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Ipsos

Prioritising climate risks for spatial assessment

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This report describes work commissioned by the Climate Change Committee (CCC). The Client's representative for the contract was Caitlin Douglas of the CCC.

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Abbreviations

CCC	Climate Change Committee
CID	Climate Impact Driver
DA	Devolved Administration
LA	Local Authority
EA	Environment Agency
FRAW	Flood Risk Assessment Wales
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
NCERM	National Coastal Erosion Risk Mapping
NRD	National Receptor Database
NRW	Natural Resources Wales
SMP	Shoreline Management Plan
SEPA	Scottish Environmental Protection Agency
UK CCRA3	UK Climate Change Risk Assessment 3
UK CCRA4	UK Climate Change Risk Assessment 4

Executive summary

This project was commissioned to advise on where spatial climate change risk assessment would be most productive in understanding UK risk and adaptation effectiveness. The project intends to inform the design of subsequent spatial research activities in the run-up to the Fourth UK Climate Change Risk Assessment (CCRA4) and sought to identify through case and pilot studies where spatial analysis would be most useful as well as the likely challenges associated with national-scale spatial risk assessments in the context of CCRA4.

This report covers the methodology, findings, outputs, lessons, wider recommendations and conclusions of the project. It covers in detail the design, evolution, purpose and outcomes of the spatial framework developed to prioritise the 52 risks identified in the Third UK Climate Change Risk Assessment (CCRA3) best suited to further spatial assessment. It highlights the implications of the framework results, which were used to identify the risks which the Climate Change Committee (CCC) should prioritise. It also covers the pilot and case studies which resulted from the assessment process. This report finishes by touching on the results of each pilot and case study, before providing concluding remarks and recommendations on the future direction of spatial climate change risk assessment.

The purpose of this project was to assess the risks for which spatial climate change risk assessment could be most productive in developing understanding of UK risk and adaptation effectiveness. The project assessed the 52 domestic risks and opportunities in CCRA3 and identified those that should be included in CCRA4 at a higher level of spatial granularity.

The 52 risks and opportunities were assessed via a spatial analysis framework, developed by the project team. The objective of the framework was to identify the priority risks and areas for spatial assessment. To achieve this the framework assessed risks at multiple spatial resolutions, identified high-scoring risks through added expert judgement and shortlisted candidate pilot and case studies (two of each).The framework disaggregated each risk into its component climate hazards and assets, before assessing each combination of asset and hazard to uncover whether it had been mapped - and if so, at what spatial scale - within CCRA3. The framework then applied a priority scoring based on the existence of mapping for hazards and assets individually, and in combination, before allowing for the addition of expert judgement on the extent to which mapping would improve adaptation across the UK, to provide an overall score for each risk. All aspects of the assessment were weighted equally. The highest scoring risks were then discussed and prioritised via an external workshop with the project team and the CCC. Following this workshop, two risks were selected to be case studies (I3 and H12), and two risks were selected to be pilot studies (N11 and H4). The objective of the case studies was to identify lessons learned for other climate risks and CCRA4 and make recommendations for future

work. The objective of the pilot studies was to explore a novel approach to spatial risk and adaptation assessment to inform future spatial commissions.

Case studies reviewed risks where some spatial climate change risk assessment is already evident and where some mapping has already been undertaken at multiple spatial scales. In contrast, pilot studies looked at risks where spatial climate change risk assessment is in its early stages and discussed how mapping might be developed over future commissions to inform CCRA4. Pilot studies reviewed and evaluated existing approaches to spatial assessment of risks, highlighting advantages and disadvantages, whilst also identifying additional components that could enhance a spatial assessment of risks (i.e. vulnerability, exposure), before moving onto provide recommendations on how risks could be spatially assessed in future. Case studies on the other hand, identified spatial mapping of risks, adaptation measures relevant to the risks and considered any costs associated with adaptation/not adapting and how these were derived. Case studies also reviewed the stated adaptation shortfall pertinent to risks and identified actions required to address this and achieve enhanced adaptation, as well as the spatial component of these and the costs where possible.

This report concludes by outlining key learning from the development and utilisation of the framework, most notably that there is a high degree of national disparity between Devolved Administrations (DAs) across the UK in terms of the maturity of spatial risk assessment and that the vulnerability of assets and receptors has often been overlooked. It also makes recommendations as to the future direction of spatial climate change risk assessment, outlining a prioritised list of risks in need of more detailed spatial risk assessment, the need for a systems-based approach when assessing risk, the importance of vulnerability in future spatial risk assessment and suggesting that the CCC should facilitate expert led discussions to help sectors understand their baseline resilience.

1 Introduction and scope of work

1.1 Introduction

The Climate Change Committee (CCC) commissioned JBA Consulting and Ipsos UK to research where spatial climate change risk assessment can be most productive for understanding UK risk and adaptation effectiveness to inform the fourth UK Climate Change Risk Assessment (CCRA4).

The intention of the research was to inform the design of subsequent spatial research activities that effectively quantify climate risk (and its variability across the UK) and the effectiveness of adaptation (including economic appraisal).

The JBA and Ipsos project team assessed the CCRA3 risks to understand where more detailed spatial climate risk and adaptation mapping would be appropriate. The assessment also aimed to understand if existing approaches used to map some risks could be used for others.

Risks relating to the International Dimensions (Chapter 7) were not considered in the framework at the client's request.

Throughout this report granularity refers to the level of detail or resolution at which data and analysis are conducted to evaluate and understand potential risks in a given geographic area. Equally, resolution refers to the level of detail or the smallest discernible feature size captured in the data or imagery used to analyse and assess potential risks in a given geographic area.

The CCRA3 chapters containing the associated risks are:

- Chapter 3 - Natural Environment and Assets;
- Chapter 4 - Infrastructure;
- Chapter 5 - Health, Communities and the Built Environment; and,
- Chapter 6 - Business and Industry.

2 Methodology

2.1 Overall approach

The purpose of the framework approach is to advise on which risks should be prioritised for spatial assessment and illustrate where spatial analysis would be most useful, as well as where the likely challenges associated with below national-scale spatial risks assessments would be, with a view to informing and supporting CCRA4 spatial commissions.

The approach to develop a framework to prioritise climate risks for spatial risk assessment was developed iteratively and collaboratively. The detail of the iterations and development of the framework can be found in the Appendix (A.1).

Figure 2-1 illustrates the framework assessment process which was undertaken to identify which risks were most relevant for more detailed spatial risk assessment.

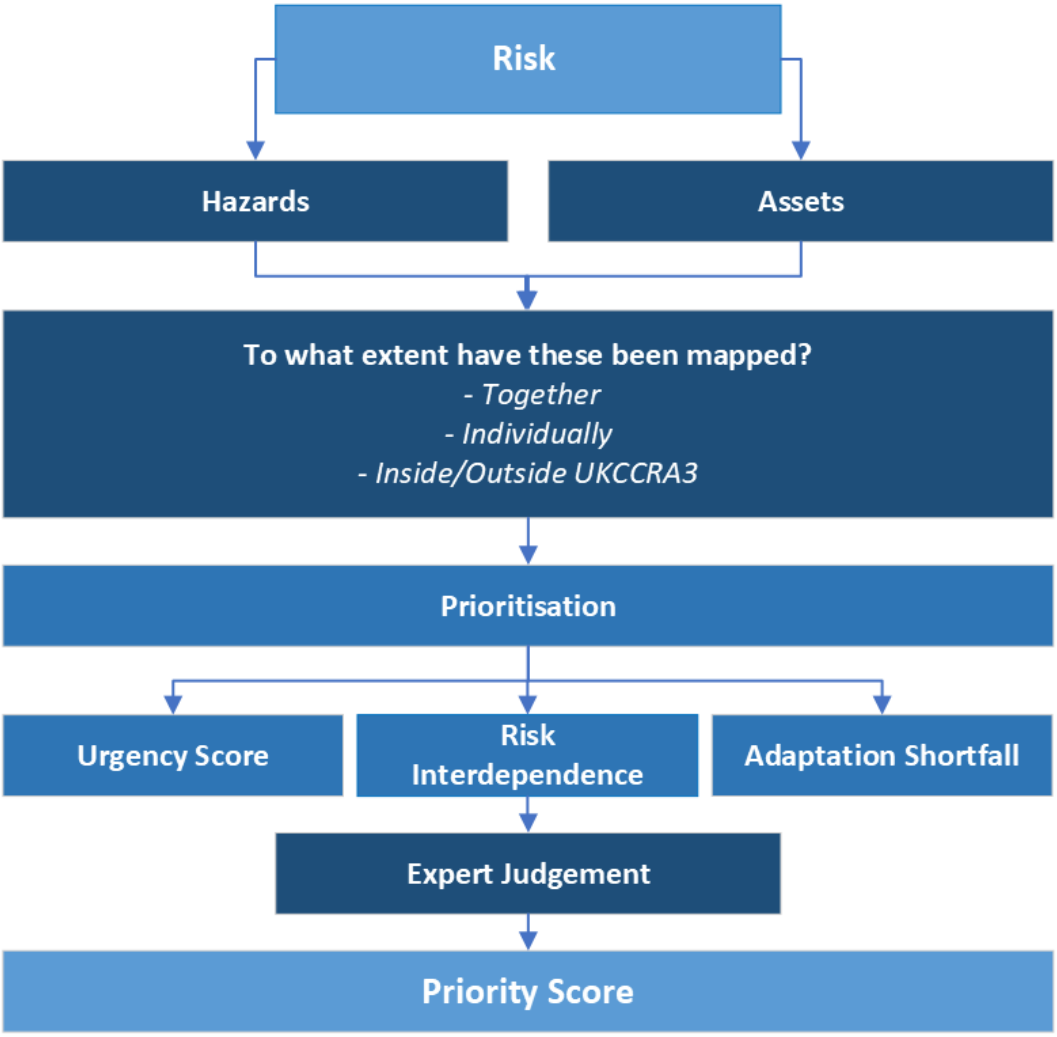

Figure 2-1. Approach to prioritisation

2.1.1 Hazard

A review of the UKCCRA3 chapters was used to create a reference document for all climate hazards associated to all climate risks and their respective assets (as described in Appendix A.3).

The framework was used to breaks down risks into their component hazards (a sub-risk). For example, for risk I3: *Risk to infrastructure services from coastal flooding and erosion* the risk was broken down by hazard (coastal flooding and coastal erosion). Resulting in two risks; risks to infrastructure services from coastal flooding and risks to infrastructure services from coastal erosion.

2.1.2 Assets Assessment

A review of the UKCCRA3 chapters was used to create a reference document for assets associated to all climate risks (as described in Appendix A.3).

To inform future stages of the assessment, an asset assessment was also developed in alignment with the UK CCRA3 chapters (Communities, Infrastructure, Business and Natural Environment). These identified:

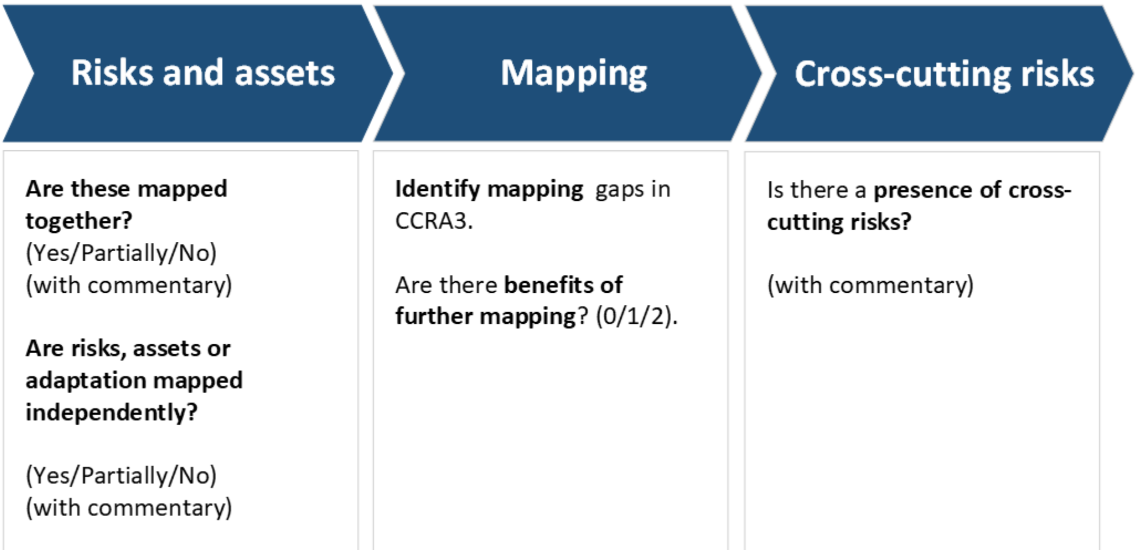

Figure 2-2 - Asset assessment process

In most instances, during this process, mapping activities were identified under the 'Future risk' UKCCRA3 subheading. Whilst gaps in mapping activities were identified from the chapter review, as well as under certain standardised sub headings, including 'knowledge gaps' and 'looking ahead'.

For example, for risk N2 (Risks to terrestrial species and habitats from pests and pathogens, including Invasive Non-Native Species) 'Looking ahead' identifies that 'UK mapping of multiple pest and pathogen observations would support communications on risk across administrations and organisations within the UK'.

2.1.3 Maturity of current mapping

Utilising information from the hazard and asset review, this section of the framework identified whether a risk had been mapped in CCRA3 below the national level, whether the hazard had been mapped at a more granular than national level outside of CCRA3, whether the hazard had been mapped at a more granular than national level in CCRA3, whether the asset had been mapped at a more granular than national level outside of CCRA3 and whether the asset had been mapped at a more granular than national level in CCRA3 (see Figure 2-3 below).

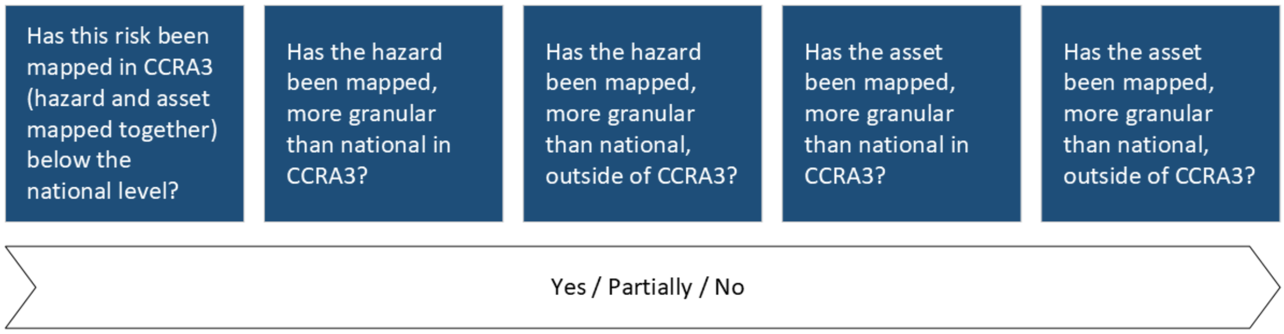

Figure 2-3 - Maturity of current mapping

In this instance partially refers to when a climate risks component assets and hazards have only been mapped in part below the national level in CCRA3. Following this step, if the answer was no or partially, the project team identified whether or not the hazard or asset was mapped at a more granular than national in CCRA3 by using information gathered from an in-depth literature review of each of the CCRA3 chapters.

Each CCRA3 risk was then assigned a data availability score ranging from 1 to 6. This allowed for shortlisted risks to be highlighted later on in the prioritisation assessment. The following matrices designate these values, see Table 2-1 below.

Table 2-1 - Data Availability Matrices

Asset	Hazard		
	Mapped or partially mapped in CCRA3	Only mapped or partially mapped outside of CCRA	Not mapped
Mapped or partially mapped in CCRA3	1	2	4
Only mapped or partially mapped outside of CCRA	2	3	5
Not mapped	4	5	6

2.1.4 Prioritisation

The prioritisation assessment utilised several criteria to fulfil the study aim, justification for these is provided below:

- Urgency Score - In the context of climate change risk assessment urgency is defined as 'the degree to which action is needed to reduce a risk or realise an opportunity from climate change' (Watkiss & Betts, 2021). The project team opted to use CCRA3 urgency scores to reflect the need for action.
- Adaptation Shortfall - Another scored aspect of CCRA3 is adaptation shortfall. Adaptation shortfall identifies if a risk is being adequately managed or if there is a shortfall, caused by barriers or constraints (Watkiss & Betts, 2021). The inclusion of this score was based on the understanding that the presence, or absence, of spatial risk assessment can often be a constraint for adaptation action.
- Interdependent risks and interactions - Within CCRA3, interdependencies, cascading risks and cross-cutting risks are considered and documented for each risk and opportunity. This is supported by analysis conducted by WSP (2020). The presence of interactions for each risk was chosen as criteria for scoring, in recognition of the interconnectedness of individual risks and the role of spatial assessment in clarifying the need for adaptation
- Expert judgement - Two aspects of expert judgement were scored and considered within the prioritisation assessment process:
    - To what extent would this risk benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK?
    - What spatial scale would most benefit the receptor or user (i.e., Local Gov, utility companies, etc.) of the risk to improve their resilience to climate change?

- The above expert judgement scoring is therefore responsive to the use of spatial risk assessment by organisations and to the potential of spatial mapping and risk assessment to provide enhanced climate adaptation in the UK.

The prioritisation assessment, therefore, identifies where spatial assessment at a sub-national level would have the largest impact on improving the understanding of UK risk, adaptation, and resilience. A sub-national level refers to spatial assessment of a risk, asset or hazard at a granularity which is greater - of higher resolution - than the national level (e.g., at a regional, local authority, or LSOA level).

Table 2-2 - Prioritisation Criteria

Criteria	Scoring explanation
Data availability score	The data availability score (from 1-6) is determined by Table 2-1 - Data Availability Matrices. This score does not contribute to the total priority score. This table splits risk and assets and pools them by presence (mapped, partial or not mapped) within CCRA3, outside of CCRA3 or where they are not mapped at all.
Are there associated interdependent risks / interactions	2 =Yes 0=No
Adaptation shortfall (& confidence)	6 = Yes (-2 if low confidence; -1 if medium confidence) 4 = Partially (-2 if low; -1 if medium) 2 = Very Partially (-2 if low; -1 if medium) 0 = No
CCRA urgency score (using the UK wide score)	6 = If more action needed; (-2 if low; -1 if medium) 4 = If further investigation; (-2 if low; -1 if medium) 0 = If sustain action
Expert judgement - To what extent would this risk benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK?	2 = Significantly benefit 1 = Moderately benefit 0 = Neutral / Do not know

Criteria	Scoring explanation
What spatial scale would most benefit the receptor or user (i.e. Local Gov, utility companies, etc.) of the risk to improve their resilience to climate change?	3 = Sub-local (e.g. LSOA, Ward, 2km2) 2 = Local (Local Authority) 1 = Regions (e.g. NE, NW, Yorkshire, Midlands, etc.) 0 = Neutral / do not know

Prioritisation: Expert judgement

Information was drawn from the sector-specific review tabs to inform expert judgement which emerged from the CCRA3 literature. Two expert judgement questions were selected and scored by Ipsos and JBA experts, utilising information from their own specialisms, CCRA3 review and other findings from a parallel commission on user needs.

2.2 Pilot and Case Studies Criteria

Further to understanding the priority risks, the team utilised a simple process to determine the suitability of prioritised risks for pilot and case studies.

The first step was an initial screening assessment to determine whether climate risks had already been mapped in CCRA3 below the national level, to some extent. These risks were then added to the case study long list as potential case studies.

If a climate risk had not been found to be spatially assessed, the risk would then follow the second step of prioritisation for spatial risk assessment based on expert judgement, and urgency and adaptation shortfall scoring from CCRA3.

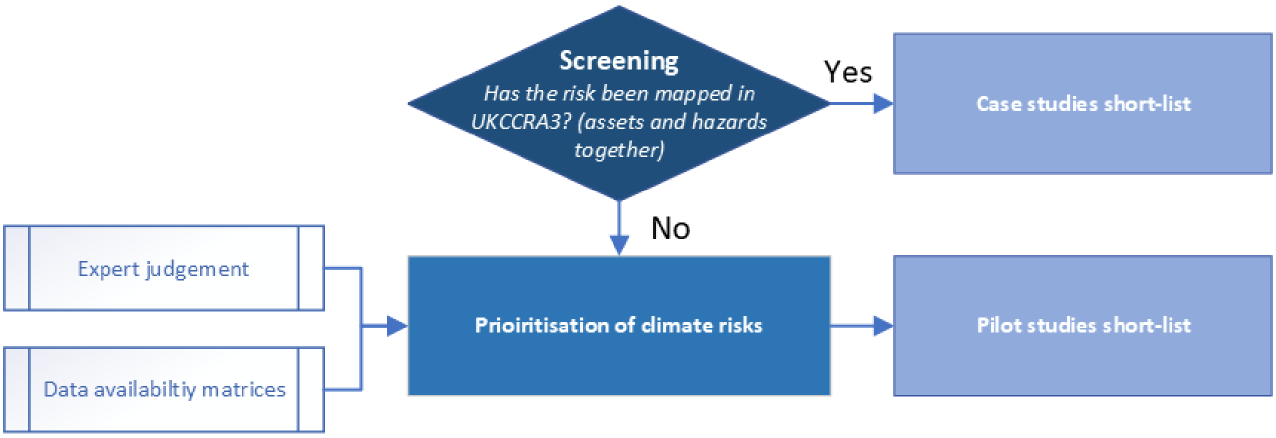

Figure 2-4 - Overall approach to prioritising spatial risk assessment

Risks within the case study longlist were then further appraised for their suitability as case studies. This appraisal was conducted by looking across the potential case study risks to ensure that a range of assets and hazards were being explored and also whether previous approaches used to spatially assess the climate risk and its adaptation could have transferable lessons to other climate risks. These case studies are further detailed in Section 5 below.

A pilot study longlist was also established by identifying all the risks which had been assigned an expert judgement score in relation to their potential benefit of spatial mapping of 'Significant benefit' and had a total score of 13 or more. The potential pilot studies were further appraised by the project team and the CCC through an online workshop. The pilot studies are detailed further in 5 below.

The project team also engaged with internal subject specialists to check and challenge expert judgment scoring and longlist selections, to ensure that a risks inclusion within either the case study or pilot study longlist was justified.

2.3 Wider Framework Limitations

Standardisation was an issue across the earlier iterations of the framework, wherein language and terminology around climate change hazards and assets differed from risk to risk, and chapter to chapter of CCRA3. Through identification of this issue and co-design intervention, we adopted the “climatic impact-driver” (CID) approach adopted in the Working Group I (WGI) contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report as a lens for assessing climate hazards (and drivers) that arise within CCRA3.

CCRA3 itself combines a scientific and methodical process, which involves the completion of literature reviews of all available evidence and the presentation of the findings. Therefore, within the early framework, some terminological differences are reflective of the CCRA3 process making it difficult to analyse spatial assessment inequalities across chapters that entail similar hazards. For example, whilst some chapters refer to 'extreme heat', others make reference to 'heatwaves', 'high temperatures' and 'heat stress'.

This reaffirms the need for demand-driven concepts (such as CID) to assess physical climate conditions that are relevant for impacts on human and natural systems. Another framework issue and limitation is the loss of information, wherein some CCRA3 risks include multiple hazards. To rectify this, the framework needed to disaggregate the risks into their corresponding hazard/asset combinations. To aid this limitation, more information was provided on hazards (and their data) in the following iterations. This was also considered during expert judgement and further discussion.

Another challenge for the framework was integrating the considerations of devolved administrations (DAs). When assessing all 52 risks, factoring in the differences between DAs into the weighting and prioritisation was often unworkable from a scoring perspective. For example, for some risks such as adaptation shortfall scores differed between separate DA. For example, for risk H1 (Risks to health and wellbeing from high temperatures) England and Northern Ireland were deemed to partially meet the criteria of being managed in the future (high confidence), whereas for Scotland and Northern Ireland 'No' (medium confidence was assigned, implying risks would not be managed. For urgency score a UK wide score was give, however, these also differed by DA.

There are also tangible differences between DA's progress in the development of spatial risk (and adaptation) assessment across many risks. For example, coastal erosion, whereby Dynamic Coasts is utilised by Scotland, NCERM by England and Wales and a Northern Ireland spatial assessment is still in development. However, it should be noted that the underlying data required for an assessment of coastal erosion risks is available across all DAs (geological mapping, sea level rise predictions, and LIDAR mapping). To rectify this, extra information in future iterations highlights DA discrepancies (such as in the sector tabs in the final framework).

Finally, an issue for the final framework was defining what 'partial' meant in the context of data availability and UK CCRA3 literature. For example, 'partial' is used where not all asset/hazard combinations are mapped within a risk. Subsequent edits were made to draw out particular instances of this issue. However, in general, the only complete objective mapping of hazards and assets that has been conducted for CCRA3 relates to supporting research projects e.g., future flood projections (Sayers et al., 2020) (wherein all sources of flooding and all physical assets are mapped now and in the future with climate change at LA level) relating to risk H3: The risk of flooding to people, communities and buildings.

Another limitation of this framework is the exclusion of vulnerability and exposure as an aspect of each risk in the prioritisation section (i.e., mapping such as multiple indices of social deprivation). This information would be useful, as this relates in part to the mapping of adaptive capacity and the shared socioeconomic pathways component of future climate risk related research.

Within the case study longlist, five of the risks were considered to be potential contenders for pilot studies as well as case studies as they included partially mapped risks.
These were:

- B4: Risks to finance, investment and insurance including access to capital for business (Mean wind speed, Landslide)
- I3: Risks to infrastructure services from coastal flooding and erosion (Coastal erosion)
- H4: Risks to coastal communities from sea level rise (Coastal erosion)
- H12: Risks to health and social care delivery (various, see A.3.5)
- H13: Risks to education and prison services (various, see A.3.5)

This highlights there are particular risks where detailed spatial assessment work has been completed but there are research gaps for understanding the spatial risk impacts of certain hazards.

2.4 User-needs touchpoints

Throughout the project the project team aimed to interface between the non-government user needs project[1] and the scoping of future work. A key juncture was the inclusion of non-government user concerns following the workshops for this aligned project during the prioritisation workshop, pilot and case study rationale and internal discussion. These included:

- Spatial information on vulnerability in terms of geographic area, socioeconomic groups and demographic groups.
- Geographical data to entail locally or regionally specific data.
- Cross-referencing with other spatial datasets and plans (e.g., shoreline management plans).
- The general need for more granular information, to consider impacts and vulnerabilities on different populations when developing CCRA4.
- A request for different timescales for spatial data, this depended on the organisation and asset. For example, land use and infrastructure sectors prefer longer timescales.
- The usefulness of having the data applied to a map on an accessible platform or website (such as MAGIC - Natural England (2023) a website providing geographic information about the natural environment from across government.

This shaped our pilot and case study process by defining more avenues to explore within the assessment of the chosen risks (considering new areas, such as vulnerability and policy alignment).

1 At the time of writing, the report for this project had not yet been published.

3 Findings

3.1 Framework

This section discusses the results of the assessment framework, highlighting the highest scoring results and the justification behind the assignment of 'significant benefit' and 'moderate benefit' to risks.

3.1.1 High-scoring results

The highest scoring risks and those deemed to have 'significant benefit' from spatial mapping are outlined in Table 0-1 in Appendix B.

Overall, for prioritised risks, total scores ranged from 8-16. A score of 13 was chosen as the threshold value as a sample size of high scoring risks - this produced 70 combinations, across seven risks over multiple sector chapters. The project team felt this would meet the goal of having a large enough sample size for internal and external discussions and also provide a good distribution across risk chapters.

For these high scoring results, tables have been split by expert judgement categories in response to the following questions:

To what extent would this risk benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK?

Risks with significant benefit were deemed to 'markedly benefit spatial mapping to improve the strategy and implementation of climate adaptation in the UK'. Others were often characteristically spatial but only perceived as having moderate benefit or remained neutral.

For example, risk H7 (Risks to health and wellbeing from changes in air quality) scores highly from interconnectedness, urgency score and adaptation score but is also very dependent on the local context as outdoor air quality is very variable across the country, with Air Quality Management Areas designated in areas where local air quality is unlikely to meet the Government's national air quality objectives. Indoor air quality is also influenced by housing type and condition and therefore also varies considerably.

Another example, risks to health and wellbeing from high temperatures, might benefit from a high resolution assessment. However, decision-making is conducted at a regional level (e.g., NHS boards) so it might not be essential for risk to be assessed at a more granular level. More detailed assessment of the potential impacts on individual assets would be better conducted at the individual site rather than area level.

Justification for high scoring risks (significant benefit):

This section highlights the justification for the highest scoring risks resulting from the assessment, which were deemed to have significant benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK.

- **H4** - Risks to coastal communities from sea level rise

The assessment highlights that whilst some mapping has been conducted, specifically on flood risk, there is no holistic assessment considering all aspects that could affect a community's long-term risks from sea level rise.

One of the key recommendations from H4 is the need for a national conversation about communities that may not be sustainable in the longer term due to climate risks and this has started to be addressed with initiatives such as the Coastal Transitions Accelerator Programme.

Previous research (Jacobs, 2018) has identified that whilst many Shoreline Management Plans (in place in England, Wales and Scotland) have policies that promote sustaining the current coastline (Hold the Line), it may be challenging to develop robust business cases to secure public sector investment to support coastal risk management schemes in these locations. Continuing to provide protection from coastal flooding and erosion may not be technically feasible or financially sustainable for some coastal communities and further work to identify these areas would help national and local decision-makers, other stakeholders and communities better prepare for the future.

The justification and prioritisation of this risk highlights intervention may be required to avoid uncertainty around risk and adaptation.

- **H13** - The assessment highlights the need to map institutional assets against hazards to plan for adaptation measures and enhance the resilience of the education and prison system.

Public information that informs resilience planning is needed for these institutions to understand the level of adaptation required and potential public expenditure. Risks such as higher temperatures may be fairly spatially homogenous for schools and prisons which are closer together, however, there will be clear and differing geographic consequences.

- **I3** - The assessment identifies that there are complex interdependencies between coastal flooding and erosion. This can lead to cascading risks that impact power, transport and sewage infrastructure with knock-on impacts to power supply disruptions and transport. These connected risks could be better mapped in more detail alongside assets and local vulnerability.

Risk I3 was directly related to one hazard which has existing partial mapping (erosion). Whilst there were efforts made in CCRA3 to outline infrastructure risk, a more expansive approach that considers a wider range (or re-categorised set) of infrastructure assets would be required to better outline complex interdependencies and their overall vulnerability to compound risks.

Secondary to these highest-scoring results are other high-scoring risks that were deemed by the expert judgement process to ‘moderately’ benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK, detailed in Table 0-2 in Appendix B.

Justification for high scoring risks (moderate benefit):

This section highlights the justification for the highest scoring risks resulting from the assessment, which were deemed to have moderate benefit from spatial mapping to improve the strategy and implementation of climate adaptation in the UK.

- **H1** - The assessment identifies the possibility of a below national spatial assessment of overheating and households, which could be beneficial alongside demographic vulnerability (older people, children and babies, those with disabilities, long-term ill-health etc). However, for decision-making, risk mapping is not needed at particularly high granularity (e.g., singular healthcare facility) as targeted interventions would be made at a NHS trust level.
- **H7** - This risk was identified due to the disconnect between air quality mapping (which is mapped in detail at a sub-national level), and climate-related air quality mapping (climate change as a driver for indoor as well as outdoor air pollution events or trends). Mapping could have moderate benefits due to the need for further research around the link between climate change, meteorological drivers and air pollution weather.

3.2 Spatially assessed climate risks: Case Study longlist

From the initial screening assessment, the climate risks that have been mapped in CCRA3 below the national level were identified. This list of climate risks, see Table 3-1 below, was used to identify suitable case studies.

Table 3-1 - List of spatially assessed climate risks (Case study longlist)

Spatially assessed climate risk	Associated hazard spatially assessed
B1: Risks to businesses from flooding	River flood, Coastal flood, Heavy Precipitation and Pluvial flood
B3: Risks to businesses from water scarcity	Hydrological drought, Mean air temperature and Coastal erosion (Saline intrusion)
B4: Risks to finance, investment and insurance including access to capital for business	Heavy precipitation and Pluvial flood

Spatially assessed climate risk	Associated hazard spatially assessed
I2: Risks to infrastructure services from river and surface water flooding	River flood, Heavy precipitation and Pluvial flood
I3: Risks to infrastructure services from coastal flooding and erosion	Coastal flood and Relative sea level
I8: Risks to public water supplies from reduced water availability	River flood, Hydrological drought, Mean air temperature, Heavy Precipitation and Pluvial flood
H3: Risks to people, communities and buildings from flooding	Heavy Precipitation and Pluvial flood, Relative sea level, Coastal flood and Mean precipitation
H4: Risks to coastal communities from sea level rise	River, Coastal and Pluvial flooding, Heavy precipitation.
H12: Risks to health and social care delivery	Mean precipitation, River flood, Coastal flood, Heavy Precipitation and Pluvial flood
H13: Risks to education and prison services	River flood, Coastal flood, Heavy Precipitation and pluvial flood

Overall, these risks were then compared with each other through internal and external consultation, to assess priorities and choose case studies. This consultation considered, amongst other aspects context, adaptation shortfall and urgency. Risks I3 - Risks to infrastructure services from coastal flooding and erosion and H12 - Risks to health and social care delivery were selected as case studies.

The approach to developing the two case studies comprised:

- Reviewing the climate risk section within the relevant chapter of CCRA3 along with any supporting research e.g. Future Flood Projections.

- Identifying what spatial mapping (hazard and asset) was conducted to inform the risk assessment and adaptation including key characteristics: source data, geographic scale, periods, with/without adaptation.
- Identifying any costs associated with adaptation/not adapting and how these were derived.
- Reviewing adaptation shortfall and identifying actions required to address this and achieve enhanced adaptation, including the spatial component of enhanced adaptation and costs where possible. The case studies involved reviewing if the enhanced adaptation actions could be mapped.

3.3 Establishment of Pilot Study longlist

The assessment results (high scoring risks that would benefit significantly from further mapping) were also used to help select the risks that would be the subject of pilot studies. The intention of these was to investigate how more detailed spatial mapping of the risk could be developed in future. The pilot study long list is provided below, Table 3-2.

The longlist of potential pilot studies was discussed with the CCC at an online workshop focusing on both the benefit that could be obtained from further mapping with regards to helping to understand risks and enhance adaptation, and also ensuring a spread of pilot studies (and case studies) across sectors. A final decision on which risks should be taken forward as pilot studies was made following the workshop by the CCC. The agreed pilot study risks were: H4 - Risks to coastal communities from sea level rise, and N11 - Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.

Table 3-2. Pilot study long list (high scoring risks of significant benefit)

Spatially assessed climate risk	Associated hazard spatially assessed
H4: Risks to coastal communities from sea level rise	River flood, Relative sea level, Coastal erosion, Coastal flood, Heavy Precipitation and pluvial flood
H11: Risks to cultural heritage	Mean air temperature, Extreme heat, Cold Spell, Frost, River flood, Heavy Precipitation and pluvial flood, Landslide, Hydrological drought, Ecological Drought, Fire Weather, Mean wind speed, Snow, Relative sea level, Coastal flood, Coastal erosion, Mean ocean temperature, Ocean acidity, Ocean salinity, Dissolved oxygen, Severe wind storm
H13: Risks to education and prison services	Extreme heat, Mean air temperature, Heavy Precipitation and pluvial flood, River

Spatially assessed climate risk	Associated hazard spatially assessed
	flood, Landslide, Fire Weather, Mean wind speed, Relative sea level, Coastal flood, Coastal erosion, Severe wind storms
I3: Risks to infrastructure services from coastal flooding and erosion	Coastal flood, Coastal erosion, Relative sea level
N5: Risks and opportunities for natural carbon stores, carbon sequestration and GHG emissions from changing climatic conditions, including temperature change and water scarcity	Mean air temperature, Hydrological drought, Heavy Precipitation and pluvial flood, Fire Weather, Relative sea level, Ecological drought
N10: Risks to aquifers and agricultural land from sea level rise, saltwater intrusion	Relative sea level, Coastal erosion, Hydrological drought, Mean precipitation
N11: Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.	River flood, Hydrological drought, Mean air temperature, Extreme heat

The approach to developing the two pilot studies comprised:

- Identifying current approaches to spatial risk assessment.
- Exploring and discussing new spatial approaches and methodologies relevant to UK CCRA4.
- Outlining key considerations for the CCC in relation to UK CCRA4.
- Assessing the benefits and disadvantages of any identified and presented methodologies.

4 Lessons and Wider Recommendations

4.1 How the framework was utilised

Overall, the purpose of the assessment framework is to advise on which risks should be prioritised for spatial assessment and illustrate where spatial analysis would be most useful for CCRA4, as well as where the likely challenges associated with below national-scale spatial risks assessments were likely to occur.

For the purposes of this commission, the project team also utilised the assessment framework to suggest potential case studies and pilot studies.

4.1.1 Results: Implications

The assessment included a consideration of CCRA urgency scoring and identified adaptation shortfalls and it was notable that those risks scoring high on these aspects tended to score high overall indicating that more granular spatial risk assessment would help these risks to be better understood and potentially better managed.

For high scoring risks, another general pattern was the presence of high data availability scores such as 1 or 2. This suggests that for high scoring risks pre-existing mapping of hazards and assets is present, but this has not necessarily been fully presented in CCRA3. In addition, it was often the case that the full mapping of risk requires an understanding of other components such as vulnerability which should be considered in any future spatial risk research.

Another theme evident across high scoring risks was the interconnectedness of hazards and assets across high-scoring risks, with all of the high scoring risks (score >13) scoring highly in the interdependency component. For example, risk H13 (risks to education and prison services) was not specific to one hazard. As H13 is connected to risks from heatwaves and flood events, some of the evidence described in Risk H1 (higher temperatures), Risks H3/H4 (Flooding and coastal change) and Risk I8 (Risks to water supplies) is also relevant here, particularly in relation to interventions in buildings and flood risk management policy. This highlights the need for future spatial assessment to take a systems view considering the integrated and cumulative impacts of multiple hazards on assets in the same location to enable a new approach to risk assessment and adaptation planning.

Numerous risks were present, and scored highly, due to imbalances between the risk mapping of different DAs, as previously discussed (for H4) there are obvious regional shortfalls in risk and adaptation mapping which may have a profound impact on the potential for adaptation in certain DAs.

Early development of the framework and assessment of the risks highlighted the issue for certain risks whereby asset observational data or spatial data may not be present, or accessible, due to security concerns. For example, there is very little publicly available information on the location of ICT assets because of the security threat this information could pose. This means that some mapping of certain risks may be limited as there is no, or very limited, observational data or spatial data. Examples include Risks to digital from high and low temperatures, high winds and lightning (I13 - score 12) and Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures (I1 - score 11). Although these risks are not very high scoring, their presence (and high expert judgement scoring) represents potential for spatial assessment, especially with a wider consideration of baseline infrastructural resilience.

What should the CCC prioritise?

The research has identified numerous risks where more detailed spatial mapping and analysis could be of benefit; these have to be prioritised to support the CCC in identifing where to prioritise its efforts and investment. Firstly, the CCC should consider regional disparities in available mapping between devolved administrations for significant climate change risks facing the UK (e.g., coastal erosion and Northern Ireland). This will prevent gaps between devolved administrations' levels of adaptation from widening further and should assist in preventing maladaptation where information is not current or existing.

The CCC should also prioritise the need for infrastructure resilience, by obtaining asset data and observational data to support additional spatial assessment (e.g., weather disruptions, infrastructure failure rates and indicators). Sector specific engagement between users and providers of climatic information is needed to form, as Dale et al., (2022) states, a better understanding of important compound parameters, to identify and provide estimates of current and future likelihood of extremes and ‘threshold breaking’ events. This could be done by utilising sector observational and historic data of the impacts from extreme events as a reference for planning responses/adaptations. This will be crucial in mitigating climate risks to transport systems (such as rail).

The CCC should consider spatial mapping of risks which scored highly in terms of interdependencies. These risks could be explored in future spatial risk assessment commissions which also consider related hazards, assets and risks to give a clearer picture of the risk. Where this is not possible, the CCC should utilise updated systems approaches (such as building upon WSP, 2020) to promote collaboration and better understand gaps.

Where public assets are involved, such as health, education and prisons, the CCC should commission spatial risk and adaptation mapping that informs resilience planning to understand the level of adaptation needed and potential public expenditure. As the related Non-Government Users research suggests, there is a clear demand for granular information that is readily accessible via online platforms to inform local action, investment planning and resource allocation by relevant bodies.

The CCC should also recognise the synergies of spatial risk assessment with national policy, particularly Net Zero planning. For example, Risk N5, (Risks and opportunities for natural carbon stores, carbon sequestration and GHG emissions from changing climatic conditions, including temperature change and water scarcity) scored highly during assessment, due to the need nationally to map and monitor habitats and land-use (extent and sequestration rates) to provide robust estimates of carbon resources and its variability through time as climate changes. Understanding this information will be key for managing pathways to Net Zero, such as through changes in carbon stocks achieved through afforestation, peatland restoration and soil carbon gains (Berry & Brown, 2021).

What does this mean for future spatial risk assessment?

Future spatial risk assessment needs to be mindful of regional disparities in spatial information across devolved administrations and there needs to be an effort to ensure that all nations have a full understanding of risk to support national adaptation planning and implementation across the UK. Future work and commissions should consider ways and means of sharing spatial assessment best practice and approaches, especially with regards to the creation and maintenance of spatial datasets relating to climate hazards and assets. Moreover, future spatial risks assessment should also reflect the needs of different institutional frameworks and the organisations that work within them, that govern the ability to adapt.

In the short term, future spatial risk assessment should take a pragmatic approach and be guided primarily by current data availability. In the medium term, spatial risk assessment should focus on the highest scoring risks but should not shy away from seeking to obtain high-quality spatial data through primary data collection which directly relates to the highest scoring risks (as identified in Table 0-1). In order to ensure that no work is redundant or abortive the CCC should further expand cross-agency and departmental links with other parts of Government (i.e., the Environment Agency, Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW)). In doing so, the CCC could also encourage and help to assist in the sharing of best practices amongst devolved administration agencies.

In the longer term, mapping should be developed for all high scoring risks (score >13). This will likely entail the creation and maintenance of new spatial datasets. Suitable owners, both within and without the CCC should be sought to enable the long-term maintenance and regular updating of the data. Also, where a risk is high scoring but there are identified research gaps, commissions should focus on building capacity, stakeholder links and trialling new methodologies to improve spatial assessment approaches.

4.1.2 Constraints

One constraint in utilising a large framework, which aggregates and disaggregates information across the catalogue of CCRA3 risks, is the sheer number of possible combinations. This can make navigating it, whilst retaining all elements of automation, difficult.

Furthermore, aggregating and disaggregating risks in the manner employed by the framework does not allow for the application of expert judgement across each singular risk combination (hazard and asset/receptor), to be assigned by expert judgment. However, future assessment by the CCC could revisit particular risks and re-assess gaps, with a view to future commissions.

Particular gaps which should be re-assessed include:

- Risks with a large number of associated hazards: for example, Risks to cultural heritage (H11). Taking H11 as an example, due to the volume of associated hazards, further expert judgement could be undertaken to develop the assessment of the utility and feasibility of varied spatial assessment of H11.
- Natural Environment risks: such as Risks to terrestrial species and habitats from changing climatic conditions and extreme events, including temperature change, water scarcity, wildfire, flooding, wind, and altered hydrology (including water scarcity, flooding and saline intrusion) (N1). More robust assessment of the need for spatial risk assessment, and the need for continued and consistent long-term monitoring will be important to inform adaptive management and building evidence bases for further action.
- Risks with a high degree of interdependency: such as risks to infrastructure networks (water, energy, transport, ICT) from cascading failures (I1), which could benefit from sector specific engagement with tailored expert judgment to assess the need for spatial risk assessment or a wider 'systems' assessment.

Another key constraint to this process is the disconnect in terminology between the CCRA3 literature and the physical climate hazards in the UK. The CCRA3 itself lacks a standardisation process in this respect, whereby physical climate conditions are not well defined. A move to the CID framework (Ruane et al., 2022) was useful for the framework to clearly outline impacts, hazards and drivers. Utilisation of the same, or a similar framework, for CCRA4, may provide benefits for future research gap-finding exercises by standardising UK climate change risks clearly and consistently.

A final constraint of the framework process is that the vulnerability of assets and receptors is often ignored in comparison to other components. Vulnerability for many assets, such as communities, is a key determinant in spatial mapping of risk and adaptation as the level of risk itself is determined by other factors. For example, socio-economic vulnerability factors, such as morbidity assists in providing context and helps to determine the level of risk for people, communities and buildings during heat extremes.

4.2 Using the framework in future

The framework has been developed in a way that ensures the possibility of future re-assessment, allowing for future optioneering for spatial risk assessment prioritisation. The scores and levels of mapping can be altered, and this will feed through to the prioritisation of climate risks. With additional information (and expert judgement) risks can be more clearly analysed. As discussed, this indicates that internal CCC reassessment could revisit particular risks and reassess gaps for any future commissions. This would enable moving from high-level analysis from risk by risk expert judgement to a more critical evaluation of every component of each risk.

The CCRA3 sector by sector assessments within the framework also allow for observations in the CCRA3 literature to benefit discussion concerning future spatial commissions. The sector by sector assessments could also be updated with new information and findings being added to the framework as appropriate. This in turn would allow for better informed future reassessment and reprioritisation of risks for more spatial assessment.

5 Case studies and pilot studies

5.1 Purpose of the case and pilot studies

Based on the results of the framework described in Section 3 above, two case studies and two pilot studies were developed to further explore the current and potential spatial risk assessment for four climate risks.

Two climate risks that presently have a spatial risk assessment completed were further explored in the case studies to identify how and to what extent the climate risk was spatially assessed and where it is possible and beneficial to provide spatial assessment of enhanced adaptation ambition. More specifically, the objectives of the case studies were to:

- Investigate previous approaches utilised to spatially assess climate risks below the national level and identify lessons that could be adopted for the assessment of other risks.
- Explore the degree to which adaptation conducted to date and potential enhanced adaptation that might be implemented in the future can be mapped, and whether costs have been, or can be, identified for existing and potential adaptation. Enhanced adaptation relates to the additional adaptation that may be required to address the identified adaptation shortfall for each of the risks.

In addition to the two case studies, two pilot studies were conducted for risks that do not have a spatial risk assessment currently completed or under development. The pilot studies aimed to explore novel and bespoke spatial modelling of a risk and adaptation potential. More specifically, the objectives of the pilot studies were to:

- Identify suitable novel methodologies for future spatial commissions which could assess the climate risks at a local level; and,
- Present and highlight existing leading and best practice methodologies, providing insight into how these methodologies could be developed further in future.

Although the case studies and pilot studies were conducted for individual climate risks, it was recognised that the climate risks within UKCCRA3 are interconnected and consequently, the current and potential spatial risk assessment should consider other relevant climate risks. For example, the risks to infrastructure assets (I3) will have a significant contribution to the long-term risks to coastal communities from sea level rise (H4). Therefore, the case study on I3 (risks to infrastructure services from coastal flooding and erosion) and pilot study on H4 (risks to coastal communities from sea level rise) explored the relevance of the lessons learned for the other risk.

5.2 Case studies

The two climate risks chosen for the case studies were:

- I3: Risks to infrastructure services from coastal flooding and erosion; and

- H12: Risks to health and social care delivery

5.2.1 Summary of I3 case study

The risks to infrastructure services in the UK from coastal flooding and erosion are significant due to its long coastline and high population density in coastal areas. CCRA3 highlights that climate change is expected to increase the rate of sea level rise and the frequency and severity of extreme weather events, such as heavy rainfall and storm surges, which can lead to coastal flooding and erosion. The risk is particularly high in areas with low-lying land and insufficient coastal defences.

Spatial mapping is available for the risk to infrastructure services from coastal flooding nationally and for different regions and areas in the UK. The supporting research to CCRA3, conducted by Sayers et al. (2020) includes maps that illustrate the potential impacts of frequent fluvial or coastal flooding (1 in 75 year event or more frequent) on different types of infrastructure, such as roads, railways, airports, and energy infrastructure. However, the infrastructure is mapped by Category A infrastructure (i.e. assets linked to water (clean and wastewater treatment sites) and energy (generation, transmission, and distribution) and Category B infrastructure (i.e. transport (railway stations), landfill sites, emergency service sites (hospitals and blue light service stations) as well as sites that provide social support services (care homes, GP surgeries, and schools).

There is no availability of spatial mapping for the risk to infrastructure services from coastal erosion. Coastal erosion was out of scope in the Sayers et al. (2020) research. However, there is research completed in 2018 by Sayers (2018) and CCC (2018) which utilised the data from the National Coastal Erosion Risk Map (NCERM) for England and Wales to identify those areas most susceptible to erosion up to 2025 with 'no active intervention'. This data was used to calculate the current and future (mid and end-century and mid and high-estimate) number of assets at risk to coastal erosion in England. These assets included some infrastructure services such as railway lines and stations, and landfill sites.

However, each of the infrastructure providers (e.g. Network Rail, water, energy and waste companies) may have spatial risk assessments that are not publicly available due to proprietary information and information security risks. For example, Network Rail regions complete their own Weather Resilience and Climate Change Adaptation (WRCCA) Plans that use a geographic information system (GIS) based decision support tool METEX (not publicly available) to analyse gridded observed weather data and rail data historically and also to identify higher-risk locations based on UKCP18 climate change projections.

Specific adaptation measures, such as Shoreline Management Plans, flood and coastal erosion defences, flood forecasting, warning and emergency responses, and planning have not been spatially mapped in CCRA3 in regard to the risk to infrastructure services from coastal flooding and erosion. However, some of the adaptation measures individually have been spatially mapped. For example, the Environment Agency, Coastal Protection

Authorities and their partners (e.g. water companies) will have spatial data on specific flood and coastal erosion defences along with schemes being developed and their impact on infrastructure services.

Lessons learned and recommendations

The importance of infrastructure services to communities, businesses, and society necessitates a **spatial systems approach** to identify interdependencies with other assets and services in different locations, taking into account geography. A vulnerability in one network can impact others, affecting the economy, health, and well-being of communities. Resilience to climate change requires a holistic approach that goes beyond the individual risks and opportunities. This strategic approach can be applied to all climate risks, using a systems approach with a geographic lens to enhance adaptation and cooperation among infrastructure providers, businesses, health and social care providers, and communities.

In addition to the spatial systems approach, the case study identified the following as the lessons learned for other climate risks and CCRA4 and recommendations for future work:

- **Better understand the current spatial risk, particularly from coastal erosion**: Identifying regionally, or sub-nationally the current effectiveness of coastal flooding and erosion defences on disaggregated infrastructure services to allow owners of the infrastructure services, risks and any assets impacts by cascading failures can better understand the magnitude and consequences of the risk and therefore prioritise adaptation measures. Additionally, an improved understanding of the impacts of highly protected critical infrastructure (e.g. nuclear sites) on wider infrastructure, communities and the natural environment is required to explore holistically the costs benefits of this standard of protection.
- **Explore thresholds and resilience on a spatial basis**: There is a need spatially to assess and understand the factors which contribute to resilience . This involves considering the unique characteristics of different regions and their vulnerability to coastal flooding and erosion, and identifying areas where infrastructure services can or cannot be made more resilient. Exploration of thresholds and resilience using a systems approach on a spatial basis will identify what resilience for various infrastructure assets looks like and the follow-on impacts to other infrastructure providers, businesses, health and social care providers and communities.
- **More research and robust economic modelling** are needed to understand the potential damages and costs of climate change impacts, including cascading risks and coastal erosion.
- **Spatial mapping at a national level, such as using Strategic Flood Risk Assessments (SFRAs)**, is useful for identifying flood risk to critical infrastructure assets. Detailed site assessments should be done at individual levels, as the primary purpose of CCRA is to provide a holistic picture across the whole country and not provide detailed site assessments.

5.2.2 Summary of H12 case study

This case study explores the risks to health and social care delivery, from floods, heatwaves and other extreme weather resulting from climate change, identified as H12 in the UK CCRA3. More widely, the risks to human health, well-being and productivity from increased exposure to heat in homes and other buildings were identified as one of CCRA3's highest priorities for further adaptation by 2024.

Spatial mapping is available for the risk of flooding to health and social care assets nationally and for different regions and areas in the UK. The supporting research to the CCRA3, conducted by Sayers et al. (2020) includes maps that illustrate the potential impacts of frequent fluvial or coastal flooding (1 in 75 years or more frequent) on different types of infrastructure, such as roads, railways, airports, and energy infrastructure. As stated in the I3 case study, the infrastructure is mapped by Category A infrastructure (i.e. assets linked to water (clean and wastewater treatment sites) and energy (generation, transmission, and distribution) and Category B infrastructure (i.e. transport (railway stations), landfill sites, emergency service sites (hospitals and blue light service stations) as well as sites that provide social support services (care homes, GP surgeries, and schools).

The risk of overheating for health and social care delivery is not mapped in CCRA3. Whilst UKCP18 can be used to identify potential future temperatures for different parts of the UK and health and social care assets can be mapped across the UK, understanding overheating risk is more complex than simply combining the two. As detailed in the chapter, the design of health and care assets is likely to have more of an impact on overheating than their location. The use of the assets is also important as, for some services such as psychiatric care, where security concerns mean that windows cannot be opened, overheating is likely to cause considerably more concern and stress than a GP surgery where windows and doors can be opened.

Lessons learned and recommendations

This case study identified the lessons learned for other climate risks and CCRA4 and recommendations for future work, as follows:

- **Vulnerability is likely to have a considerable influence** on the overheating impacts for specific health and social assets than location. Whilst increasing temperatures are likely to differ in scale in different parts of the UK, these will be broadly similar at regional level, whereas vulnerability will differ on a site by site basis affected by occupant, use and design. This is likely to be similar for other overheating risks and to some degree applies to all risks when trying to understand the impacts at a site rather than regional or national level.
- **The impact of infrastructure disruption** will also be an important consideration for many other risks within the health, communities and built environment, business, and indeed infrastructure sections of CCRA4. Infrastructure disruption has the potential to affect people's and organisation's day to day activities and

therefore more focus is needed on cascading and cumulative risks. This brings in the importance of adopting a systems and place based approach that considers multiple risks and how they may impact communities, economies, and the natural environment rather than assessing them on a risk by risk basis as has been deployed in previous CCRAs.

- **Liaise with Greener NHS** to identify any monitoring on overheating of health and social care assets that they are conducting or could be conducted and consider how this can be built into the next CCRA.
- **Conduct research on health and social care building archetypes** to identify those that have a propensity to overheat or flood and their prevalence across the UK. From this, conduct a high level risk assessment that can be applied sub-nationally as well as at the national level. This will enable more consideration of vulnerability to be built into the risk assessment.
- Further development of a **systems-based approach** including the mapping of key infrastructure services linked to other assets – health and social care, plus businesses, homes and other services such as schools and prisons. This will enable a more holistic assessment of risk at national and sub-national levels.

5.3 Pilot studies

The two climate risks chosen as pilot studies were:

- N11: Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.
- H4: Risks to coastal communities from sea level rise.

5.3.1 Summary of N11 pilot study

N11 is a complex and significant risk. Alongside eight other priority areas, the CCC identified that risks to the viability and diversity of freshwater (and terrestrial) habitats and species from multiple hazards was identified as a risk requiring the most urgent action in the next two years (by 2024). There is added significance as freshwater habitats and species in the UK are under growing threat from an array of interacting human-induced risks such as abstraction, nutrient loading, water demand and obstacles to passage, which have the potential to worsen climate change impacts.

The N11 pilot study outlines pre-existing spatial mapping approaches across the UK, as well as highlighting the disparity in progress between devolved administrations. Notably, the Scotland River Temperature Monitoring Network (SRTMN) is an example of best practice, as it utilises climate data to map the vulnerability of streams across Scotland. In contrast, there is no equivalent scheme for any other DA across the UK. Equally, the Keeping Rivers Cool project (Woodland Trust and Environment Agency Initiative - restricted to England) aims to update riparian shade mapping for England. However, there is no equivalent process or project for Wales or Northern Ireland.

Building on methods outlined in the literature, the N11 pilot study also explores and evaluates other novel methodologies which are being conducted across a broad range of scales, from the catchment to national level. The explored methodologies include improved adaptation mapping, distribution mapping, spatial risk mapping, ecosystem service integration and the development of future metrics.

Lessons learned and recommendations

The N11 pilot study identified the following lessons learnt for other climate risks and CCRA4, as well as the following recommendations for future work:

- The clear and strong interaction between N11 and other freshwater risks, such as Risks to freshwater species and habitats from pests, pathogens, and INNS (N12) and Opportunities to freshwater species and habitats from new species colonisations (N13) would benefit from the development of T_w (water temperature) projections. The climatic ranges of freshwater species that might benefit or be harmed from warming could then be better understood.

- A possibility for future spatial assessment would be to use shared socio-economic pathways (SSPs) alongside representative concentration pathways (RCPs) to produce participatory scenarios to address uncertainty in adaptation decision-making. This would help to recognise that freshwater species and habitats are affected by the human-water system. This could form part of a systems approach for freshwater systems, if desirable in the context of CCRA4.

Recommendations for spatial assessment are split between risk and adaptation.

Adaptation spatial assessment:

- Aid in the development of riparian shade mapping for DAs to improve catchment management resilience and reduce national information disparity.
- Research the trade-offs and synergies between Nature-based solutions (NbS) techniques and freshwater-specific adaptation, such as riparian shading and natural flood management (NFM).
- Aid research by commissioning spatial mapping of groundwater inputs (and their adaptive management capability, such as spatial distribution of cold springs) as well as scoping the possibility of combining with other elements of spatial risk assessment, such as water temperature projections.

Risk spatial assessment:

- Commission spatial assessment of climate change impacts upon freshwater species distribution mapping. These methods could utilise UKCP18 data and build upon existing identified methodologies**,** pre-existing monitoring and datasets.
- Develop resilience metrics which could have cross-applicability for multiple DAs. Currently, the EA is developing catchment specific metrics, but cross-agency engagement between the CCC and EA could explore resilience metrics which could function across UK catchments.
- Consider N11 spatial assessment in the context of an ecosystem services approach, future commissions could identify synergies with natural capital approaches, with a particular focus on quantifying the extent and condition of assets such as rivers and streams.
- Build on the SRTMN methodology and outputs of the EA water temperature projections work to develop risk and adaptation spatial assessment for CCRA4, across the UK.

5.3.2 Summary of H4 pilot study

This pilot study explored previously utilised approaches to spatial risk assessment relating to H4 and presented two potential improved approaches for assessing the risks to coastal communities from sea level rise.

This is a significant risk, with major implications. According to research conducted by the CCC (2018), by the 2080s up to 1.5 million properties may be in areas with a 0.5% of greater annual level of flood risk and over 100,000 properties may be at risk from coastal erosion. It was identified as a priority risk with more research required within CCRA3 (2021). Within the Health, Communities and Built Environment chapter Kovats and Brisley (2021) indicate that it is increasingly unrealistic to 'hold the line' for all the coastline, given the high costs and major safety implications.

Risk H4 addresses risks from sea level rise. These include an increased likelihood and severity of coastal flooding from both tides and storm surges due to higher mean sea levels, as well as impacts on other coastal processes due to deeper nearshore waters. This may influence processes such as coastal erosion, landslips, or coastal accretion.

For some exposed, and vulnerable coastal communities, sea level rise related acceleration of these processes may have major implications, with buildings and infrastructure at risk of damage and loss. In the future, it may be that the economic and environmental costs of coastal protection outweigh the benefits, or there may be areas where communities cannot be made safe regardless of the investment.

Various elements can contribute to a community's long term level of risk in relation to risks from sea level rise. This study identifies the need for a holistic understanding of the risks to coastal communities in the UK from sea level rise, which could be addressed through more granular spatial assessment.

This exploratory pilot study therefore presents and reviews existing methodologies, before providing an inventory of indicators on vulnerability, resilience and exposure for coastal communities, before finally assessing the advantages and drawbacks of each reviewed methodology in relation to the risks for coastal communities to future sea level rise and coastal change.

Lessons learned and recommendations

In addition to identifying two potential spatial approaches, this pilot study also identified the following as the lessons learned in the context of CCRA4 spatial commissions, as well as the following recommendations for future work :

- There is a need to consider vulnerability within spatial assessments of climate risks. Consideration of vulnerability assists helps to provide important context and adds depth and quality to spatial assessments of risks.
- Spatial risk assessment of H4 at the national scale using either of the two identified approaches would be a significant undertaking. Consideration should therefore be given to the proportionality of spatial risk assessment of climate change risks. An approach that allows for the identification of 'hot spot' areas before zooming in on these areas to provide a more localised and detailed assessment is more likely to be feasible and achievable.

Within this study, **two methodological options** were presented for future risk assessment. The first is to build upon and improve the methodology utilised in the Isle of Man Coastal Strategy Evidence Report. This could be achieved by incorporating the following elements:

- **Integration of a Social Vulnerability Indicator:** Including an indicator of social vulnerability, such as the NFVI (National Flood Vulnerability Index). This indicator could be integrated into the overall risk calculation. One possible approach would be to rank communities based on their vulnerability to flooding through use of the NFVI, for example. The most vulnerable community would therefore receive the highest score and the least vulnerable the lowest score. Alternatively, a more detailed approach could be adopted, incorporating weightings and scoring with some categories of the NFVI being assigned higher weightings.
- **Incorporation of Natural Capital Approaches:** Drawing upon methods used in the Hurst Spit to Lymington strategy. This entails considering natural capital elements in the risk assessment to gain a more comprehensive understanding of the interactions between the risk and changes in the natural environment.
- **Integration of SMP Policy Unit Management Options:** Incorporating the management options chosen by the SMPs (Shoreline Management Plans) policy units would provide contextual information regarding local coastal change management policy. The management options which are mapped in the National Coastal Erosion Risk Mapping (NCERM) for all epochs should be included. Values could be applied by scoring management options.
- **Incorporation of Benefit-Cost Ratio (BCR):** Utilizing the BCR findings from the Jacobs (2018) report in alignment with each SMP. Multiplying the management option score by the BCR for either a high or low climate scenario, as identified by Jacobs (2018) would allow for a more bespoke assessment of the coastal change management strategy. This step provides an approach for undertaking a quantitative assessment of the benefits and costs associated with each management option.

  It should be noted that BCR values from the Jacobs (2018) report are not spatial data, and that analysis would need to be conducted likely via Microsoft Excel or similar software, to combine BCR scoring of SMPs with SMP policy unit management option scorings.

By integrating SMP policy unit management options, BCR scores, NFVI, and natural capital assessments, along with the existing elements of the Isle of Man methodology - whilst also utilising the best available mapping data - a more comprehensive understanding of the interactions between vulnerability and risk could be achieved at a range of spatial scales.

Additionally, by modelling a range of SMP policy unit management options for both BCR (high and low) climate scenarios, the assessment could reflect a variety of adaptation strategies.

The second option proposed is to build upon and improve the methodology utilised in the Flood Risk Assessment for Wales. This approach considers all sources of flood risk and uses a combination of local and national modelling (similar in design to the currently in development NaFRA2[2]). This could be achieved by incorporating the following elements:

- **Integration of SMP Policy Unit Management Options:** Incorporating the management options chosen by the SMPs (Shoreline Management Plans) policy units would provide contextual information regarding local coastal change management policy. The management options which are mapped in the National Coastal Erosion Risk Mapping (NCERM) for all epochs should be included. Values could be applied by scoring management options.
- **Incorporation of Benefit-Cost Ratio (BCR):** Utilizing the BCR findings from the Jacobs (2018) report in alignment with each SMP. Multiplying the management option score by the BCR for either a high or low climate scenario, as identified by Jacobs (2018) would allow for a more bespoke assessment of the coastal change management strategy. This step provides an approach for undertaking a quantitative assessment of the benefits and costs associated with each management option. As above, it should be noted that this is not spatial data and analysis would be required to transform the data into a spatial format.
- **Integration of Vulnerability Indicator**: Inclusion a vulnerability indicator, such as the National Flood Vulnerability Index (NFVI). This indicator could be integrated into the overall risk calculation in a similar manner to that outlined above.
- **Utilise Updated and Refined Datasets**: Improve the accuracy and completeness of datasets used for flood risk assessment. Consider utilising the updated National Receptors Database (NRD, 2021) to include previously unclassified receptors within key sites like schools and hospitals.
    - Also, future work could develop a separate dataset summarizing unique properties at flood risk to avoid double or triple counting of properties at risk from multiple flood sources.
    - Consider recommendations for representing flooded buildings within the FRAW (Flood Risk across Wales).
    - Where spatial risk assessment chooses to use Economic Tools for Flood Risk Analysis and Investment Planning, improve its functionality to avoid double counting of properties at risk from multiple flood sources.

Finally, to address concerns from CCRA3, it is recommended that further work is required in the run-up to CCRA4 to identify current and future spatial distribution of risk in the long-term, and the methods to monitor this. As such, an independent and objective methodology will be critically important to ensure that decisions are made based on evidence-led inquiry.

2 Release date expected summer of 2024

6 Conclusions and Recommendations

6.1 Conclusions

The research culminated in the identification of several CCRA3 risks that would benefit from more detailed spatial risk and adaptation assessment. In the short term, those with the highest scores would benefit from greater spatial representation to improve the strategy and implementation of enhanced adaptation ambition in the UK.

Case studies outlined previous approaches utilised to spatially assess climate risks below the national level and identified lessons that could be adopted for future assessment. The case studies have also explored the degree to which existing and potential enhanced adaptation can be mapped and where costs can be identified to cover these.

Pilot studies outlined novel methodologies to inform future spatial commission to assess risk at a sub-national level. These studies have also presented existing best practice methodologies which could be progressed to provide more granular spatial risk assessment in UKCCRA4.

6.2 Recommendations

From conducting the research, we recommend that a more detailed spatial assessment is conducted for the following risks:

- **H4 - Risks to coastal communities from sea level rise**.
  Whilst some mapping has been conducted for H4, specifically on flood risk, there is no holistic assessment considering all aspects of the risk, that could affect a community's long-term risks from sea level rise.
- **H13 - Risks to delivery of education and prison services from extreme weather.**
  The framework highlights the need to map institutional assets against hazards to assist in planning for adaptation measures and enhance the resilience of the education and prison system assets.
- **I3 - Risks to infrastructure services from coastal flooding and erosion.**
  There are complex interdependencies between coastal flooding and erosion that could be mapped in greater detail, in combination with infrastructure assets and local vulnerability.
- **H11 - Risks to cultural heritage.**
  Increasing mapping of some specific hazards and heritage assets would improve understanding of where assets are most at risk and what adaptation actions could be undertaken.
- **N5 - Risks and opportunities for natural carbon stores, carbon sequestration and GHG emissions from changing climatic conditions,**

including temperature change and water scarcity.
There is a need for further and on-going mapping and monitoring of habitats (extents and sequestration rates) to provide robust estimates of carbon resources and their variability through time.

- **N10 - Risks to aquifers and agricultural land from sea level rise, saltwater intrusion.**
  There is a need to better understand the impacts of saltwater intrusion on agricultural land. Additionally, since agricultural abstraction is more localised, spatial mapping would improve the understanding of the magnitude of this risk to agricultural land.
- **N11 - Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.**
  Future changes in water temperatures are likely to be spatially and seasonally variable. Spatial modelling and assessment to understand the impact of temperature changes and extreme events will allow for the risk to be better understood and therefore the adaptation actions.

As a result of conducting the assessment, the case studies and pilot studies, we recommend the following in relation to CCRA4 in general, and for the case study and pilot study risks:

- This project has identified the need for further development of systems-based approaches which include the mapping of multiple assets (including natural capital) and services, and their interdependencies to enable a more holistic assessment of risk at national and sub-national levels. It is also important that more consideration is given to place-based issues rather than individual risk-based assessment (focus should be given to the physical challenge of a given risk), as this would facilitate a greater understanding of interdependent, cascading and cumulative impacts.
- For all risks, but in particular for those where hazards are likely to have less spatial differentiation such as overheating, it is important to consider vulnerability which relates to the specific context of individual assets and receptors. Developing archetypes of different types of assets, receptor and services and how they may be affected by different climate hazards could support the assessment of vulnerability at the national scale.
- It is also crucial for the CCC to develop knowledge-sharing networks across different government agencies and different devolved administrations. Currently, there are various institutional frameworks under different DAs that govern the ability to adapt. Therefore, under some prioritised risks there are disparities in spatial risk assessment, with some DAs having more mature forms of spatial risk assessment than others. As such there needs to be an effort to ensure that all DAs have a full

understanding of the risks to support national adaptation planning and implementation across the UK.

- Future spatial assessment for risk and adaptation purposes will be heavily dependent on interaction with a range of specialists in this area to develop holistic approaches for UK-wide spatial assessment which take account of risk, adaptation and resilience. Currently, various sectors in the UK are in different places with regards to understanding their resilience to climate change. Data to support a baseline understanding of resilience varies by sector, but in some cases (e.g. water resources), considerable data exists in the public domain. For other sectors, focussed engagement will likely be necessary to achieve a meaningful understanding. Therefore, efforts need to be made to baseline resilience, to feed into sub-national spatial assessment. The CCC should facilitate sector-led, expert discussion to lay the groundwork for resilience which can be integrated into further spatial assessment

References

Berry, P. and Brown, I. 2021. National environment and assets. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

Climate Change Committee (CCC). 2018. Managing the coast in a changing climate [online]. Available at: https://www.theccc.org.uk/publication/managing-the-coast-in-a-changing-climate/

Dale, M., Ngai, R., Brook, E and Venton, B. 2022. Recommendations for filling current gaps in climate information - Climate Information to Support UK Decision-making [Online] Available at: https://www.ukclimateresilience.org/wp-content/uploads/2021/04/CR20-5-Climate-Information-to-inform-UK-decision-making_Recommendations-Report_JBA.pdf

IPCC. 2021. Annex VI: Climatic impact-driver and extreme indices. In J. M. Gutiérrez, R. Ranasinghe, A. C. Ruane, & R. Vautard (Eds.), Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Changing Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 2205– 2214). Cambridge University Press.

Jacobs, 2018. Research to Assess the Economics of Coastal Change Management in England and to Determine Potential Pathways for a Sample of Exposed Communities, B2334200. Prepared for the Committee on Climate Change, London.

Jaroszweski, D., Wood, R., and Chapman, L. 2021. Infrastructure. In: The Third UK Climate Change Risk Assessment Technical Report. [Betts, R.A., Haward, A.B., Pearson, K.V. (eds)] Prepared for the Climate Change Committee, London.

Kovats, S. and Brisley, R. 2021. Health, communities and the built environment. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B., Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

MAGIC. 2021. Magic Map Application [online]. Available at: https://magic.defra.gov.uk/MagicMap.aspx?startTopic=Designations&activelayer=sssiIndex&query=HYPERLINK%3D%272000480%27

Ruane, A.C., Vautard, R., Ranasinghe, R., Sillmann, J., Coppola, E., Arnell, N., Cruz, F.A., Dessai, S., Iles, C.E., Islam, A.S. and Jones, R.G. 2022. The Climatic Impact-Driver Framework for Assessment of Risk-Relevant Climate Information. Earth's Future. 10(11).

Sayers, P.B. 2018. Managing future coastal flood and erosion - Supporting analysis risk. Research undertaken by Sayers and Partners on behalf of the Committee on Climate Change. Published by Committee on Climate Change, London.

https://www.theccc.org.uk/publication/managing-future-coastal-flood-and-erosion-risk-sayers/

Sayers, P.B, Horrit, M.S, Carr, S., Kay, A., Mauz, J., Lamb, R., Penning-Rowsell, E. 2020 Third UK Climate Change Risk Assessment (CCRA3) Future Flood Risk Main Report. Published by Committee on Climate Change, London. https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Future-Flooding-Main-Report-Sayers-1.pdf

Sayers, P.B., Kay, A., Mauz, J., Horritt, M., Carr, S., Lamb, R., Renning-Rowsell, E. 2020. Climate Change Risk Assessment 2022: Projections of future flood risk in the UK. Research undertaken by Sayers and Partners for the Committee on Climate Change. Published by Committee on Climate Change, London. https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Future-FloodingMain-Report-Sayers-1.pdf

Watkiss, P. and Betts, R.A. 2021. Method. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

WSP. 2020. INTERACTING RISKS IN INFRASTRUCTURE AND THE BUILT AND NATURAL ENVIRONMENTS: Research in Support of the UK's Third Climate Change Risk Assessment Evidence Report [Online] Available at: https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Interacting-Risks_WSP.pdf

A Appendix

A.1 Framework Development

The development of the framework for spatial assessment was a collaborative and iterative process. Developing a clear system that de-aggregates the climate risks identified into UK CCRA3 required discussion and cooperation between the Climate Change Committee (CCC) and project team throughout the development stage.

The framework went through three main iterations, as demonstrated in Figure 0-1 below and further detailed in the sections below. These were:

1. An initial iteration, informed by co-design and discussion around the number of risks and their depth of study, which enabled the production of a draft framework.

2. A second iteration, with an improved ability to filter risks spatially and the addition of an international risk framework approach incorporating climate impact drivers.

3. The final iteration, with adjusted expert judgement and an improved prioritisation process that was considerate of the full spectrum of hazards, assets and their associated risks.

Whilst the framework was used to prioritised case studies and pilots, the final framework also allows for further analysis of impactful risks. Allowing for identification of risks that would receive real benefit from spatial assessment and adaptation.

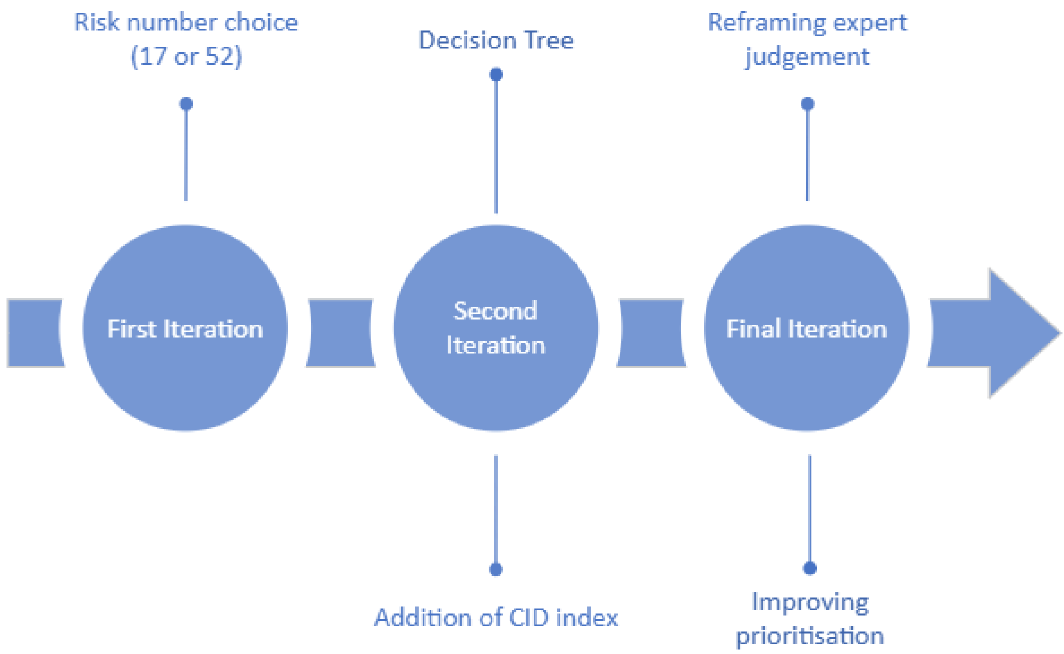

Figure 0-1 - Framework development

A.2 First iteration

Following early consultation and an agreement on the co-design process of the framework, three early possibilities for the framework were identified.

The three options are described in further detail below.

- Option A - to undertake a high-level analysis of the full 52 risks identified in the UK CCRA3, identifying key constituent factors such as urgency scoring and gaps in research, although providing less in terms of expert judgement.
- Option B - Producing a more detailed analysis and expert judgement of the 17 risks which were defined as the highest priorities for adaptation in the next 5 years (CCC, 2021).
- Option C - An alternate third option suggested by the team, involved utilisation of a screening stage which could break risks down by hazard as a first step, and then identify the spatial association of hazard data and the available spatial mapping data.
- This would then be appraised against the relevant climate change projection data and its spatial resolution.
- This first step would be used to shortlist risks which would then be considered in a subsequent step, which would involve a more detailed examination of risks to assets.

Options A and C were combined for the first iteration of the framework. This combination was chosen due to have a wider frame of analysis that was not constrained by a select few risks detailed as the highest priority for adaptation. Therefore, allowing for gaps in spatial assessment of all risks to be identified.

A.3 The process

Early literature review for the framework focused on available spatial data and gaps in external spatial assessment to satisfy the 'hazard' stage of assessment as outlined in options C. This included:

- A review of the UKCCRA3 chapters to create a reference document for all climate hazards associated to all climate risks.
    - A list of 47 unique hazards/drivers were identified - although with some overlap.
- A review of the UKCCRA3 chapters to identify where mapping was used (or ascribed to in either supporting commissions or the literature referenced.
- A review of external literature to identify if there was other mapping available.
- A general review of UKCCRA3 to outline expert judgement commentary around mapping (and potential for CCRA4 mapping).

A.3.1 The framework

The assessment contained scored columns for:

- Associated climate hazards, impacts and drivers
- Can the hazard be spatially mapped? (Yes or no)
- Is the associated hazard mapping ascribed within CCRA3? (Yes or no)
- Is there other mapping available? (Yes or no)
- Links to external mapping if the above was answered 'yes'
- Are climate change (CC) projections applicable or present to the hazard available? (Yes or no)
- CC Projections with a more granular Spatial Dimension:
  - High 1 - Local projections
  - Medium 2 - Regional projections
  - Low 3 - National projections
  - Does not Feature for this risk 4
- Number of Associated risks for the given hazard (>3 high, 2-3 med., 1 low)
- Limitations - Expert Judgement & Scoring (+2/+1/-1/-2)
  - At this stage, expert judgement outlined limitations for current spatial mapping of certain hazards.
  - For example. Where mapping uses UKCP09 rather than up to date UKCP18 modelling this was highlighted and scoring adjusted so as to push the hazard priority up for further assessment. As an update to modelling may provide new avenues for spatial risk mapping and assessment.
- General comments - highlighting possible gaps for further assessment, such as whether or not a particular hazard lent itself to a spatial context.

Early scoring attempted to produce a mixture of hazards that met the threshold to take into asset assessment. Asset assessment involved reviewing re-aggregated risks by their scoped hazards against these columns:

- Do the assets impacted have a spatial association (Yes/No)
- Is the asset mapped within CCRA3? (Yes/No)
- Asset Environment (Urban/Rural/Both) (Coastal/Inland/Both)
- UK-wide CCRA3 Urgency Score (High 6, Med 4, Low 0)
- Adaptation Shortfall (Yes 6, In part 4, No 0)

The UK CCRA3 supporting information was used to confirm and tabulate these values - as well as urgency score.

A.3.2 Early Limitations

The first iteration identified a range of hazards (and their associated risks) that may have been suitable for further prioritisation and assessment. However, these were not clearly defined as suitable for pilot or case studies.

Moreover, the process was convoluted and lacked simplicity. After early quality assurance and review, the project team identified that a process that engaged with the UK CCRA3 chapters more and used straightforward distinctions would be more desirable and help to justify decision making. Another limitation to this iteration of the framework was the shortcomings of utilising CCRA3 terminology that was not standardised for hazards, risks and assets across chapters of CCRA3. Though, heatwaves, high temperature and heat stress are all distinct and it is reasonable to apply these in differing contexts of assets, this made it difficult to understand the usefulness of mapping wherein there is not much that separates the actual spatial assessment indicators.

This highlights that the CCRA3 process itself lacks a standardisation process, whereby physical climate conditions are not formalised. As a consequence of this further review of chapters was required to assure findings, followed by further cross-referencing to identify available spatial data. Expert judgment at this stage also highlighted whether it would be useful or not for the risk to be spatially mapped or whether it would contribute to enhanced adaptation potential within the CCRA4 scope of works.

A.3.3 Climate Impact Driver Framework

To standardise CCRA3 hazard, impact and driver terminology an international framework, the Climate Impact Driver (CID) Framework (IPCC, 2021) was used (see Figure 0-2 below). Consequently, the climate hazards, drivers and impacts identified in the UK CCRA3 were mapped across to the CID framework terminology. One exception explored with the CCC such as the addition of risks such as 'wind drought'. Ruane et al. (2022) supporting the inclusion of certain hazards and drivers into the CID framework by describing the formal approach to categorising climatic impact-drivers according to specific connections between physical climate conditions and affected assets. To aid the scoping of CIDs internal discussion, the team engaged with (Ruane et al., 2022) summary tables displaying confidence in the direction of projected changes of CIDs for European regions (for Northern Europe).

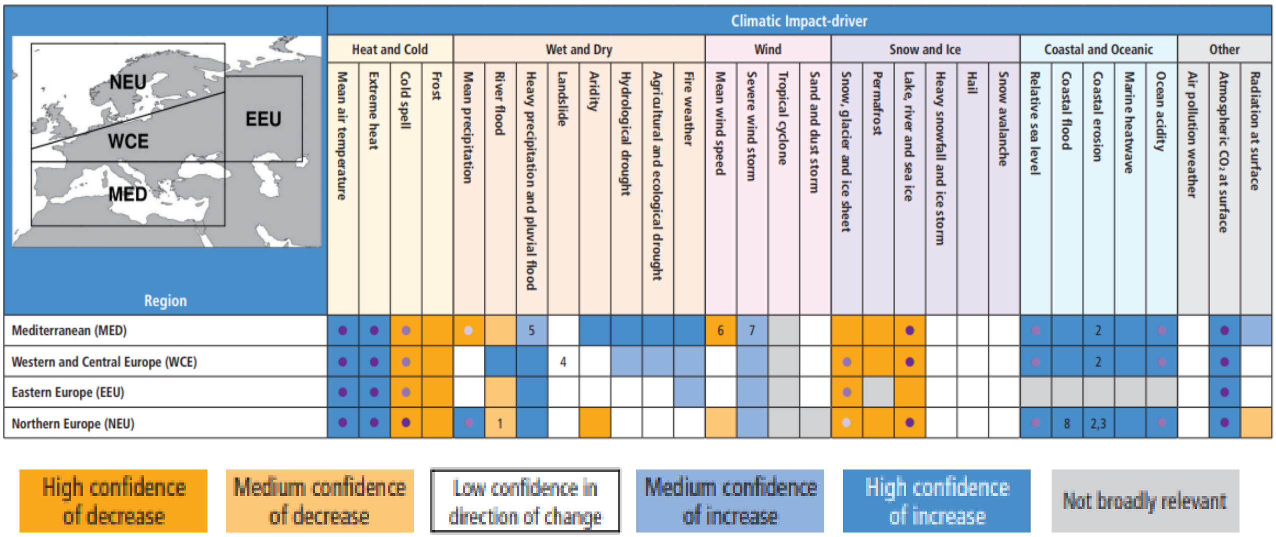

Figure 0-2. Summary of the confidence in direction of projection changes in CID in Europe

A.3.4 Decision Tree Model - Second iteration

Following client feedback and internal discussion, a second iteration of the framework was developed. This iteration aimed to simplify the process and further divide and assess the risks to prioritise risks for spatial assessment. The framework utilised a scoping tree (Figure 0-3 below) to inform the assessment. At the outset, this process offered a clearer way of identifying a suitable long list of risks across assessments. The assessment aimed to better identify the priority areas for spatial risk assessment as well as case and pilot studies, illustrating the priority risks where spatial analysis would be most useful and the likely

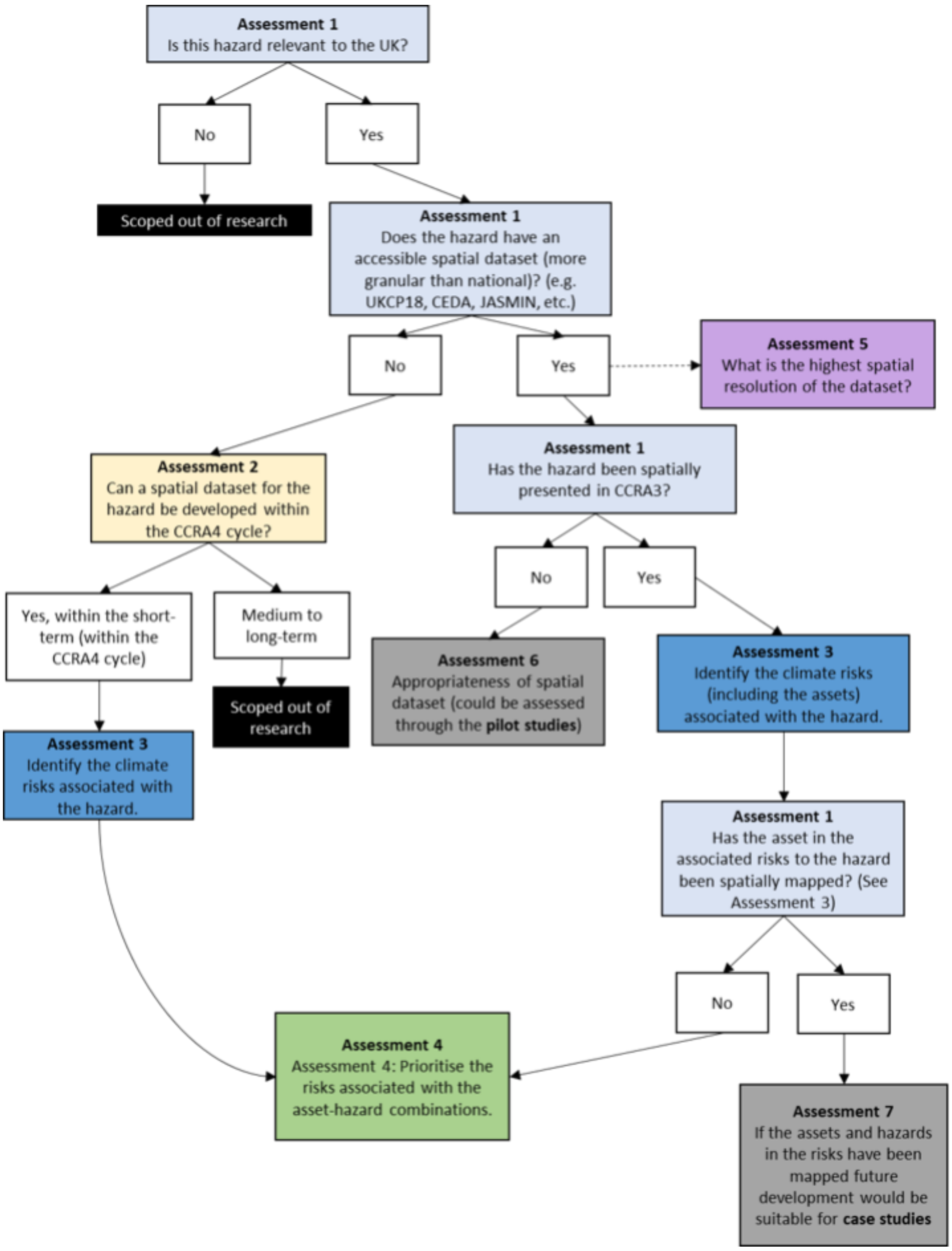

Figure 0-3. Decision tree from second iteration of framework

associated challenges. Expert judgement was integrated later into the assessment and was moved into the prioritisation step.

Early referencing tables, information and prior literature review were used to inform the methodology and prioritise areas for spatial risk assessment for UK CCRA4.

Seven assessments were developed within this iteration of the framework (see Figure 0-3). These assessments initially focussed on the climate hazards identified in IPCC AR6, identifying relevant climate hazards to the UK and whether a spatial dataset already existed for the hazard.

Following assessments identified whether the relevant receptors or assets identified for each climate risk associated with each hazard also had a spatial dataset. Assessments also identified whether there was the time and resources required to develop the spatial dataset for a hazard. This process created a short list of climate risks, which could be prioritised for spatial risk assessment.

To prioritise this short list, a follow-on assessment identified the risks with the greatest urgency and adaptation shortfall according to CCRA3, but also included expert opinion on the impact a spatial dataset may have on improving the UK's climate resilience and whether the dataset would align with identified user needs.

This prioritisation identified the climate risks that may have the largest impact on improving the understanding of the UK's risks and consequently, the resilience of the UK. This framework did not complete the spatial risk assessment for each climate risk for each country but prioritised climate risks relevant to all countries - England, Wales, Scotland and Northern Ireland.

A.3.5 Case Study Longlist - Overlap with Pilot study Risks

Spatially assessed climate risk	Associated hazard spatially assessed	Associated hazards that were considered for pilot assessment
B1: Risks to businesses from flooding	River flood, Coastal flood, Heavy Precipitation and Pluvial flood	N/A
B3: Risks to businesses from water scarcity	Hydrological drought, Mean air temperature and Coastal erosion (Saline intrusion)	N/A
B4: Risks to finance, investment and insurance including access to capital for business	Heavy precipitation and Pluvial flood	Mean wind speed and Landslide

Spatially assessed climate risk	Associated hazard spatially assessed	Associated hazards that were considered for pilot assessment
I2: Risks to infrastructure services from river and surface water flooding	River flood, Heavy precipitation and Pluvial flood	N/A
I3: Risks to infrastructure services from coastal flooding and erosion	Coastal flood and Relative sea level	Coastal erosion
I8: Risks to public water supplies from reduced water availability	River flood, Hydrological drought, Mean air temperature, Heavy Precipitation and Pluvial flood	N/A
H3: Risks to people, communities and buildings from flooding	Heavy Precipitation and Pluvial flood, Relative sea level, Coastal flood and Mean precipitation	N/A
H4: Risks to coastal communities from sea level rise	River, Coastal and Pluvial flooding, Relative sea level, Heavy precipitation.	Coastal erosion
H12: Risks to health and social care delivery	Mean precipitation, River flood, Coastal flood, Heavy Precipitation and Pluvial flood	Mean air temperature, Extreme heat, Cold spell, Landslide, Hydrological drought, Fire Weather, Mean wind speed, Snow, Relative Sea level, Coastal erosion and Severe windstorm
H13: Risks to education and prison services	River flood, Coastal flood, Heavy Precipitation and pluvial flood	Extreme heat, Mean air temperature, River flood, Landslide, Fire Weather, Mean wind speed, Relative sea level, Coastal flood, Heavy Precipitation and Pluvial flood

A.3.6 Learning from the first iteration

Following an internal workshop to discuss preliminary results the project team and CCC discussed the need to condense the prioritisation list. The decision tree framework provided a number of different lists of hazard/asset combos but not necessarily the prioritisation of risks identified in CCRA3. Following this discussion, the decision was made to not take the prioritised list from Assessment 4 any further within this research.

The output of hazard/asset/risk combinations meant that a phase of expert judgement across 52 risks would be required within Assessment 4.

Therefore, the project team assessed two options:

1. Rework the framework to provide more clarity for expert judgement around top-scoring risks.
2. Consult with chapter authors from UK CCRA3 to look at the top-rated risks identified from the scoring for a sense check (and to prioritise the risks where possible).

Through further internal discussion with the CCC, we identified the need to use the pre-existing review to identify where asset-hazard combinations had already been spatially mapped together.

Moreover, this exercise needed to be supplemented with information relating to whether there was a recommendation for more spatial information for a risk within CCRA3. Equally, there needed to be a consideration of whether further spatial information was recommended for adaptation actions.

Finally, we discussed the difference between how we prioritise data availability, as opposed to the urgency and shortfall of the risk (including opportunity and adaptation). There was a clear need to separate these considerations for earlier stages of the assessment, contrasted by the need to reaggregate and re-assess them later on in the assessment, to shortlist pilot and case studies.

B Results of assessment framework

Table 0-1 - High scoring risks (significant benefit)

Risk ID	Risk	Score	Data availability score (*not included within the total score*)	Are there associated interdependent risks / interactions (0-2)	Adaptation shortfall (& confidence) (0-6)	CCRA urgency score (using the UK wide score) (0-6)	Expert judgement (0-2)	What spatial scale would most benefit the receptor or user of the risk to improve their resilience to climate change? (0-3)
H4	Risks to coastal communities from sea level rise	16	2/1	2	3	6	2	3
H11	Risks to cultural heritage	14	2	2	5	3	2	2
H13	Risks to education and prison services	16	1	2	5	5	2	2
I3	Risks to infrastructure services from coastal flooding and erosion	15	1	2	5	3	2	3
N5	Risks and opportunities for natural carbon stores, carbon sequestration	13	1	2	2	4	2	3

Risk ID	Risk	Score	Data availability score (*not included within the total score*)	Are there associated interdependent risks / interactions (0-2)	Adaptation shortfall (& confidence) (0-6)	CCRA urgency score (using the UK wide score) (0-6)	Expert judgement (0-2)	What spatial scale would most benefit the receptor or user of the risk to improve their resilience to climate change? (0-3)
	and GHG emissions from changing climatic conditions, including temperature change and water scarcity							
N10	Risks to aquifers and agricultural land from sea level rise, saltwater intrusion	13	1	2	5	2	2	2
N11	Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.	13	1	2	2	5	2	2

Table 0-2 - High scoring risks (moderate benefit)

Risk ID	Risk	Score	Data availability score (*not included within the total score*)	Are there associated interdependent risks / interactions (0-2)	Adaptation shortfall (& confidence) (0-6)	CCRA urgency score (using the UK wide score) (0-6)	Expert judgement (0-2)	What spatial scale would most benefit the receptor or user of the risk to improve their resilience to climate change? (0-3)
H1	Risks to health and wellbeing from high temperatures	15	1, 2, 4	2	4	6	1	2
H7	Risks to health and wellbeing from changes in air quality	15	1, 2, 4	2	4	5	1	3
H10	Risks to water quality and household water supplies	14	2	2	3	6	1	2
I11	Risks to offshore infrastructure from storms and high waves	13	2	0	5	4	1	3
B2	Risks to businesses and infrastructure from coastal change	13	1	2	2	5	1	3

Risk ID	Risk	Score	Data availability score (*not included within the total score*)	Are there associated interdependent risks / interactions (0-2)	Adaptation shortfall (& confidence) (0-6)	CCRA urgency score (using the UK wide score) (0-6)	Expert judgement (0-2)	What spatial scale would most benefit the receptor or user of the risk to improve their resilience to climate change? (0-3)
N1	Risks to terrestrial species and habitats from changing climatic conditions and extreme events, including temperature change, water scarcity, wildfire, flooding, wind, and altered hydrology (including water scarcity, flooding and saline intrusion)	13	1	2	3	5	1	2

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