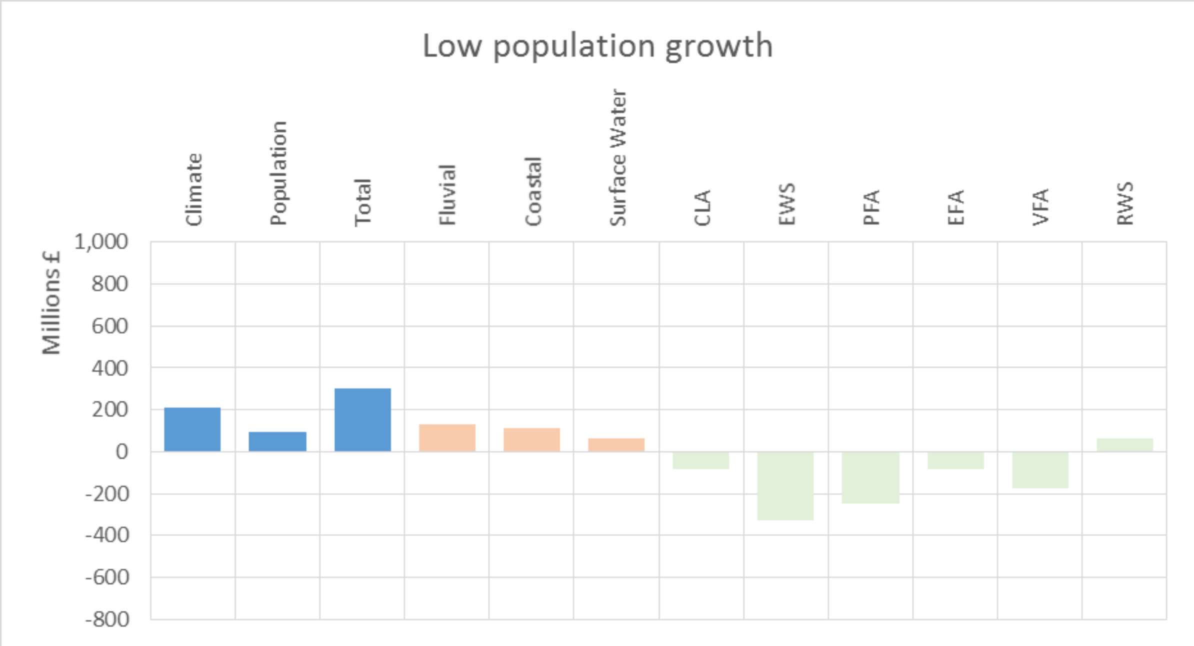
Table 6-7 UK: The influence of alternative adaptation scenarios on headline risks (4° climate change)

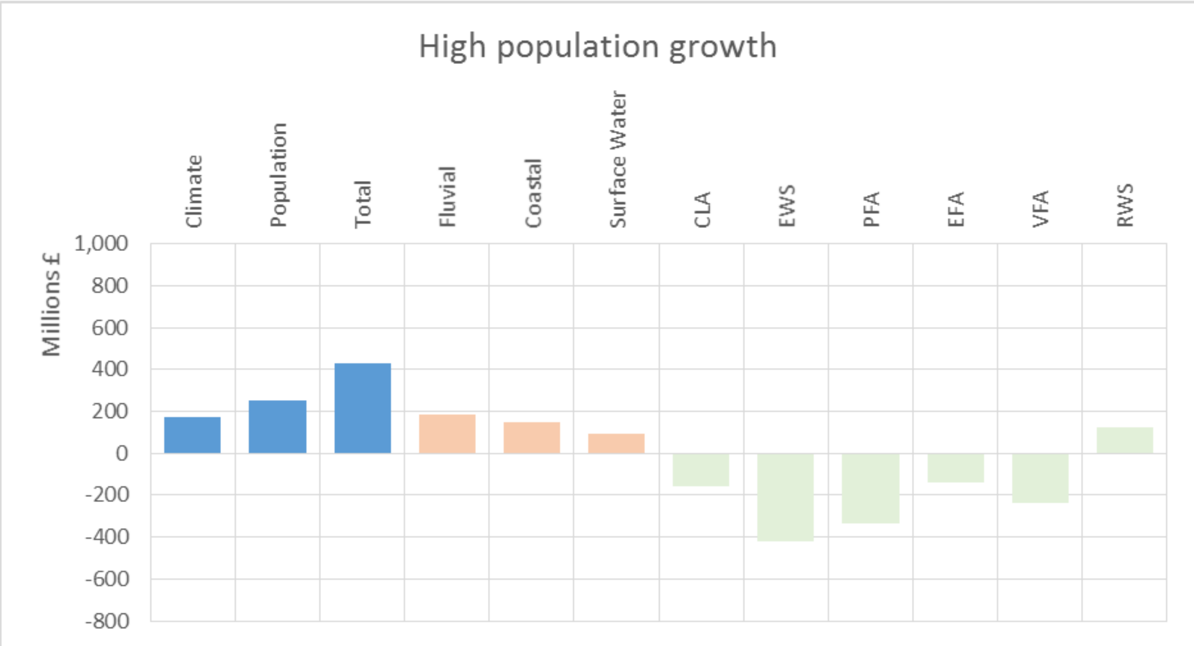
		2020s						2050s						2080s					
		Adaptation Scenario						Adaptation Scenario											
Risk Metric	Present Day	CLA	EWS	RWS	PFA	EFA	VFA	CLA	EWS	RWS	PFA	EFA	VFA	CLA	EWS	RWS	PFA	EFA	VFA
No population growth																			
Properties																			
at risk																			
No. residential	2,800,000	0%	-	-	-	-	-	0%	-	-	-	-	-	0%	-	-	-	-	-
No. non-residential	1,100,000	0%	-	-	-	-	-	0%	-	-	-	-	-	0%	-	-	-	-	-
at risk of flooding more frequent than 1:75																			
No. residential	860,000	24%	-	-	-	-	-	53%	-	-	-	-	-	93%	-	-	-	-	-
No. non-residential	420,000	18%	-	-	-	-	-	42%	-	-	-	-	-	68%	-	-	-	-	-
Low population growth																			
Properties																			
at risk																			
No. residential	2,800,000	9%	8%	13%	9%	8%	9%	23%	17%	33%	22%	17%	23%	26%	18%	42%	26%	18%	26%
No. non-residential	1,100,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75																			
No. residential	860,000	35%	12%	42%	14%	34%	35%	86%	57%	110%	64%	79%	86%	140%	91%	170%	99%	130%	140%
No. non-residential	420,000	19%	11%	20%	11%	19%	19%	42%	28%	45%	28%	42%	42%	69%	42%	74%	42%	69%	69%
High population growth																			
Properties																			
at risk																			
No. residential	2,800,000	13%	11%	18%	13%	11%	13%	43%	32%	64%	43%	32%	43%	78%	50%	130%	77%	50%	78%
No. non-residential	1,100,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
at risk of flooding more frequent than 1:75																			
No. residential	860,000	39%	15%	48%	17%	37%	39%	120%	76%	160%	92%	100%	120%	230%	140%	320%	180%	190%	230%
No. non-residential	420,000	19%	11%	20%	11%	19%	19%	42%	29%	45%	29%	42%	42%	70%	43%	75%	43%	70%	70%

Table 6-8 UK by the 2080s: Increases in residential EAD due to population growth and climate change offset by adaptation

Climate change	Population scenario	Increase from climate change*	Increase from population*	Total increase in the absence of adaptation	Risk offset by Adaptation		Net change in risk by the 2080s	
					CLA	EWS	CLA	EWS
2°C projection	Low	£210m	£95m	£305m	£83m	£330m	£222m	-£25m
	High	£170m	£250m	£420m	£160m	£420m	£260m	£0m
4°C projection	Low	£610m	£160m	£770m	£170m	£550m	£600m	£220m
	High	£530m	£430m	£960m	£390m	£710m	£570m	£250m
H++ scenario	High	£2,300m	£1,300m	£3,600m	£2,000m	£2,700m	£1,600m	£900m

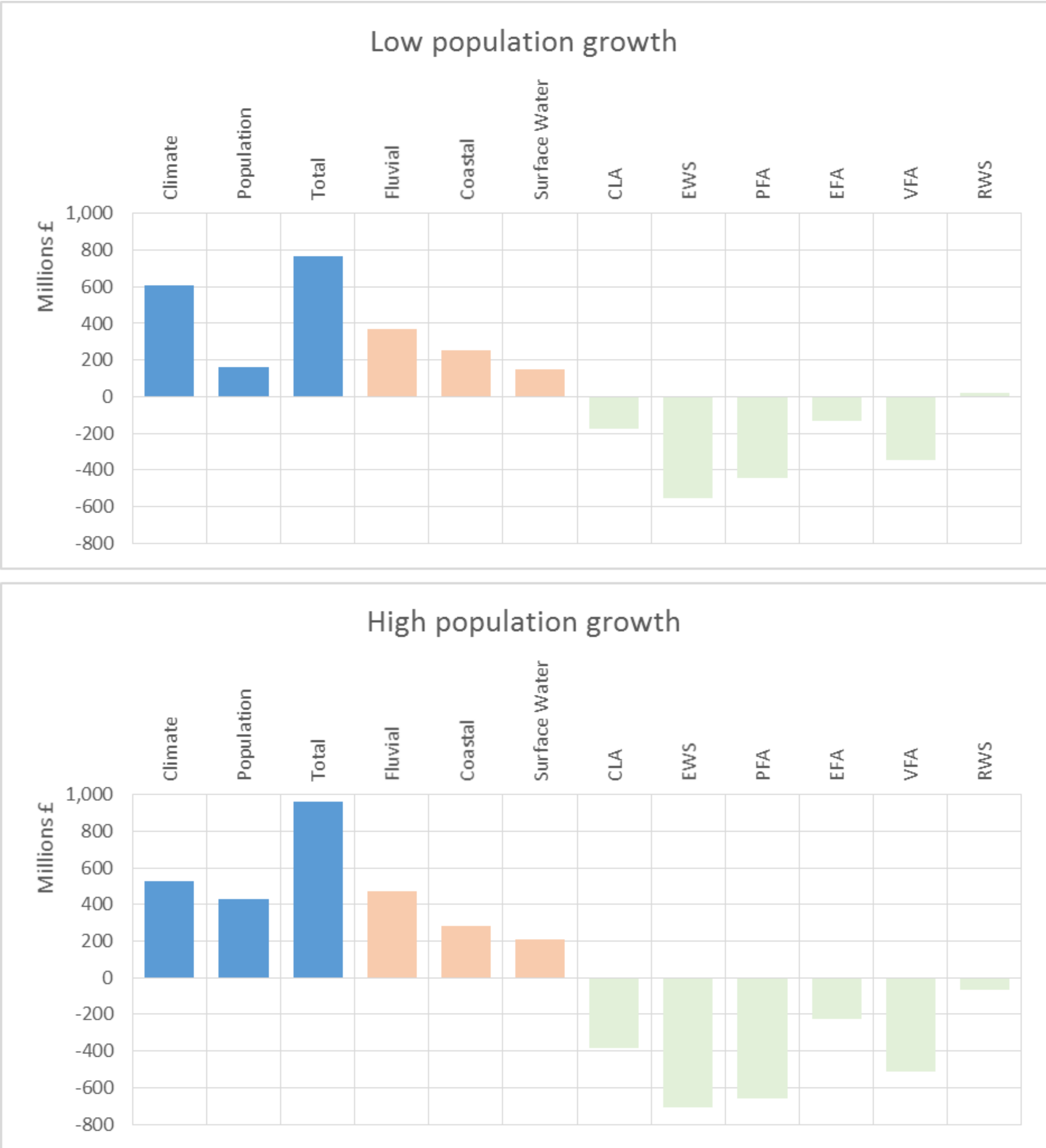
**The disaggregation of risk between climate and population should be considered as an approximation.*





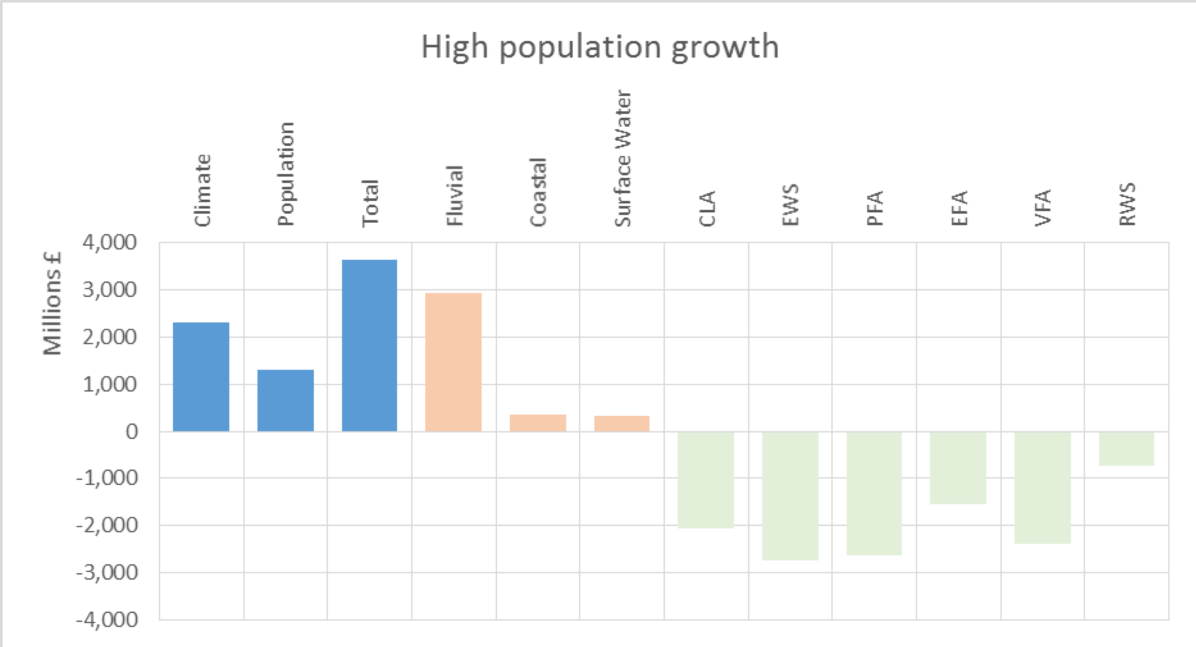
Note: The charts show contributions to increase in EAD from climate and population (blue bars), contribution of different sources to total risk (pink bars) and effect of different adaptation scenarios on reducing risk (green bars).

Figure 6-1 UK by the 2080s: Disaggregation of the influences on future Expected Annual Damages (2°C climate change projection)



Note: The chart shows contributions to increase in EAD from climate and population (blue bars), contribution of different sources to total risk (pink bars) and effect of different adaptation scenarios on reducing risk (green bars).

Figure 6-2 UK by the 2080s: Disaggregation of the influences on future Expected Annual Damages (4°C climate change projection)



Note: The chart shows contributions to increase in EAD from climate and population (blue bars), contribution of different sources to total risk (pink bars) and effect of different adaptation scenarios on reducing risk (green bars).

Figure 6-3 UK by the 2080s: Disaggregation of the influences on future Expected Annual Damages (H++ scenario and high population growth).

Table 6-9 Changes in Expected annual Damages and Properties at risk by the 2080s for each Reporting Region

Country	Reporting Region	Present Day			2080s 2°C Low population growth			2080s 4°C Low population growth		
		EAD	Properties at risk > 1:75	Properties at risk > 1:75 in deprived areas	EAD	Properties at risk > 1:75	Properties at risk > 1:75 in deprived areas	EAD	Properties at risk > 1:75	Properties at risk > 1:75 in deprived areas
England	Cambs and Bedfordshire	£11,000,000	26,000	1,400	£18,000,000	46,000	2,600	£28,000,000	76,000	5,400
					59%	76%	86%	150%	190%	290%
	Cumbria and Lancashire	£11,000,000	25,000	4,300	£16,000,000	37,000	5,800	£31,000,000	47,000	8,200
					40%	45%	36%	170%	88%	91%
	Derbys Notts and Leics	£16,000,000	43,000	7,400	£28,000,000	75,000	13,000	£41,000,000	110,000	18,000
					71%	75%	77%	150%	150%	140%
	Devon and Cornwall	£9,600,000	26,000	1,600	£19,000,000	43,000	2,800	£35,000,000	53,000	3,600
					100%	64%	70%	260%	100%	120%
	Essex Norfolk and Suffolk	£15,000,000	35,000	3,000	£22,000,000	64,000	6,600	£32,000,000	83,000	9,400
					47%	81%	120%	110%	140%	210%
	Gtr Mancs Mersey and Ches	£12,000,000	36,000	13,000	£22,000,000	77,000	31,000	£42,000,000	110,000	45,000
					88%	110%	140%	260%	210%	250%
	Herts and North London	£19,000,000	71,000	13,000	£40,000,000	160,000	34,000	£62,000,000	240,000	55,000
					110%	120%	160%	230%	240%	320%
	Kent and South London	£33,000,000	86,000	9,800	£66,000,000	200,000	24,000	£92,000,000	270,000	30,000
					100%	130%	150%	180%	210%	210%
	Lincs and Northants	£26,000,000	59,000	7,900	£35,000,000	95,000	14,000	£48,000,000	120,000	18,000
					36%	62%	73%	85%	96%	120%
	Northumberland Durham and Tees	£3,800,000	15,000	4,800	£6,800,000	21,000	7,100	£12,000,000	32,000	11,000
					78%	47%	49%	220%	120%	120%
	Shrops Heref Worcs and Glos	£7,700,000	16,000	1,900	£11,000,000	25,000	3,200	£20,000,000	36,000	4,400
					46%	54%	67%	160%	120%	130%
	Solent and South Downs	£10,000,000	27,000	2,300	£21,000,000	53,000	5,200	£55,000,000	71,000	6,500
					100%	95%	120%	430%	160%	180%
	Staffs Warks and West Mids	£9,700,000	35,000	11,000	£17,000,000	60,000	21,000	£28,000,000	88,000	30,000
					79%	72%	89%	180%	150%	170%
	Wessex	£19,000,000	44,000	3,800	£33,000,000	84,000	8,900	£55,000,000	110,000	10,000
					75%	91%	130%	200%	140%	180%
	West Thames	£31,000,000	60,000	1,000	£45,000,000	97,000	1,800	£79,000,000	170,000	3,400
					43%	63%	80%	150%	190%	240%
	Yorkshire	£32,000,000	87,000	18,000	£44,000,000	130,000	26,000	£80,000,000	170,000	33,000
					38%	51%	41%	150%	92%	79%
Wales	Mid	£1,900,000	3,100	59	£2,400,000	3,600	63	£4,200,000	4,500	65
					31%	15%	7%	120%	44%	10%
	North	£5,900,000	11,000	1,200	£7,500,000	16,000	1,500	£18,000,000	22,000	1,900
					26%	42%	28%	200%	90%	63%
	South East	£9,800,000	25,000	4,700	£17,000,000	42,000	7,200	£31,000,000	60,000	13,000
					73%	64%	52%	210%	140%	180%
	South West	£4,600,000	11,000	3,200	£8,700,000	16,000	4,300	£16,000,000	22,000	5,200
					88%	41%	34%	240%	91%	65%
Scotland	Ayrshire	£3,500,000	8,200	2,800	£4,100,000	7,100	2,300	£6,200,000	8,800	2,800
					19%	-14%	-16%	79%	6%	3%
	Clyde and Loch Lomond	£12,000,000	31,000	11,000	£19,000,000	34,000	13,000	£29,000,000	41,000	15,000
					54%	9%	14%	140%	29%	33%
	Findhorn, Nairn and Speyside	£1,900,000	3,500	160	£2,500,000	3,300	130	£3,500,000	3,600	140
					33%	-7%	-19%	84%	2%	-16%
	Forth	£1,300,000	3,000	670	£2,100,000	3,900	820	£3,300,000	4,700	970
					60%	31%	22%	150%	58%	44%
	Forth Estuary	£6,700,000	19,000	2,600	£13,000,000	30,000	3,900	£23,000,000	39,000	5,000
					96%	56%	52%	240%	110%	95%
	Highland and Argyll	£2,400,000	5,200	1,300	£5,000,000	6,000	1,700	£13,000,000	7,400	2,100
					110%	14%	37%	440%	41%	63%
	North East	£4,200,000	9,200	310	£7,000,000	14,000	520	£9,100,000	16,000	580
					66%	56%	65%	110%	72%	86%
	Orkney	£290,000	650	0	£970,000	850	0	£3,200,000	910	0
					240%	32%	0%	1000%	40%	0%
	Outer Hebrides	£210,000	230	0	390000%	170%	0%	610000%	180%	0%
					89%	-26%	0%	200%	-23%	0%
	Shetland	£41,000	61	0	£150,000	73	0	£160,000	77	0
					260%	19%	0%	300%	26%	0%
	Solway	£2,500,000	3,900	500	£2,900,000	3,100	410	£4,500,000	3,600	450
					17%	-21%	-18%	84%	-9%	-9%
	Tay	£2,700,000	4,100	420	£4,400,000	6,400	750	£5,300,000	7,000	870
					63%	58%	79%	96%	73%	110%
	Tay Estuary and Montrose Basin	£1,900,000	4,700	800	£3,300,000	5,800	1,000	£5,900,000	6,800	1,200
					70%	22%	25%	200%	44%	47%
	Tweed	£2,100,000	3,500	45	£2,500,000	3,300	41	£3,300,000	3,500	48
					18%	-8%	-8%	53%	1%	6%
Northern Ireland	Neagh Bann	£1,800,000	5,800	800	£2,900,000	6,600	1,000	£4,800,000	9,000	1,500
					61%	14%	24%	160%	55%	85%
	North Eastern	£5,100,000	13,000	4,000	£7,100,000	15,000	4,900	£11,000,000	21,000	7,100
					37%	15%	22%	110%	59%	77%
	North Western	£1,200,000	3,600	1,300	£1,600,000	3,700	1,300	£2,500,000	4,600	1,600
					39%	3%	3%	120%	25%	23%

6.2.2 Results: Maps

Within this section each map is presented in a common format, with the present day risks provided in the top left (using a scale based on absolute values) and the future risk under the 2°C and 4°C climate change projections and H++ scenario are presented below (using a percentage change scale).

Note:

Proportional versus absolute change: To understand the significance of the proportional change in risk shown in the following figures in the context of the national risk, it is important to understand the present day. A large proportional increase does not necessarily mean a large absolute risk. Additional mapping is therefore provided in Appendix H that recasts the summary results presented here in absolute terms.

National risks under the Baseline adaptation

Figure 6-4 to Figure 6-12 show how each risk metric changes under the Baseline Adaptation scenario (CLA) in response to climate change alone (i.e. in the absence of population growth).

National risks under alternative Adaptation Scenarios

Figure 6-13 to Figure 6-18 show how the different Adaptation Scenarios influence future risk. Two risk metrics are presented (properties at risk of flooding more frequently than 1:75 years and Expected Annual Damages). The influence of the Reduced Whole System (RWS), CLA and Enhance Whole System (EWS) adaptation scenarios on these metrics by the 2050s and 2080s under each climate change and population growth scenario are presented. On each Figure the present day risks are given as absolute values (top left in green) together with percentage change in risk under the alternative scenarios (in yellow to brown scale). Figures 6-13-15 focus specifically on the changing risk associated with individual flood sources.

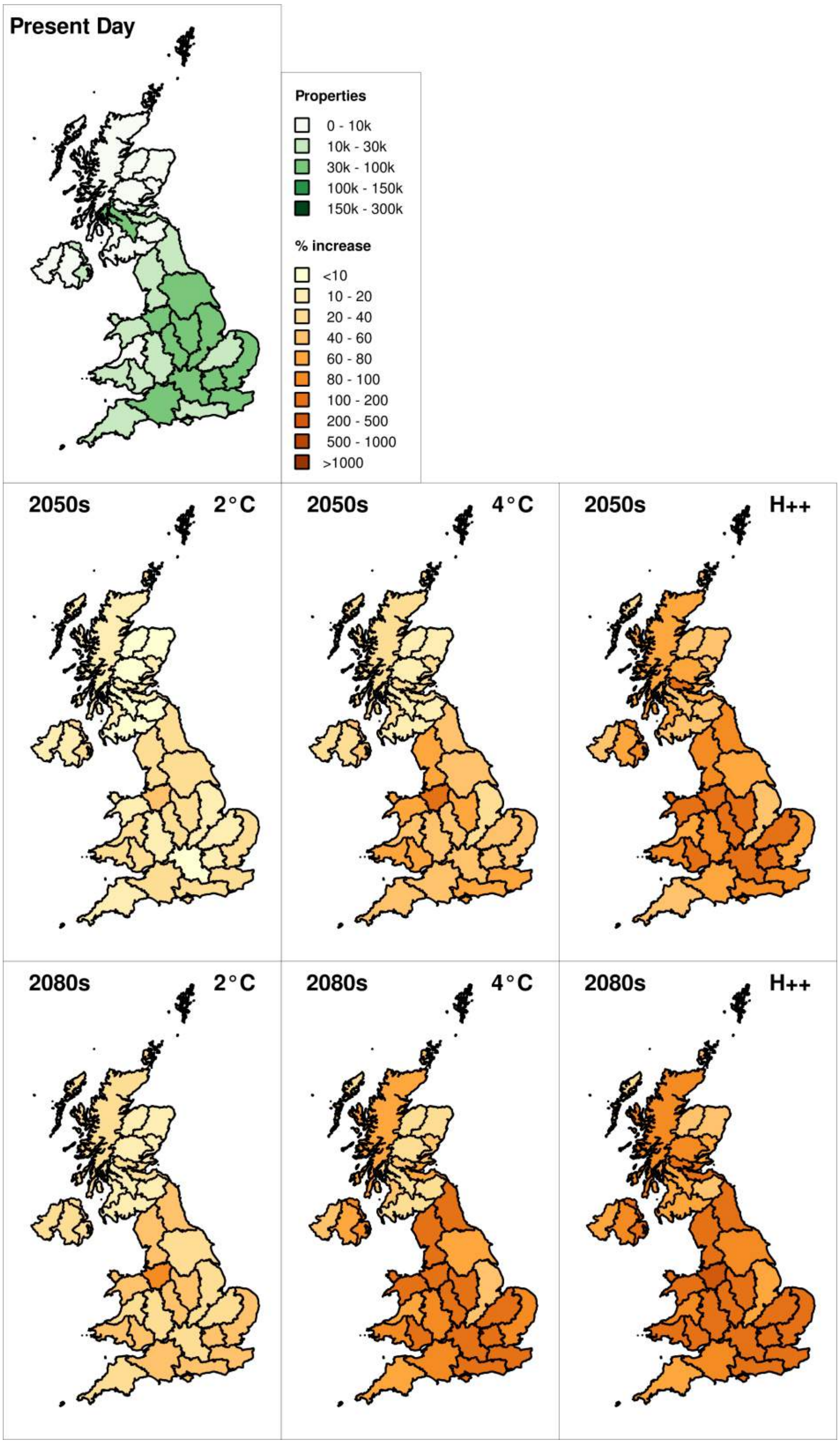


Figure 6-4 UK: Change in residential properties at risk of flooding (more frequent than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

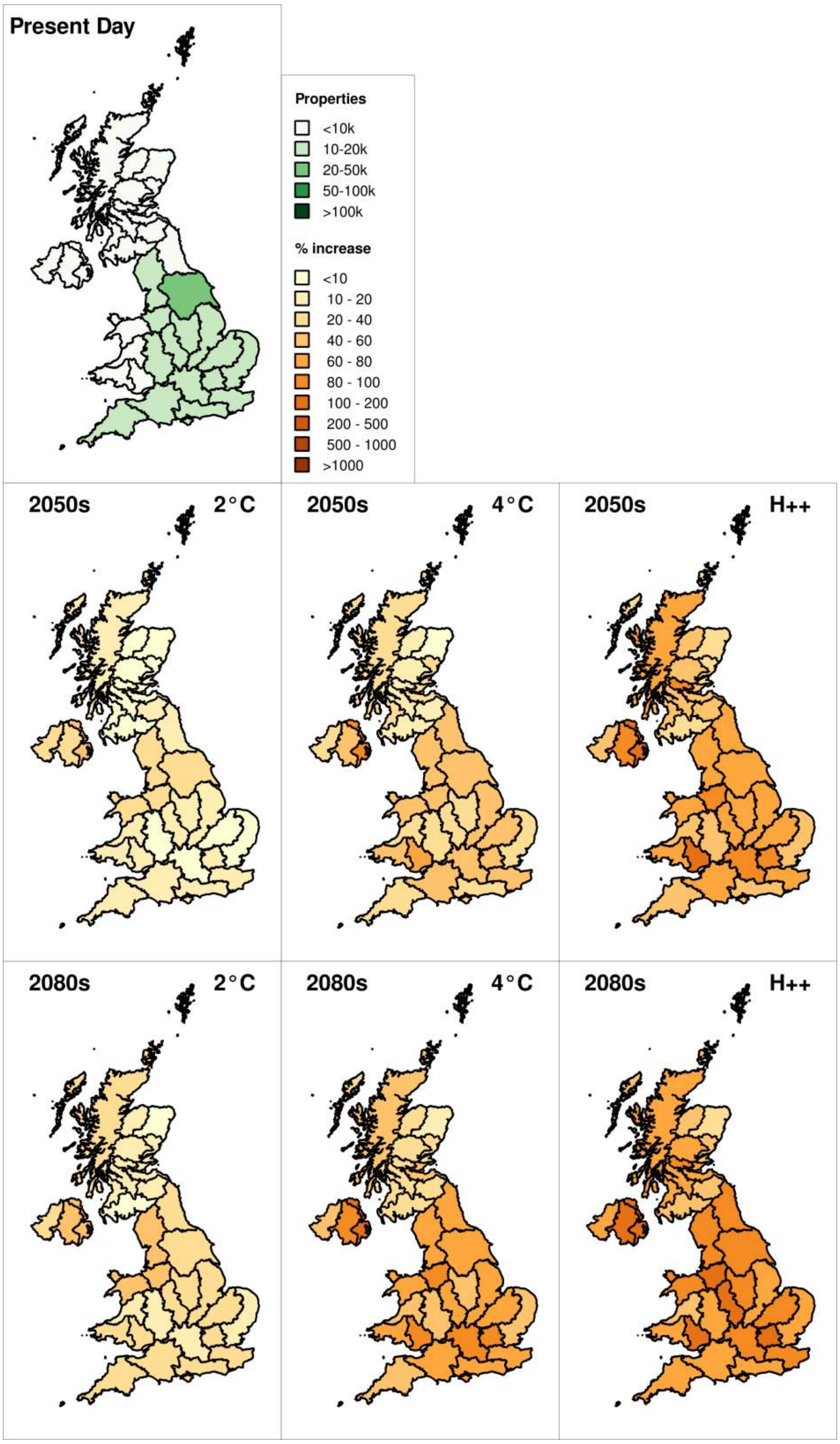


Figure 6-5 UK: Change in non-residential properties at risk of flooding (more frequently than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

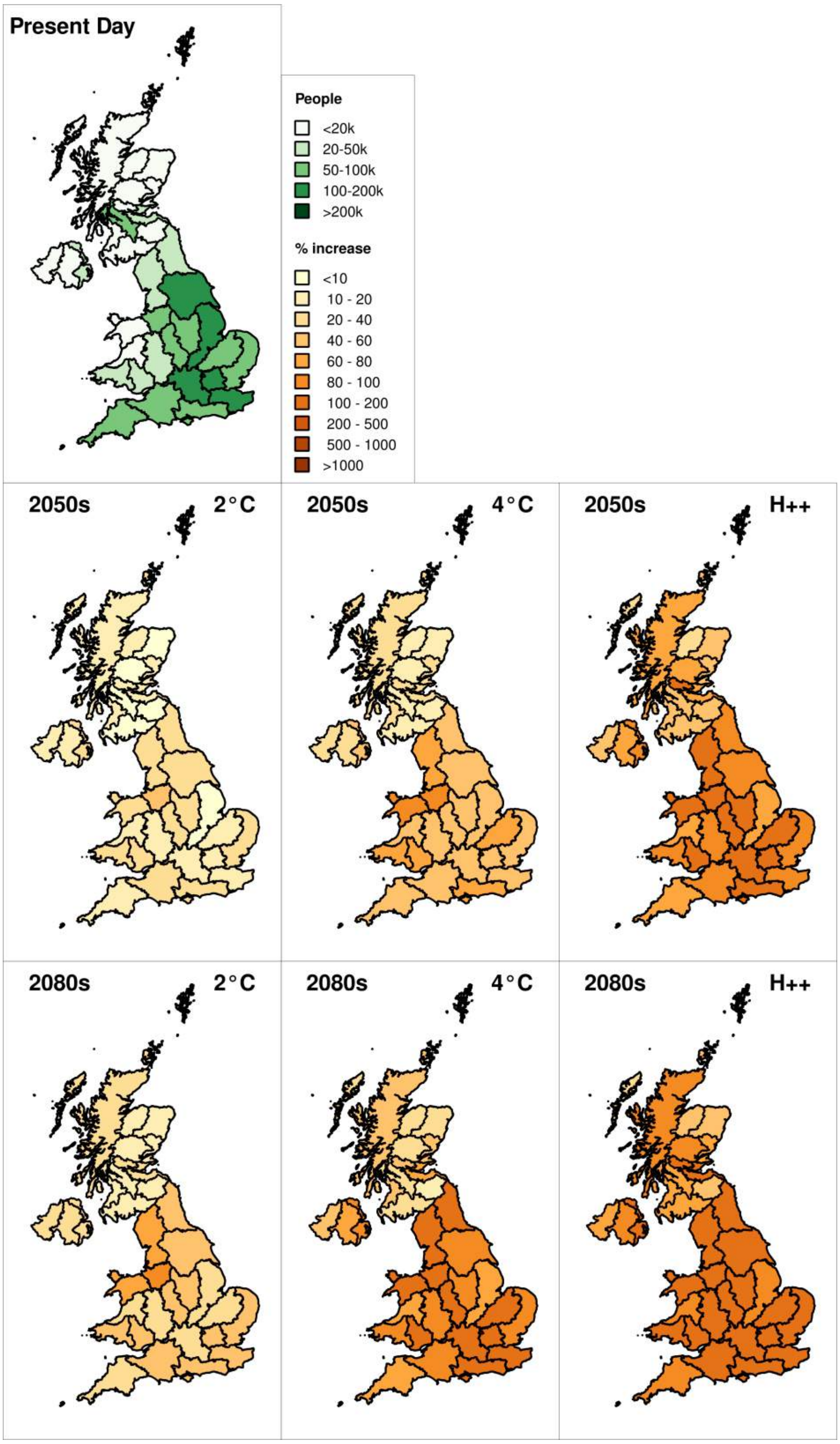


Figure 6-6 UK: Change in people at risk of flooding (more frequently than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

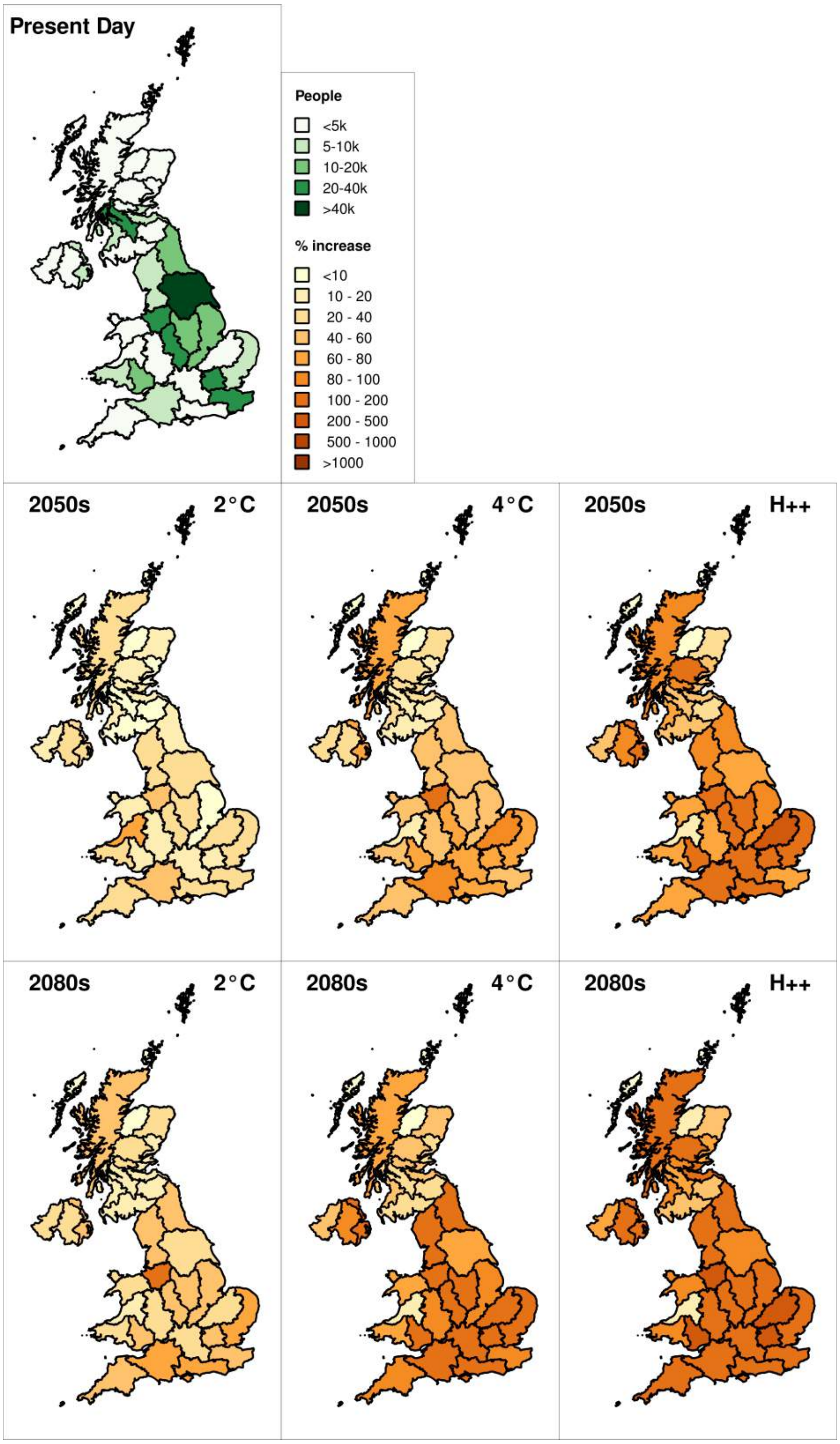


Figure 6-7 UK: Change in people at risk of flooding (more frequently than 1:75 years) in deprived areas assuming the CLA Adaptation Scenario (no population growth)

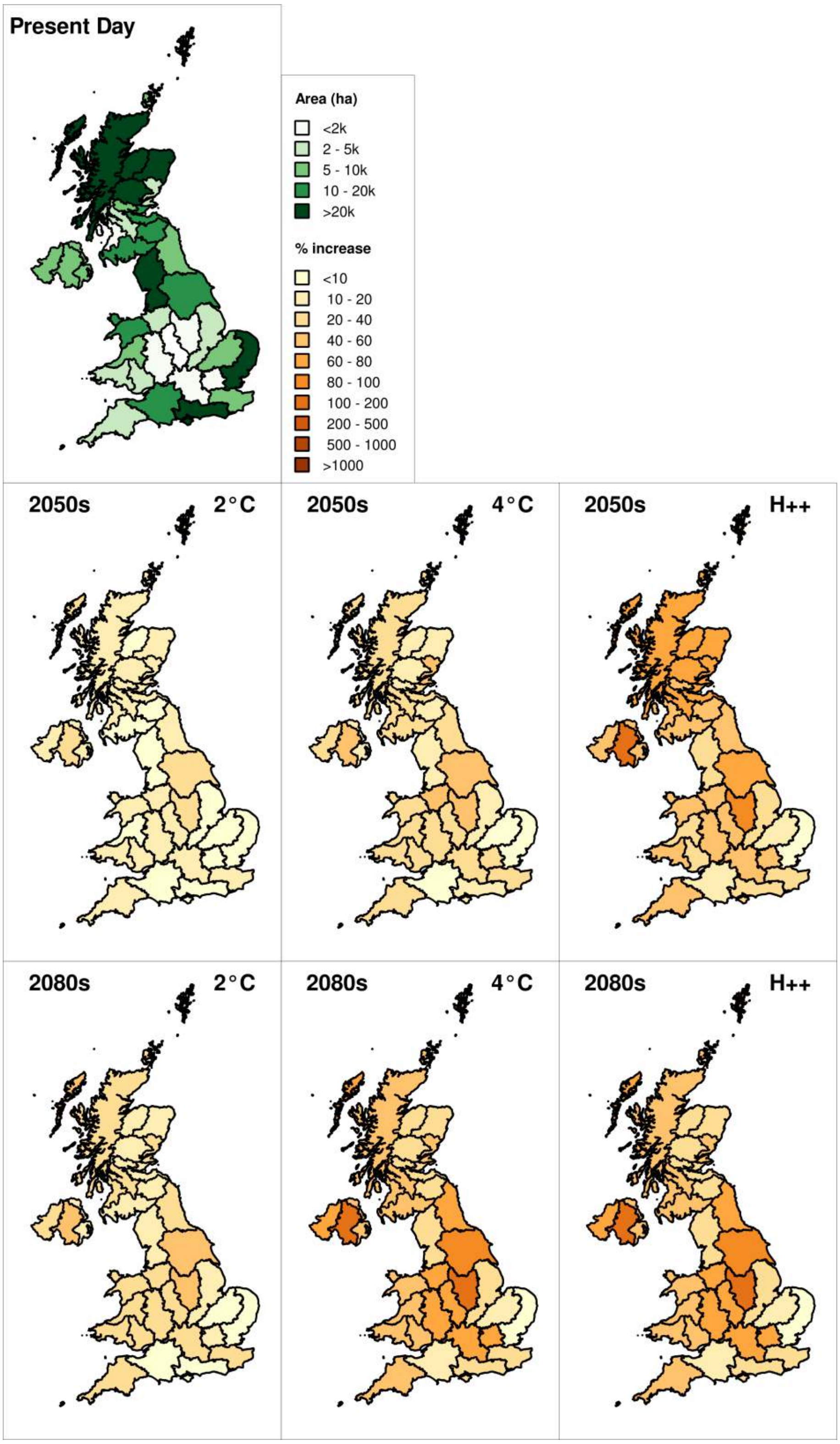


Figure 6-8 UK: Change in natural capital at risk of flooding (more frequently than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

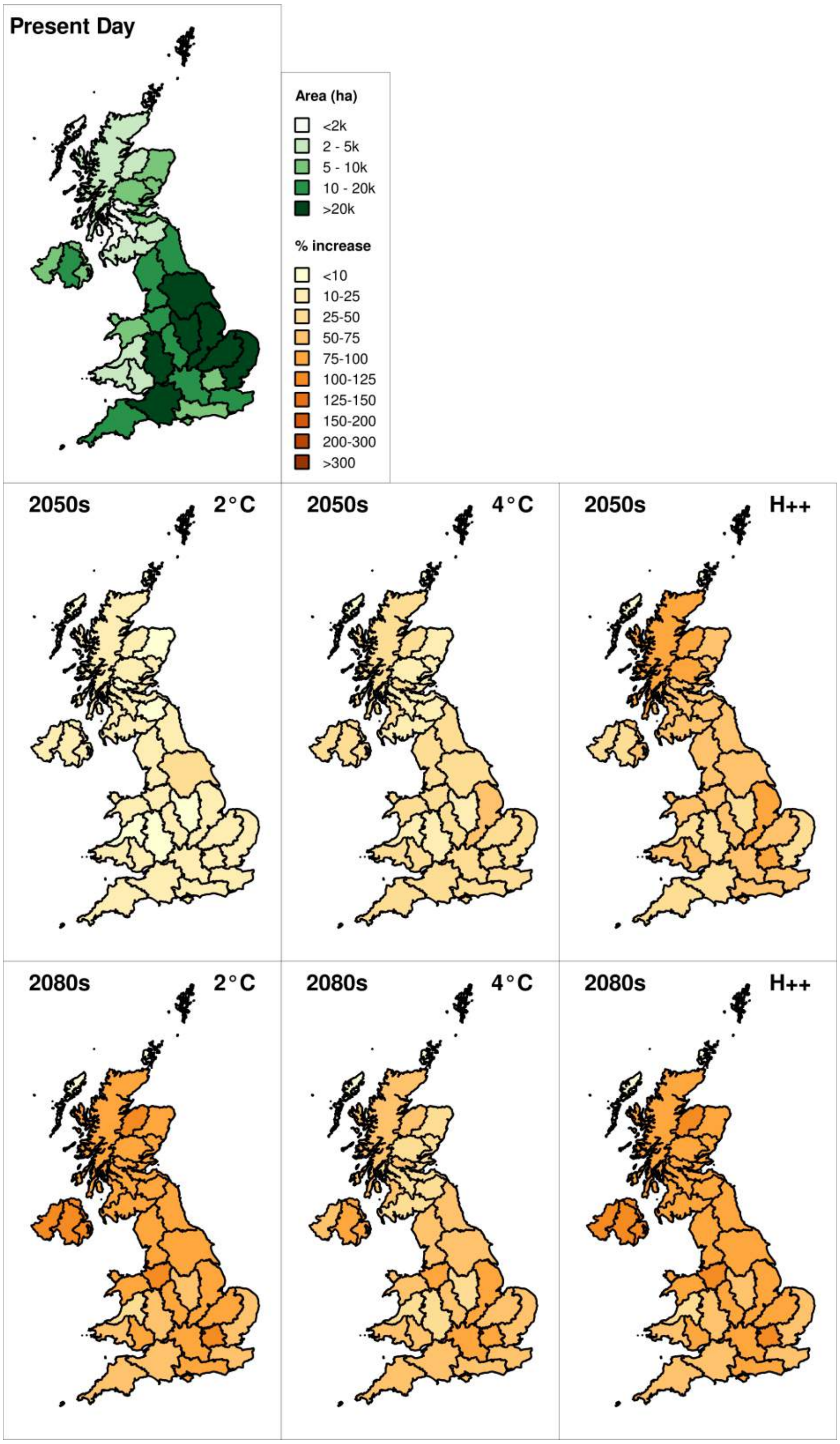


Figure 6-9 UK: Change in BMV agricultural land at risk of flooding more frequently than 1:75 years assuming the CLA Adaptation Scenario (no population growth)

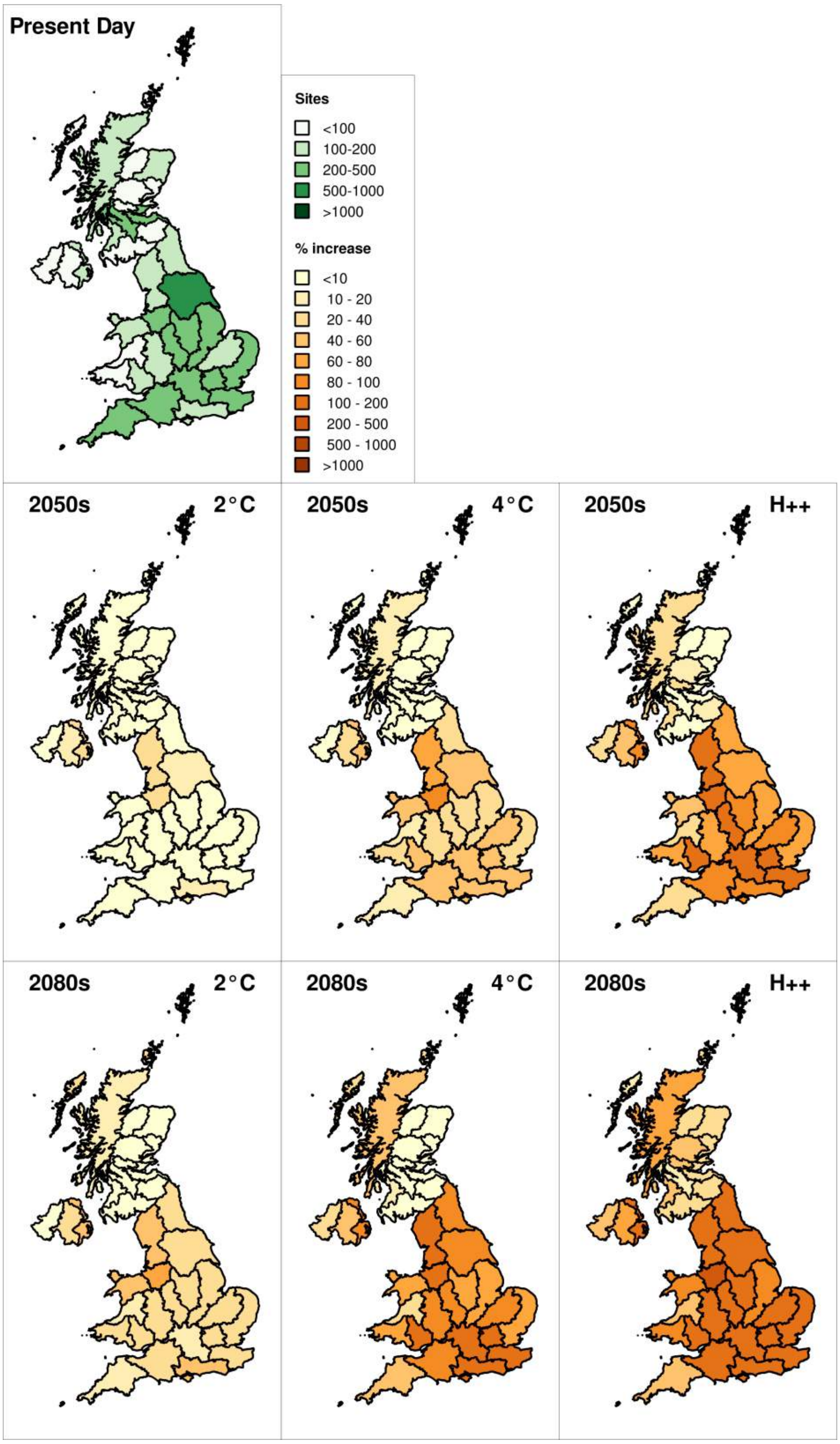


Figure 6-10 UK: Change in infrastructure sites at risk of flooding (more frequently than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

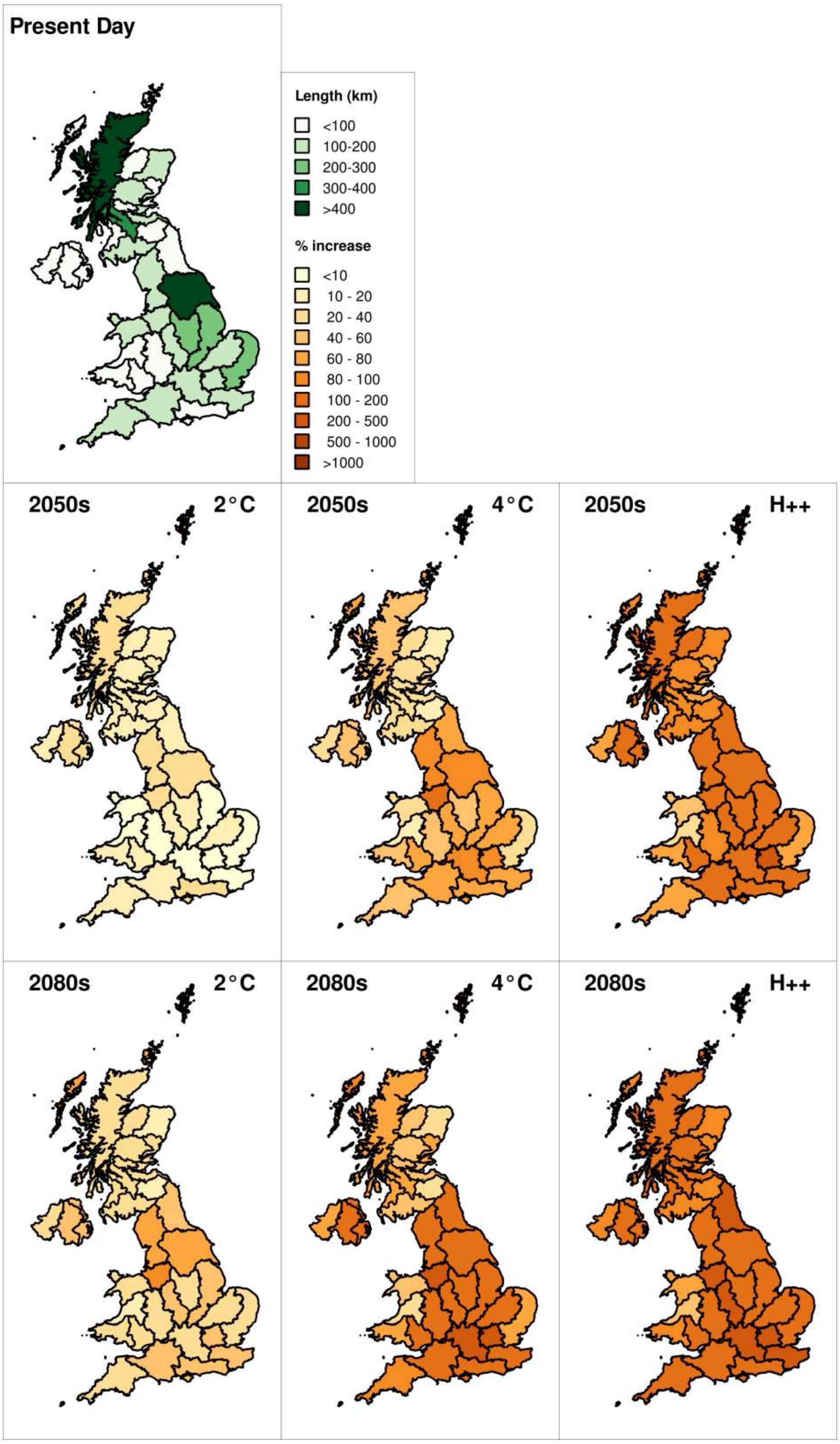


Figure 6-11 UK: Change in infrastructure road and rail networks at risk of flooding (more frequently than 1:75 years) assuming the CLA Adaptation Scenario (no population growth)

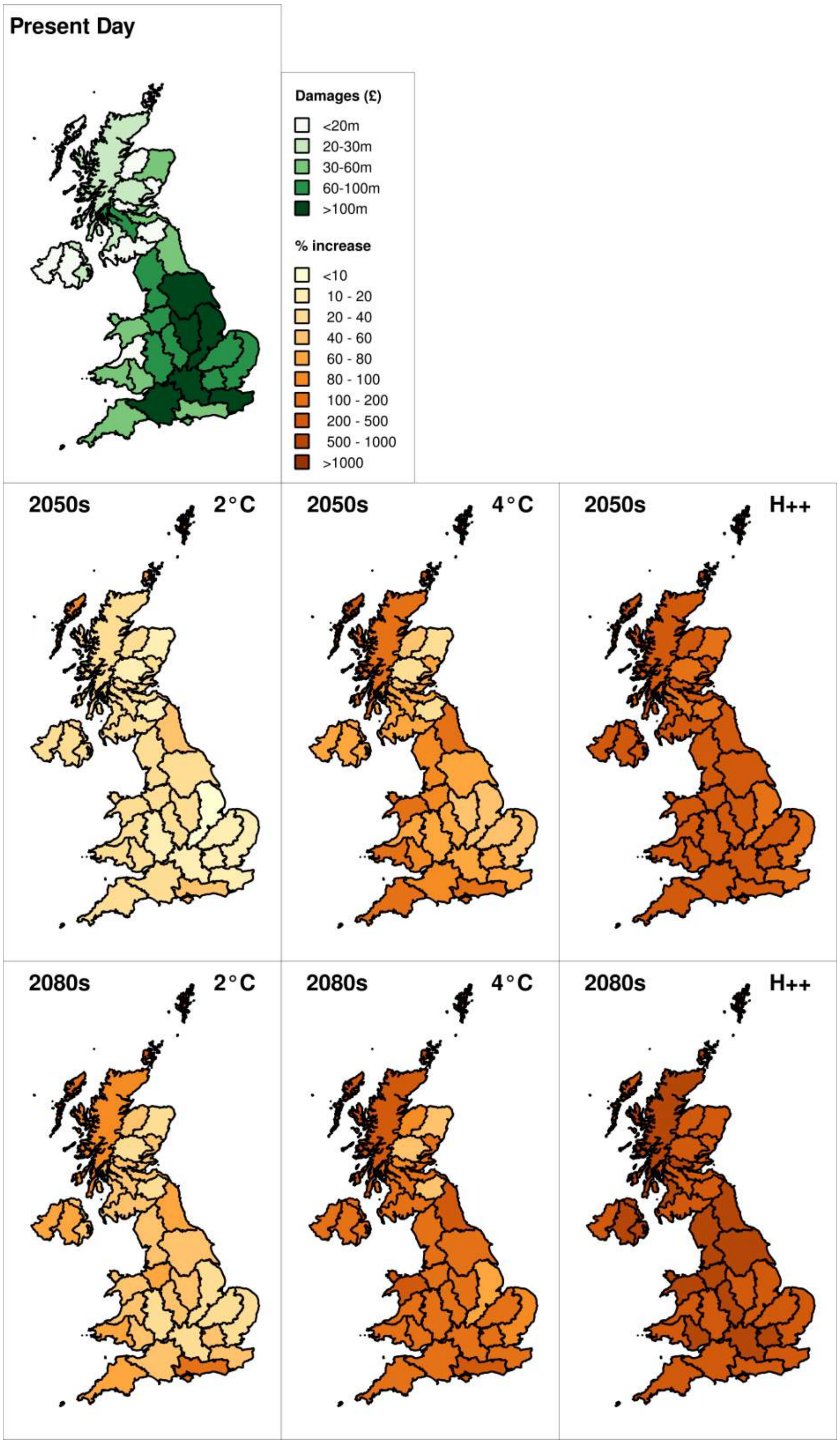


Figure 6-12 UK: Change in Expected Annual Damages (direct and indirect) assuming the CLA Adaptation Scenario (no population growth)

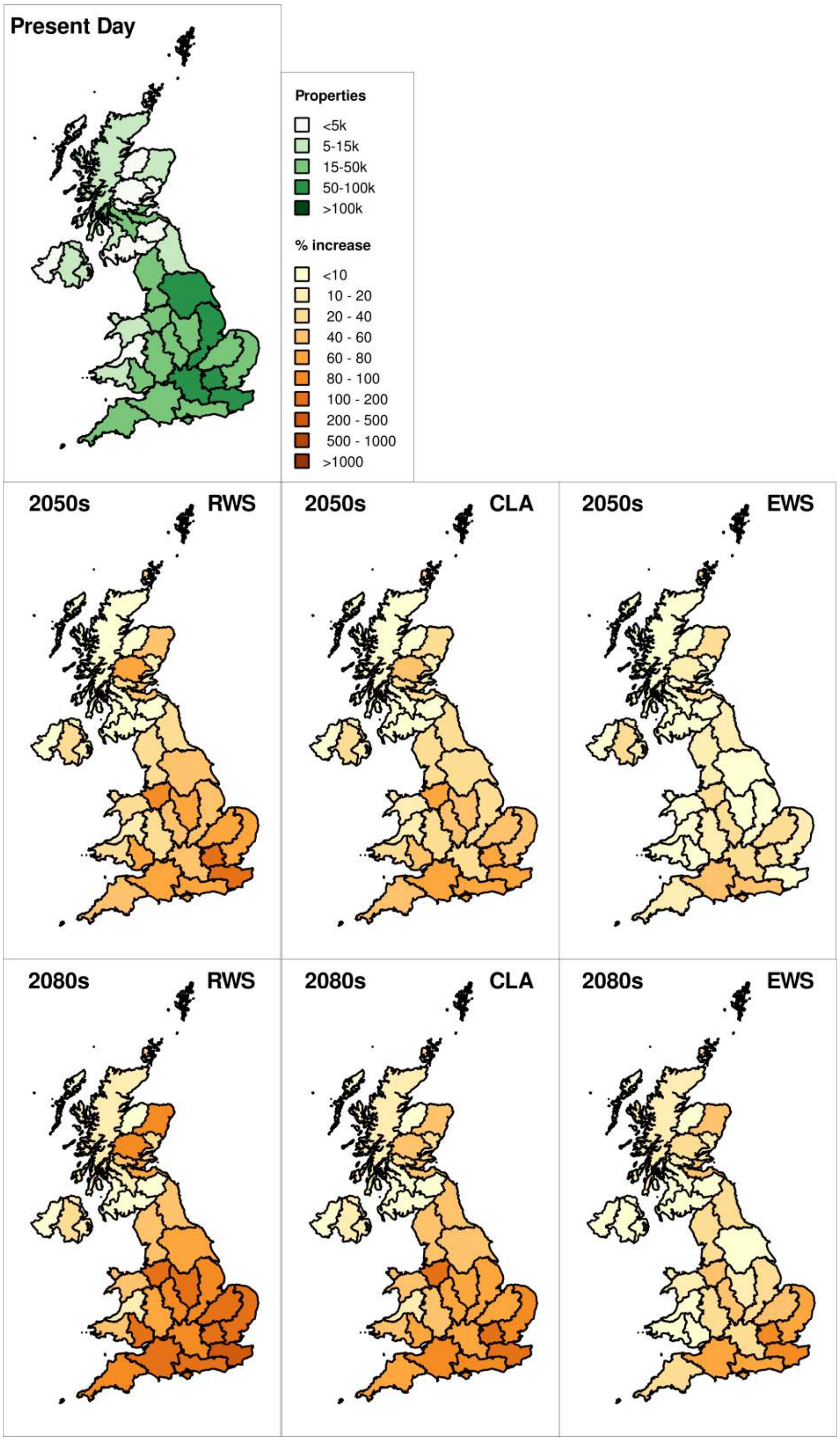


Figure 6-13 UK: The influence of alternative Adaptation Scenarios on properties at risk of flooding (more frequently than 1:75 years) (2°C climate change projection and low population growth)

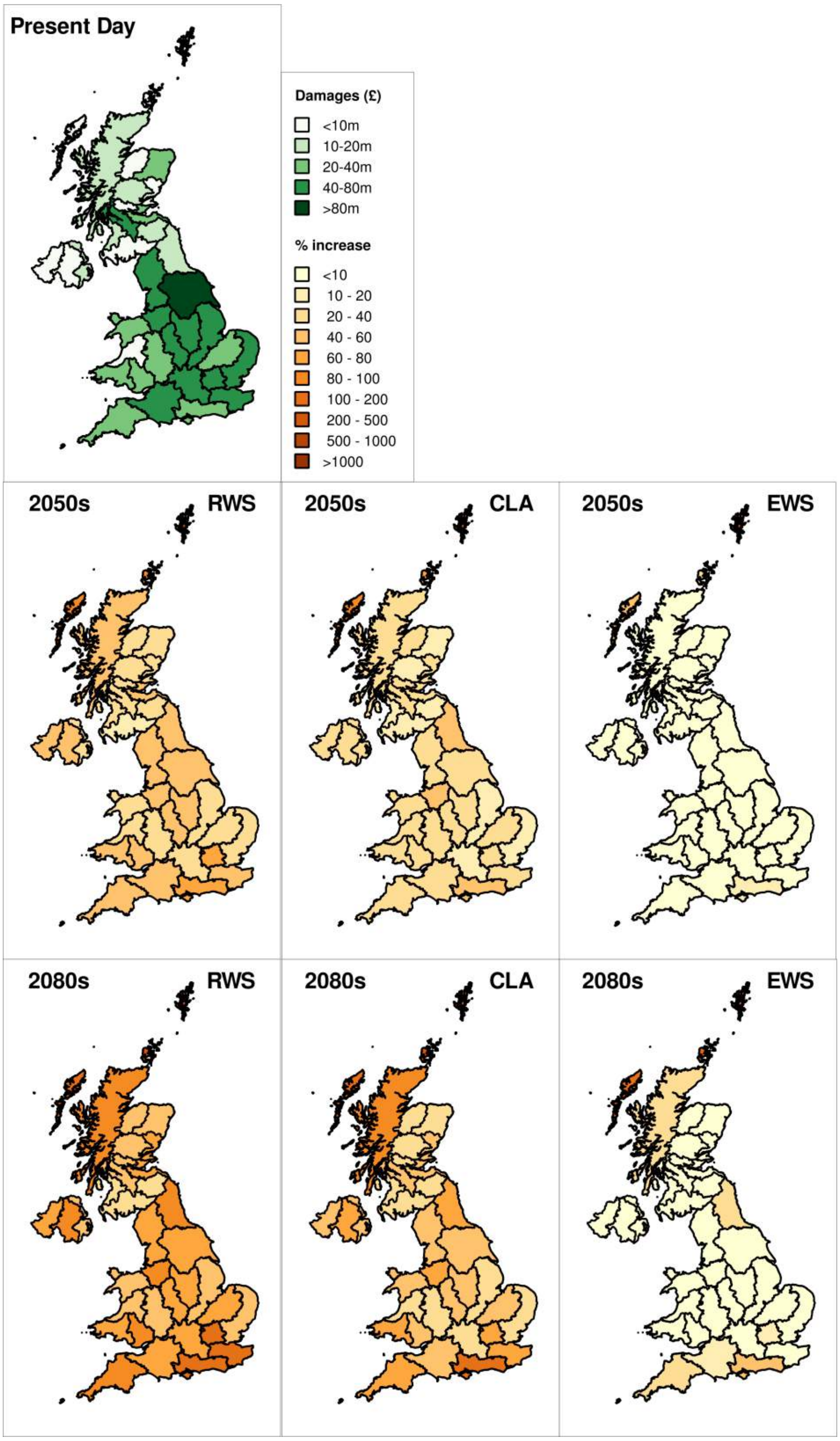


Figure 6-14 The influence of alternative Adaptation Scenarios on Expected Annual Damages (2°C climate change projection and low population growth)

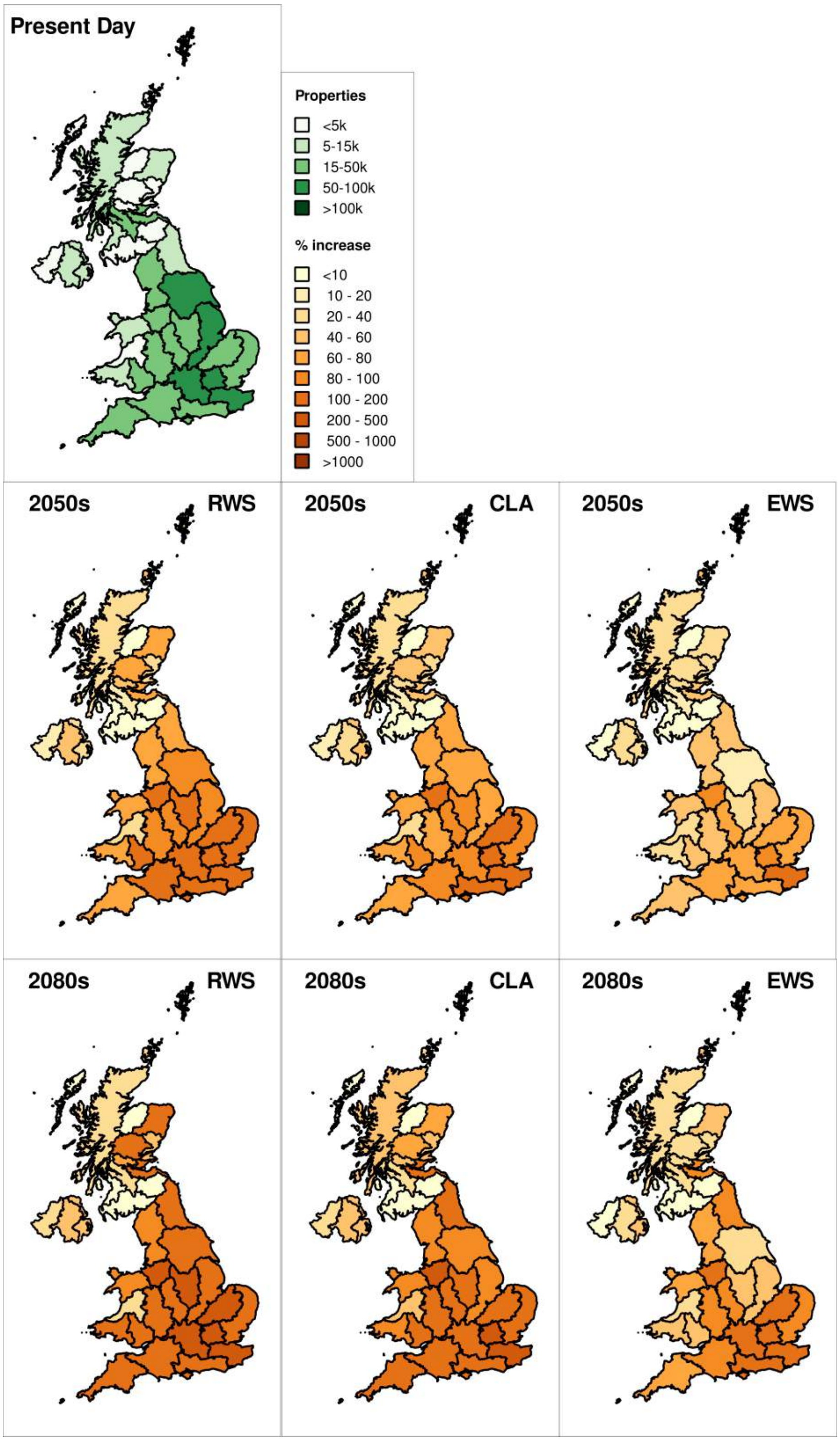


Figure 6-15 The influence of alternative Adaptation Scenarios on properties at a high chance of flooding (more frequently than 1:75 years) (4°C climate change projection and low population growth)

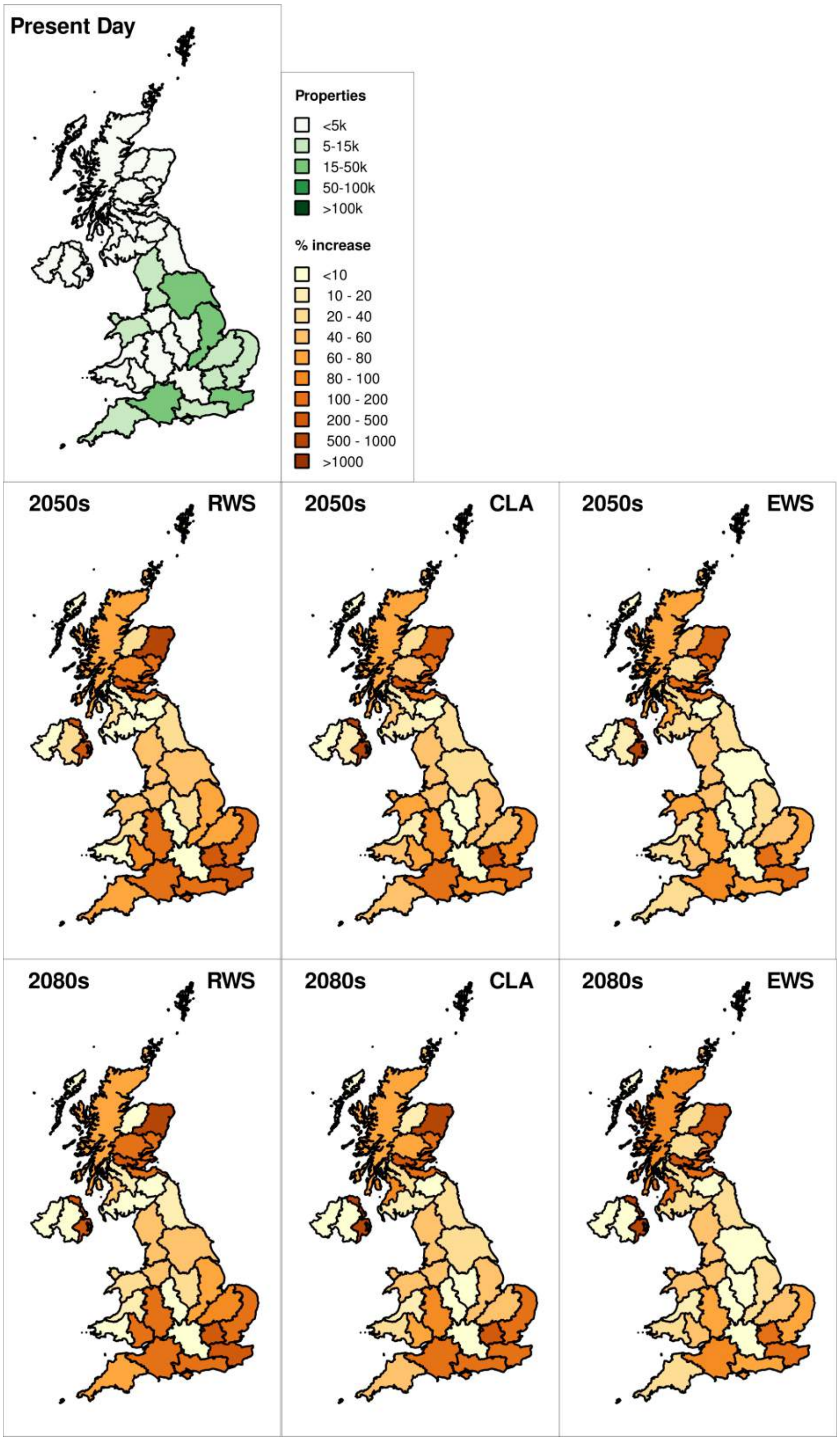


Figure 6-16 The influence of alternative Adaptation Scenarios on coastal flood risk (residential properties exposed to flooding more frequently than 1:75 years) (2^{o}C climate change projection and low population growth)

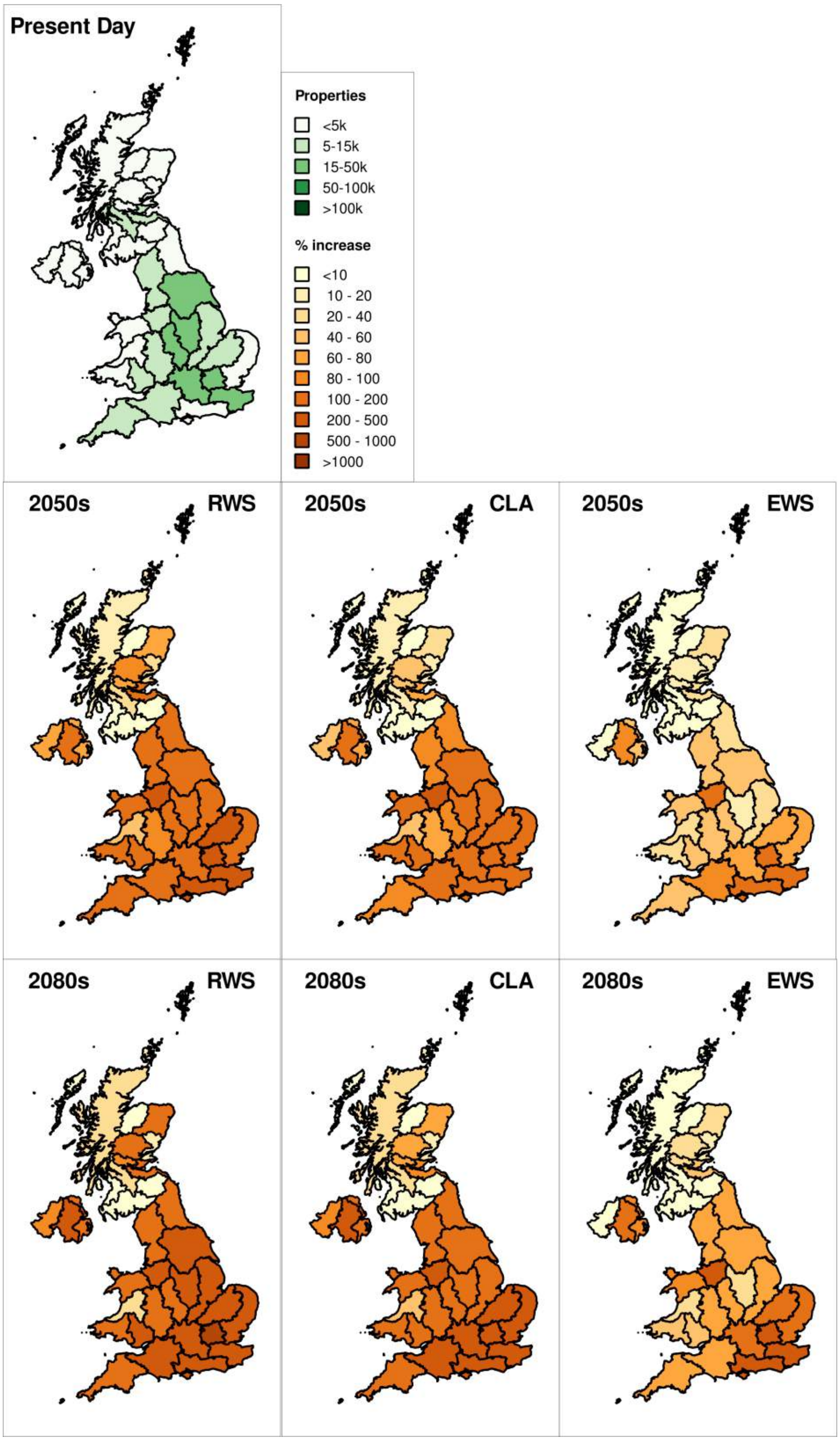


Figure 6-17 The influence of alternative Adaptation Scenarios on fluvial flood risk (residential properties exposed to flooding more frequently than 1:75 years) (2^{o}C climate change projection and low population growth)

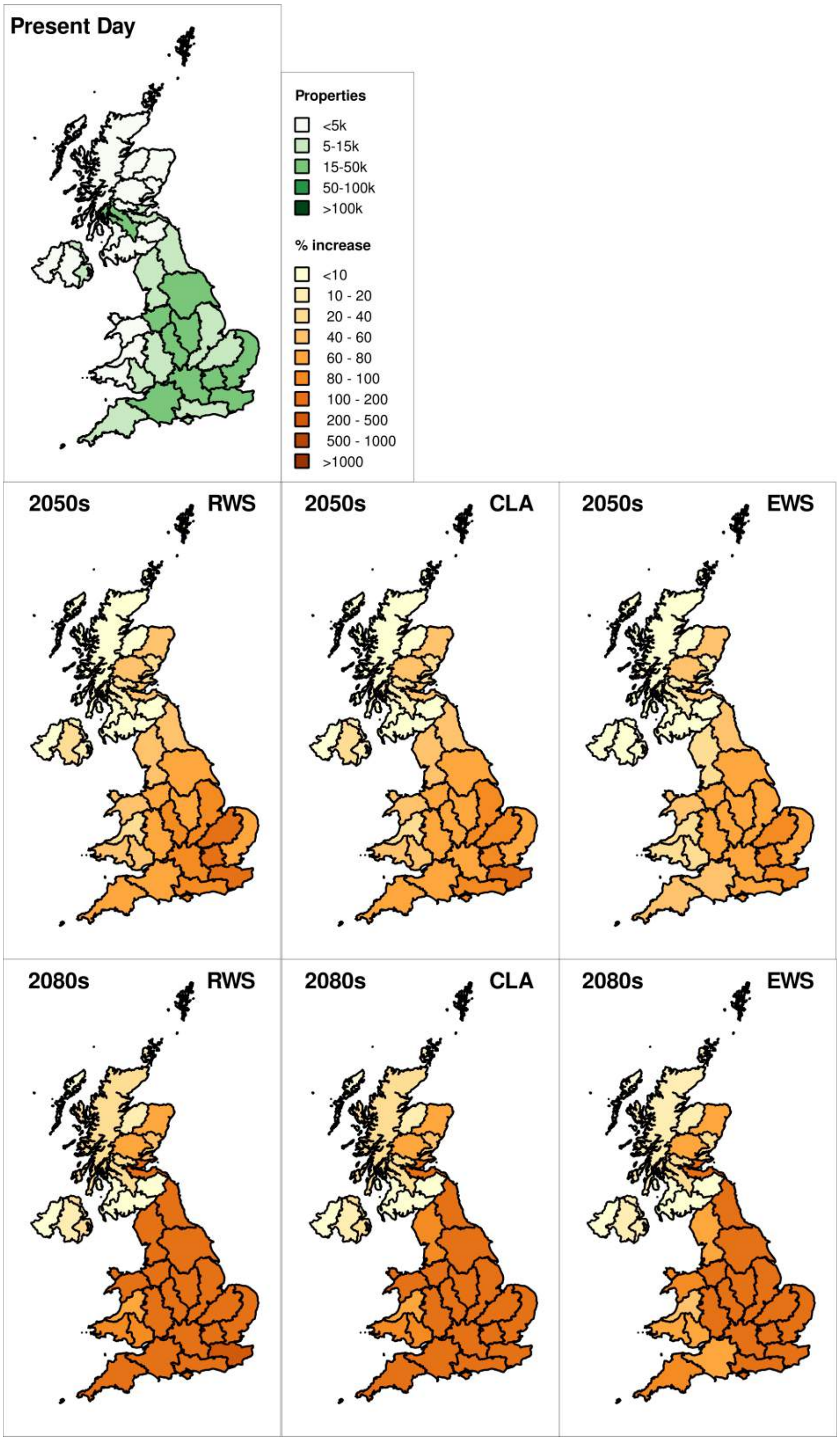


Figure 6-18 The influence of alternative Adaptation Scenarios on surface water flood risk (residential properties exposed to flooding more frequently than 1:75 years) (2°C climate change projection and low population growth)

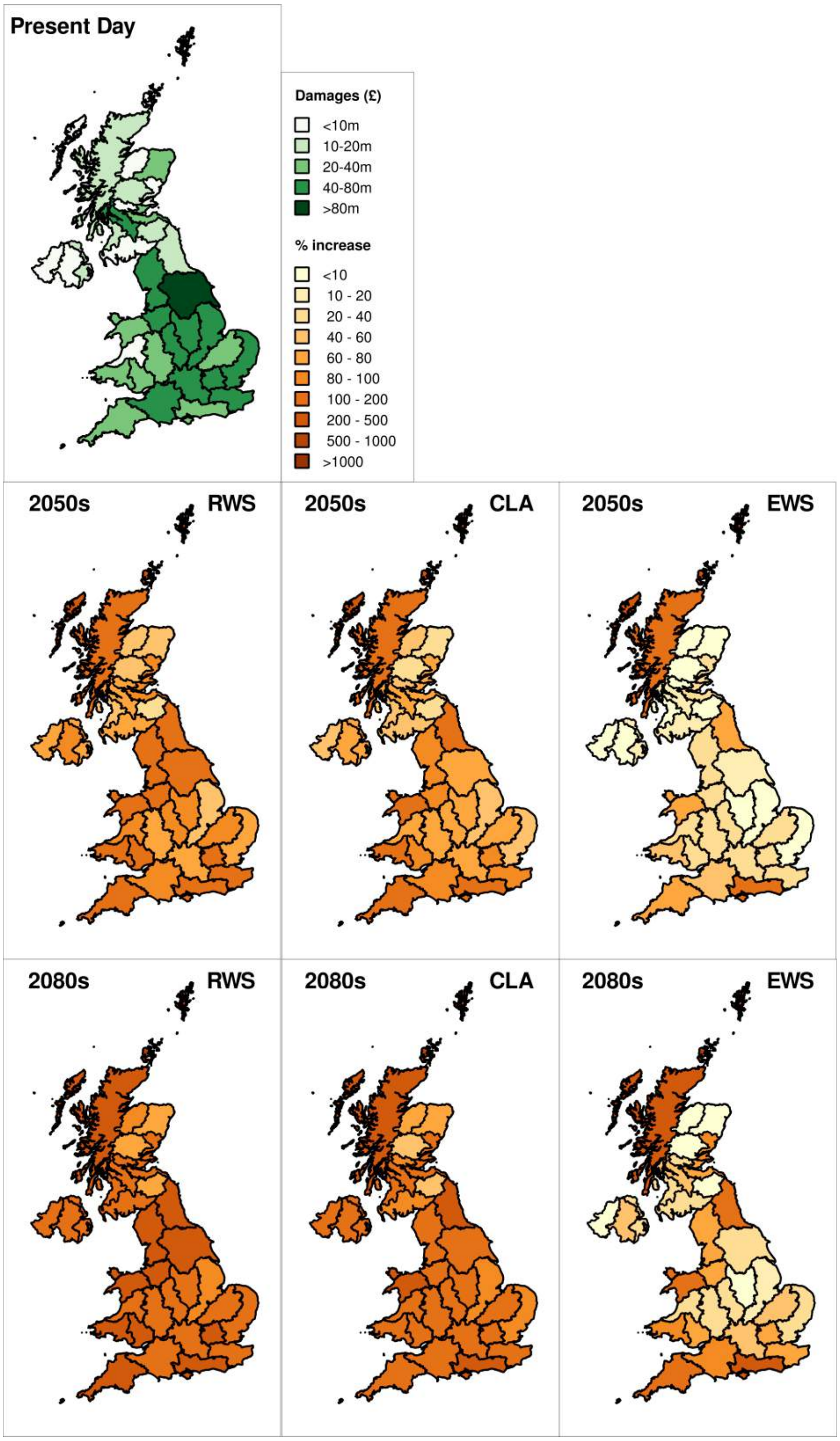


Figure 6-19 The influence of alternative Adaptation Scenarios on Expected Annual Damages (4°C climate change projection and low population growth)

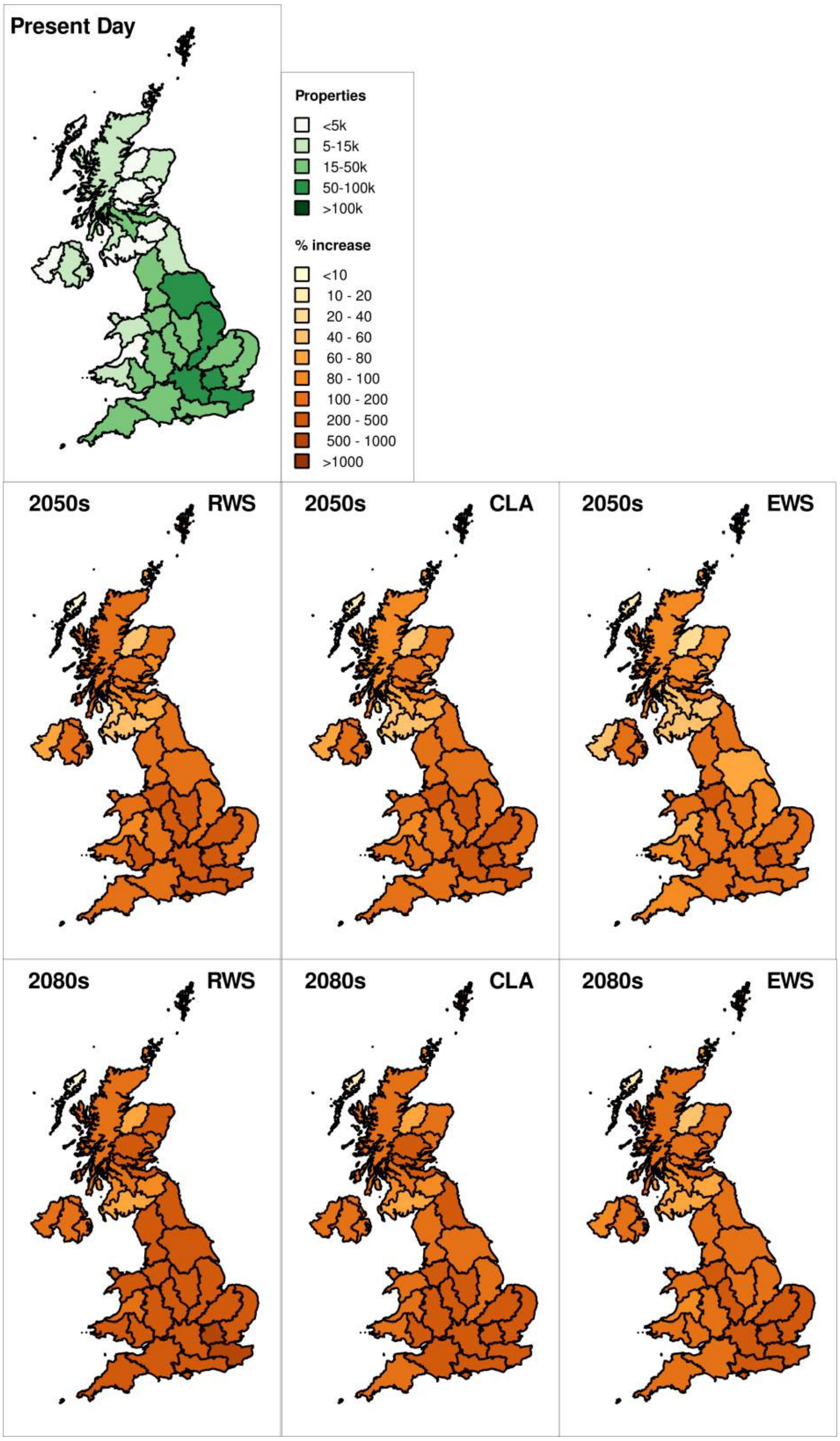


Figure 6-20 The influence of alternative Adaptation Scenarios on properties at risk of flooding (more frequently than 1:75 years) (H++ scenario and high population growth)

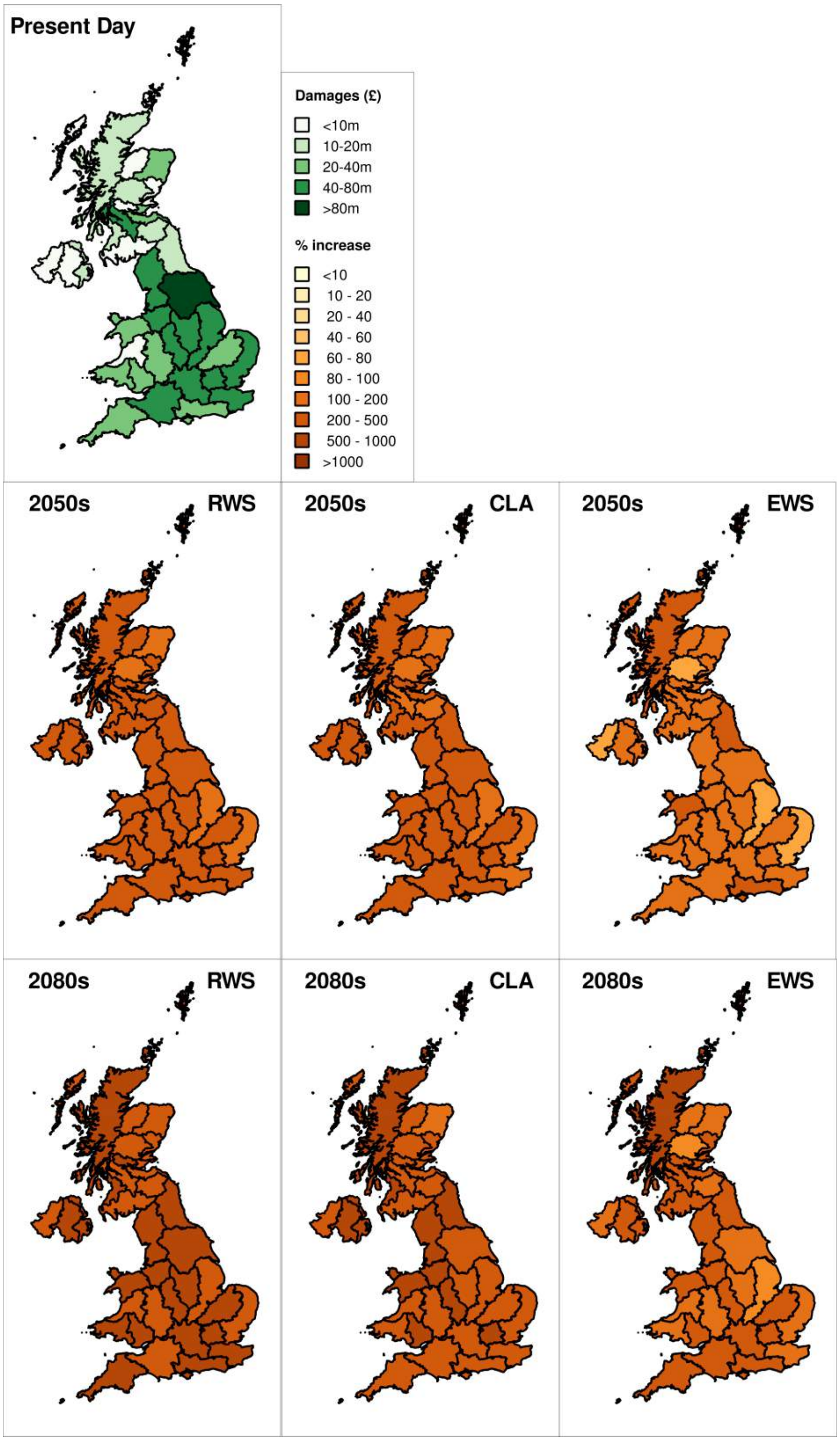


Figure 6-21 The influence of alternative Adaptation Scenarios on Expected Annual Damages (H++ scenario and high population growth)

6.3 Groundwater: Estimates of future flood risks

The assessment of future changes in groundwater flooding has been undertaken using the BGS Groundwater Susceptibility Model (as described in detail in Appendix D). The FFE has then been used to translate these changes in flooding to changes in risk. Because the modelling approach and underlying data are different in nature, and no adaptation measures have been applied to groundwater, the results are presented separately to the other sources of flooding.

6.3.1 Results: Tables and graphs

National headline groundwater risks

Tables 6-13 to 6-16 summarize the expected changes in groundwater flooding for the UK, England, Wales, Scotland and Northern Ireland. They show the number of residential and non-residential properties at risk of experiencing groundwater flooding and the associated Expected Annual Damages. These metrics are for scenarios of climate change only and exclude population growth. Adaptation is assumed not to affect groundwater flooding. The metrics for fluvial flooding for present day are also shown as a reference only (to show the magnitude of groundwater flooding to fluvial flooding).

The contribution from different forms of groundwater flooding

Table 6-17 shows the breakdown of Expected Annual Damages for the UK by the different types of groundwater flooding: Clearwater (CW) and Permeable Superficial Deposits (PSD) on and off the floodplain. The expected changes in CW flood damage are relatively small and highlight the complex interactions between evapotranspiration and recharge volumes For example, under 2^{o}C and H ++ climate change scenarios CW flooding increases by the 2050s and 2080s, while the 4^{o}C climate change projection drives a decrease in risk because the increase in evapotranspiration outweighs precipitation increases.

6.3.2 Results: Maps

Figure 6-19 summarizes the spatial distribution of groundwater risk in terms of residential expected annual damages and projected increases/decreases.

Figure 6-20 presents the figures in terms of the number of residential properties at risk.

Table 6-10 UK: Future groundwater risks

		2020s			2050s			2080s			
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	Fluvial Present
No population growth											
Properties											
at risk											
No. residential	470,000	0%	0%	2%	1%	2%	7%	2%	3%	15%	749,000
No. non-residential	210,000	0%	0%	2%	1%	1%	5%	1%	2%	10%	188,000
at significant chance of flooding											
No. residential	210,000	-1%	10%	65%	-1%	10%	120%	31%	90%	140%	270,300
No. non-residential	110,000	-1%	10%	56%	10%	43%	89%	30%	71%	100%	178,800
Expected Annual Damage											
residential only (direct)	£77,000,000	4%	24%	80%	30%	62%	350%	58%	140%	890%	£162,500,000
Non-residential only (direct)	£140,000,000	4%	22%	72%	27%	57%	300%	49%	130%	670%	£400,900,000

Table 6-11 England: Future groundwater risks

		2020s			2050s			2080s			
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	Fluvial Present
No population growth											
Properties											
at risk											
No. residential	360,000	0%	0%	0%	0%	0%	1%	0%	1%	3%	600,000
No. non-residential	170,000	0%	0%	0%	0%	0%	1%	0%	1%	2%	130,000
at significant chance of flooding											
No. residential	160,000	-3%	10%	71%	-3%	9%	120%	31%	97%	120%	210,000
No. non-residential	90,000	-2%	8%	54%	8%	41%	83%	27%	69%	84%	150,000
Expected Annual Damage											
residential only (direct)	£56,000,000	1%	24%	74%	26%	58%	330%	54%	140%	880%	£120,000,000
Non-residential only (direct)	£100,000,000	3%	23%	72%	26%	56%	300%	49%	130%	670%	£280,000,000

Table 6-12 Wales: Future groundwater risks

		2020s			2050s			2080s			
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	Fluvial Present
No population growth											
Properties											
at risk											
No. residential	44,000	0%	0%	0%	0%	0%	1%	0%	0%	1%	60,000
No. non-residential	26,000	0%	0%	0%	0%	0%	0%	0%	0%	1%	35,000
at significant chance of flooding											
No. residential	15,000	2%	25%	110%	2%	26%	190%	60%	170%	190%	21,000
No. non-residential	13,000	2%	18%	68%	18%	63%	96%	38%	88%	96%	17,000
Expected Annual Damage											
residential only (direct)	£4,500,000	6%	37%	130%	40%	120%	670%	71%	250%	1900%	£10,000,000
Non-residential only (direct)	£14,000,000	4%	27%	87%	28%	80%	360%	49%	160%	750%	£29,000,000

Table 6-13 Scotland: Assessment of future groundwater risks for Scotland

		2020s			2050s			2080s			
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	Fluvial Present
No population growth											
Properties											
at risk											
No. residential	69,000	1%	3%	11%	5%	8%	36%	8%	14%	79%	75,000
No. non-residential	12,000	2%	3%	11%	5%	8%	36%	9%	13%	79%	18,000
at significant chance of flooding											
No. residential	37,000	2%	5%	19%	2%	8%	87%	15%	24%	150%	35,000
No. non-residential	5,500	4%	8%	32%	16%	24%	120%	26%	41%	200%	10,000
Expected Annual Damage											
residential only (direct)	£16,000,000	11%	22%	88%	41%	62%	320%	67%	110%	650%	£27,000,000
Non-residential only (direct)	£19,000,000	8%	15%	61%	28%	43%	240%	46%	77%	590%	£83,000,000

Table 6-14 Northern Ireland: Future groundwater risks

		2020s			2050s			2080s			
Risk Metric	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	Fluvial Present
No population growth											
Properties											
at risk											
No. residential	5,700	3%	6%	23%	12%	20%	80%	23%	41%	120%	14,000
No. non-residential	5,700	3%	6%	24%	12%	20%	83%	24%	43%	130%	5,000
at significant chance of flooding											
No. residential	1,400	14%	25%	120%	14%	51%	390%	120%	240%	760%	4,300
No. non-residential	1,800	24%	44%	130%	63%	86%	300%	130%	190%	610%	1,800
Expected Annual Damage											
residential only (direct)	£1,000,000	9%	16%	62%	30%	51%	400%	62%	150%	1200%	£5,500,000
Non-residential only (direct)	£3,000,000	12%	21%	83%	37%	67%	420%	83%	190%	1000%	£8,900,000

Table 6-15 UK: Contribution to future risk from different groundwater sources

		2020s			2050s			2080s		
	Present day	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++	2 Deg	4 Deg	H++
Expected Annual Damage - Residential										
PSD - on floodplain	£45,000,000	7%	36%	100%	34%	87%	470%	64%	190%	1300%
PSD - off floodplain	£21,000,000	3%	19%	75%	23%	61%	270%	48%	120%	480%
Clearwater flooding	£11,000,000	-8%	-11%	-1%	26%	-35%	14%	54%	-11%	23%

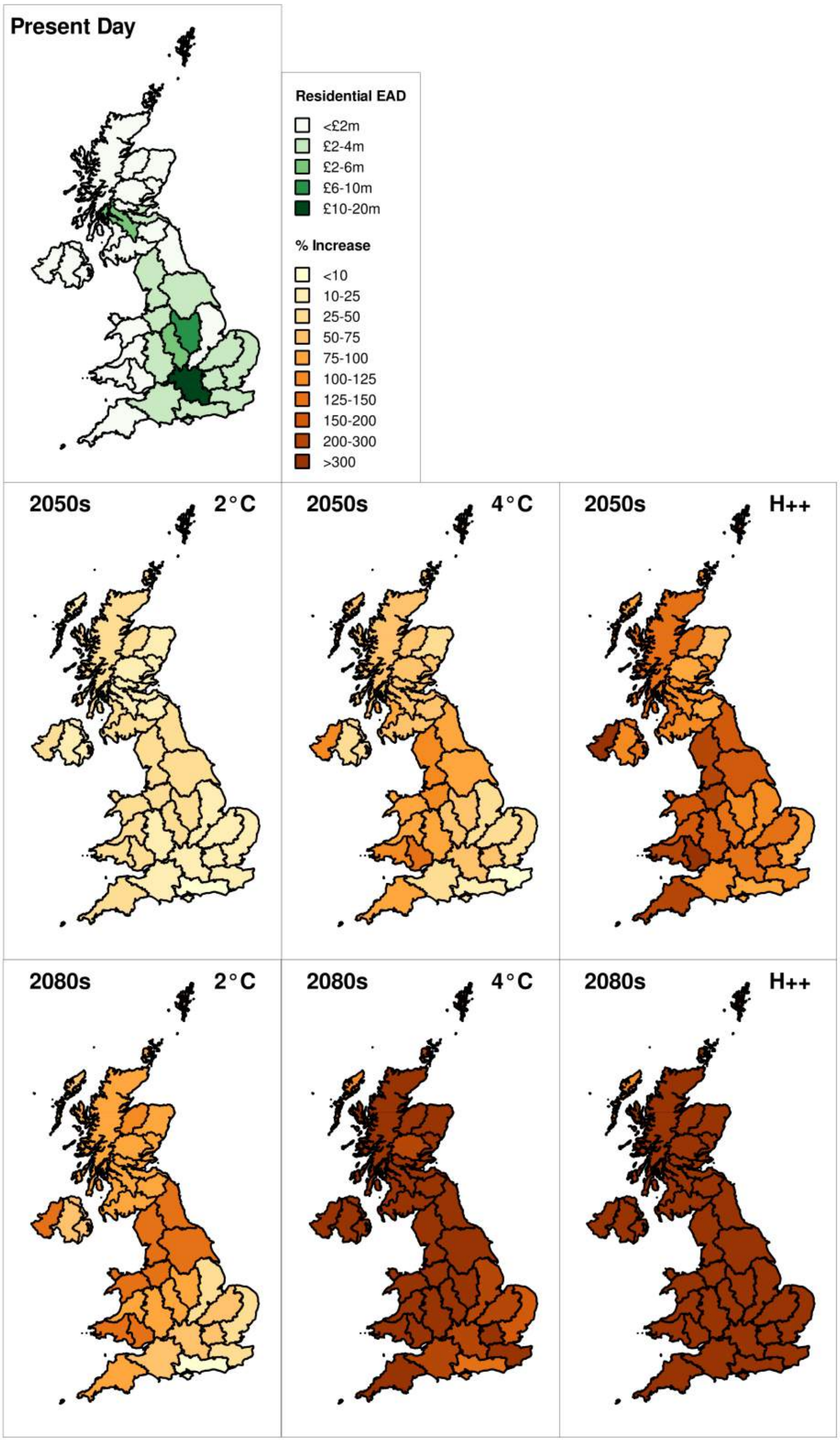


Figure 6-22 UK: Groundwater risk: Residential Expected Annual Damages

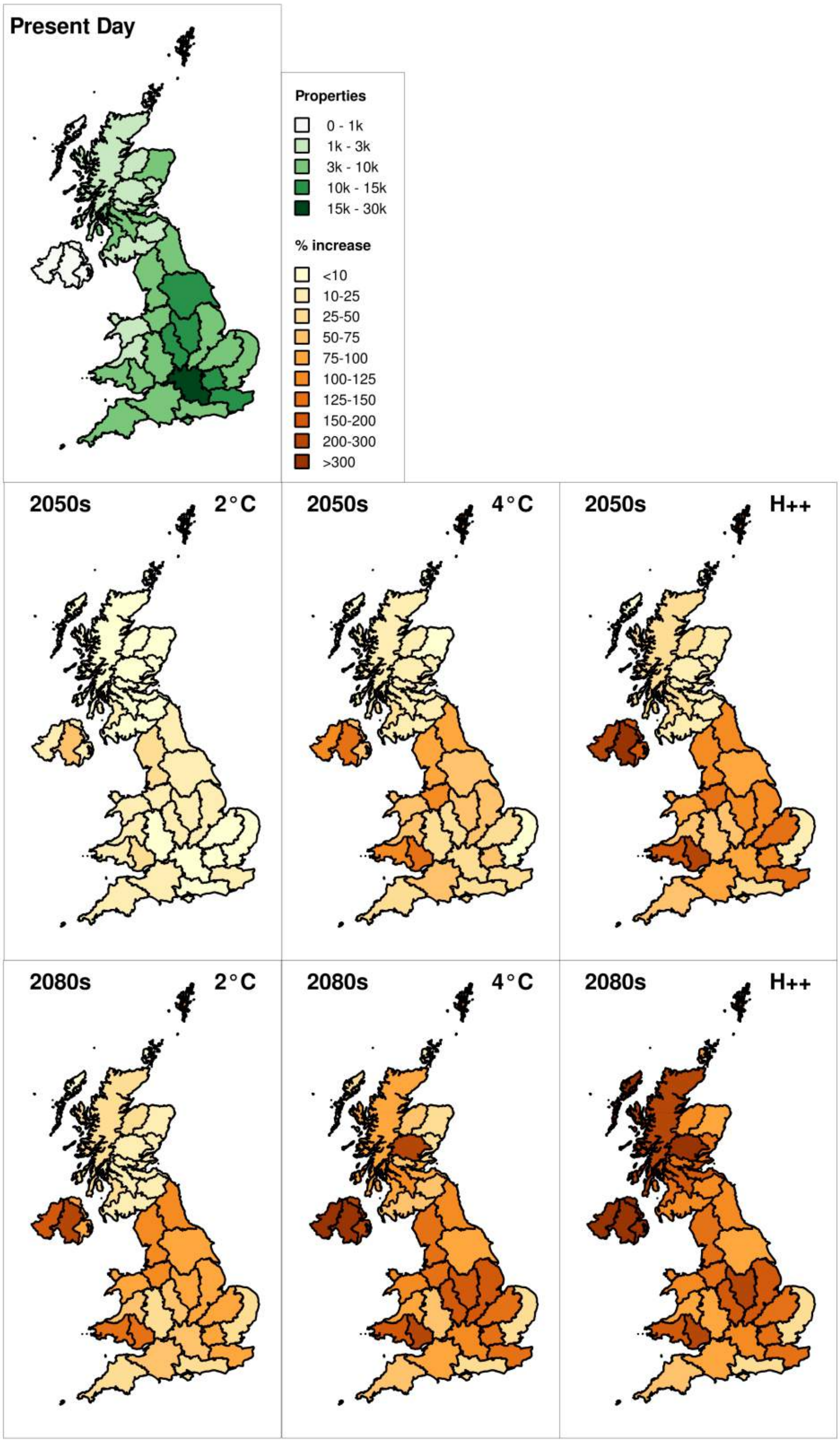


Figure 6-23 UK: Groundwater risk: Residential properties exposed to flooding more frequent than 1:75 years

6.4 All sources: Estimates of future risk

The following figures (Figure 6-24 to 6-29) present the contribution to future risk from climate change under the 2°C and 4°C projection and H++ scenario. The figures disaggregate the contribution made each source of flooding and the ability of the alternative Adaptation Scenarios to offset risk.

The figures highlight that the H++/High Population scenario increases risk more significantly than either the 2°C or 4°C (as expected) and the increase in risk is dominated by changes in fluvial flooding (although coastal and surface water flood risk is also significant). Groundwater flooding also makes a significant contribution; this is driven primarily by PSD flooding, where changes in response to climate follow those for fluvial flooding.

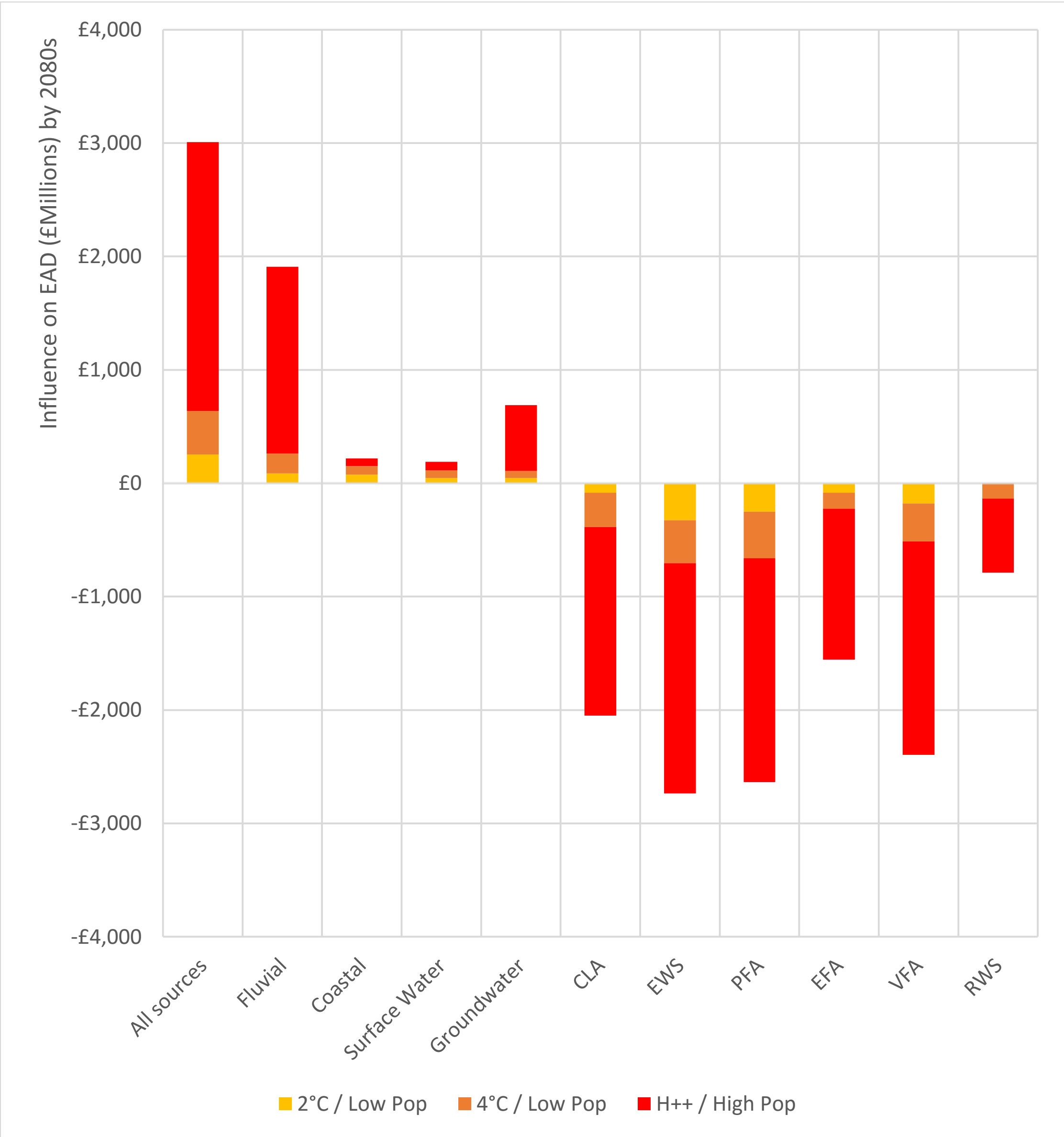


Figure 6-24 UK 2080s: Disaggregation of the drivers of future risk and the ability of adaptation to offset that risk

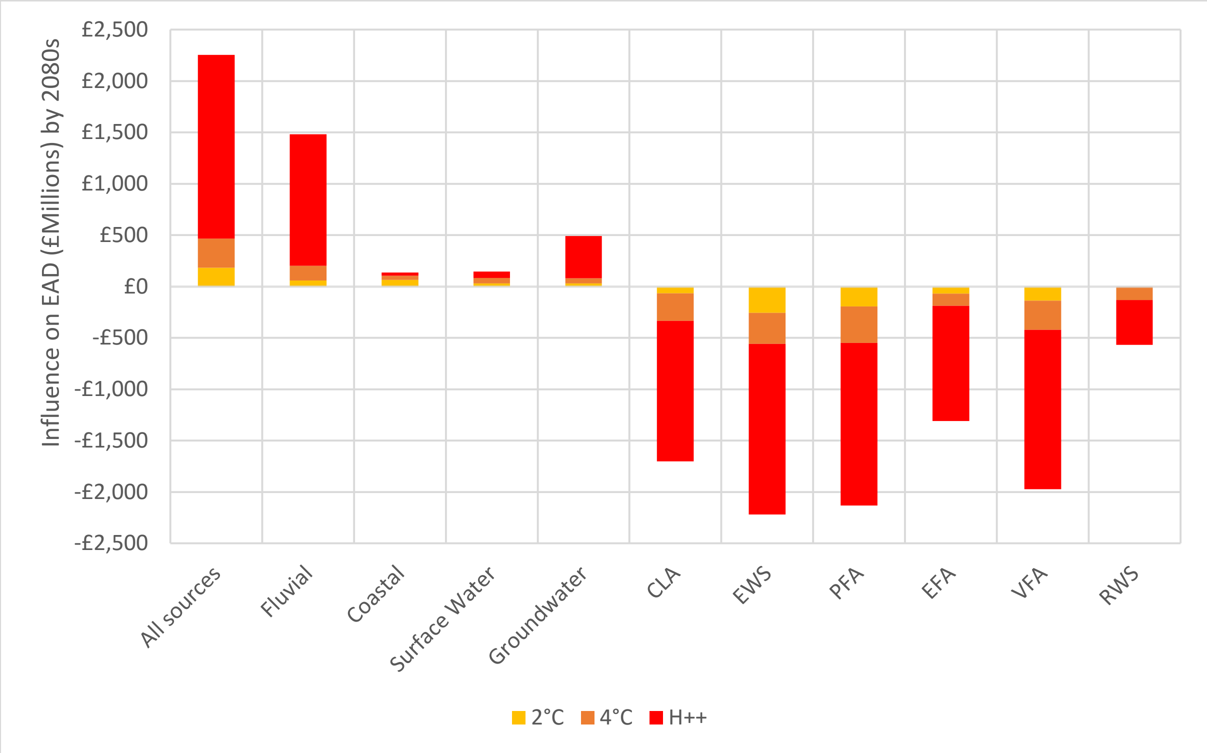


Figure 6-25 England 2080s: Disaggregation of the drivers of future risk and the ability of adaptation to offset that risk

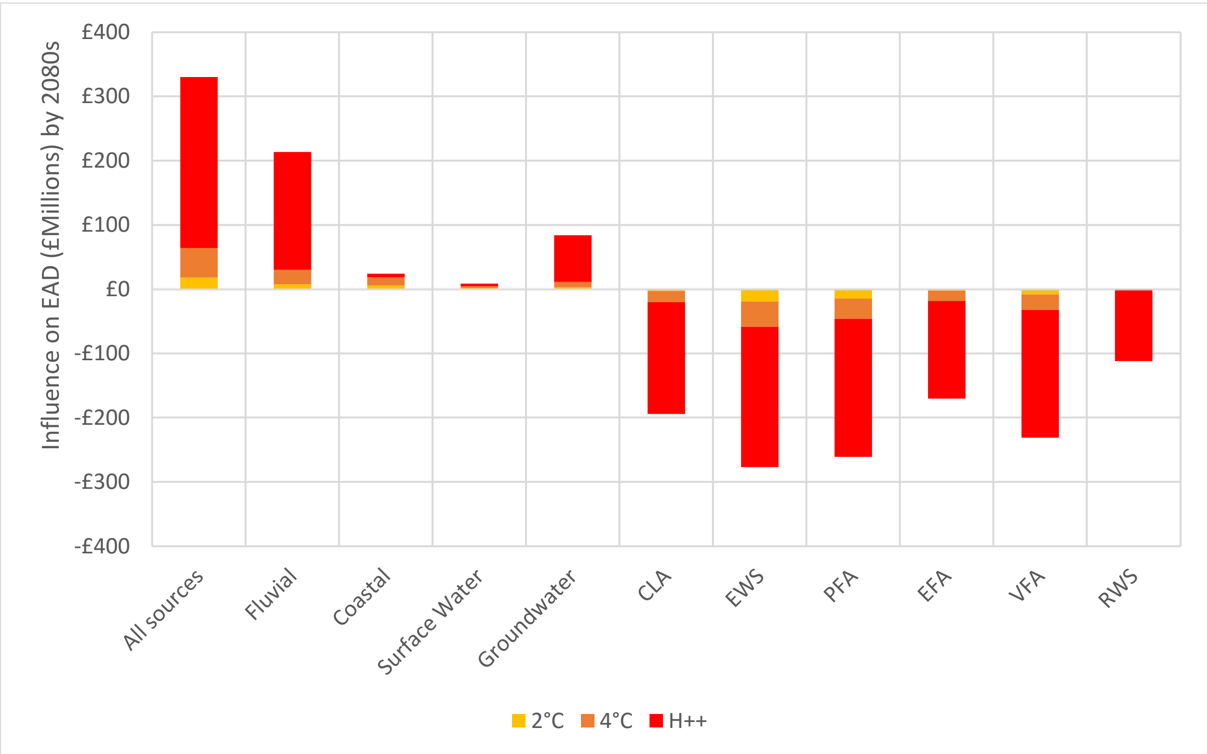


Figure 6-26 Wales 2080s: Disaggregation of the drivers of future risk and the ability of adaptation to offset that risk

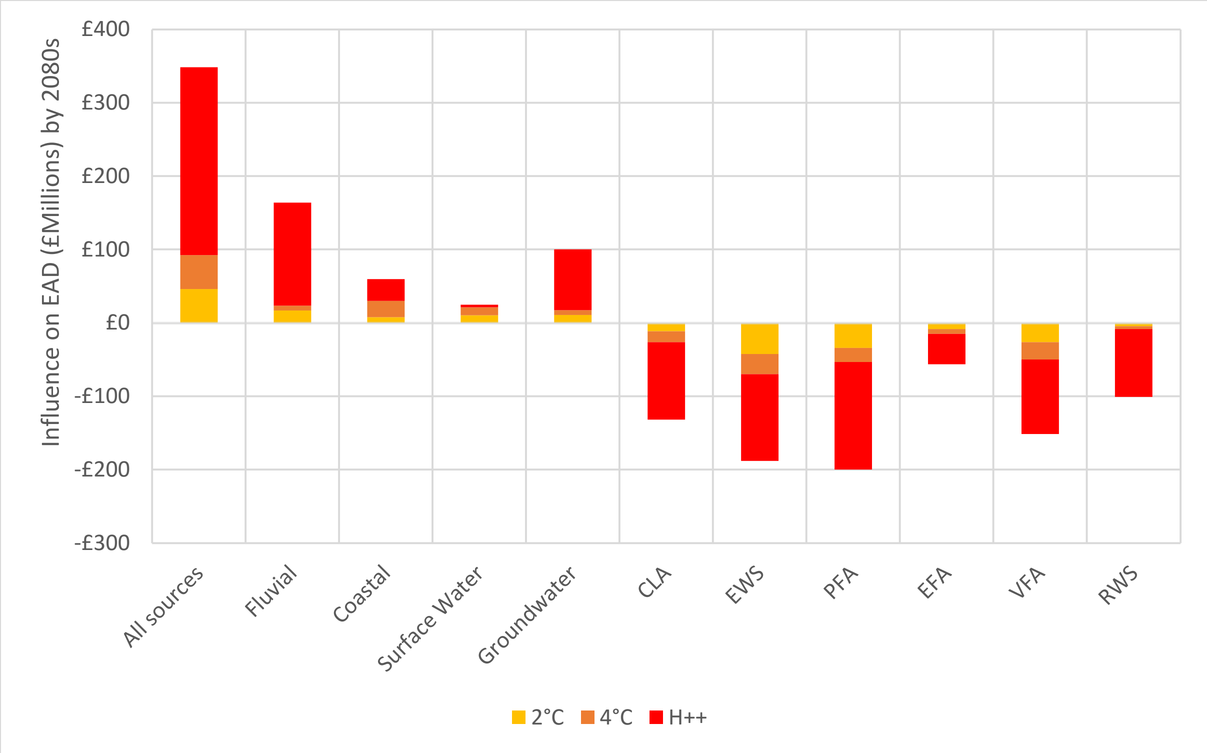


Figure 6-27 Scotland 2080s: **Disaggregation of the drivers of future risk and the ability of adaptation to offset that risk**

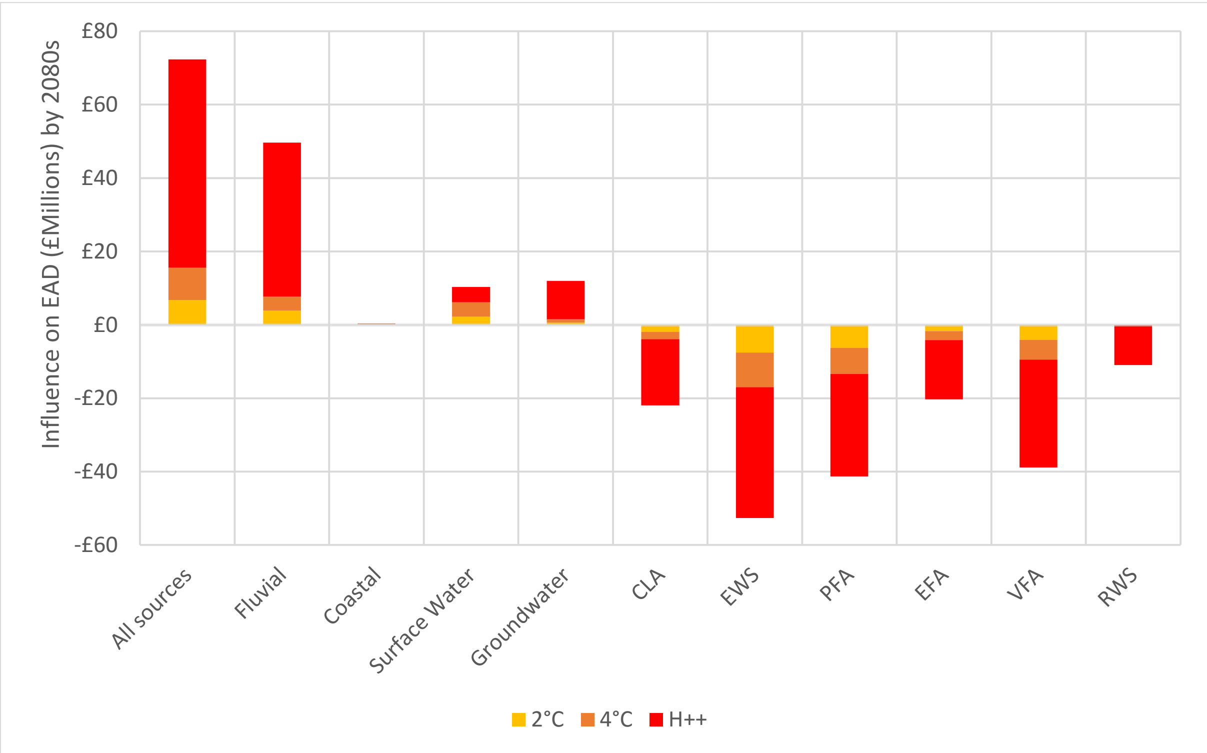


Figure 6-28 Northern Ireland 2080s: **Disaggregation of the drivers of future risk and the ability of adaptation to offset that risk**

7.0 IMPACT OF SEA LEVEL RISE IN ENGLAND: A "WHAT IF" ANALYSIS

The analysis presented elsewhere in this report assumes that climate change has no influence on the spatial extent of the coastal floodplain (i.e. it remains as presently defined); climate change is assumed to influence the probability of flooding only within that floodplain. The location of the shoreline is also assumed fixed, and the defences remain in place, albeit with effectiveness reduced by climate change or enhanced by adaptation. Under more extreme sea level rise projections this assumption becomes increasingly unrealistic.

Analysis separate from the Future Flood Explorer has been undertaken to determine the impact of increased sea levels on two aspects of the coast: (i) the vulnerability of the existing defence line, and (ii) the potential extent of the coastal floodplain (and number of properties impacted) should the existing defences be lost.

The analysis has been undertaken separately from the FFE because of the very different method used, and the results are therefore presented separately in this section. This analysis applies to England only because it relies on detailed defence toe level data, available for England through the Continuous Defence Line dataset (completed in 2015), but not available for other countries.

Note:

This analysis focuses on the vulnerability of coastal defences to sea level rise and the associated 'what-if' inundation should the defences be lost. No effort is make to assess the benefits and costs of maintaining the defences in their current location.

7.1 Identification of highly vulnerable defences under future climates

Given the depth limited nature of the wave conditions along much of the coast of England, sea level (and hence rSLR) is the most significant factor affecting loading on coastal defences. Defences with low toe levels (elevation of the lowest exposed part of the defence on its seaward side) typically experience more severe incident wave conditions and are therefore likely to be more expensive to maintain. As sea level rises, more defences will be subject to erosion as the depth limited wave height increases.

To provide a simple, but credible means, of representing the complex relationship between sea level rise and defence performance, a critical mean water depth at the toe of the defence has been defined for each defence (if the mean water depth at the defence exceeds this value it is assumed that wave action will be frequent and significant and the defence can be considered highly vulnerable). .

Vulnerable defences are therefore identified as those where the toe level satisfies the inequality:

$$Toe \leq SLR - h_c$$

Where

- *Toe* is the toe level of the defence (taken from Continuous Defence Line (CDL) dataset for England, provided to the project in July 2015) (mOD)
- *SLR* is the rise in mean sea level compared to present day (mOD)
- h_c is critical water depth (a proxy for a series of complex factors such as beach slope, depth limitation of wave conditions, wave direction and period.

Within this inequality both SLR and *toe* are known. A calibration exercise has been undertaken to determine h_c. The value of h_c has been calibrated to yield the same percentage length of managed realignment (current and future) as set out within the Shoreline Management Plans. It is likely that areas identified for managed realignment within Shoreline Management Plans will tend to be locations with the greatest potential for realignment to be delivered. They are also likely to focus on defences with the lowest benefit cost case for continued protection and hence, in the absence of a more comprehensive analysis beyond the scope of this study, have been used here to provide an indication of how many defences are potentially at risk.

Results of this calibration are shown in Table 7-1 for a value of 0.2 m, with sea level rise taken from the 2°C climate change projection. The results show that this value of h_c gives a length of defences at risk which is broadly in line with realignment strategy.

Table 7-1 Length at coastline at risk for different epochs as a percentage of total coastal defence length, and length of coastline identified for managed realignment by Shoreline Management Plans

Epoch	Length of coastal defences at risk	% of total coastal defence length at risk	% coastline identified for managed realignment
2020s	114 km	11%	9%
2050s	119 km	11%	14%
2080s	171 km	16%	16%

The total length of defences at risk identified using this criterion, as it varies with sea level rise (this is a climate neutral view, no scenario is assumed), is shown in Figure 7-1. This figure is of course sensitive to the chosen value h_c; a greater value of h_c would move the curve to right (implying defences to be less sensitive to sea level rise).

This simplified approach yields an approximately linear relationship between sea level rise and the length of defences at risk. Given this relationship a change in the calibration of h_c would generate a proportional change in the length of coastline at risk.

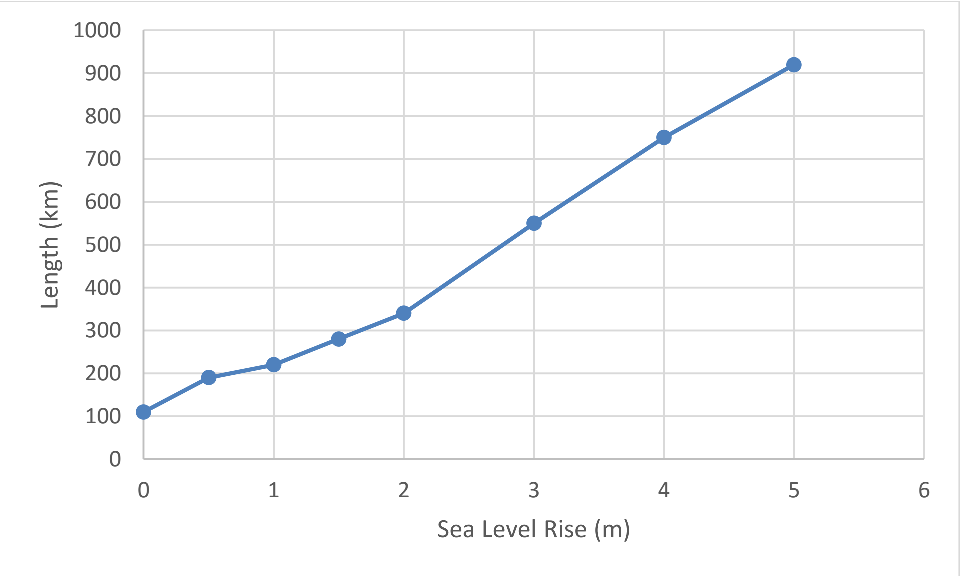


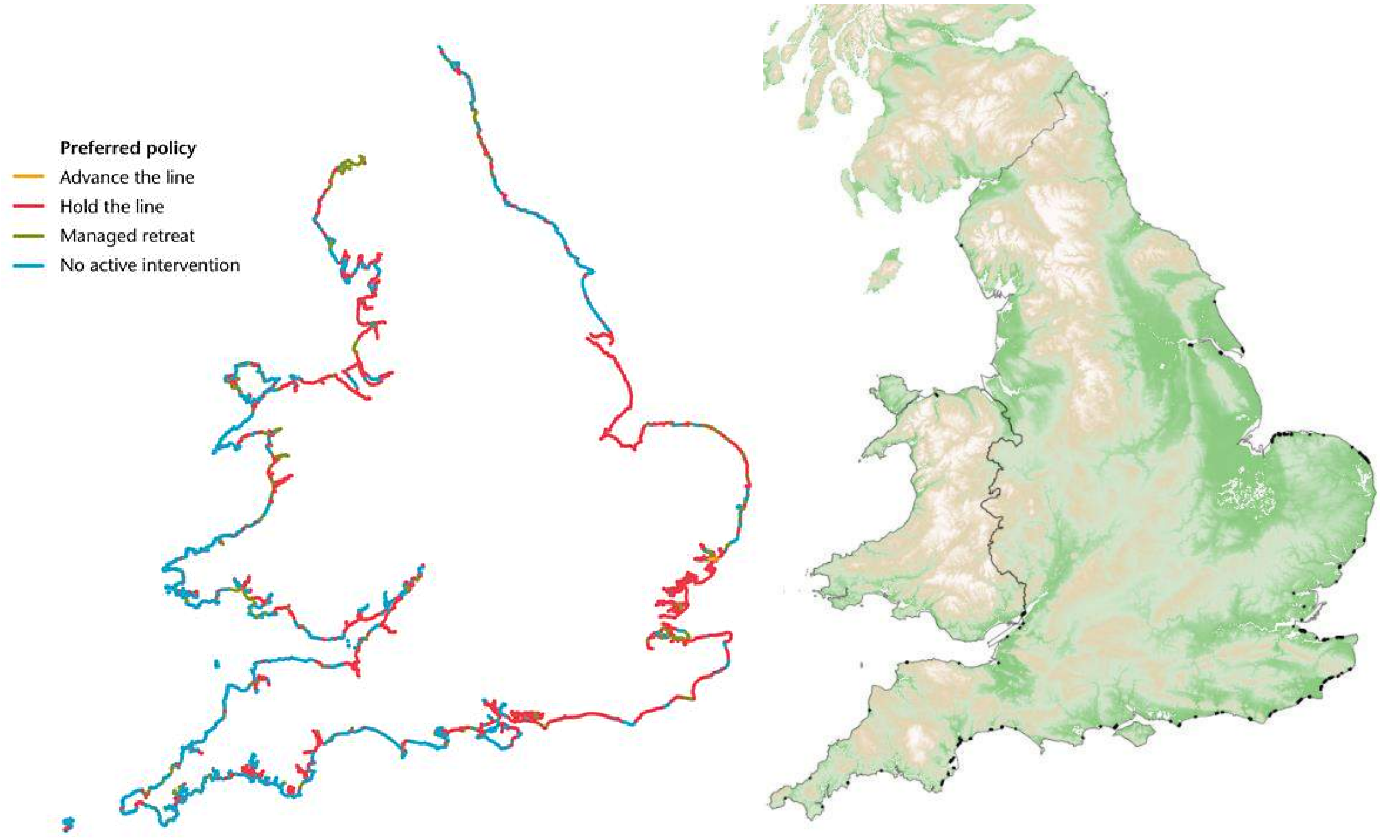
Figure 7-1 The length of coastal flood defences that may become highly vulnerable as mean sea levels rise

The location of the most vulnerable coastal defences today (i.e. with zero sea level rise) estimated using this approach are compared with the SMP policy options in Figure 7-2. Visual inspection shows some areas where vulnerable defences coincide with an SMP policy selection of managed retreat: East Anglia, North Kent and the Severn Estuary for example.

Note:

Natural beach systems are excluded: Natural beach systems are not considered in this analysis, as it is assumed that they will be able to respond naturally to raised sea levels. In reality this may not be the case (due, for example, to limited space to roll back). Further more detailed analysis would be required to estimate the vulnerability of natural system that is beyond the scope here.

Spatial comparison has not been possible: Unfortunately the spatial data on SMP policy are not readily available and therefore it has not been possible to provide a more direct spatial comparison (by overlaying these results with the SMP policy options).



Left: SMP options for the first epoch (2010-2030) taken from ASC (2013) (green represents managed realignment); **Right:** The present day vulnerable defences (no SLR) shown as black lines

Figure 7-2 Comparing the location of vulnerable coastlines to SMP policies

7.2 Inundation extent assuming highly vulnerable coastal defences fail

Having identified the defences at risk, the impact of losing these defences is assessed using a simplified model of coastal inundation S-Grid. S-Grid is a flood hydraulics model designed to produce broad scale maps of flood depths and extents rapidly and robustly for large areas (typically catchment to national scale). The model represents flow on a grid of large (typically 1km) square cells, with sub-grid parameterisation of flow between and storage within cells, using inertial hydrodynamic equations.

S-Grid works by modelling flow on a grid of square cells, in the same way as many other cellular flow models (e.g. LISFLOOD, JFLOW, FlowRoute). The model uses large cells, and to compensate for this, parametrizes storage within each cell as a level-volume curve, and represents topography controlling flow between cells as a level-conveyance curve. This means it can still represent many of the small scale controls on flooding while maintaining fast computation times.

For the assessment of impacts of defence loss, an S-Grid model of England is set up using 1km cells. Topography for the model is taken from the 50m resolution Ordnance Survey Panorama DTM. Boundary conditions are an imposed water level (with the hydrograph as described below) at all cells which contain a defence at risk. This will produce a flood map which captures the broad scale patterns of inundation caused by absence of that defence; the nature of the S-Grid model means that inundation patterns affected by small scale topographic features will not be represented fully. The model will also capture the dynamics of inundation due to tidal forcing, rather than simply representing land below tide/surge level.

The hydrograph used in the boundary condition is shown in Figure 7-3. It covers three high tides: the first and last peak at the 1 year return period level, the central peaks at the 200 year return period level. The curve is sinusoidal, with a period of 12.5 hours to represent the principal lunar semi diurnal component. A series of sea level rise values are used to shift the curve uniformly upward. These cover a range of values through to the limiting case of 5m (i.e. 0, 0.5, 1, 1.5, 2, 3, 4 and 5m). This values do not represent expected values and are only used in the context of a 'what-if' analysis.

The sea level rise values have been superimposed on a 1:200 year return period tidal surge event. This has been chosen as an indicative coastal storm return period that represents the typical standard of protection that is considered appropriate at the coast.

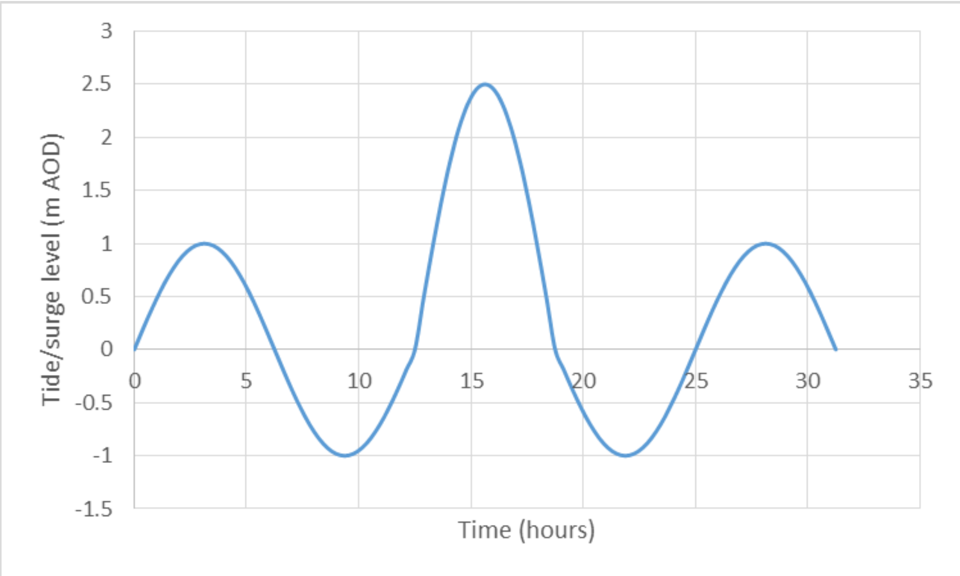
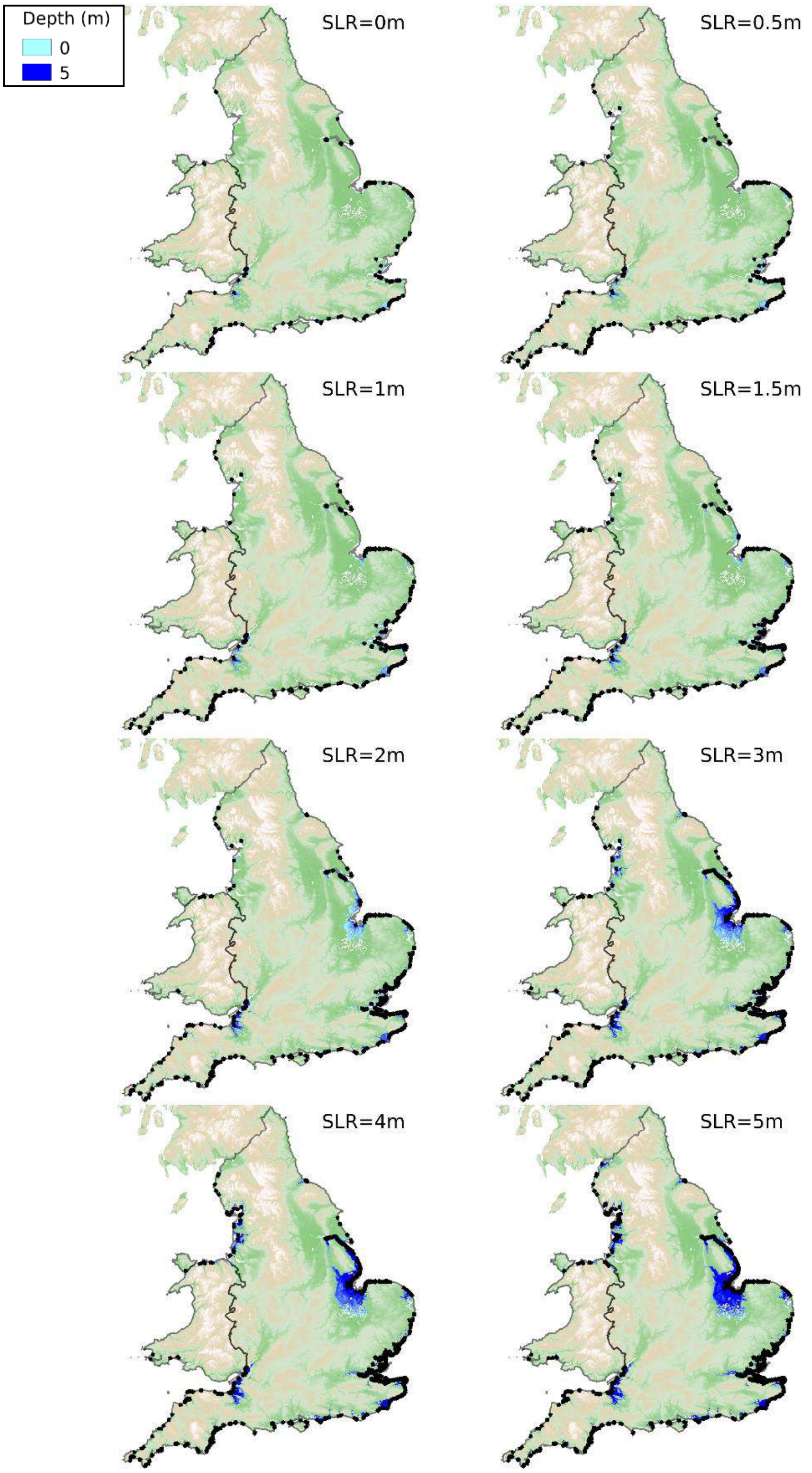


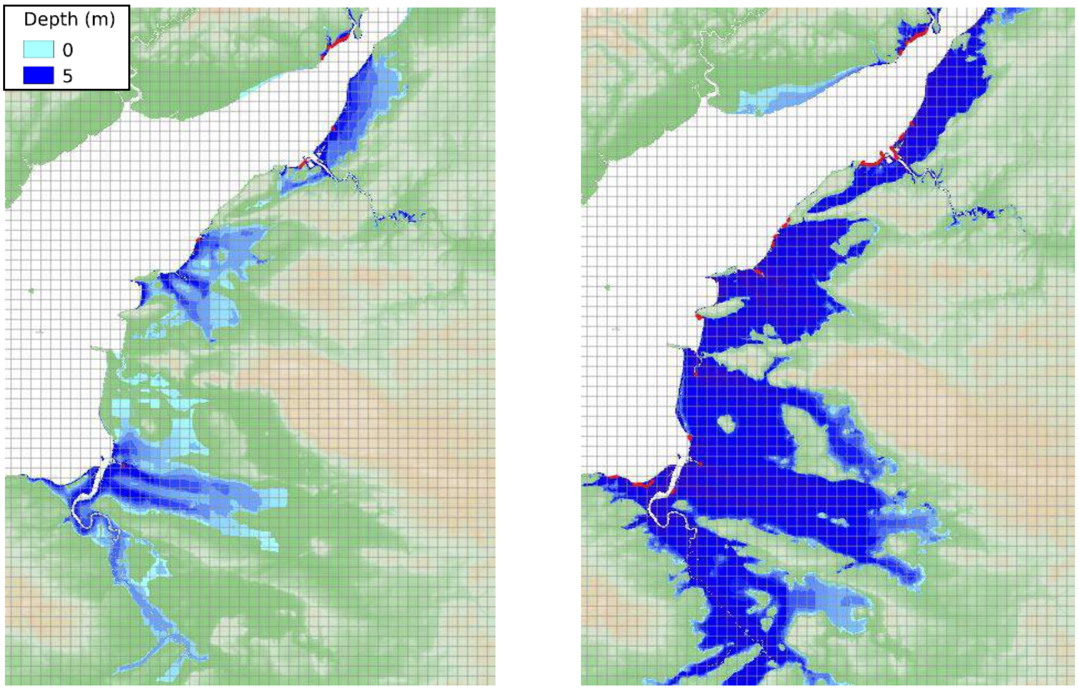
Figure 7-3 Example of boundary condition hydrograph

The resulting inundation maps for eight values of sea level rise are shown in Figure 7-4. At current sea levels, there are already some areas which are identified as being at risk according to the criteria used (see Figure 7-5, Figure 7-6 and Figure 7-7); there are some large areas inundated due to quite short lengths of defences at risk (in particular in the Severn estuary example). This indicates that when only short lengths of defences are vulnerable, the approach may over estimate risk (although without action to strengthen neighbouring defences it is reasonable to consider that the whole defence system may be compromised). Elsewhere, there are many areas where the length of vulnerable defences exceeds 1km or more, where the approach is expected to generate reliable estimates of inundated area. **These results assume no additional adaptation; it is assumed that all defences become ineffective when sea level exceeds a threshold above toe level.**



Defences at risk are shown in black.

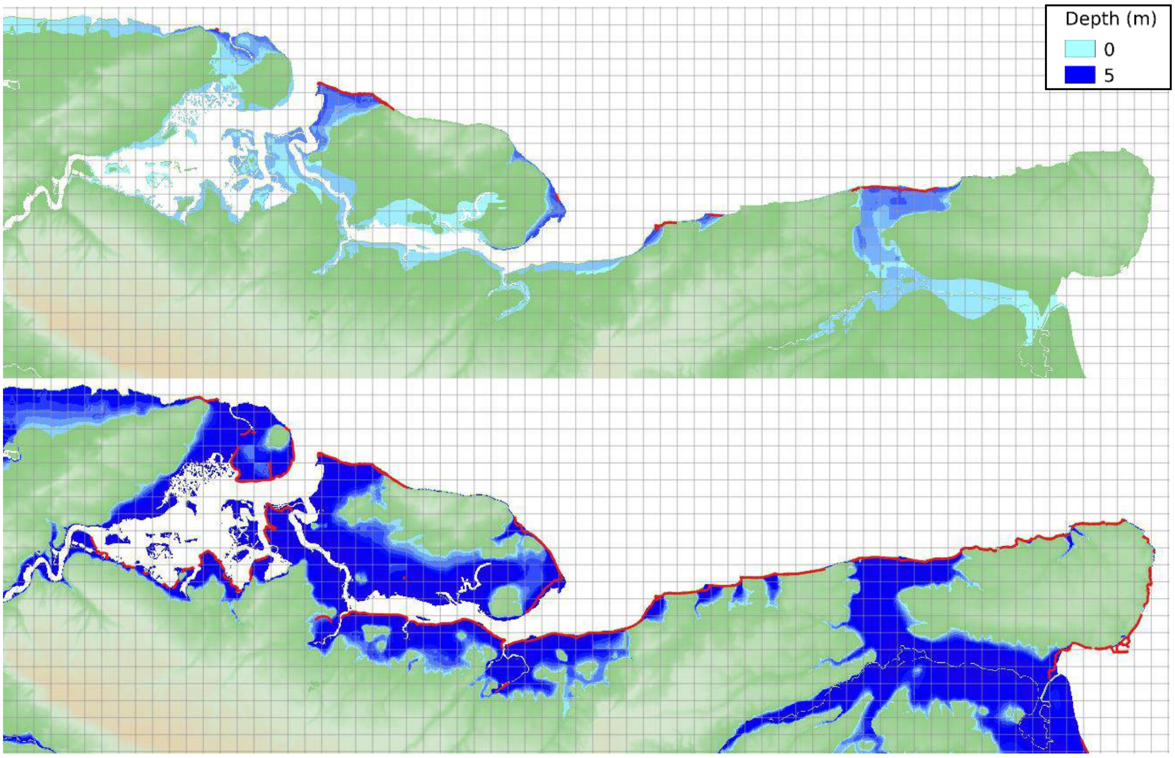
Figure 7-4 UK: Temporary inundation extent under a 1:200 year return period tidal surge and a range of assumed values of sea level rise



Defences at risk are shown in red. The 1km grid used by the model is also shown.

Left: Present day sea levels. Right: 5m of sea level rise

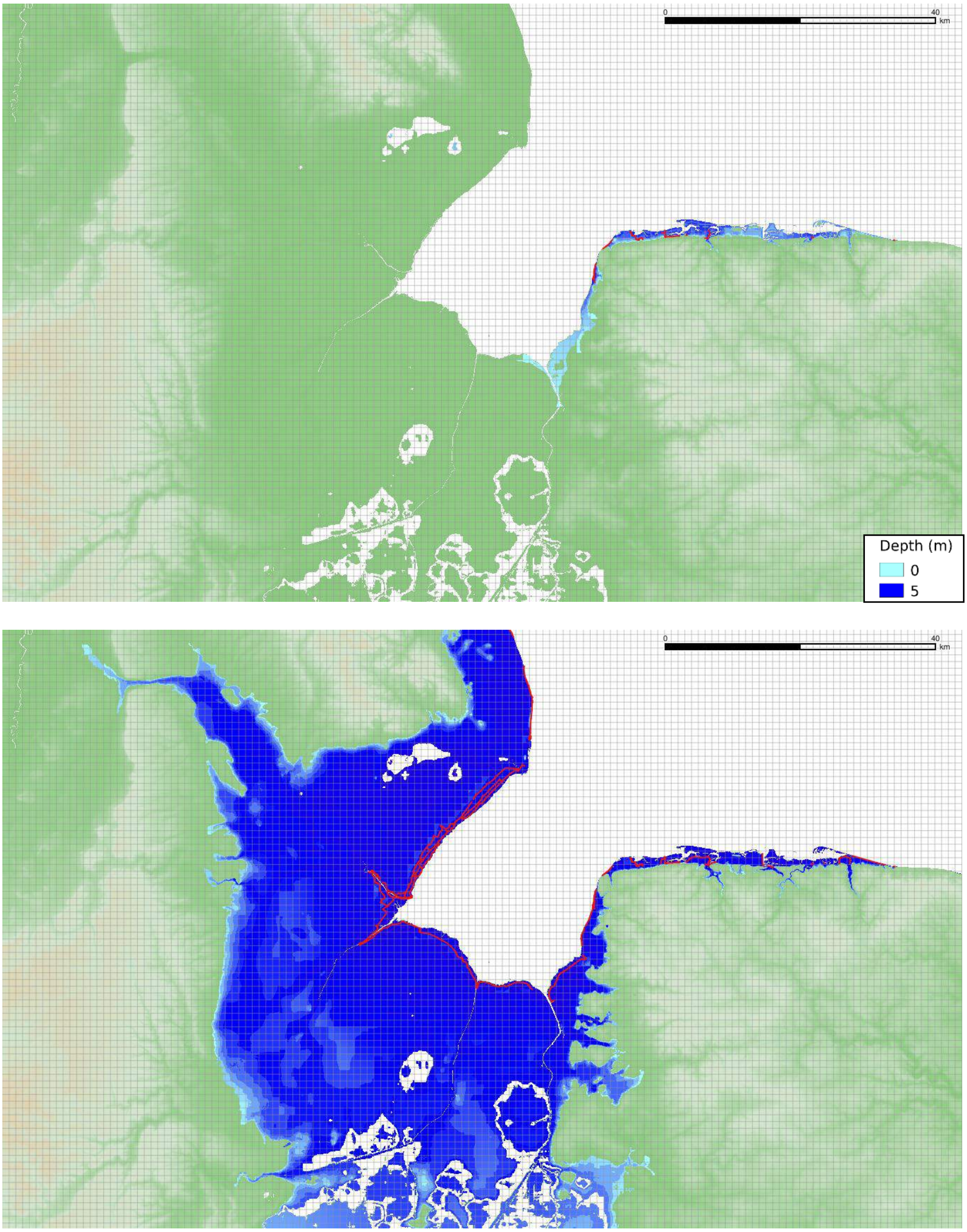
Figure 7-5 Severn Estuary: Temporary inundation extent under a 1:200 year return period tidal surge



Defences at risk are shown in red. The 1km grid used by the model is also shown.

Top: Present day sea levels. Bottom: 5m of sea level rise

Figure 7-6 North Kent coast: Temporary inundation extent under a 1:200 year return period tidal surge



Defences at risk are shown in red. The 1km grid used by the model is also shown. The inland areas visible in white in the south of the maps are areas currently below sea level, which are assumed to be adequately defended now and under future sea level rises.

Top: Present day sea levels. Bottom: 5m of sea level rise

Figure 7-7 The Wash: Temporary inundation extent under a 1:200 year return period tidal surge

7.3 Impact on number of properties affected

The number of properties currently located in areas that could potentially be affected as sea level rises is shown in Table 7-2 and Figure 7-8. The number of properties and area affected rise approximately linearly with sea level; there are no obvious tipping points where number of properties affected starts to rise more rapidly.

There is a significant length of defences at risk currently: for current sea levels, 110km (10% of the total length of coastal defences in England) have a toe level low enough to be considered vulnerable. This finding is robust to the assumed calibration of critical toe depth (h_c). An alternative value of h_c would still generate significant numbers of properties affected by the 1:200 year return period flood because of the approximately linear relationship between impact and sea level rise.

In Appendix E (Table E1) the number of residential properties in defended coastal areas is given as 740 000 (for England and Wales). If all coastal defences became ineffective due to sea level rise, it is reasonable to expect the coastal floodplain to expand and additional properties would be placed at risk. The numbers of properties affected a 4m or 5m increase in mean sea levels (where nearly all defences become vulnerable) are significantly more than 740 000, in line with expectations.

Table 7-2 Number of properties and area potentially affected assuming the absence of vulnerable defences and 'what-if' values of sea level rise

Sea level rise (m)	Length of defences at risk (km)	Percentage of coastal defences at risk	Residential properties	Non-residential properties	Area (km^2)
0	110	10	86 000	36 000	580
0.5	190	18	220 000	92 000	1 700
1.0	220	21	290 000	120 000	2 100
1.5	280	27	390 000	150 000	2 700
2.0	340	32	510 000	210 000	4 100
3.0	550	52	800 000	320 000	6 400
4.0	750	71	1 000 000	390 000	7 600
5.0	920	88	1 200 000	460 000	8 700

Note: The Table above simply provides 'what if' values – no suggestion is made regarding the likelihood of the values provided for SLR, or the timescales by when they could potentially occur. The IPCC note that paleo records from the last interglacial period suggest that sea level has reached more than 5m above today's levels when temperatures have been up to 2°C warmer than pre-industrial levels, but this occurred with quite different orbital forcing and with high latitude surface temperature, averaged over several thousand years, at least 2°C warmer than present.

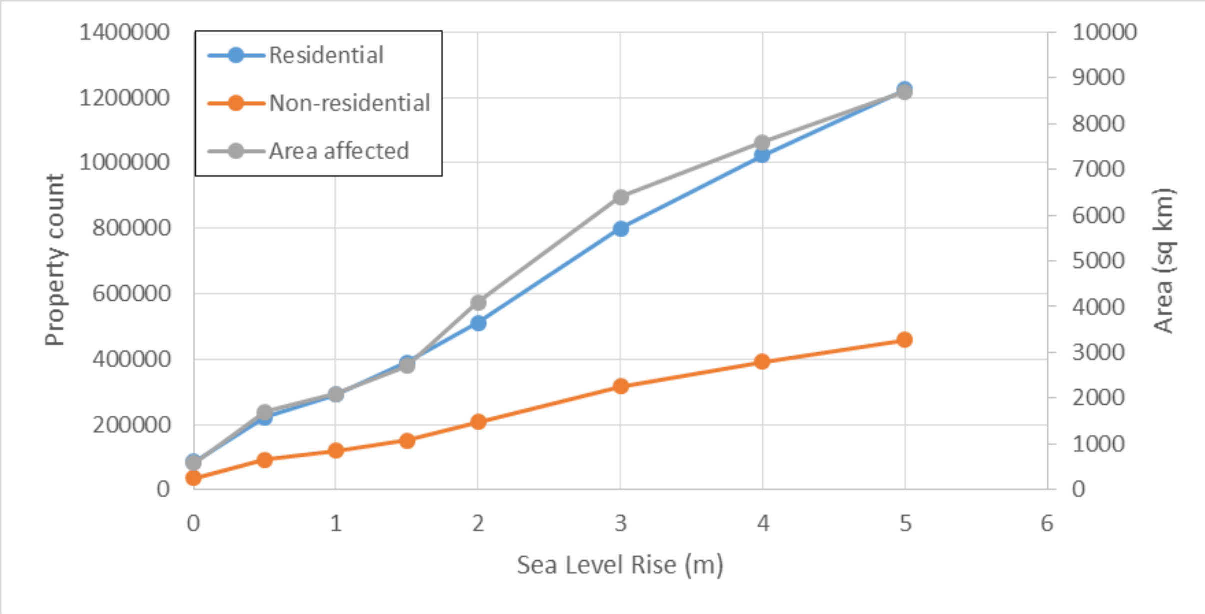
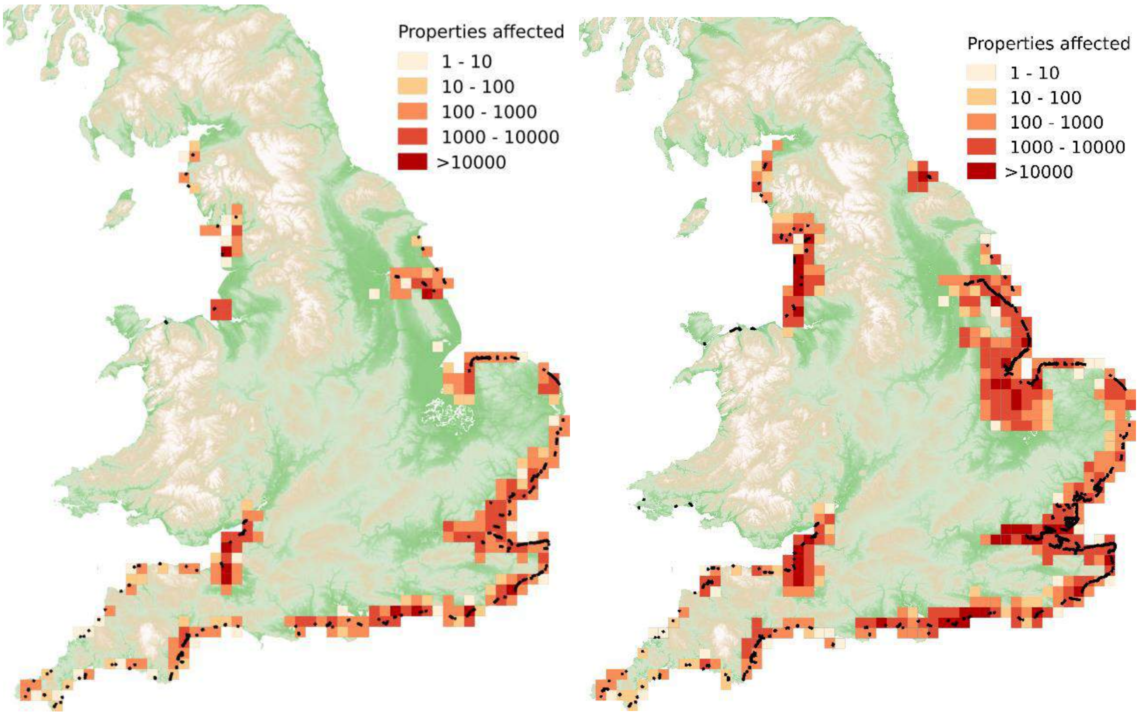


Figure 7-8 Number of properties and area potentially affected by coastal flooding assuming the absence of vulnerable defences and 'what-if' values of sea level rise

Figure 7-9 shows the spatial distribution of the number of properties potentially affected, in the form of counts of properties affected in 10 km squares. For sea level rise of 1m, the most significant impacts are in the Thames and Severn estuaries and the South Coast. For higher sea level rises, the impacts are more widely spread, with Lincolnshire and the North- West also being at risk.



Note: 10 x10 km squares (left) for 1m sea level rise (right) 4m sea level rise

Figure 7-9 Number of properties (residential and non-residential) potentially affected by a future 1:200 year coastal surge

Table 7-3 shows "hotspots" of risk from vulnerable defences: these are the top ten 10x10 km squares by property count (in areas affected by the 1:200 year return period surge after removal of defences vulnerable to sea level rise). For a 1m rise, the most vulnerable areas are Somerset and the

South Coast, but the most vulnerable locations are Cleethorpes and Fleetwood. For a 4m rise the focus shifts to the North West (Fleetwood, Southport and Blackpool) and London.

Table 7-3 Top 10 locations by number of properties affected by a future 1:200 year coastal surge

	1m Sea Level Rise			**4m Sea Level Rise**	
	Location	**Properties affected**		**Location**	**Properties affected**
1	Cleethorpes	27,000		Barking	86,000
2	Fleetwood	24,000		Fleetwood	46,000
3	Weston-super-Mare	22,000		Greenwich	43,000
4	Eastbourne	19,000		Kensington and Chelsea	40,000
5	Burnham on Sea	14,000		Southport	33,000
6	Bognor Regis	13,000		Cleethorpes	33,000
7	Worthing	13,000		Blackpool	31,000
8	Bridgwater	11,000		Weston-super-Mare	28,000
9	New Romney	10,000		Littlehampton	26,000
10	Portishead	9,600		Lea Valley	26,000

8.0 DISCUSSION OF RESULTS

8.1 Confidence in the results

In common with any analysis of future risks the results are subject to uncertainty. Chapter 5 provides a discussion of the range of uncertainties and the approach taken here to explore, and where possible quantify, their importance. Significant effort has been directed towards confirming that the approach taken is fit for purpose (as reported in Appendix G). Given the inherent uncertainties in estimating both present day and future risk however higher confidence should be placed in the relative changes in risk and lesser confidence in absolute estimates of future risk.

8.2 Fluvial, coastal and surface water flood risk: Baseline scenario

8.2.1 Headline results

Assuming current levels of adaptation continue (the baseline adaptation scenario), climate change has the potential to increase risk significantly by the 2050s (Table 6-2). The number of properties exposed to frequent flooding (more often than 1:75 years on average) increases by approximately 20% under the 2^{o}C climate change projection, by 50% under 4^{o}C and by 90% under the H++ scenario (assuming no population growth). Expected Annual Damages (EAD) also increase: 25% for 2^{o}C, 70% for 4^{o}C, and more than 200% under the H++ scenario.

In the longer term, by the 2080s, the 2°C climate change projection (in the absence of population growth) leads to significant increases in risk. This includes a 40% increase in the number of residential properties exposed to flooding more frequently than 1:75 years (on average) and 49% increase in EAD (from all sources of flooding). The 4°C climate change projection drives a 93% increase in residential properties at risk of flooding more frequently than 1:75 years (on average) and 150% increase in EAD. The projected change under the H++ scenario is even more significant, with 120% increase in residential properties at risk of flooding more frequently than 1:75 years and 470% increase in EAD.

8.2.2 Changes in risk by country

The countries making up the UK respond broadly similarly to climate change, when current levels of adaptation are continued (Table 8-1). Beyond this headline the table shows that England generates around 80% of the UK future flood risk for all the climate scenarios considered here (slightly less than pro rata by population, as England represents 85% of the UK population). In Wales the proportional increased risk under the 2°C climate scenario is 56%, this is similar to England (48%) and the UK as a whole (52%). The proportional increase in flood risk in Wales under the 4°C climate scenario is greater than for the UK (210% compared to 150% for UK) whereas the proportional increase for the H++ scenario is less than for the UK.

Increases in Scotland are similar to those for the UK, as are those for Northern Ireland; although Northern Ireland is the most vulnerable to the H++ scenario (showing a 570% increase in EAD by the 2080s). The greater sensitivity to climate change in Northern Ireland may, in part be explained by the nature of the underlying data provided that includes an larger floodplain extent under climate change that is not reflected in the other countries.

Table 8-1 Summary of risk increase in terms of EAD by country, for no population growth and the CLA scenario.

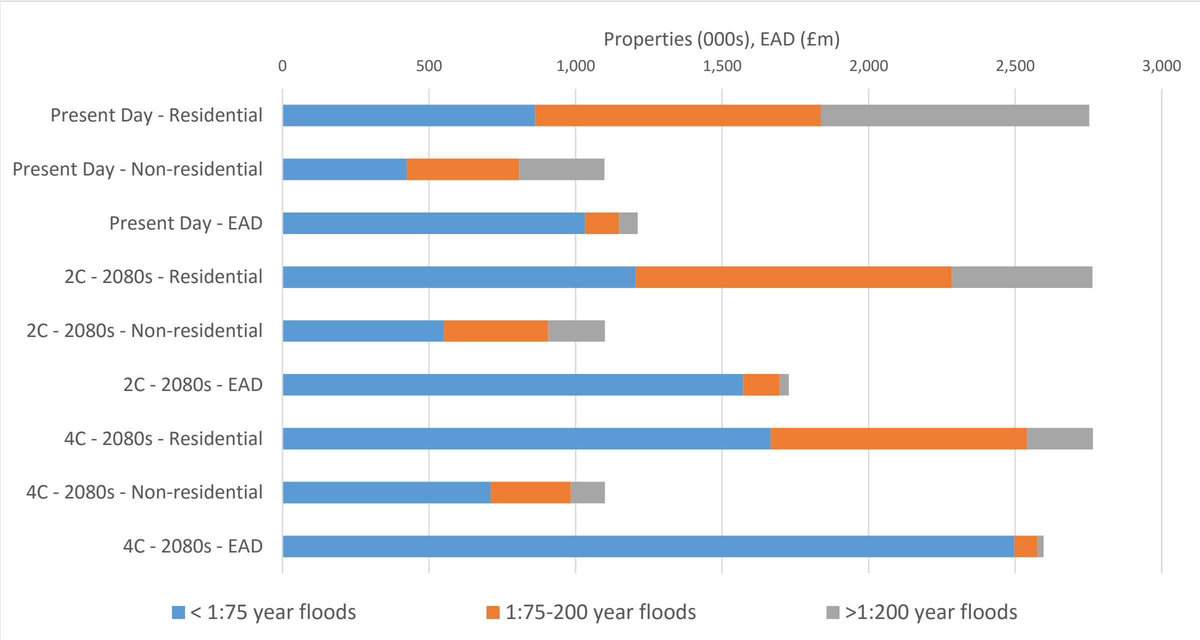
Country	Present Day EAD[1]	Absolute increase by 2080s			Percentage increase by 2080s		
		2°C	4°C	H++ scenario	2°C	4°C	H++ scenario
UK	£1128m	£553m	£1640m	£5160m	49%	145%	457%
England	£860m	£410m	£1,200m	£4,000m	48%	140%	470%
Wales	£81m	£45m	£170m	£260m	56%	210%	320%
Scotland	£160m	£81m	£230m	£750m	51%	140%	470%
Northern Ireland	£27m	£17m	£40m	£150m	63%	150%	570%

1 – To ensure a valid comparison with future estimates of risk, the present day estimates presented are those derived from the Future Flood Explorer. Although the FFE has been verified against nationally available estimates and shown to be fit for purpose (see Appendix G) these values presented above will differ from those estimated by the individual countries (based on different assumptions or more locally resolved analysis).

8.2.3 Changes in the risk profile

Figure 8-1 shows the risk profiles (i.e. the contribution that different return period events make to the overall EAD) for present day and 2080s for 2°C and 4°C climate scenarios (assuming no population growth and the CLA scenario). This disaggregation of the EAD results suggest that, damage incurred from small, frequent events has a more significant influence than less frequently occurring (large) events. Therefore the number of properties exposed to flooding more frequently than 1:75 years (on average) contributes to the majority of EAD. This is an important relationship to consider when interpreting Figure 8-1.

The number of properties in each probability band for the present day is approximately the same. With climate change, those properties exposed to flooding more frequently than 1:75 years (on average) makes a proportionally greater contribution; for example, under the 4°C climate scenario the EAD by the 2080s is almost entirely from this band. This has implictions for Adaptation Measures, as to be effective future adaptations will need to focus on properties exposed to a high probability of flooding.



Note: As no population growth is assumed the total number of properties does not change from the present day.

Figure 8-1 CLA Adaptation: Risk profile for present day and 2080s, under 2°C and 4°C climate change projections

8.2.4 Changes in the contribution of different flood sources to risk

Table 8-2 shows the Expected Annual Damages (direct, residential and non-residential) by country and source of flooding. Fluvial flooding is the most significant source of present day risk, contributing half of the total, with coastal and surface water contributing approximately a quarter each. By the 2080s (under 4°C climate and no population growth scenario) the contribution each makes to the UK risk increases by approximately the same proportion (130-140%).

This overall statement however hides some significant variation by country. Contributions for **England** follow those for the UK as a whole (as expected given England contributes most of the risk). In **Wales** however the largest proportional increases are driven by fluvial and coastal sources (around 200% compared to 140% in England) whereas the proportional increase in surface water related risk is much less (130%, similar to England). In **Scotland**, increases are dominated by changes in coastal flood risk, increasingly significantly (by 460%). Confidence in this finding is lower than the coastal changes projected elsewhere, reflecting the need to synthesise various datasets for Scotland based on analogues from England. The proportional increase for surface water is also greater in Scotland than elsewhere (160% compared to 140% in England) whereas the proportional increase in fluvial flood risk is significantly less (54% compared to 130% in England). For Northern Ireland, increases for coastal flooding are less than for the UK (64% compared to 140% for England; the proportionally increases from fluvial and surface water flood sources are however similar to elsewhere in the UK.

Table 8-2 EAD increases for the 4°C climate scenario, no population growth, CLA scenario

Country	EAD - Present Day			EAD Absolute Increase - 2080s			% Increase – 2080s		
	Coastal	Fluvial	Surface Water	Coastal	Fluvial	Surface Water	Coastal	Fluvial	Surface Water
UK	£316m	£564m	£255m	£554m	£735m	£351m	175%	130%	138%
England	£260m	£400m	£200m	£350m	£590m	£270m	135%	148%	135%
Wales	£28m	£40m	£14m	£83m	£63m	£18m	296%	158%	129%
Scotland	£26m	£110m	£30m	£120m	£59m	£48m	462%	54%	160%
Northern Ireland	£2.2m	£14m	£11m	£1.4m	£23m	£15m	64%	164%	136%

8.2.5 Relative importance of climate change and population growth

Table 8-3 shows increases in the number of residential properties at risk of frequent flooding (i.e. more frequent than 1:75 years on average) and the associated EAD for all three population scenarios (no, low and high growth) and two climate change projections (2°C and 4°C). The impact of climate change and population growth appear to be broadly similar given that the combined 2°C/High population growth future yielding a similar increase in risk as the 4°C/Low population growth future.

EAD values show less sensitivity to population growth with broadly similar increases in risk under all three population growth scenarios (no, low and high). This is likely to be a result of continued adaptation. Under the baseline scenario (a continuation of current levels of adaptation) the high take-up rates of receptor level protection and surface water management measures (including SUDS) associated with new development limit the impact of new development on EAD values.

Table 8-3 Relative effects of climate change and population growth

Climate scenario and indicator risk metric		CLA 2080s No population growth	CLA 2080s Low population growth	CLA 2080s High population growth
2°C	Residential Properties at risk of flooding more frequently than 1:75 years (on average)	+40%	+73%	+140%
	Expected Annual Damages (EAD) – Residential properties	+50%	+58%	+63%
4°C	Residential Properties at risk of flooding more frequently than 1:75 years (on average)	+93%	+140%	+230%
	Expected Annual Damages (EAD) – Residential properties	+150%	+160%	+160%

8.2.6 Changes in the spatial pattern of flood risk

Table 8-4 summarizes the change in EAD together with the number of residential properties exposed to flooding more frequently than 1:75 years (on average). The largest percentage increases (under all climate scenarios) are projected in the north east of England, the Midlands, north London, Greater Manchester, Merseyside and Cheshire as well as east-central Scotland. The impact on people living in deprived areas (inferred from the property counts) shows a slightly different pattern (Figure 6-7). As well as Greater Manchester, Merseyside and Cheshire, large percentage increases are seen for London, West Thames, Cambridgeshire, Bedfordshire and South Wales.

As might be expected the majority of infrastructure (Category A and B) is located near the major urban centres and hence the largest percentage/absolute increases in risk are seen around Greater Manchester, Merseyside and Cheshire and North London (Figure 6-10). Similarly the impact of climate change on the road and rail networks is greatest around Greater Manchester, Merseyside and Cheshire and North London than for the rest of the UK, although West Thames also sees large increases (Figure 6-11).

The largest increases in the risks to natural capital (SPA, SAC and Ramsar sites) appear in the, the Humber, Trent, and the Neagh Bann region of Northern Ireland (Figure 6-8). In part this reflects the simple definition of natural capital used here (the area of SPA, SAC or Ramsar site inundated) and hence not all this increase will translate into an adverse impact.

Impacts on the Best and Most Versatile (BMV) agricultural land are evenly spread across the UK with little spatial variation in sensitivity to climate change (Figure 6-9).

8.2.7 Changing risk in particular sectors

In recent years energy providers have taken significant steps towards the protection of power transmission and distribution sites. This process of adaptation is expected to continue and by the 2020s is projected to reduce the number of energy assets exposed to frequent flooding (more frequent than 1:75 years, on average) (Table 6-1). Similar figures are projected for water infrastructure; however the evidence for adaptation is much more limited (see Appendix G) and hence there is a lower confidence in the projected reduction being achieved.

More schools, care homes, emergency services (police, ambulance and fire), hospitals and transport assets (e.g. lengths of road and rail) are expected to become increasing exposed to frequent flooding by the 2020s (more frequent than 1:75 years on average).

8.3 Fluvial, coastal and surface water flood risk: Alternative Adaptation Scenarios

8.3.1 The ability of adaptation to offset future risk

The preceding discussion has focussed on the changes in risk assuming the current level of adaptation continues into the future. This section explores how the alternative Adaptation Scenarios may impact future risk.

The risks projected for each of the five alternative Adaptation Scenarios (under each climate and population scenarios) are shown in Table 6-7 in terms of properties at risk and Table 6-8 in terms of EAD. Table 8-4 provides a summary of the benefits of each Adaptation Scenario is given for the 4°C climate scenario in the 2080s. The present day risks, the increased risk produced by climate and population change, and the benefit of each adaptation scenario are all shown.

In terms of properties at risk, the different Adaptation Scenarios generate significant differences for both low and high population growths. Compared to the baseline Current Level of Adaptation (CLA), Enhanced Whole System (EWS) represents a significant reduction in properties at higher risk of flooding, e.g. for low population growth, a 140% increase by 2080s is limited to a 91% increase. The Probability Focused Adaptation (PFA) scenario also does well in limiting growth in numbers of properties at risk, as might be expected as the adaptation measures making up PFA tackle the probability of flooding directly. Maintaining and strengthening the implementation of appropriate planning policies is a significant activity under the majority of Adaptation Scenarios. The Exposure Focused Adaptation (EFA), which is successful in limiting the number of new properties on the floodplain has a weaker influence on EAD when compared to other Adaptation Scenarios. This reflects the dominance of existing properties within the national risk calculation and the relative small contribution made to this by new-build properties. It also highlights the need to strengthen an 'all source' planning approach that avoids replacing the risk arising from one source of flooding with another and the need to promote retrofit receptor level protection measures. Vulnerability Focused Adaptation (VFA) has no effect on the numbers of properties at risk, as expected, as property level protection measures do not actually remove properties from risk, but affect the damage when they are flooded. The population growth scenario has a large effect on the number of residential properties at risk, but there is also a small effect on the number of non-residential properties at risk greater than 1:75 years. This is likely to be due to the increased urban runoff from residential property development, and hence increased surface water risk for non-residential properties.

In terms of EAD, Table 6-8 shows that the EWS scenario gives significantly larger reductions in risk than the baseline CLA scenario, for all climate and population scenarios, showing that greater adaptation effort results in risk increases lower than would otherwise occur. Figures 6-16 to 6-18 show the benefits of the different adaptation scenarios along with a breakdown of the total risk by source (excluding groundwater); these figures are also presented in Table 8-4 for the 4°C climate scenario. For the low population growth scenario, a 2°C climate change makes a higher contribution to increases in EAD (£210m) than population (£95m), with the coastal and fluvial sources making similar contributions to the final risk. The EWS, PFA and VFA adaptation scenarios all produce significant reductions in risk (£180m - £330m), with the other scenarios making smaller reductions. For the 2°C climate and high population growth scenario, population produces a bigger increase than climate; again fluvial and coastal make the largest contributions to future risk. For the 4°C climate scenario, climate produces a bigger increase than either the low or high population growths.

Table 8-4 Adaptation benefits

Population growth	Property type	Present day EAD	Climate change projection (2080s 4°C)	Population growth projection	Total increase in risk	Changes in risk arising from adaptation					
						CLA Current level of adaptation	**EWS** Enhanced Whole System	**RWS** Reduced Whole System	**PFA** Probability Focussed Adaptation	**EFA** Exposure Focused Adaptation	**VFA** Vulnerability Focussed Adaptation
Low	Res.	£340m	£+610m	£+160m	£+770m	£-170m 22%	£-550m 71%	£+20m 0%	£-440m 57%	£+130m 0%	£-340m 44%
	Non-res.	£800m	£+1,300m	£-85m	£+1,200m	£-120m 10%	£-750m 62%	£+60m 0%	£-630m 52%	£-120m 10%	£-300m 25%
High	Res.	£340m	£+530m	£+430m	£960m	£-390m 41%	£-720m 75%	£-80m 8%	£-680m 71%	£-240m 25%	£-630m 66%
	Non-res.	£800m	£+1,700m	£+16m	£1,700m	£-620m 36%	£-1,250m 73%	£-440m 26%	£-1,100m 65%	£-620m 36%	£-800m 47%

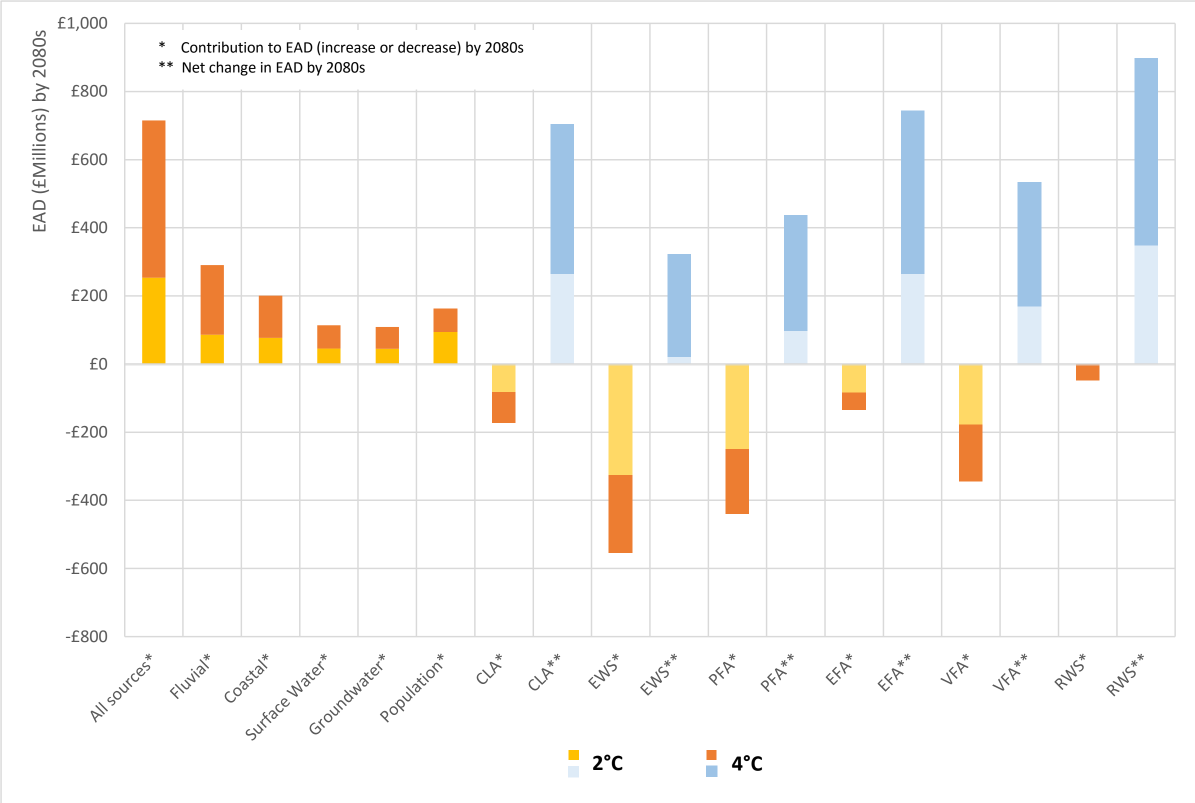
Note: The percentage of the total increase in risk offset by adaptation (for adaptation scenarios that lead to increases in risk, 0% is shown).

Table 8-4 shows that by focusing adaptation efforts on reducing the probability of flooding (i.e. the Probability Focused Adaptation – PFA -scenario) achieves a greater reduction in EAD than either focussing solely on planning measures (Exposure Focused Adaptation – EFA) or focussing on reducing the damage incurred when flooded through receptor level protection and forecasting and warning measures (Vulnerability Focused Adaptation – VFA). The EFA scenario is the most limited in reducing risk (but doing better in terms of properties at risk than EAD), perhaps surprisingly given the general assumption that planning is one of the most effective tools in managing risk. The flood risk management options affecting the probability of flooding and damage to properties (PFA and VFA) are better at reducing risk, because these influence both new and existing properties (albeit with different uptakes), whereas planning controls affect new properties only.

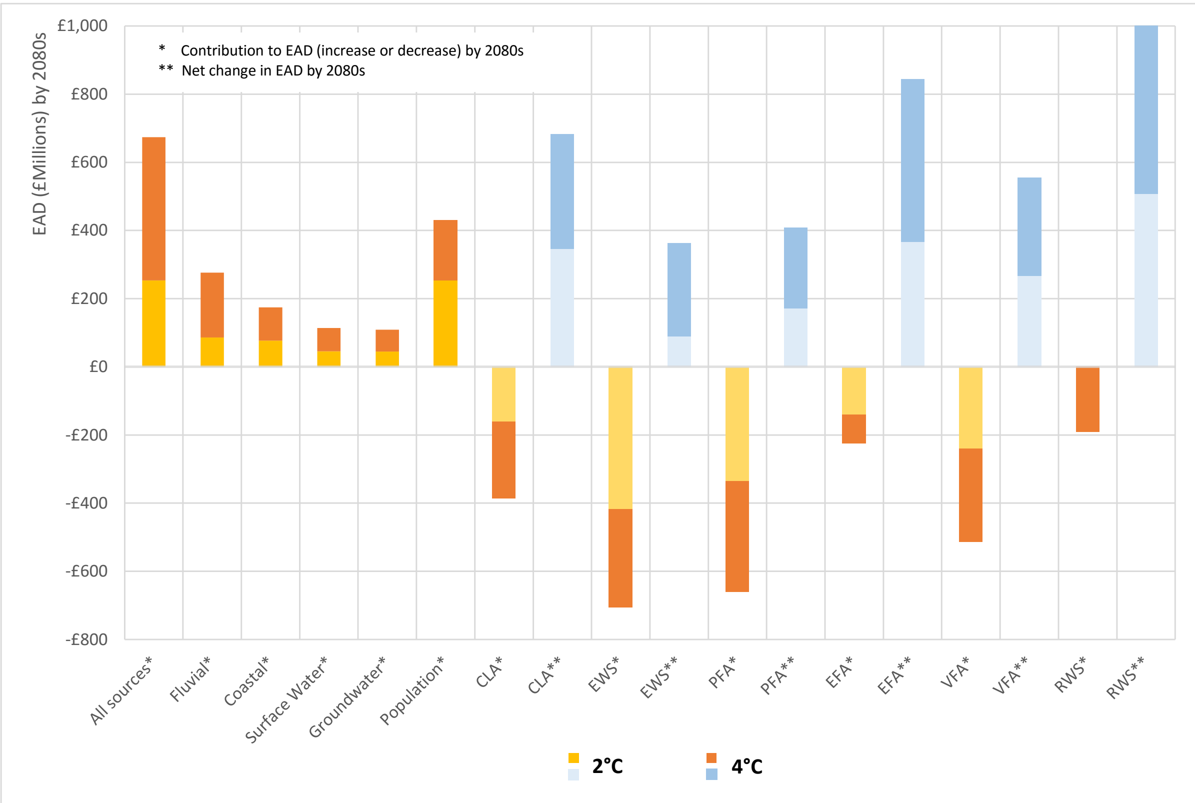
Figure 8-2 summarises these changes, and highlights (i) the increase in risk from all sources of flooding by the 2080s attributable to climate change (2°C and 4°C); (ii) the contribution that each source of flooding makes to the increase under each climate projection; (iii) the additional contribution to risk that population makes under each climate projection; (iv) the risk that is offset by alternation Adaptation Scenarios, and (v) the net change in the future EAD taking account of all of these influences.

Note:

No consideration is given here to the cost benefit of adaptation measures, so no judgement on cost effectiveness is made here.



Top: Low population growth



Bottom: High population growth

Figure 8-2 The influence of climate change and adaptation on future risk (2080s, residential properties)

8.3.2 Evidence in support of a portfolio approach to managing future risk

Under the EFA scenario the number of residential properties at risk of flooding more frequently than 1:75 years (on average) increases by 79% by the 2050s compared to 86% under CLA scenario (assuming 4°C and low population growth) (see Table 6-7). The associated EAD however increases under the EFA scenario when compared to the CLA scenario. This could be explained by the EFA scenario focusing on stricter planning controls within the fluvial and coastal floodplain, but without comparable approaches across all sources of flooding. As a result, development takes place in areas at risk of surface water and/or groundwater flooding under less control, which in turn increases EAD from these sources. This suggests that focusing on a single response, without associated adaptation elsewhere, is unlikely to be effective in managing risk. This finding supports conclusions from previous studies (e.g. Evans *et al*, 2004) that a portfolio approach to managing flood risk is needed.

8.3.3 Other findings of interest

Under the CLA scenario, 4°C climate change and high population growth, EAD is slightly lower than for the low population scenario. This can be seen in see Table 6-8: for low population growth, the total increase from climate and population is £770m, which is reduced by £170m from CLA, to give a final EAD of £600m. For high population growth, the increase from climate and population is £960m, which is reduced by £570m from CLA, giving a final EAD of £570m. It would be expected that the high population growth scenario would result in a higher EAD than low population growth after adaptation is taken into account. This result may be due to complexities in the interactions between the measures making up the adaptation scenarios and population growth. For example, high population growth combined with a high uptake of SUDS in an already urbanised setting may lead to a reduction in urban runoff that in turn reduces EAD.

The Reduced Whole System (RWS) adaptation scenario achieves no reduction in risk under the 2°C climate projection by 2080s. Under the 4°C scenario the portfolio approach represented by the RWS is however able to offset more risk than the EFA scenario.

8.4 Groundwater flood risk: All adaptation scenarios

Present day estimates of the number of properties at risk, and at significant risk, of groundwater flooding are generally lower than for fluvial flooding, the exception being non-residential properties at risk. EAD estimates are very roughly half those of fluvial flood risk. The biggest contribution to groundwater risk is from PSD on the floodplain, which is bigger than the off floodplain PSD and Clearwater combined. Clearwater flooding makes a significant contribution to risk for England only; the Clearwater contribution for Wales is <2% of the total groundwater risk in terms of EAD; Clearwater flooding is not modelled for Northern Ireland and Scotland because generally there is a low potential for Clearwater flooding (although there remains the possibility of raised likelihood in local circumstances).

The dominance of on-floodplain PSD is reflected in the response of groundwater risk to climate change. On-floodplain PSD risk will tend to follow the changes in fluvial risk, resulting in large increase in risk by the 2080s (+50% for 2°C, an eightfold increase under the H++ scenario). Some small reductions in numbers of properties at risk are seen for 2020s and 2050s for 2°C; these reflect small decreases in fluvial risk for some catchments in the UK under some climate scenarios (e.g. the Thames which includes large areas of PSD).

Future changes for each UK nation broadly follow the UK pattern. Wales and Northern Ireland see larger changes assuming the 4°C projection and H++ scenario than England and Scotland. The spatial pattern of EAD increases is perhaps counter intuitive: bigger relative increases are seen for the North West of England, Scotland, South Wales and parts of Northern Ireland, which are not traditionally regarded as groundwater risk areas. These areas are starting from a low level of risk, so despite the large relative increases, these areas remain a small contribution to UK groundwater risk in future epochs. The Thames Valley, while representing the most at risk location currently, sees smaller changes than other areas, but remains the area with the most risk in future epochs.

As noted before, risk is dominated by on-floodplain PSD, with off-floodplain PSD making the second largest contribution. These sources both respond to fluvial drivers, and thus are subject to large changes for future epochs. The climate signal for Clearwater flooding is less straightforward. Several projections suggest a short term reduction in recharge, with substantial increases in recharge in 50 to 75 years. In the Thames catchment, representative of an area of England where significant groundwater flooding has occurred in the past, the probability of future increases in long term recharge is lower. The result is that there are no simple trends (i.e. increasing both with epoch and with future temperature) in risk from Clearwater flooding. For example, by the 2080s, the 4°C scenario represents the lowest risk (actually a slight decrease), because increased rainfall is balanced by increased evapotranspiration, resulting in recharge similar to present day values. The 2°C scenario represents a worst case for Clearwater flooding.

8.5 All sources: The influence of insurance and experience

The increased incidents of flooding suggested by the analysis presented here could trigger a behavioural response in those exposed to more frequent flooding and modify the insurance regime designed to compensate them for their losses. Neither of these factors, which could be significant, are covered in the estimates of risk presented in this report.

The results reported here suggest the large number of people already exposed to flooding more frequently than 1:75 years (1.8 million people today) could increase by between 40% and 130% by the 2080s (2°C and H++ respectively). Many properties will be covered by subsidized flood insurance for the next 25 years under the Flood Re scheme (Defra, 2013) after which full actuarial pricing will be used. It is not known, at this stage, how this transition will take place[1]. An increased cost of insurance – substantial for those at greatest risk - will however send a strong signal to those at risk, and it would be surprising if this not did change attitudes towards flooding and hence behaviour. It is likely to encourage greater levels of (and demand for) intervention in the form of flood defence works, larger and more reliable community contributions towards the funding of FRM activities, and greater numbers of individuals investing more of their own resources in property level protection measures.

The numbers of people living in deprived areas who suffer increased exposure to flooding rises slightly more by the 2080s than the general average. There is significant uncertainty as to whether more households in deprived communities will be able to afford any level of property protection and affordability is likely to be a major constraint on take up of insurance cover.

The influence of any change in risk on flood risk management actions will also reflect what is considered tolerable. With regard to individual behaviour the research evidence suggests that those who suffer flooding are more likely to take risk-reducing actions, including self-help measures and applying political pressure for increased investment. With the added incentive of reducing insurance costs by taking action to reduce their risk (which is not the case currently as premiums are now poorly risk related), it is likely that individuals and organizations will increasingly act to reduce their risk (particularly in the aftermath of a flood). It is impossible at this stage to quantify the extent of this reduction, but it is likely to be significant.

Evidence for this feedback already exists. During the past 15 years, for example, the investment on flood risk management measures has increased, despite severe cutbacks in government expenditure

[1] A transition plan for the Flood-Re scheme is due to be published in the Autumn of 2015

elsewhere. This has been coupled with increased pressure on flood risk management authorities to increase their performance levels, a significant change in the insurance industry towards Flood-Re, and far greater public pressure on governments, insurers and spatial planners to reduce existing levels of flood risk. These trends are likely to be reinforced with increased future risk but the full extent of this feedback cannot yet be established.

9.0 RECOMMENDATIONS

The analysis presented here provides a significant advance on previous studies and the Future Flood Explorer has been shown to be a useful and powerful tool to explore future changes in risk at a national scale. The recommendations to improve future application, arising from the lessons learnt during this study, include:

- **Establish a more consistent approach to reporting of official estimates of present day risks:** Comparison with the official figures highlights the difficulty in assembling consistent data sets across the UK, and comparing a UK consistent approach with figures from constituent countries, which are based on different hazard and risk assessment methods. Further engagement with authorities could help to develop a consistent UK wide approach, which uses best practice from different countries.
- **A medium term focus is also needed:** The CCRA has primarily focused on the 2050-2080s; FFE results indicate that significant change may occur in the shorter term. Understanding this short term risk change requires a better understanding of current baseline risk, and how it is defined (e.g. consistent reference epochs across sources).
- **Improved representation of response of the flood system to climate change:** In particular, both coastal and fluvial response to climate change is based on approaches developed some years ago (using Flood Studies Report regional growth curves for fluvial, NAAR changes for coastal) that require translation to Scotland and Northern Ireland by analogy. Although considered fit for purpose there is an opportunity to improve this element of the analysis for future studies.
- **Improve the representation of impacts on natural capital and the representation of green infrastructure responses:** The evidence for green infrastructure (catchment based approaches and natural flood management) is growing but both the influence on flood risk and the impacts of climate change on the environment remain difficult to capture.
- **Improve the linkage between adaptation and investment planning:** Across the UK decisions to adapt are typically based upon a consideration of costs and benefits. Incorporating a consideration of both costs and benefits into the FFE would link the adaptation scenarios more closely with the process of decision making within each country. This would add some additional complexity and care would to be needed to maintain a high level and comprehensive analysis.
- **Looking at FFE outputs at national and regional scales may obscure important behaviours:** **L**ooking at a smaller scale (e.g. individual cities or catchments) could help in understanding the impact of different adaptation strategies. A number of test cities, catchments or coastal zones could be looked at in detail. The narrative of responses at this scale could then be used to understand better the responses we see at national scale.
- **Take advantage of recent advances in the underlying datasets to support this more local credibility:** The underlying datasets are continually being improved by each lead authority. Significant recent improvement, such as the Continuous Defence Line for England, would reduce the need for data gap filling and support more locally credible results from the FFE.
- **Assessing risk from surface water maps is subject to significant uncertainty:** There may be improvements in property counting methods from current or future projects that can increase confidence in this aspect of risk.
- **Continued focus on validation and verification:** Significant effort has been directed here to validate the input datasets and verity the FFE as a good emulator. The issue of the verification and validation of national risk estimates remains a significant challenge and should form part of future studies.

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APPENDIX A. Supporting datasets

See separate file.

APPENDIX B. Population growth projections

See separate file.

APPENDIX C. Climate change projections

See separate file.

APPENDIX D. Groundwater analysis approach

See separate file.

APPENDIX E. Individual adaptation measures: The evidence base

See separate file.

APPENDIX F. The Future Flood Explorer: Overview of approach

See separate file.

APPENDIX G. Exploring the validity of present day risk estimates and verifying the Future Flood Explorer

See separate file.

APPENDIX H. Additional supporting tables and figures

See separate file.

APPENDIX I. Independent Review Comments and Responses

See separate file.