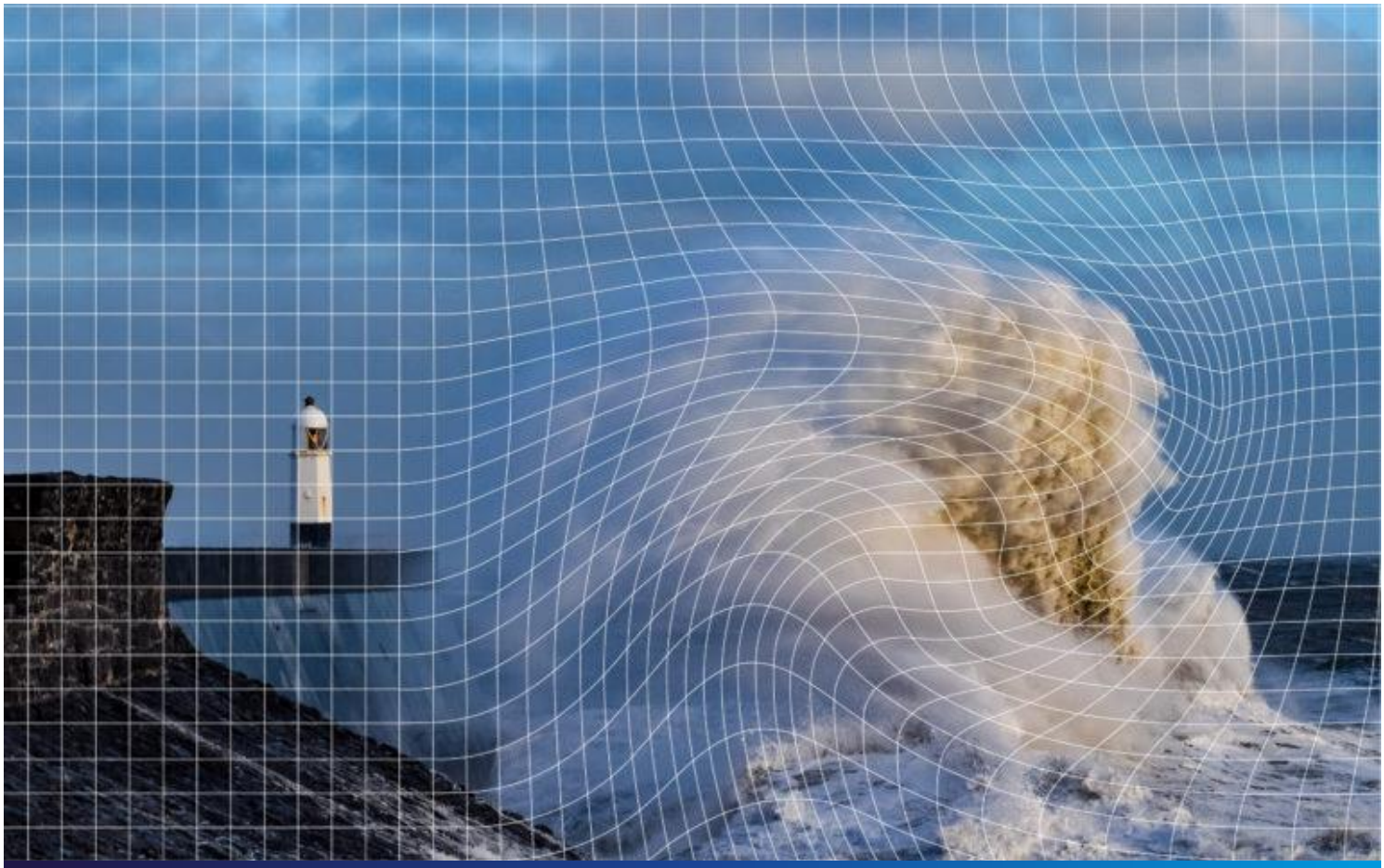

SURVEYING THE EVIDENCE LANDSCAPE FOR UK-FOCUSED SPATIAL CLIMATE RISK ASSESSMENT

Technical report

Report for: Climate Change Committee

Ref. ED17569

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22/06/23

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Appendices

1. INTRODUCTION

1.1 PURPOSE OF THIS REPORT

Ricardo Energy & Environment (Ricardo) and the Tyndall Centre for Climate Change Research (Tyndall) have undertaken this study 'Surveying the Evidence Landscape for UK-Focused Spatial Climate Risk Assessment' on behalf of the Climate Change Committee (CCC).

The fourth Climate Change Risk Assessment (CCRA4) aims to provide a greater level of spatial granularity in its assessment of the climate risks across the UK and present a more localised view of adaptation needs than previous CCRAs. The key purpose of this study is to survey the existing evidence landscape for UK-focused spatial climate risk assessment. This will provide a foundation for the CCC's next Evidence Report – 'The Well-Adapted UK Report' to inform CCRA4.

The study identified existing spatial models, datasets and research initiatives that can be used to assess the spatial distribution of climate risks across the economy and the natural environment. Ricardo has focused on 29 climate risks that received the highest urgency score (more action needed) in the third CCRA (CCRA3), excluding those that are international.

1.2 REPORT STRUCTURE

This report sets out the work undertaken in the following sections:

- Section 2 sets out the methodology of the project and summary statistics for the literature search, survey questionnaire and evaluation;
- Section 3 presents the results in the form of a RAG analysis; and
- Section 4 presents the conclusions and recommendations for further work.

2. METHODOLOGY

The aim of the study was to survey the existing evidence landscape for UK-focused spatial climate risk assessment to inform the CCC's next CCRA Evidence Report. The study had the following research question:

'What is the existing evidence landscape (comprised of spatial models, spatial datasets and research initiatives) for UK-focused spatial climate risk assessment covering the relevant sectors (infrastructure, the built environment, health and communities, the natural environment and business and industry)?'

To answer this research question, we set out the scope of the study based on climate risks to the UK identified in CCRA3. We collected information on spatial models, datasets and research initiatives focused on the UK climate risks with a literature search, survey questionnaire, additional web searches and web scraping. Lastly, the models, datasets and research initiatives were evaluated using pre-defined evaluation criteria in an Excel document (which has been submitted alongside this report). A RAG analysis was conducted which is presented in the Results section of this report to identify gaps for each risk.

2.1 SCOPE OF THE STUDY

The scope of the study was agreed based on the climate risks identified in CCRA3. The Technical Report for CCRA3 identified 61 climate risks cutting across multiple sectors of society. The risks are divided into four different risk areas: 'Infrastructure', 'Health, communities and the built environment', 'The natural environment' and 'Business and industry'. The CCRA3 risks have codes (I1, I2 etc.) which we have retained in our study. Ricardo focused on 29 climate risks that received the highest urgency score ('more action needed') in CCRA3, excluding those that have international impacts. B6 Risks to business from disruption to supply chains and distribution networks was scoped out. Some risks were combined. The full list of risks assessed is shown in Table 1.

Table 1 Climate risks for this project taken from CCRA3

Climate Risks from CCRA3
Infrastructure
I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures
I2 Risks to infrastructure services from river and surface water flooding
I3 Risks to infrastructure services from coastal flooding and erosion
I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events
I8 Risks to public water supplies from drought and low river flows
I9 Risks to energy generation from reduced water availability
I10 Risks to energy from high and low temperatures, high winds, lightning
I12 Risks to transport from high and low temperatures, high winds, lightning
Health, communities and the built environment
H1 Risks to health and wellbeing from high temperatures
H3 Risks to people, communities and rivers from river, surface and coastal flooding
H4 Risks to people, communities and buildings from sea level rise
H6 Risks from summer and winter household energy demand
H8 Risks to health from vector-borne diseases
H12 Risks to health and social care delivery
H13 Risks to education and prison services
The natural environment
N1 + N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))
N4 Risk to soils from changing conditions, including seasonal aridity and wetness
N5 Risks to natural carbon stores and carbon sequestration
N6 + N7 + N8 Risks to agricultural and forestry productivity (including from pests, pathogens and INNS)
N11+ N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS)
N14 + N16 Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS)
N17 Risks to coastal species and habitats due to coastal flooding, erosion and climate factors
Business and industry
B1 Risk to business sites from flooding
B2 Risks to business locations and infrastructure from coastal change

In order to accurately assess spatial climate risks, datasets and models that cover the different components of each risk are required. In other words, evidence is required not only on the changing climate hazard but also the evolving exposure of the asset or system at risk, and the vulnerability of that system or asset. The Intergovernmental Panel on Climate Change (IPCC) defines these terms as follows[1]:

- Hazard – "*The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.*"
- Exposure – "*The presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.*"
- Vulnerability – "*Propensity or predisposition to be adversely affected. Vulnerability encompasses sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*"

To illustrate, the table below outlines the type of data that could be used to spatially assess the risk to health and wellbeing from high temperatures.

[1] IPCC Glossary. Available at: https://apps.ipcc.ch/glossary/

Table 2 The type of data that could be used to spatially assess the risk to health and wellbeing from high temperatures.

Climate Risk	Data required		
	Hazard	Exposure	Vulnerability (combining sensitivity and adaptive capacity)
Risks to health and wellbeing from high temperatures	Spatial data on current temperatures and forecast temperatures in different climate scenarios	Spatial map of existing and planned buildings and population densities	Characteristics of existing and planned buildings with regard to heat waves, current and forecast demographics (age, income level, etc) and other indicators of sensitivity to high temperatures

For this study, a research initiative is defined as an organisation, funding body, funding scheme or program that conducts or promotes ongoing or future research on the spatial climate risks assessed in this study.

2.2 LITERATURE SEARCH

2.2.1 Search criteria

The literature search conducted by Tyndall was intended to reveal academic sources of models and datasets referenced in publications. The search used the Web of Science search engine and focused on literature from 2015 onwards.

The search terms were specific to the climate risk areas from CCRA3 identified as relevant for this study and were categorised into central, primary, secondary and tertiary search strings. The central search string, applicable to all risks, aimed to narrow the search to papers that referred to spatial models or datasets. The primary search string focused on the hazard for a given risk and the secondary one on the asset or system at risk. The tertiary search string narrowed the search to the relevant geography.

A preliminary list of search terms was developed by Ricardo and quality assured and tested by Tyndall. The search terms were then refined to increase the relevance of the search results. The final search terms are shown in Table 3. Additional changes were made to five CCRA3 risks in which the initial results yielded few papers. These are shown in Table 4. Tyndall first screened the papers by the title, then by the abstract for relevance. Links to the final set of papers were shared with Ricardo to conduct the evaluation.

Table 3 Search terms used in the literature search for each CCRA3 risk

Climate risk areas	Search strings		
	Central		
	(model* OR spati* OR GIS*)		
	Primary (hazard)	Secondary (asset or system at risk)	Tertiary (geographic location)
Infrastructure			
I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures	(drought* OR energy OR transport OR ICT OR climate cascade OR cascade infrastructure failure OR cascade failure)	(water infrastructure* OR water sector OR energ* infrastructure* OR power infrastructure* OR energ* system* OR power station* OR electricity substation* OR transport infrastructure* OR road network* OR rail network* OR train station* OR airport* OR telecommun* infrastructure* OR ICT infrastructur* OR sewer network* OR highway* OR rail network* OR canal* OR inland waterway*)	(United Kingdom OR UK OR Great Britain OR England OR Northern Ireland OR Wales OR Scotland NOT Australia)
I2 Risks to infrastructure services from river and surface water flooding	(river flood* OR surface water flood* OR surface flood* OR fluvial flood*)	(water infrastructure* OR water sector OR energ* infrastructure* OR power infrastructure* OR energ* system* OR power station* OR electricity substation* OR transport infrastructure* OR rail network* OR train station* OR road network* OR airport* OR telecommun* infrastructure* OR ICT infrastructur* OR sewer network*)	
I3 Risks to infrastructure services from coastal flooding and erosion	(coast* flood* OR coast* erosion OR coast* processes OR sea level* OR water level* OR storm surge* OR astronomical tide* OR wave* OR cliff break* OR cliff fall*)	(water infrastructure* OR water sector OR energ* infrastructure* OR power infrastructure* OR energ* system* OR power station* OR electricity substation* OR transport infrastructure* OR rail network* OR train station* OR road network* OR airport* OR telecommun* infrastructure* OR ICT infrastructur* OR sewer network*)	
I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events	(heavy rain* OR slope fail* OR embankment fail* OR embankment slip*)	(transport* network OR transport infrastructure* OR road network* OR highway* OR rail network* OR canal* OR inland waterway*)	
I8 Risks to public water supplies from drought and low river flows	(drought OR low river flow* OR arid*)	(water suppl*)	
I9 Risks to energy generation from reduced water availability	(water availab* OR reduced water availab* OR water suppl* OR water deficit* OR drought* OR water resource* OR groundwater recharge OR reservoir*)	(energy* OR energ* generation OR electricity generation OR power station OR electricity substation OR energ* infrastructure OR power suppl* OR energy suppl* OR electricity suppl* OR power infrastructure)	

Climate risk areas	Search strings		
	Central		
	(model* OR spati* OR GIS*)		
	Primary (hazard)	Secondary (asset or system at risk)	Tertiary (geographic location)
I10 Risks to energy from high and low temperatures, high winds, lightning	(extreme* temperature* OR high temperature* OR heatwave* or heat wave* OR heat island* OR hot day* OR maximum* temperature* OR Tmax OR tropical night* OR heating degree day* OR summer day* OR low temperature* OR minimum temperature* OR Tmin OR cooling degree day* OR frost day* or icing day* OR snow* OR sleet* or ice* OR wind* OR high wind* OR severe wind* OR wind storm* OR windstorm* OR wind chill* OR wind* speed* OR storm track* OR lightning* OR lightning strike* OR lightning flash*)	(energy* OR energ* generation OR electricity generation OR power station OR electricity substation OR energ* infrastructure OR power system* OR power suppl* OR energ* suppl* OR electricity suppl* OR power infrastructure OR energ* demand* OR heating demand* OR cooling demand* OR energ* consum* OR power consum* OR electricity consum* OR distribut* OR energ* efficien* OR power line* OR wind turbine* OR energ* sector OR energ* network* OR power system*)	
I12 Risks to transport from high and low temperatures, high winds, lightning	(extreme* temperature* OR high temperature* OR low temperature* OR high wind* OR lightning*)	(transport* network* OR rail network* OR road network* OR bridge* OR highway* OR air travel OR port)	
Health, communities and the built environment			
H1 Risks to health and wellbeing from high temperatures	(high temperature* OR heatwave* OR heat wave* OR overheat* OR heat island*)	(public health OR mental health OR maternal health OR wellbeing OR productivity OR built environment)	(United Kingdom OR UK OR Great Britain Britain OR England OR Northern Ireland OR Wales OR Scotland) NOT Australia)
H3 Risks to people, communities and rivers from river, surface and coastal flooding	(river flood* OR fluvial flood* OR surface flood* OR pluvial flood* OR coast* flood*)	(people* OR communit* OR river* OR propert* OR household* OR residential* OR public health OR mental health OR wellbeing OR cultural heritage)	
H4 Risks to people, communities and buildings from sea level rise	(sea level* ris* OR sea-level ris* OR coastal change*)	(people* OR communit*OR settlement* OR property*)	
H6 Risks from summer and winter household energy demand	(temperature variabilit* OR variab* temperature* OR high temperature* OR low temperature*)	(hous* energ* demand OR home* energ* demand OR residential energ* demand OR hous* cooling demand OR hous* heating demand)	
H8 Risks to health from vector-borne diseases	(vector-borne disease* OR vector borne disease* OR mosquito-transmitted disease* OR dengue OR chikungunya OR malaria)	(health)	

Climate risk areas	Search strings		
	Central		
	(model* OR spati* OR GIS*)		
	Primary (hazard)	Secondary (asset or system at risk)	Tertiary (geographic location)
H12 Risks to health and social care delivery	(flood* OR heatwave* OR extreme weather OR heat* OR storm* OR drought*)	(health care OR healthcare OR social care OR ICT OR IT service* OR laboratory service* OR patient* discomfort OR patient* distress OR visitor* discomfort OR visitor* distress OR medicine degradation OR medicine loss OR care home* OR hospital* OR GP surger* OR emergency service*)	
H13 Risks to education and prison services	(heat risk* OR internal temperature* OR overheat* OR indoor temperature OR flood* OR heavy rain* OR landslide* OR slope failure* OR ambient temperature* OR exceed comfortable condition*)	(education* OR prison* OR school* OR penitentiar*)	
The natural environment			
N1 + N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))	(chang* clima* OR var* clima* OR climat* chang* OR temperature OR water scarc* OR wildfire* OR flood* OR wind OR altered hydrology OR saline intrusion OR pest* OR pathogen* OR Invasive Non-Native Species OR INNS OR non-native species OR invasive species)	(terrestrial species OR terrestrial habitat* OR terrestrial fauna OR terrestrial flora)	(United Kingdom OR UK OR Great Britain OR England OR Northern Ireland OR Wales OR Scotland) NOT Australia)
N4 Risk to soils from changing conditions, including seasonal aridity and wetness	(arid* OR wet* OR heavy rain* OR cha* condition* OR chang* climat* OR climat* chang*)	(soil*)	
N5 Risks to natural carbon stores and carbon sequestration	(chang* clima* OR var* clima* OR climat* chang*)	(carbon sto* OR carbon sequest*	
N6 + N7 + N8 Risks to and opportunities for agricultural and forestry productivity (including from pests, pathogens and INNS)	(temperature chang* OR water scarcity OR wildfire* OR flood* OR coast* erosion OR wind* OR pest* OR pathogen* OR Invasive Non-Native Species OR INNS OR non-native species OR invasive species)	(agricult* productivit* OR agricult* yield* OR farm* productivity* OR farm yield* OR forest* productivit* OR timber* yield)	
N11 + N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS)	(reduce* water availability OR high* water temperature* OR water scarcity OR flood* OR phenological shift OR pest* OR pathogen* OR Invasive Non-Native Species OR INNS OR non-native species OR invasive species)	(freshwater species OR freshwater habitat* OR aquatic animal*)	

Climate risk areas	Search strings		
	Central		
	(model* OR spati* OR GIS*)		
	Primary (hazard)	Secondary (asset or system at risk)	Tertiary (geographic location)
N14 + N16 Risks to marine species habitats and fisheries (including from pests, pathogens and INNS)	(temperature* rise* OR acidification OR stratification OR oxygenation OR salinity OR high* water temperature* OR pest* OR pathogen* OR Invasive Non-Native Species OR INNS OR non-native species OR invasive species)	(marine species OR marine animal* OR marine habitat* OR fisheries)	
N17 Risks and opportunities to coastal species and habitats due to coastal flooding, erosion and climate factors	(coast* flood* OR coast* ero* OR clima* factor*)	(coast* species OR coast* habitat*)	
Business and industry			
B1 Risks to business sites from flooding	(flood*)	(business* site*)	(United Kingdom OR UK OR Great Britain OR England OR Northern Ireland OR Wales OR Scotland) NOT Australia)
B2 Risks to business locations and infrastructure from coastal change	(coast* chang*)	(business* location* OR infrastructure OR business* site)	

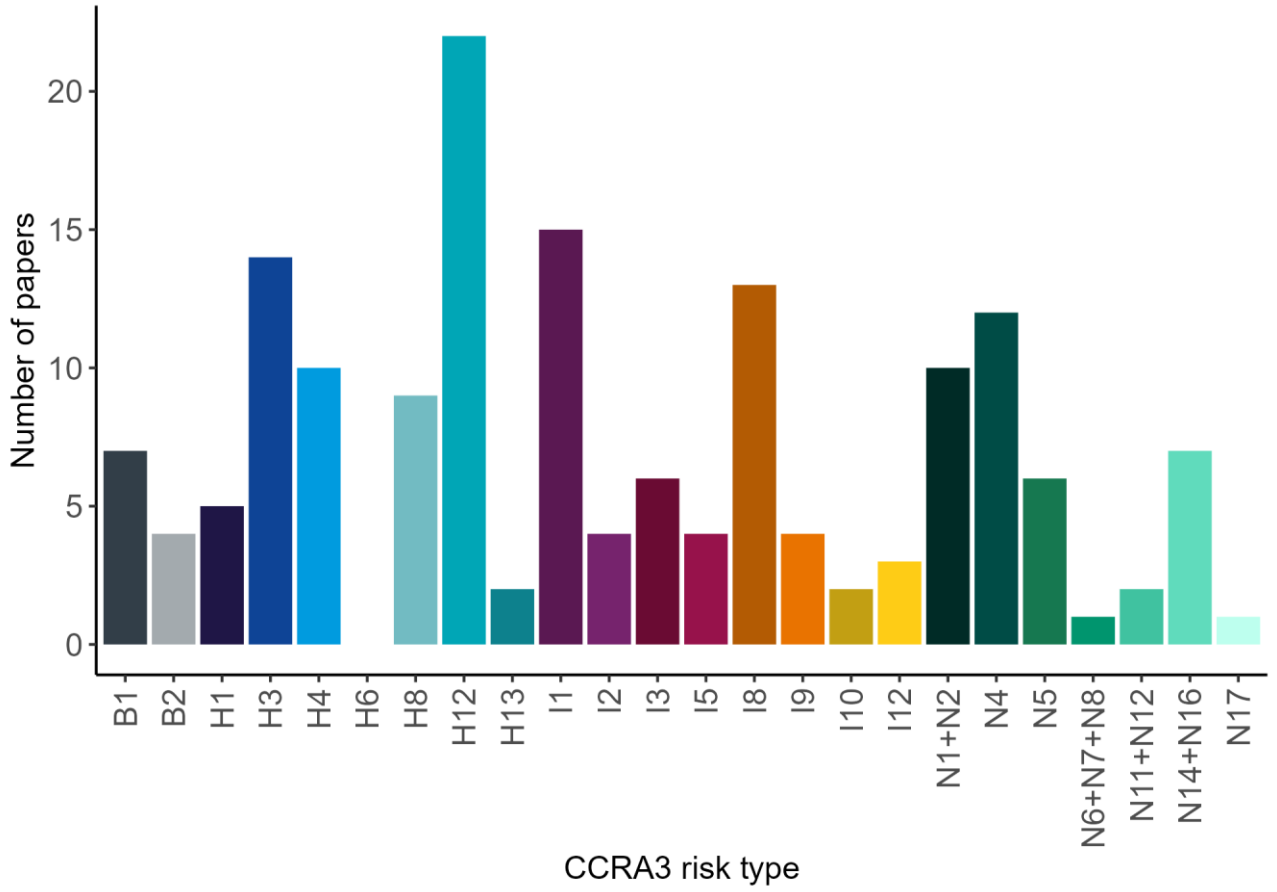
Table 4 Modified search terms and justification

CCRA3 risk	Justification	Revised search terms	Result
B1	No results from initial search terms	Search undertaken without <(model* OR spati* OR GIS*)> as Central search term	61 results - of which 5 were added after 'title' and 'abstract' screening
H6	No results from initial search terms	Search undertaken without <(model* OR spati* OR GIS*)> as Central search term	1 result - not relevant after 'title' and 'abstract' screening
I1	Utilising term 'critical infrastructure' which was omitted from initial search terms	Search undertaken with <“critical infrastructure”> as Secondary (asset or system of risk) search term	11 results - of which 2 were added after 'title' and 'abstract' screening
I2	Utilising term 'critical infrastructure' which was omitted from initial search terms	Search undertaken with <"critical infrastructure"> as Secondary (asset or system of risk) search term	1 result - not relevant after 'title' and 'abstract' screening
I3	Utilising term 'critical infrastructure' which was omitted from initial search terms	Search undertaken with <"critical infrastructure"> as Secondary (asset or system of risk) search term	9 results - of which 2 were added after 'title' and 'abstract' screening

2.2.2 Findings

The literature search identified 163 papers. The number of papers for each CCRA3 risk type are shown in Figure 1. The search revealed variation in the number of papers identified for each CCRA risk type, with H12 Risks to health and social care delivery having the highest number of papers, whilst H6 Risks from summer and winter household energy demand had no papers. Only 6 risk types had 10 or more papers, with approximately half of the risk types with less than 5 papers - indicating possible research gaps.

Figure 1 Bar chart of the number of papers identified in the literature search per CCRA3 risk type



2.3 SURVEY QUESTIONNAIRE

In addition to the literature search a supporting stakeholder survey was conducted in order to fill any gaps in knowledge on models and datasets that have not been included in any publications or that are forthcoming from ongoing projects. At least one stakeholder for each UK constituent country and each CCRA3 risk type were contacted. The questionnaire was conducted using the software Alchemer[2] and was opened from 10th March 2023 to 12th May 2023. The questionnaire was structured so that if a respondent answered affirmatively that they were aware of models, datasets or research initiatives relevant to a given risk, they were then asked a further set of questions to determine information on the models, datasets and research initiatives pertaining to the pre-defined evaluation criteria. The questionnaire is provided in Appendix 1.

There were 45 survey respondents with **a third having expertise in more than one risk area** (Figure 2). The number of respondents with expertise in the CCRA3 risk types varied. CCRA3 risk type expertise was **greatest for H3 Risks** to **people, communities and rivers** from river, surface, and coastal flooding and **lowest for H13 Risks** to education and prison services and **I9 Risks to energy generation from reduced water availability** (Figure 3). Although survey questionnaires were sent to respondents from all four constituent countries in the UK, **most of the responses came from England** (Figure 4).

[2] Alchemer software: https://www.alchemer.com/survey/

Figure 2 Venn diagram showing the number of survey respondents per CCRA3 risk area

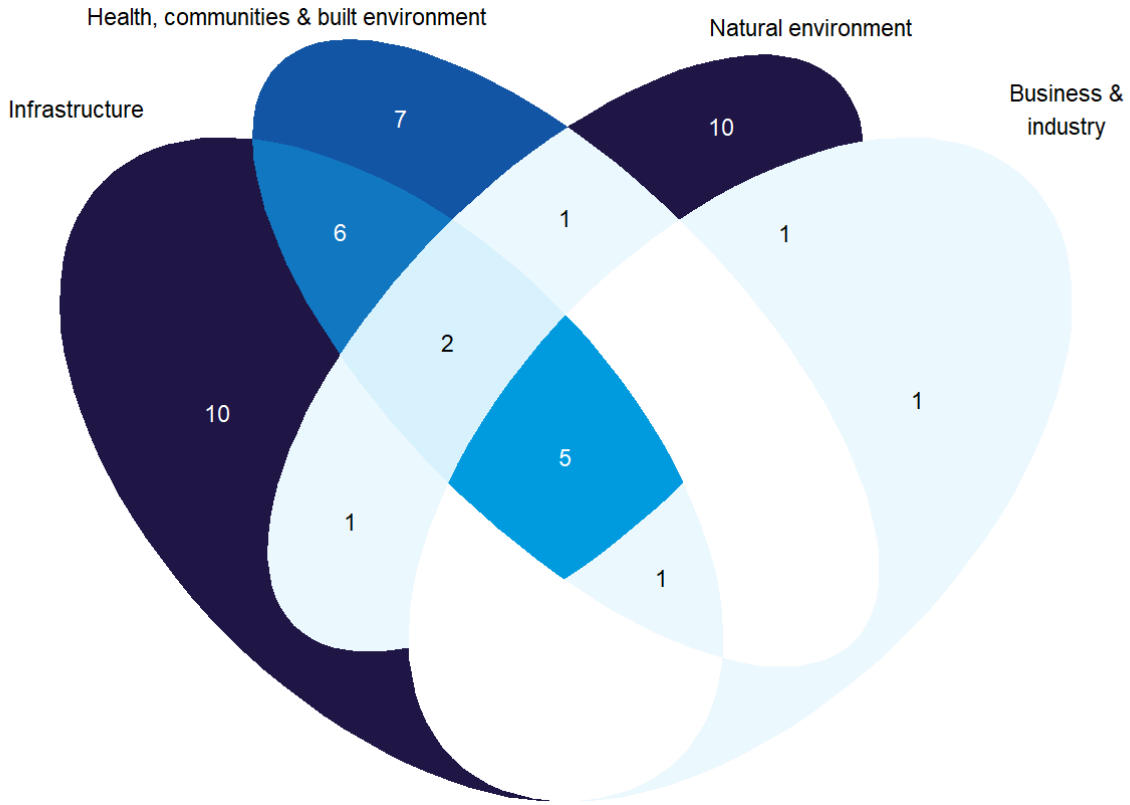


Figure 3 Bar chart showing the number of survey respondents with expertise in the CCRA3 risk types

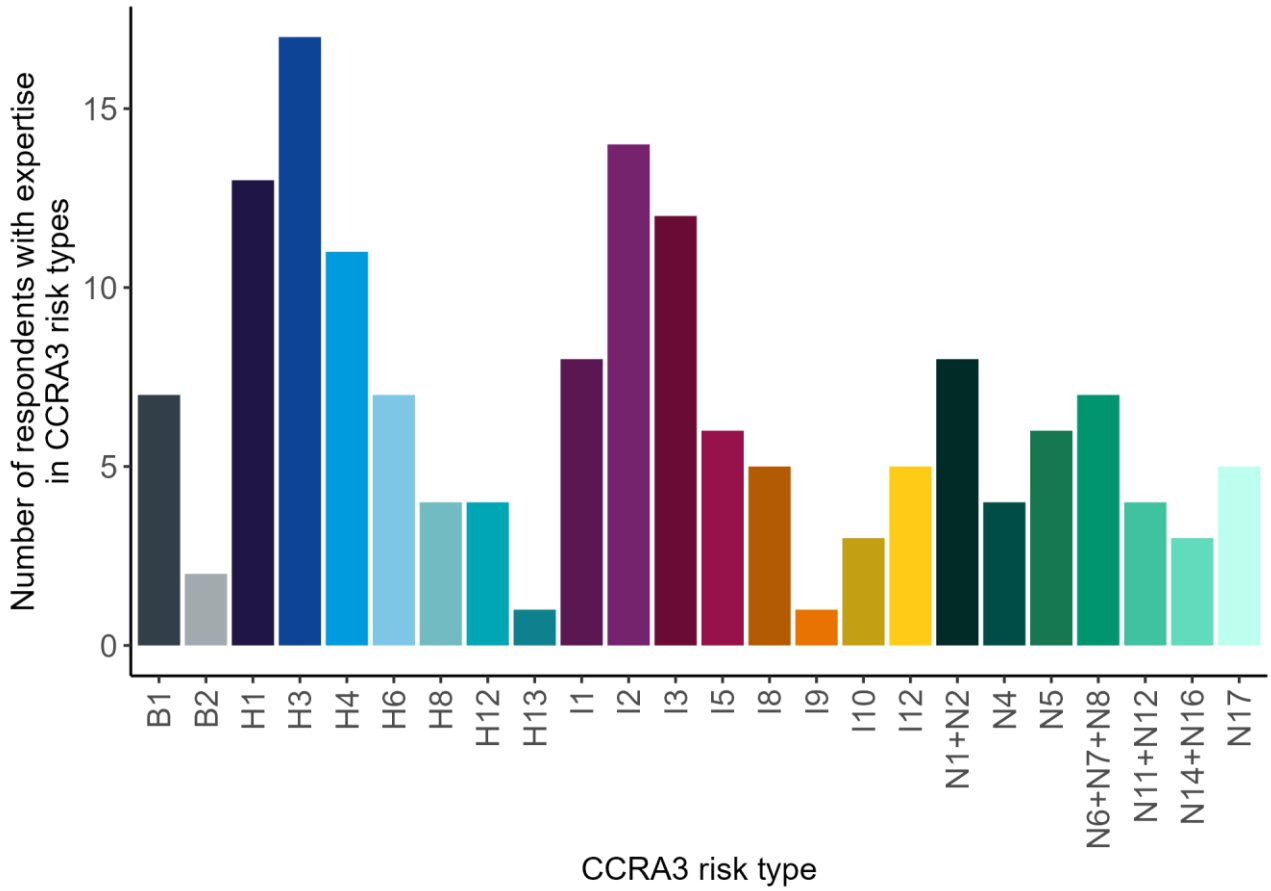
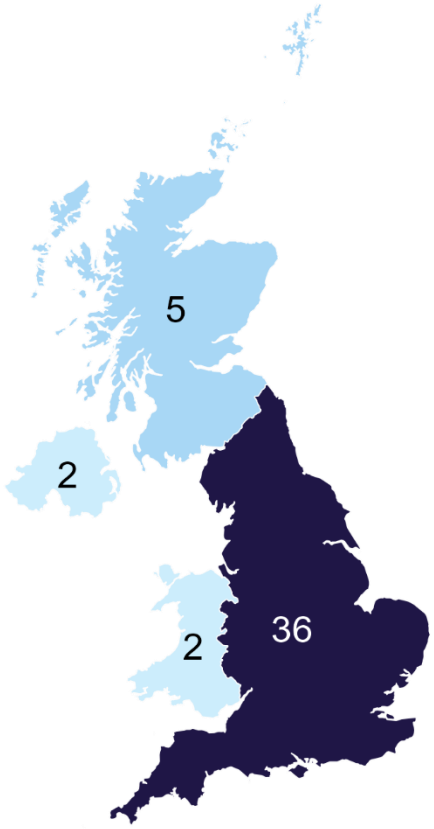


Figure 4 Map showing the number of survey respondents per country



2.4 WEB SCRAPING AND ADDITIONAL DATABASE ENTRIES

To supplement the literature search and survey questionnaire, additional spatial models, spatial datasets and research initiatives were added to the database based on CCC's recommendation, Ricardo experts' recommendations, through a web search and by web scraping the Defra Data Services Platform[3] and the Cefas Data Portal[4]. Additional research initiatives were added to the database from the UKRI NERC List of Awards website[5] by searching for 'climate change' and downloading an Excel file.

2.5 EVALUATION

The project methodology was also finalised in the Inception Phase, including the methods for the literature scan, the stakeholder survey, and the evaluation of the models, datasets, and research initiatives identified. Each model, dataset, and research initiative identified from the literature search, web search and survey questionnaire was evaluated against pre-defined criteria as shown in Table 5. This report is complemented by the evaluation database provided as an Excel document to quickly assess which models and datasets can be used in each sector.

The methods used in this study tried to give an extensive list of existing spatial models, datasets and research initiatives, however, it is possible that some have not been detected by the methods used.

Table 5 Model, dataset and research initiative evaluation criteria

Model evaluation	Dataset evaluation	Research initiative evaluation
CCRA3 Risk	CCRA3 Risk	CCRA3 Risk

[3] https://environment.data.gov.uk/
[4] https://data.cefas.co.uk/
[5] http://gotw.nerc.ac.uk/list_short.asp?searchterm=climate+change&Submit=Search&sb=t&cookieConsent=A

Model evaluation	Dataset evaluation	Research initiative evaluation
Year	Risk component (exposure, hazard, vulnerability)	Research initiative name
Model name	Dataset name	Lead organisation
Ownership	Ownership	Participating organisations
Description	Accessibility	Project timeframe
Paper link	Paper link	Link
Model link	Link	Spatial coverage
Spatial coverage	Time period (years)	Spatial resolution
Spatial resolution	Temporal resolution	Spatial disaggregation
Temporal resolution	Data format	Methodology
Time period (years)	Coordinate reference system	Outputs
Inputs	Data creation method	Limitations
Output data format	Use of dataset in studies	Assumptions
Outputs	Limitations	Source
Uncertainty	Assumptions	
Pre-processing steps	Source	
Assumptions		
Source		

2.5.1 Database completeness

Due to the size of the database following the web scraping and the information available it was infeasible for each column to be completed. Figure 5, Figure 6 and Figure 7 show the percentage completeness for each column. The most important columns (CCRA3 risk, name, link, description etc) are 100% complete.

Figure 5 Bar chart showing the percentage completeness of the model evaluation database by column name

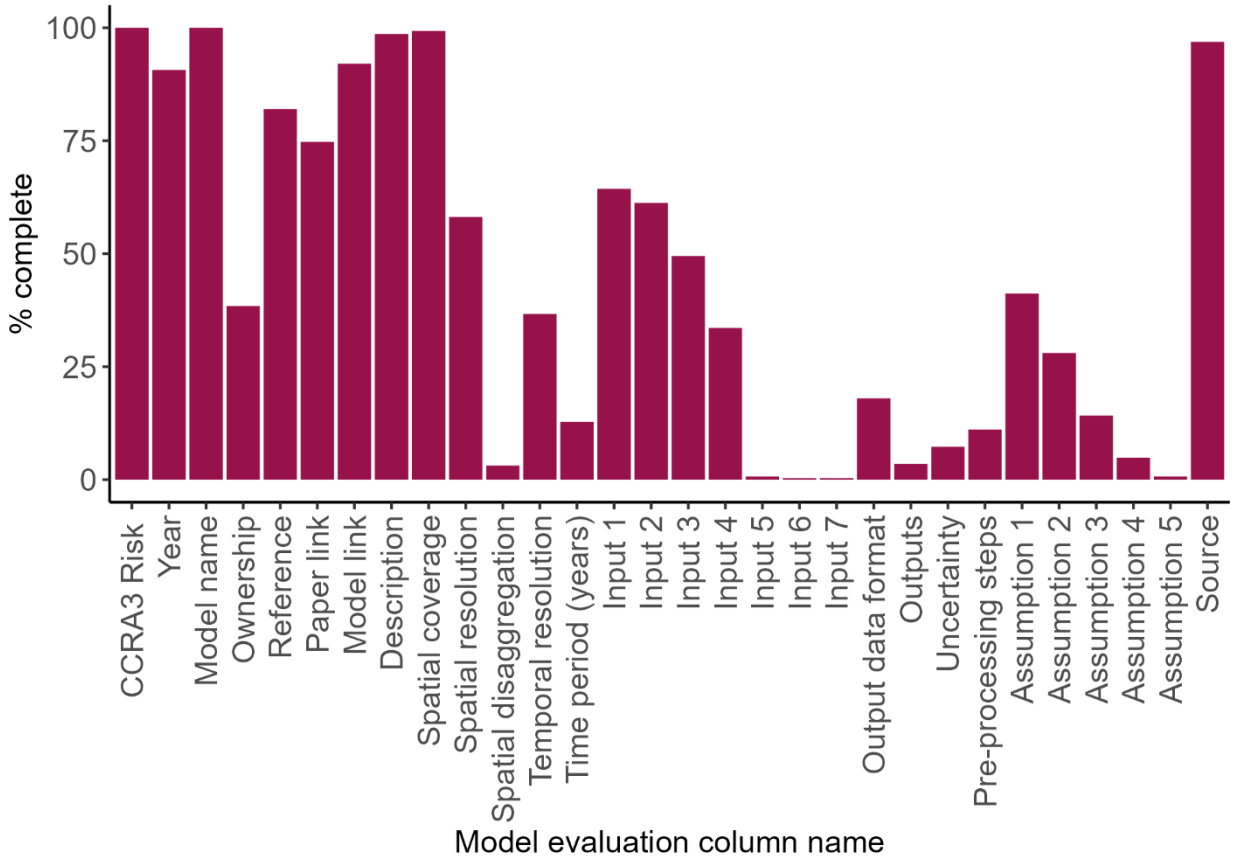


Figure 6 Bar chart showing the percentage completeness of the dataset evaluation database by column name

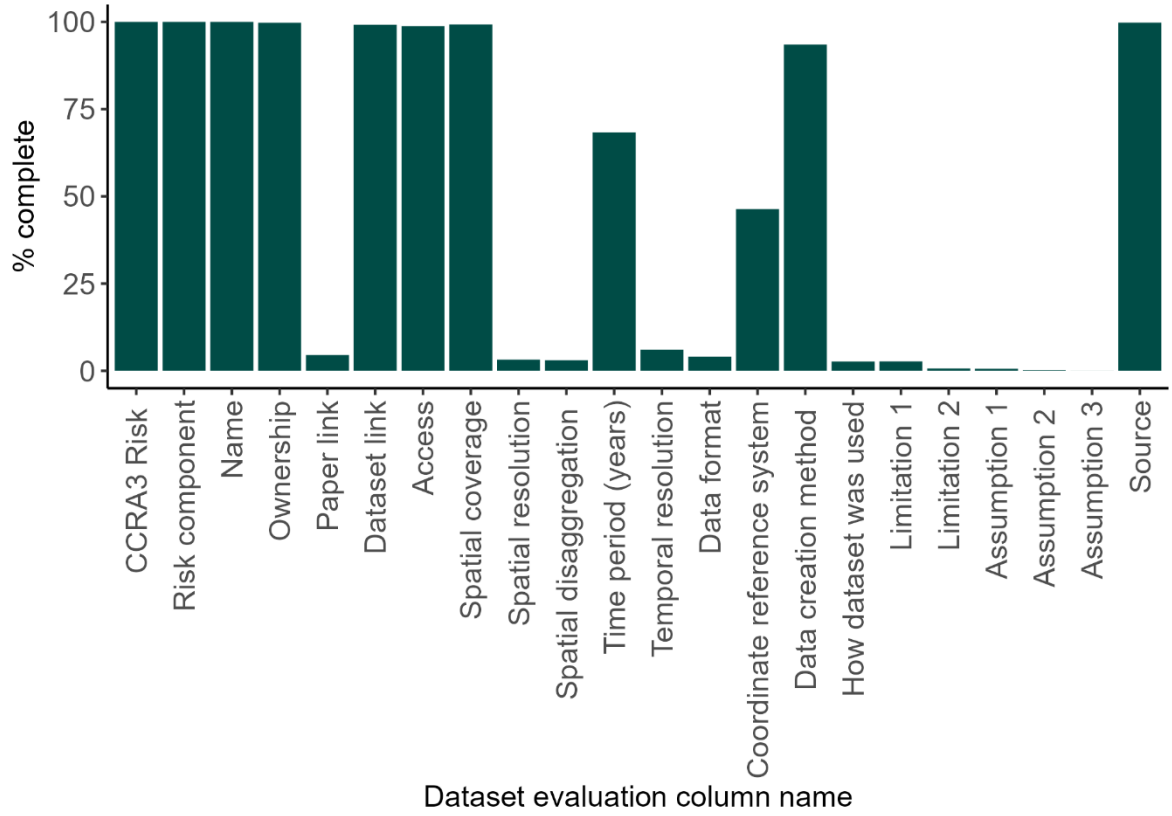
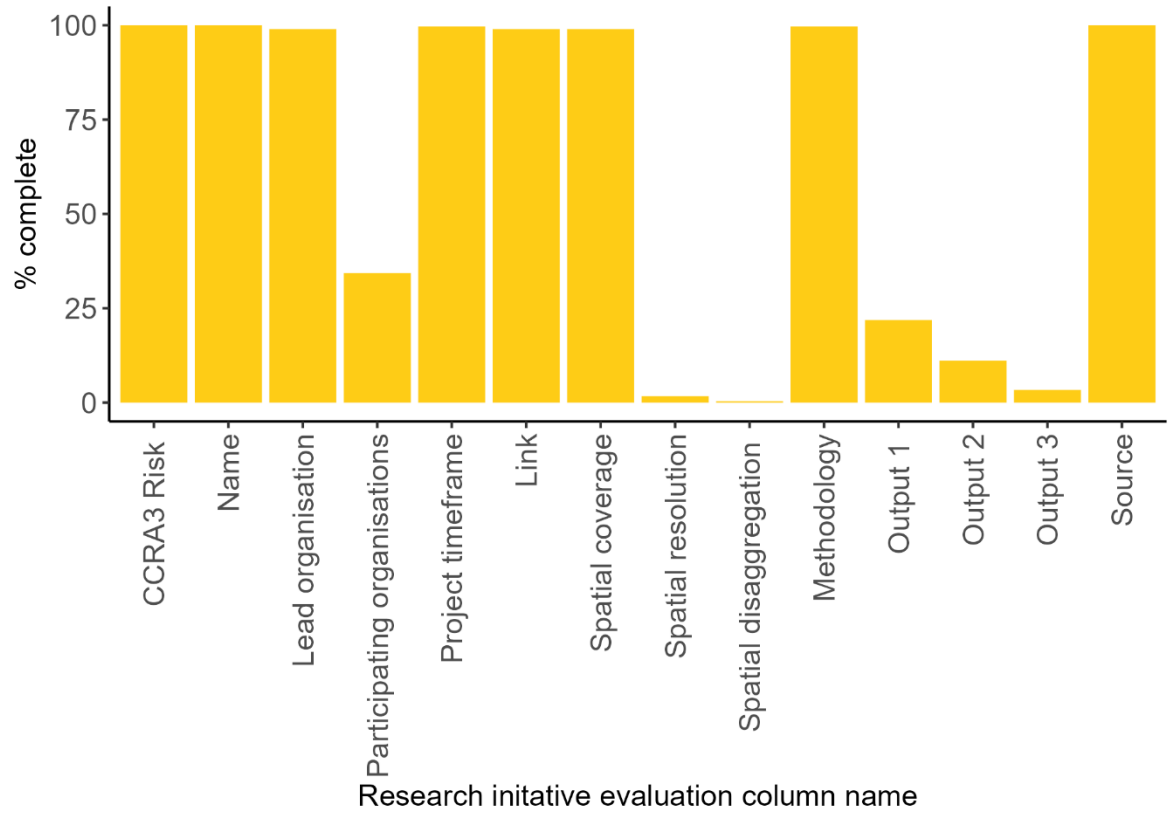


Figure 7 Bar chart showing the percentage completeness of the research initiative evaluation database by column name



2.5.2 Number of models, datasets and research initiatives

Figure 8 shows the number of spatial models identified for each CCRA3 risk type. This number varied between risk types with the highest number of spatial models for H3 Risks to people, communities and rivers from river, surface, and coastal flooding (24 models) and lowest for H13 Risks to education and prison service (1 model).

Figure 9 shows the number of datasets identified for each CCRA3 risk type. Over 50% of the CCRA3 risk types had fewer than 50 datasets identified. The majority of the datasets were found for the natural environment CCRA3 risk group, with the risk group N6+N7+N8 having almost 3500 datasets. From the remaining 3 risk type groups, H3 Risks to people, communities and rivers from river, surface, and coastal flooding had the highest number of datasets identified (~100).

Figure 10 shows the number of research initiatives per CCRA3 risk type. N1+N2 Risks to terrestrial species and habitats (including from pests, pathogens, and invasive non-native species (INNS)) had the largest number of research initiatives followed by N5 Risks to natural carbon stores and carbon sequestration. I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures had the lowest number of research initiatives. Most CCRA3 risk types had 10 or more research initiatives.

Figure 8 Bar chart showing the number of spatial models per CCRA3 risk type

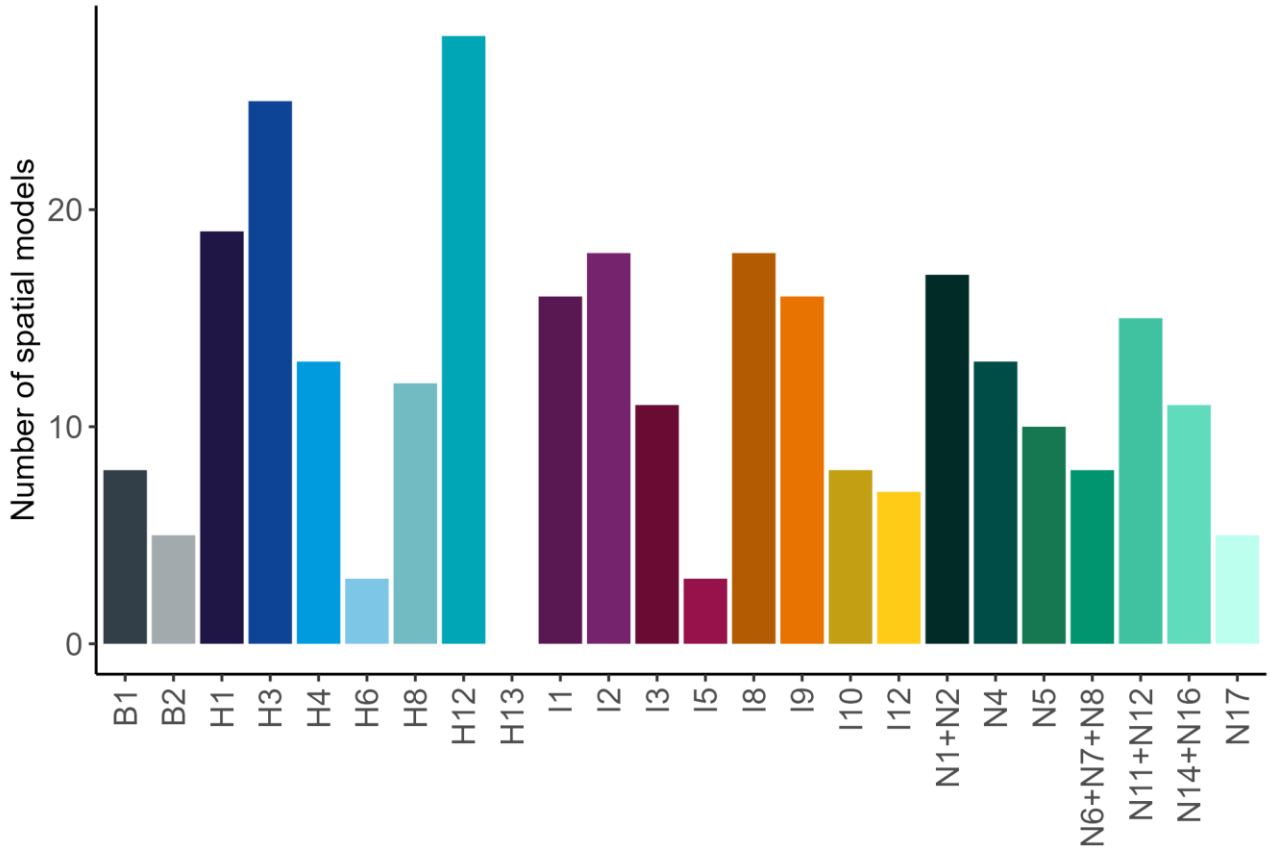


Figure 9 Bar chart showing the number of datasets per CCRA3 risk type

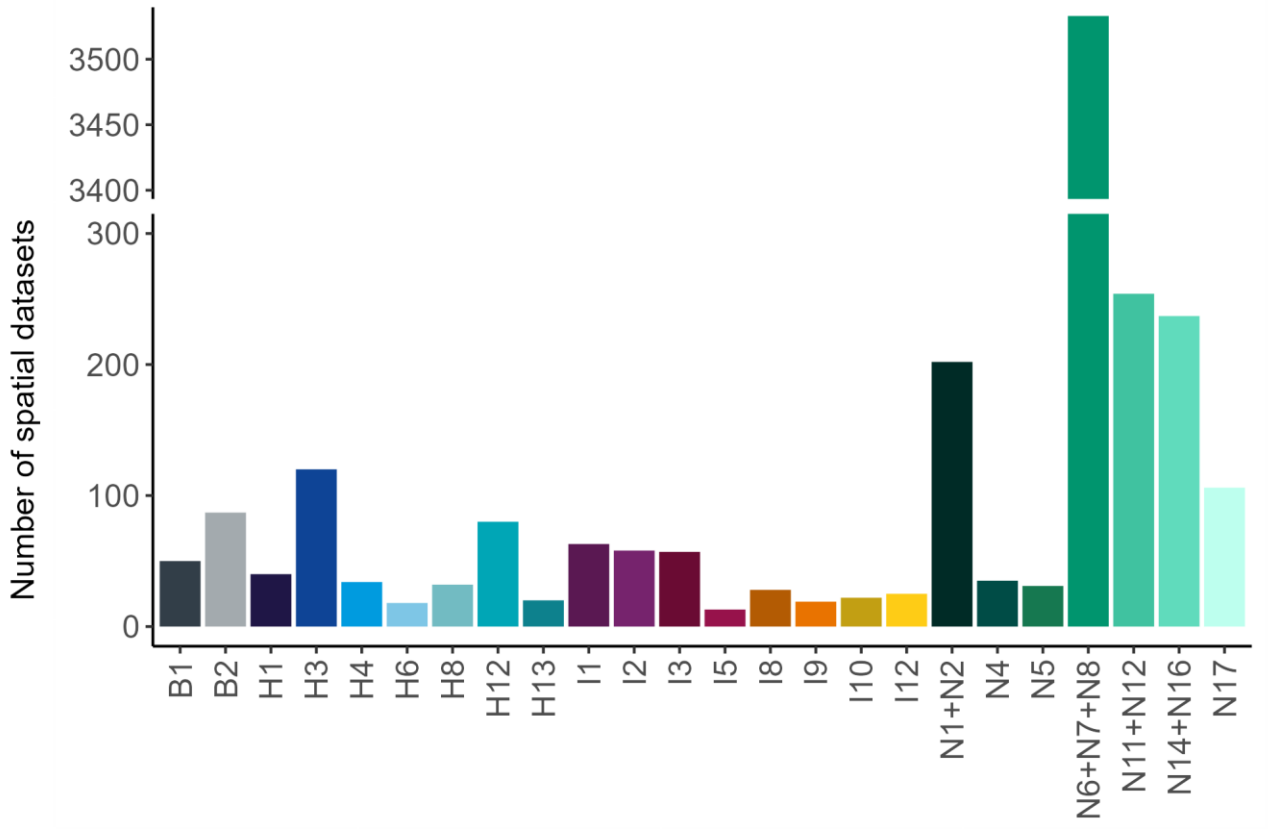
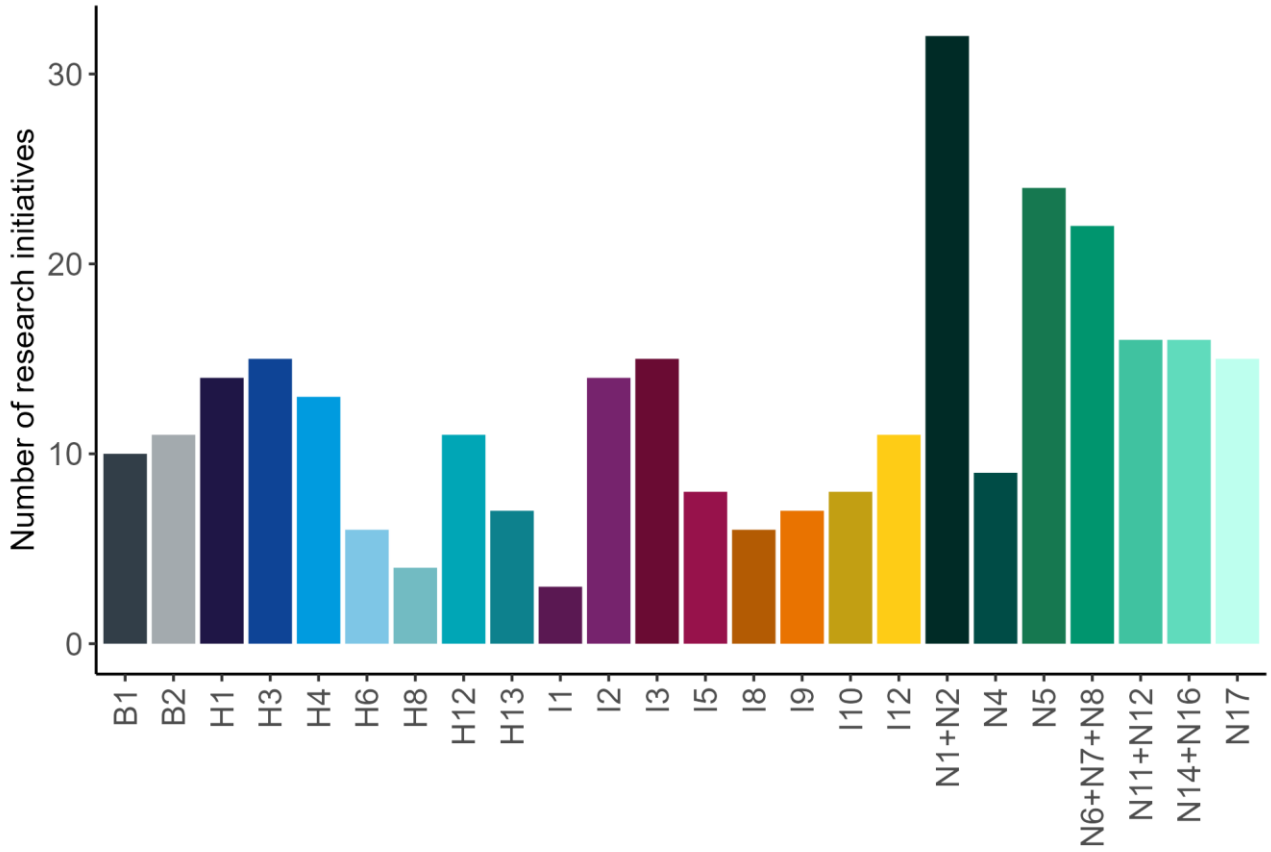


Figure 10 Bar chart showing the number of research initiatives per CCRA3 risk type



2.5.3 Sources

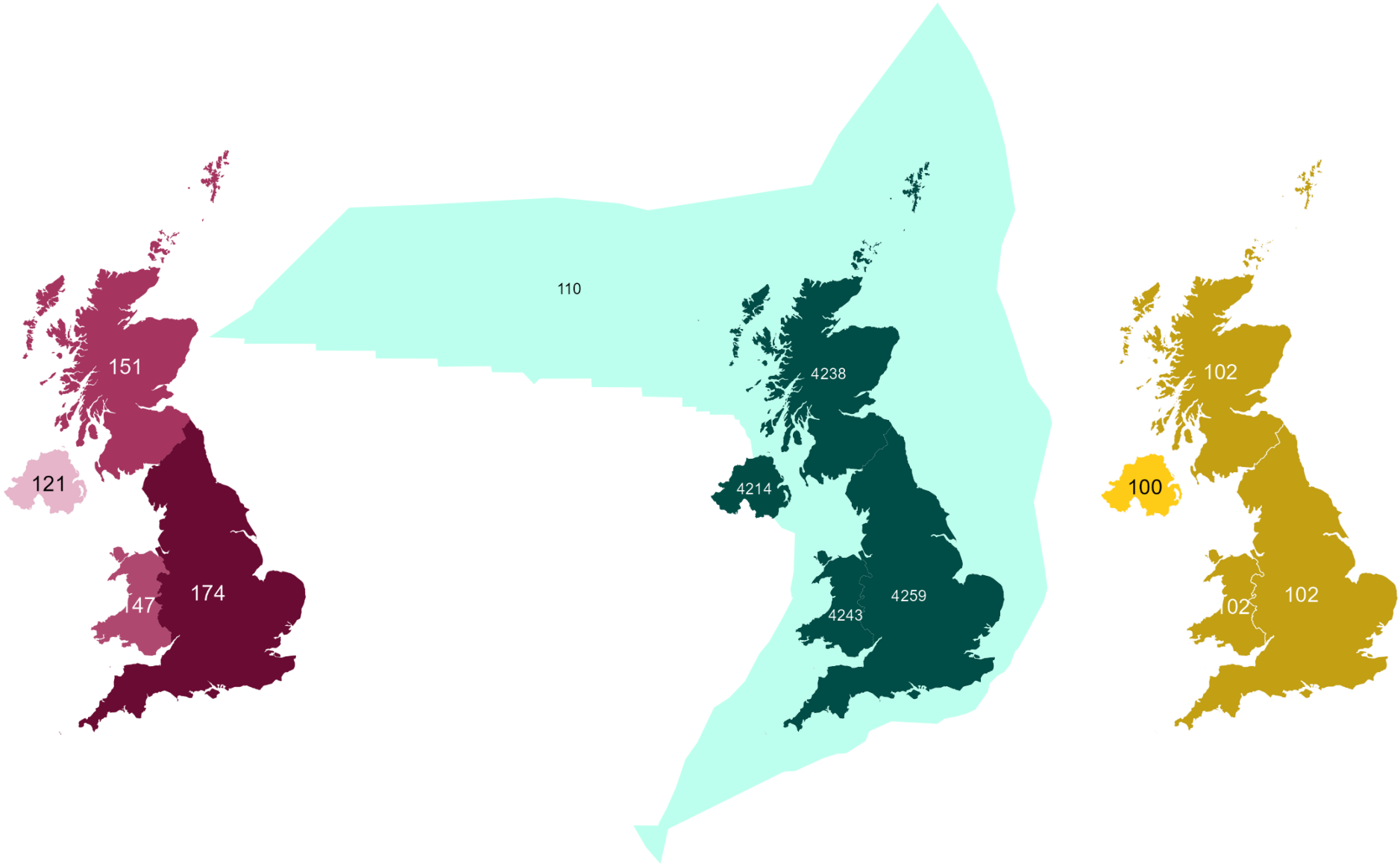
The majority of spatial models were identified in the literature search. Spatial models sourced via the questionnaire, web search and Ricardo expert knowledge, together made up only around 20% of the total spatial models identified. The majority of spatial datasets were sourced from Defra's Data Services Platform (~4300). Literature research and Cefas provided the second and third highest source of spatial datasets. The lowest number of spatial datasets were sourced from the questionnaire and CCC expertise (which together identified less than 40). The majority of research initiatives were sourced from web NERC search (~170), with others sourced from web search and the questionnaire (~50) (see Figure 11).

2.5.4 Coverage

The greatest number of spatial models covered England, with Northern Ireland having the fewest (see Figure 12). Almost all (~4000) spatial datasets covered the UK mainland (i.e., England, Scotland, Wales, and Northern Ireland), with only 110 covering the surrounding marine habitat areas. There were ~100 research initiatives identified for Scotland, England, Wales, and Northern Ireland.

Figure 11 Donut charts showing the sources of the models (in red), datasets (in green) and research initiatives (in yellow)

Figure 12 Maps showing the number of spatial models (in red), datasets (in green) and research initiatives (in yellow) for each country and the UK seas



3. RESULTS

This section details the findings of our analysis on the existing evidence landscape (comprised of spatial models, spatial datasets and research initiatives) for UK-focused spatial climate risk assessment in the following sectors: infrastructure; health, communities and the built environment; the natural environment; and business and industry.

For each risk, the overall availability of models, datasets and/or research initiatives pertaining to each component of risk (hazard, exposure and vulnerability) was evaluated using a RAG analysis. Red indicates that there are significant evidence gaps, yellow indicates minor gaps and green, no gaps. A significant gap (red) constitutes a component of the hazard/exposure/vulnerability that is missing completely. For example, the spatial model covered only one geographical area and cascading failures are not included as per description of the risk area. A minor gap (yellow) is where detail on the risk component is available, but the detail is not sufficient; for example, the spatial data was only focused on England or it covers some types of the asset/system at risk but not others (e.g. energy infrastructure, but not ICT infrastructure).

The results of these RAG ratings are presented in a table at the end of each climate risk's sub-section. The tables present the type of data that could be used to spatially evaluate the hazard, exposure and vulnerability components of each specific risk in question. The colour coding indicates our evaluation of whether this data exists.

It should be noted in the collection of models, datasets and research initiatives, and the categorisation of each climate risk, we followed a conservative approach in refining the database to ensure we kept as much information as possible which could be relevant. One result of this conservativeness, for example, is that some datasets are categorised as potential indicators of vulnerability to a risk, when they are only a loose or partial indicator (such as Agricultural Land Classification or landfill sites). Further research would be required to develop comprehensive methods and data needs for modelling each of the risks.

For spatial model and dataset availability and accessibility, please refer to the accompanying Excel document where this information is provided.

3.1 INFRASTRUCTURE

3.1.1 I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures

Infrastructure networks are interdependent because

(i) their services are reliant on other networks for power, fuel supplies and ICT; or

(ii) they are co-located and experience the same hazard; or

(iii) they are managed or used by the same organisations or people.

Failures can cascade from one infrastructure network to another, often caused by multi-hazards, cascade hazards and compound hazards. The climate drivers of cascade events are increases in summer temperatures, reduction in summer mean rainfall, extreme winter rainfall events and increases in winter mean rainfall. Examples of cascading failures include:

- Flooding (or other significant disruption) of transport networks that can prevent key workers from operating other pieces of critical infrastructure.
- Access to routes to key assets (e.g. nuclear power plants) may not be protected to the same level as the asset itself.
- Reliance on IT and communications infrastructure as an example of a current and increasing risk.

3.1.1.1 Spatial models

Several models were identified for I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures. One notable model identified is NISMOD (National Infrastructure Systems MODel) which models cascading failures of infrastructure networks. In addition, the 'Critical infrastructure impact assessment due to flood exposure model' covers the indirect impacts on critical infrastructure from floods.

3.1.1.2 Datasets

The majority of datasets cover hazards, and specifically flooding. One dataset covers the flood impacts on electricity infrastructure. Other datasets address hydrological, rainfall, air temperature data or present different climate forecasts. Datasets are also available to spatially assess the exposure of infrastructure to hazards. Existing locations of energy, electricity (including transmission and distribution), and transport (including road and rail) are addressed in global, European and UK-specific datasets. Locations of UK water towers and telecom masts are also covered. However, planned infrastructure is not covered and specifications of existing and planned infrastructure is not covered.

3.1.1.3 Research initiatives

There are three research initiatives for I1: the Power and Infrastructure Research Group, the Discipline Hopping (DH) for Discovery Science and DAFNI (Data & Analytics Facility for National Infrastructure).

3.1.1.4 Summary of findings

Current and future hazards are sufficiently covered by the models, datasets and research initiatives. The exposure of infrastructure to hazards is covered for water and transport infrastructure. Both real time data and climate projections are included. Several datasets are available to spatially assess exposure, but none have actually been used to spatially assess exposure to climate risks. There are also some gaps, such as ICT and power infrastructure. There is a lack of vulnerability information on specifications of infrastructure with respect to cascading failures.

Table 6 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures	Cascading failures under current and future climate change scenarios (from changing temperatures and rainfall regimes)	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned water, energy, transport and ICT infrastructure networks with respect to cascading failures

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.2 I2 Risks to infrastructure services from river, surface water and groundwater flooding

River, surface water and groundwater flooding risks are expected to increase across the UK. Especially winter flooding and intense summer and autumn rainfalls are a risk to railway infrastructure. It is considered a high risk at medium confidence and adaptation is slow.

3.1.2.1 Spatial models

There are a total of 15 models within I2 Risks to infrastructure services from river, surface water and groundwater flooding. In comparison to Risk I1, the models focus on the different types of flooding and less so on network impacts. Spatial flood models on 10m to 1km spatial resolution for the UK and Northern Ireland are included. There is no model directly considering the risk of flooding to railway infrastructure or ICT.

3.1.2.2 Datasets

There is sufficient data on flooding risk in the UK. Pluvial (surface water), fluvial (river), groundwater and coastal flooding are all covered. Real time flood data, flood risk hazard maps as well as data on rainfall under different climate scenarios are included. There are six datasets on anticipated future rainfall peaks, river flow peaks, groundwater recharge and climate projections. Existing locations of energy, electricity, and transport (including road and rail) are covered. The vulnerabilities of infrastructure to flooding are only covered in two datasets, which cover public administrative boundaries and drainage boards. These are indicators of adaptive

capacity indicating where a governing body responsible for addressing the risk of river and surface flooding exists, as well as possible sources of funding for adaptation.

3.1.2.3 Research initiatives

There are 13 research initiatives specialising in these infrastructure risks. OpenCLIM and DAFNI (Data & Analytics Facility for National Infrastructure) together fill an important research gap with the National Infrastructure Database and National Infrastructure Modelling Service (with real-time flood modelling and infrastructure impact assessments).

3.1.2.4 Summary of findings

The current and forecast spatial mapping of river, surface water and groundwater flooding hazards are well covered within the models, datasets, and research initiatives. Exposure is only covered by OpenCLIM and DAFNI with the National Infrastructure Database and National Infrastructure Modelling Service. These research initiatives consider several climate risks, and however, there may be information gaps such as for water infrastructure. Vulnerability is a significant gap for this risk because network impacts, railway infrastructure and ICT are not covered by models and only covered by two datasets and research initiatives.

Table 7 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I2 Risks to infrastructure services from river, surface water and groundwater flooding	Spatial data on current flood zones and future ones in different climate scenarios	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned power, transport, ICT and water infrastructure with respect to flooding

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.3 I3 Risks to infrastructure services from coastal flooding and erosion

Coastal flooding and erosion risks from waves, astronomical tides, storm surges and relative mean sea level rise are highest for railway infrastructure and sewage treatment works in the UK.

3.1.3.1 Spatial models

There are a total of 10 models that examine I3 Risks to infrastructure services from coastal flooding and erosion. For coastal flooding there is the JBA UK Flood Model and Fathom UK Flood Map at 5m and 10m resolution respectively. Both are not open access, but the latter has academic licenses available. There is one model for erosion risk covering Scotland. Flooding risk to railways is covered but not to sewage treatment works.

3.1.3.2 Datasets

There are two coastal erosion hazard datasets: the Environment Agency National Coastal Erosion Risk Mapping (NCERM) and the Natural Resources Wales National Coastal Erosion Risk Management map which are used to produced Shoreline Management Plans (SMPs). Other datasets cover sea-level such as Mean Sea Level Data, Tide Gauge Data and Bottom Pressure Records and UK flood risks such as the National Flood Risk Assessment (NaFRA) flood likelihood map data. The exposure of infrastructure to hazards is also covered. In fact, existing locations of energy, electricity, landfill sites and transport (including road and rail) are covered, as well general overviews of coastal areas (including topographic surveys). Data about sewage treatment works is not included. The vulnerabilities of the infrastructure are covered only in four datasets. These cover public administrative boundaries, coastal legislation, the distribution of flood insurance and the presence of decommissioned flood defence assets.

3.1.3.3 Research initiatives

There are 15 research initiatives specialising in these infrastructure risks. Erosion is prioritised by some, especially with regards to flooding, pollution, and water treatment. Green approaches to tackling coastal flooding are also featured but most initiatives are broader, with only the initiatives 'Sustainable development and resilience of UK coastal communities' and 'Resilient UK coastal communities and seas: outline stage' specialising in these risks.

3.1.3.4 Summary of findings

The hazards are covered by coastal flood model and coastal erosion predictions which include forecasts under different climate scenarios.

Exposure is well covered although data is lacking for planned infrastructure and data on sewage treatment works is lacking. There is some vulnerability information on energy infrastructure from the NaFIRS dataset on fault performance (although this was completed in 2007), ERA datasets with historical meteorological information and the Abaqus model simulating stress and deformation of materials under different conditions. However, there are still some significant gaps for vulnerability.

Table 8 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I3 Risks to infrastructure services from coastal flooding and erosion	Current and forecast coastal flood zones and coastal erosion in different climate scenarios	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned coastal energy, transport, telecommunications and water infrastructure with respect to flooding and coastal erosion

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.4 I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events

Wetting-drying and freeze-thaw cycles are one of the major risks to slope failure within transport networks and their deterioration of mechanical and hydraulic properties of engineered fill forming infrastructure slopes. It is considered a medium risk at low confidence because these processes are not fully understood yet and as adaptation is slow.

3.1.4.1 Spatial models

There is a total of 3 models that examine I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events. Landslide risks are captured with regards to slope and embankment failure. Rainfall and infiltration are only an input parameter into one of the 3 models.

3.1.4.2 Datasets

Two datasets include real-time rainfall data and the spatial risks of landslides in the UK. Datasets specifically on slope and embankment failure were not found (however such data was used as inputs for the models). Current road and rail infrastructure datasets that could be used to map exposure are in the database. Planned expansions to road and rail networks that could be used to map future exposure are covered in UK-SSPs.

3.1.4.3 Research initiatives

There are eight research initiatives focusing on risks to transport from slope and embankment failure caused by heavy rainfall. Public transport and roads are both covered; however the majority of research initiatives appear to be generalised, without specific focus on transport networks or landslides.

3.1.4.4 Summary of findings

Hazards from rainfall are largely covered by the datasets and slope and embankment failure is covered by the models. Risks to transport networks such as rail and road infrastructure are somewhat covered although planned networks are not covered. Vulnerabilities and specifications of embankment failure are not specified.

Table 9 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events	Current and forecast summer temperatures, summer mean rainfall, winter rainfall events and winter mean rainfall under different climate scenarios	Existing and planned engineered cuttings and embankments supporting transport infrastructure	Specifications of existing and planned slope and embankment supporting transport infrastructure e.g. older, less compacted earthworks not built to modern construction standards

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.5 I8 Risks to public water supplies from drought and low river flows

By the late 21st century, a demand/supply deficit of around 1220 and 2900 Ml of water per day (for between 2 °C to 4 °C global warming) is expected across the UK[6]. The 5-yearly water resources management plans have been the key driver of adaptation, however, compared to Northern Ireland, Scotland and Wales, adaptation in England has been slow. Concrete surfaces used to build water reservoirs, overflow structures or spillways are vulnerable to low water flows and drought potentially causing cracking, joint movement or an increase of debris and vegetation. Heat induced expansion can be a major threat to valves and draw off towers, for example.

3.1.5.1 Spatial models

There is a total of 21 models on I8 Risks to public water supplies from drought and low river flows. Both surface water and groundwater levels are covered. One model, the Water Resources England and Wales (WREW) model, takes public, non-public and irrigation water demand into its input variables and can be used to estimate surface water and groundwater available in England and Wales. Models considering reservoirs, overflow structures and spillway constructions specifically are not covered.

3.1.5.2 Datasets

General hazard information is covered on current drought and river flows, and future forecasts in different climate scenarios. This includes the eFlag (enhanced Future Flows and Groundwater) dataset, which simulates future river flow, groundwater level and groundwater recharge. Other datasets cover the availability of water, historical hydrological droughts, river and water flows, and rainfall estimates such as UKCP18. Three datasets cover catchments, water supplies, reservoirs and their exposure to drought today and in the future. Specific data on overflow structures or valve replacements are missing in the public domain.

3.1.5.3 Research initiatives

Eight research initiatives cover I8 risks. One focuses primarily on lakes rather than rivers while another focuses on generalised drought risks and resilience. Most of the I8 research initiatives are generalised around climate change as a whole.

3.1.5.4 Summary of findings

Hazards of current drought and river flows across different future climate scenarios are well covered. For exposure, the WREW model captures a lot of the large-scale water supply infrastructure such as reservoirs,

[6] CCRA3 Technical Report. Available at https://www.ukclimaterisk.org/

surface water abstraction, ground water extraction, and the connectivity of the system. However, there is a lack of models and data on with planned water infrastructure locations. Regarding vulnerability, specific data and models on the effect of heat on reservoirs or spillway construction effects are missing. Water companies are in possession of data and models related to exposure and vulnerability which are not in the public domain.

Table 10 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I8 Risks to public water supplies from drought and low river flows	Spatial data on current drought and river flows, and future forecasts in different climate scenarios	Existing and planned abstraction locations and public water infrastructure such as reservoirs, overflow structures and spillways constructions or valves and draw off towers	Specifications of existing and planned public water infrastructure such as reservoirs, overflow structures and spillways or valve and draw off towers with respect to drought and low river flows

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.6 I9 Risks to energy generation from reduced water availability

Currently, reduced water availability risks are highest to the operation of thermal plants. Low water levels may lead to restrictions on abstracting and discharging cooling water to protect aquatic ecology. Where today, the risk is not severe yet, the ambition of the UK government to become carbon net zero puts emphasis finding suitable locations where water availability will be a minimised risk for Net Zero compliant energy plants. It is worth noting in the future the highest risks from reduced water availability for the energy sector may be for electrolysis-derived hydrogen production, not thermal plants.

3.1.6.1 Spatial models

There are a total of 12 models within risk I9 Risks to energy generation from reduced water availability. Risks from cooling water shortages on power plants and electricity supply and demand are covered, specifically by the DECIPHeR (Dynamic fluxEs and Connectivity for Predictions of Hydrology) and Weather@Home2 models.

3.1.6.2 Datasets

Meteorological forecasts in different climate scenarios are covered by the UKCP18 dataset which includes data on hot summer days, hot spells and summer mean precipitation. eFlag used UKCP18 data to make hydrological projections of river flow, groundwater level and groundwater recharge for UK catchments from 1981 to 2080. Three datasets cover catchments and water supplies and their exposure to drought today and in the future. One dataset covers the vulnerability of rivers and lakes to drought and low river flows.

Six datasets present the location of energy and electricity infrastructure. One dataset covers their vulnerability by presenting details of battery producer responsibility schemes which have registered with the Environment Agency.

3.1.6.3 Research initiatives

Seven research initiatives cover risks to energy generation from reduced water availability. The B-WEX Balancing clean Water and Energy provision under changing climate and extremes (ERC Starting Grant laureates) is specifically looking at the relationships between water availability and energy production. There is a CS-N0W project 'Future Water Availability for Water-intensive Energy Infrastructure' lead by UKCEH which is creating a dataset on future water availability for energy infrastructure.

3.1.6.4 Summary of findings

Current and future drought and river flows are well covered. Both models and datasets cover the exposure in terms of existing and planned energy power plant infrastructure. There are models directly linked to hydrogen

production, but datasets might be missing. Research Initiatives consider the transition to becoming net zero overall. Vulnerability of energy infrastructure with respect to water scarcity is expected to be covered by the CS-N0W research project.

Table 11 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I9 Risks to energy generation from reduced water availability	Spatial data on current drought and freshwater river flows, and future forecasts in different climate scenarios	Existing and planned energy infrastructure of operational thermal power plants	Specifications of existing and planned energy infrastructure of thermal power plants and electrolysis derived hydrogen plants with respect to water scarcity

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.7 I10 Risks to energy from high and low temperatures, high winds, lightning

High temperatures reducing electricity generation from thermal generators or photovoltaic cells, low temperatures, snow and ice, fallen trees and debris from high wind, and fire outbreaks, power surges and shock waves from lightning, all cause faults on the electricity network and risks to energy supply.

3.1.7.1 Spatial models

There are 8 models within I10 Risks to energy from high and low temperatures, high winds, lightning. Only high winds are covered by the models by the Met Office UK unified model. Wildfire risk is covered by three models. The CGEN+ model could be used to determine exposure of the risk to planned energy infrastructure. It is an optimisation tool for long term infrastructure planning of interdependent gas and electricity networks. For the vulnerability of energy infrastructure, the model Abaqus can simulate stress and deformation of materials at different temperatures, strains and strain rates.

3.1.7.2 Datasets

Current and forecast high and low temperatures and in different climate scenarios hazard information is covered by UKCP18 at a resolution of 2.2 km. UKCP18 provides wind direction, speed and gust data but it has not been evaluated yet. Snow is also provided but it should be used with caution. Lightning is not available yet under UKCP18 as further evaluation is required before its use. There are no data on fire outbreaks.

Six datasets present the location of energy and electricity infrastructure. Locations of energy infrastructure that could be exposed to this risk National Grid provides electricity transmission network data including critical sub-stations, towers, overhead lines and cables are also included. Electricity distribution data is not covered in this dataset (data could be accessed by contacting local electricity distribution companies[7]. Alternatively, OpenStreetMap has electricity pylon data. UK Power Networks has a data portal with both network infrastructure and usage datasets covering London and the East and Southeast of England as well as setting out future network developments and scenarios. Planned locations of energy infrastructure for the rest of the UK is not available. Two UK-SSP datasets present the future energy and electricity usage in the UK however these are not geospatial datasets. There is vulnerability information from the NaFIRS dataset on fault data and European reanalysis (ERA) dataset with historical meteorological data (e.g. wind speed) which has been used to develop fragility curves.

[7] https://www.energynetworks.org/

3.1.7.3 Research initiatives

There are 8 research initiatives within risk I10. Two are worldwide, six are UK-risk focused. Only the University of Manchester is looking specifically at heat from fire danger. The CS-N0W project 'Enhancing Resilience in UK Energy Networks' is modelling the vulnerability of energy infrastructure to climate change.

3.1.7.4 Summary of findings

Current and forecast hazards from high and low temperatures, high winds, snow are covered, and lightning data will become available. There are no data on fire outbreaks. Exposure is broadly covered throughout models, datasets, and research initiatives however there is a lack of information on planned energy infrastructure (apart from in London, Southeast and East of England). There is vulnerability information from the NaFIRS dataset on fault performance (although this was completed in 2007), ERA datasets with historical meteorological information and the Abaqus model simulating stress and deformation of materials under different conditions.

Table 12 RAG analysis of the models, datasets and research initiatives indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I10 Risks to energy from high and low temperatures, high winds, lightning	Current and forecast high and low temperatures, high winds, snow, fire outbreaks and lightning and in different climate scenarios	Existing and planned energy infrastructure	Specifications of existing and planned energy infrastructure with respect to extreme temperatures (high and low), as well as high winds and lightning

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.1.8 I12 Risks to transport from high and low temperatures, high winds, lightning

Risk from high and low temperatures, high winds and lightening to network rail, roads, air travel and water such as port operations have been identified as medium at a high confidence level across the UK. Line-side fires from lightning to rail infrastructure, road expansion or rutting to roads from high temperatures and damage to road signs from high winds are included in the risk. Air travel disruption and vessel operations can also be disrupted from weather extremes described here. Future uncertainty is high and more detailed identification of interdependencies between sectors is needed to fully assess these risks.

3.1.8.1 Spatial models

There are 4 models within I12 Risks to transport from high and low temperatures, high winds, lightning. Two models cover weather-related hazards across the UK, which can be potentially used to identify high-risk areas for the transport sector. One model covers heat-related incidents in railway networks, while the other covers impacts on road transport. Air travel and water travel are not covered.

3.1.8.2 Datasets

Current and forecast high and low temperatures and in different climate scenarios hazard information is covered by UKCP18 at a resolution of 2.2 km. UKCP18 provides wind direction, speed and gust data as well as snow data but it has not been evaluated yet. Lightning is not available yet under UKCP18 as further evaluation is required before its use. There is a dataset on European Forest Fire Information, and the Met Office MIDAS dataset comprises data on weather measurements including snow.

There are eight exposure datasets on current transport infrastructure covering road, rail and air transport with Ordnance Survey products. Two UK-SSP datasets (UK-SSPs – Road infrastructure and UK-SSPs - Rail infrastructure) describe the location of the transport infrastructure, including road and rail transport, in the UK in m/km^2 for each local authority district. The OS MasterMap Integrated Transport Network (ITN) presents trunk road network data. One dataset addresses the vulnerability of the transport network by covering all failures and incidents logged for the rail network. Vessel operations and air travel disruptions are not directly covered.

3.1.8.3 Research initiatives

There are 8 research initiatives within risk I12. Two are worldwide, five are UK-risk focused. They generally focus on climate change, but none focuses specifically solely on high and low temperatures, high winds or lightning.

3.1.8.4 Summary of findings

Hazards from high and low temperatures, wildfire risk and high winds are covered. Snow is covered by UKCP18 but should be used with caution. Lightning specifically is not covered. The exposure of planned infrastructure to hazards is covered in datasets but not specifically in models. Network Rail has data on climatic and network rail data. Data or models on air travel or vessel operations are missing. There is only one vulnerability dataset on train delays, failures and incidents.

Table 13 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I12 Risks to transport from high and low temperatures, high winds, lightning	Current and forecast high and low temperatures, high winds, snow and wildfire lightning in different climate scenarios	Existing and planned transport networks	Specifications of existing and planned transport infrastructure with respect to extreme temperatures (high and low), as well as high winds and lightning

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2 HEALTH, COMMUNITIES AND THE BUILT ENVIRONMENT

3.2.1 H1 Risks to health and wellbeing from high temperatures

Heat from high temperatures and the associated risk of buildings overheating, and also the combined stresses from heat, air pollution, drought and wildfires are recognised as negatively impacting mortality, health, wellbeing and social outcomes. Especially maternal and mental health, unintentional injury and accidents, and labour productivity are affected by high temperatures.

3.2.1.1 Spatial models

There are 9 models within H1 Risks to health and wellbeing from high temperatures. Climate and surface energy flux models include: Met Office Hadley Centre Regional Climate Model (HadRM3), WRF (Weather Research and Forecasting) model and Noah Land Surface Model (Noah-LSM) computing surface energy fluxes using vegetation and soil characteristics. Models of heat stress and the combination with socioeconomic factors include: the OpenCLIM heat stress model, Integrated Environmental Solutions (IES) dynamic thermal model (modelling the impact of overheating of hospital wards) and HEAT (which provides a series of different heat stress metrics and hotspots accounting for socio-economic factors). Models of heat-related mortality include: Distributed Lag Nonlinear Model (DLNM)-based method for estimating heat-related mortality and HARM (Heat Adaptation and Risk Model). The Health Impact of Domestic Energy Efficiency Measures (HIDEEM) model has building physics-based models of the indoor environment in UK houses (including: temperature, concentrations of particle pollution, second hand tobacco smoke, radon, and risk of mould growth) and models to quantify associated health impacts of exposure changes using life table methods. It is the only model that address air pollution. Three models cover wildfire risk. Drought is covered by one model. The models also do not assess maternal and mental health, unintentional injury and accidents directly, but rather indirectly through considering the risks to heat attributed deaths or urban heat islands. Labour productivity is covered but the knock-on impacts on social outcomes are not covered.

3.2.1.2 Datasets

Hazard data regarding current, historical and forecast temperatures are covered which include UKCP18 data. Drought is covered by eFlag data. Exposure information UK – SSPs datasets on population growth, health,

healthcare and urbanisation, listed buildings, registered parks and gardens, scheduled ancient monuments and census data are covered; such data is downscaled from IPCC global scenarios. The UK SSP outputs are derived with the use of ONS datasets as the baseline which is why no further projection datasets such as the Population Projections[8] have been included here. Vulnerability information (occupation, healthcare, demographics, population, health, cause of death, excess mortality due to heatwaves, capital availability, income, inequality and urbanisation) are covered. There are datasets which address existing but not planned buildings.

3.2.1.3 Research initiatives

There are 10 research initiatives within risk H1. Three are worldwide and seven are UK-risk focused. Health impact of climate change, urbanization and heat effects, fire danger, community engagement and resilience are themes covered. A CS-N0W project 'Projections of Temperature Change and Impacts in UK Housing' led by UCL Building Stock Laboratory will produce a dataset on climate change impacts on heating costs, thermal conditions within poorly insulated homes for lower income households and future cooling needs of the housing stock.

3.2.1.4 Summary of findings

Hazards are thoroughly covered throughout models, datasets and research initiatives. Existing buildings' exposure (but not that of planned buildings) has been assessed. Current and forecast demographics are covered in the vulnerability risk component however heat-related illness and the relevant healthcare are not specifically covered but indirectly assessed in models and datasets.

Table 14 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H1 Risks to health and wellbeing from high temperatures	Current and forecast temperatures, fire outbreaks, air pollution and drought in different climate scenarios	Existing and planned buildings and population density	Characteristics of existing and planned buildings with regard to heatwaves. Current and forecast demographics (age, income level, etc.) and other indicators of sensitivity to high temperatures (e.g. availability of healthcare, quality of healthcare for temperature related illnesses such heat stress, heat stroke, etc.)

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.2 H3 Risks to people, communities and rivers from river, surface and coastal flooding

Surface and coastal flooding present a significant risk to people. People in Northern Ireland, Scotland and Wales are more exposed to river (fluvial), sea (coastal), surface water (pluvial) and groundwater flooding risks on average than people living in England. Coastal flooding is the highest risk to life and properties because of the velocity of and depths of flooding, but more people are affected by surface water floods are the highest risks to the number of properties, and river flooding causes the highest damage.

3.2.2.1 Spatial models

There are 22 models within H3 risks to people, communities and rivers from river, surface and coastal flooding. River, sea, surface water and groundwater flooding models are included. 54% (12 models) are on the overall risks of flooding and their likelihood. One model is a commonly known climate model, HadGEM2-GC3. The rest of the models assess water levels to predict flooding. Spatial resolutions vary between 5m to 60km.

[8] ONS Population Projections available: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections

3.2.2.2 Datasets

There is sufficient data on flooding risk in the UK. Surface water, coastal and river flooding are all covered. Data on rainfall under different climate scenarios is also included. Exposure information (Indicative Flood Risk Areas - Communities at Risk & Clusters, UK – SSPs (population, urbanisation), listed buildings, registered parks and gardens, scheduled ancient monuments and census data) is covered. Vulnerability information (demography, inequality, income, capital availability and urbanisation) is available. No information regarding flood risk to planned buildings was collected.

3.2.2.3 Research initiatives

There are 12 research initiatives within risk H3. Two are worldwide, ten are UK-risk focused. Sustainable development and resilience are themes covered. SEARCH (2020-2023) evaluates how climate predictions from UKCP18 downscale to flooding impact, and SENSUM proposes to develop innovative smart tracking devices in rivers to give real-time warning of flood processes.

3.2.2.4 Summary of findings

Models, datasets and research initiatives cover the hazards risk components. Data gaps for exposure and vulnerability are identified for planned buildings. Further to this, vulnerabilities to flood and water related health problems are not specified. Current and forecast demographics are covered.

Table 15 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H3 Risks to people, communities and rivers from river, surface and coastal flooding	Current and future flood zones	Existing and planned buildings	Characteristics of existing and planned buildings with regard to flooding. Current and forecast demographics (age, income level, etc.) and other indicators of sensitivity to flooding and potential water-borne diseases or health problems exacerbated by exposure to water/flooding (e.g. availability of healthcare, including mental health support, quality of healthcare for potential water-related illnesses, etc.)

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.3 H4 Risks to people, communities and buildings from sea level rise

Sea level rise over the past 50 years and its associated storminess and sediment erosions, are a risk to people living on and visiting the coast. Coastal change and flooding from waves, astronomical tides, storm surges and relative mean sea level rise also pose risks to social, cultural and health implications. Coastal change might make it infeasible to invest in communities living next to the sea in the long-term.

3.2.3.1 Spatial models

There are 7 models within H4 Risks to people, communities and buildings from sea level rise. Six of these are forecast prediction models, such as SWEEP OWWL and Delft-3D. one is an exposure model directly determining the exposure of flooding to people in UK floodplains. The Fathom UK coastal flood map accounts for sea level rise and the Fathom-UK CAT model looks at risks to buildings. Risks to communities and people are not directly addressed.

3.2.3.2 Datasets

Hazard datasets include oceanographic, earth observation, geophysical, national tide and sea level, coastal observation, fisheries and aquaculture, wave overtopping estimates and wave buoy network datasets. Existing exposure information including listed buildings, registered parks and gardens, scheduled ancient monuments

and census data is covered. Planned exposure datasets are also present in the form of the UK – SSPs (population, urbanisation, road and rail). Vulnerability information (UK – SSPs demography, inequality, income, capital availability and health) is available. No information regarding flood risk to planned buildings was collected.

3.2.3.3 Research initiatives

There are 12 research initiatives within risk H4 including: Resilient UK coastal communities and seas, Quantifying the Impact of Extreme Storms on Slope Erosion: Improving our Capacity to Forecast Erosion Hazards, Sustainable development and resilience of UK coastal communities and UPSURGE: Helping storm surge barriers prepare for climate change. Three are worldwide and 10 cover the UK. Sustainable development, storm surge barriers and projecting sea-level change are themes covered.

3.2.3.4 Summary of findings

The hazard of sea level rise and sediment erosion are covered throughout models, datasets and research initiatives. There is a minor gap for exposure in that there is missing information on planned buildings, housing and community infrastructure. There is a significant gap for vulnerability as there is missing data on characteristics of planned coastal buildings and infrastructure and future demographics.

Table 16 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H4 Risks to people, communities and buildings from sea level rise	Areas at risk from sea level rise and sediment erosion	Existing and planned buildings, housing and community infrastructure	Characteristics of existing and planned coastal buildings, community infrastructure and future demographics with regard to sea level rise

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.4 H6 Risks from summer and winter household energy demand

Overall risks from summer and winter household energy demand are expected to be low, however, the associated economic costs from especially increased summer cooling demand, which is likely to increase, may be high. It is not well understood yet if warmer winter temperatures will lead to reduced winter heating due to household behaviours. The uptake of mechanical cooling is likely to vary between low-and high-income groups. Net Zero policies will be a key driver of change and risk mitigation.

3.2.4.1 Spatial models

There are three spatial models for H6 Risks from summer and winter household energy demand: 3DStock, London Building Stock Model (part of the CS-N0W programme led by UCL Building Stock Laboratory) and SimStock. Simstock is particularly useful in that it estimates the overheating risk of the stock as whole, a stock segment or individual buildings under both current climate conditions and predictions of future climate condition.

3.2.4.2 Datasets

Hazard information on current and future seasonal temperature changes (hotter summers and winters) in different climate scenarios is covered by UKCP18 data. The National Energy Efficiency Data-Framework (NEED) and Smart Energy Research Lab (SERL) has data on energy use in the UK. The latter has data on 13,000 UK households with daily half-hourly electricity/gas data readings, weather variables dwelling and household information and Energy Performance Certificates. General vulnerability data (UK – SSPs demography, inequality, household income and capital availability) are covered.

3.2.4.3 Research initiatives

There are six research initiatives within risk H6. Two are worldwide and four are UK-risk focused. Decarbonisation, net-zero, air quality and overall climate change impacts are covered. The CS-N0W 'Projections of Temperature Change and Impacts in UK Housing' work package led by the UCL (completing this year), which was described previously under risk H1, is worth mentioning here as well.

3.2.4.4 Summary of findings

Datasets and research initiatives cover the hazard risk component. There are two datasets on energy use with SERL data being most useful with weather variable data and a high temporal resolution. Vulnerability is covered for most aspects however there is a minor gap pertaining to availability of regulations and governance structures to provide financial support for low-income communities to aid in the uptake of mechanical cooling vulnerability.

Table 17 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H6 Risks from summer and winter household energy demand	Current and future seasonal temperature changes (hotter summers and winters) in different climate scenarios	Spatial data on energy consumption correlated with temperature	Characteristics of existing and planned buildings with regard to insulation to retain heat/cool down efficiently in extreme temperatures. Current and forecast demographics (age, income level etc.) and other indicators of sensitivity to higher temperatures and to potential inflation of energy prices due to higher demand (for mechanical cooling). Availability of regulations and governance structures to provide financial support for low-income communities to aid in the uptake of mechanical cooling

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.5 H8 Risks to health from vector-borne diseases

Since 2016, changes in vector distribution and seasonal activity have been observed. Climate change is projected to increase tick-borne diseases (e.g. Lyme disease), *Culex*-transmitted diseases, or mosquitoes (*Aedes*) transmitted diseases. Especially in Southern England, risks are highest. Malaria, chikungunya and dengue fever are expected to be found in the UK in the future. The reduced access to international surveillance systems due to Brexit increases the risk of vector-borne diseases in the UK.

3.2.5.1 Spatial models

There are 12 models within H8 Risks to health from vector-borne diseases. Three of these models are on a global scale, for example the Liverpool Malaria Model. Vectors covered are malaria, albopictus, Ixodes cicinus ticks transmitting Borrelia burgdorferi sensu lato, cx. Pipiens, zika virus, BT transmission, bluetongue virus, H. marginatum nymphs, and a mosquito-borne arbovirus. Following the pathogens population development rate, primary input is almost always temperature or climate projections.

3.2.5.2 Datasets

Current distribution/risk of vector-borne diseases and forecast under different climate scenarios are not covered by the datasets (only meteorological and climate projection data was included). Exposure data covers current and projected population data but not population data in the zones where vector-borne diseases are expected to spread to. Five other datasets concern various variables of bathing waters (ornithology, health risks, monitoring locations and Zone of Influence Catchments). Vulnerability data covers projected demographic, inequality, health and healthcare data.

3.2.5.3 Research initiatives

There are four research initiatives within risk H8. Two are worldwide and three UK-risk focused. They include research initiatives on Vibrio pathogens from shellfish, tick-borne zoonotic pathogens and a Horizon 2020 project focussing on three vector groups (mosquitoes, ticks and snails) and a range of their diseases (Rift Valley Fever, ehrlichiosis, theileriosis and fasciolosis).

3.2.5.4 Summary of findings

Hazard and exposure are somewhat covered by models and datasets respectively. The vulnerability risk component is covered for population characteristics and healthcare availability however there are some gaps especially in other indicators of sensitivity to potential vector-borne diseases.

Table 18 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H8 Risks to health from vector-borne diseases	Current distribution/risk of vector-borne diseases and forecast under different climate scenarios	Current and projected population data in the zones where vector-borne diseases are expected to spread to	Characteristics of populations (including demographic, recreation, workplace data which might indicate populations that are sensitive) and other indicators of sensitivity to potential vector-borne diseases (e.g. availability and quality of healthcare for vector-borne diseases, etc.)

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.6 H12 Risks to health and social care delivery

Floods, heatwaves and other weather extremes can create disruptions to health and social care services such as hospitals, residential and nursing homes or transport infrastructure. Risks include sudden demand increases and flooding of hospitals and other health infrastructure. Overheating of buildings can cause for example disruptions in laboratory services, distress to patients and degradation or loss of medicines.

3.2.6.1 Spatial models

There are 28 models within H12 Risks to health and social care delivery. The models cover risks of floods, heatwaves, weather extremes and landslides. Models include: Spatial coverage of all Ambulance Service and Fire and Rescue Service stations in England during flooding of varying severity under compliant response times, Effects of coastal and fluvial flooding on the efficiency of ambulances evacuating care home residents and Study developed a distributed lag non-linear model (DLNM) exploring a 'Climate Threshold' for emergency hospital admissions of chronic lower respiratory diseases. General health, nursing homes, care homes, the vulnerability to climate risks and its impact on hospital admission are covered, risks to transport infrastructure has been modelled in Norfolk and Suffolk. Fathom-UK CAT model incorporates building characteristics.

3.2.6.2 Datasets

UKCP18 covers projects of heatwaves and other weather extremes. Various datasets cover the probability of flooding from rivers and sea and landslide risks. Exposure datasets cover: population data, healthcare (GPs per capita), road infrastructure, rail infrastructure, hospital data and buildings. There is no coverage of the existing and planned health and social care buildings. Vulnerability data concerns the general information (demography, inequality, household income and capital availability). Two further datasets cover information regarding design and delivery of healthcare in a changing climate, and indices of deprivation.

3.2.6.3 Research initiatives

There are 6 research initiatives within risk H12. Two are worldwide initiatives, four are UK-risk focused. The Governing the Climate Adaptation of Care Settings looks at overheating risks in the 2050s and 2080s and aims to quantify climate related heat risks in care settings nationwide and enhance understanding of human behaviour, organisational capacity and governance to enable the UK's care provision to develop equitable adaptation pathways to rising heat stress under climate change.

3.2.6.4 Summary of findings

Hazards are covered throughout models, datasets and research initiatives. There are some minor gaps in exposure regarding the existing and planned health and social care buildings. For vulnerability, building characteristics are covered. Transport infrastructure characteristics and characteristics of health and social care workers, such as age, that may indicate the sensitivity of staff delivering care are not covered.

Table 19 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H12 Risks to health and social care delivery	Current and forecast floods, heatwaves, other weather extremes and landslide risk in different climate scenarios	Existing and planned health and social care buildings and infrastructure (e.g. laboratory services) and transport infrastructure	Characteristics of existing and planned health and social care buildings and transport infrastructure with regard to extreme weather events including floods, heatwaves, landslides etc. Characteristics of health and social care workers, such as age, that may indicate the sensitivity of staff delivering care

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.2.7 H13 Risks to education and prison services

Major risks for education services are from the impact of heat inside and outside of school buildings. Surface flooding and landslides are further risks, especially in England. For prisons, evidence is even smaller, but summer heat, flooding and increased intensity of storms are a threat to increased financial costs of prisons in the UK.

3.2.7.1 Spatial models

There are no models within H13 Risks to education and prison services.

3.2.7.2 Datasets

Hazard data on current and forecast floods, heatwaves, other weather extremes and landslide risk in different climate scenarios has been covered.

Location data on existing schools and prisons from OpenStreetMap data could be used to assess exposure to climate hazards. There is no coverage of planned education and prison services.

Characteristics of existing and education and prison infrastructure with regard to extreme weather events including floods, heatwaves and landslides has not been covered. Characteristics of education and prison workers, such as age, that may indicate the sensitivity of staff delivering the services has not been covered.

3.2.7.3 Research initiatives

There are 7 research initiatives within risk H13. Two are worldwide, and the rest are UK-risk focused. Floods and landslides are themes covered such as SENSUM: Smart SENSing of landscapes Undergoing hazardous hydrogeological Movement. There are no research initiatives specifically looking at education or prison services.

3.2.7.4 Summary of findings

Datasets and research initiatives both cover the hazard risk component. For exposure, there is an OpenStreetMap dataset for the existing building footprints of prisons and schools. Planned schools and prisons are unknown however the UK-SSP population or urbanisation datasets could prove to be informative. Vulnerability information is poor.

Table 20 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H13 Risks to education and prison services	Current and forecast floods, heatwaves, other weather extremes and landslide risk in different climate scenarios	Existing and planned education and prison services	Characteristics of existing and education and prison infrastructure with regard to extreme weather events including floods, heatwaves, landslides etc. Characteristics of education and prison workers, such as age, that may indicate the sensitivity of staff delivering the services

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3 THE NATURAL ENVIRONMENT

3.3.1 N1 + N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))

Risk of extinction and loss of terrestrial species and habitats is high generally but also variable. For example, for some species, community, or population changes in distribution might be beneficial, for others, they are a threat. Habitat restoration and the reduction of climate change impacts are expected to decrease these risks, but there is little evidence up to today. INNS such as the oak processionary moth (*Thaumetopoea processionea*), are introduced to the UK through especially high-risk products, for example horticultural plants and wood packaging. Warmer winters which are expected with more frequency provide better climatic conditions for these to establish in the future.

3.3.1.1 Spatial models

There are a total of 12 models within risk N1 and N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS)). Risks and effects of changing temperature, aridity and precipitation on UK species (including on distribution and reintroduction) are covered. Risks from pests is only covered by two models and pathogens and INNS are not covered.

3.3.1.2 Datasets

There are around 50 datasets covering the hazard component of risks which cover a range of topics including landslide risk, flood risk, temperature projections, pathogen risk and historic pathogen occurrence datasets (e.g. malaria, foulbrood in bees, rabies susceptible mammals imports, sweet chestnut blight). The NBN Atlas is also included because of its data on INNS. It represents the largest repository for biodiversity data on British species that is publicly available

There are over 100 datasets identified for exposure. The datasets cover topics such as trees, natural capital, bird conservation, protected areas, habitat networks, priority habitats. The datasets also include performance dashboards for several metrics.

There are a total of 18 vulnerability datasets covering many aspects such as conservation, permitting regulations and wild bird releases.

3.3.1.3 Research initiatives

There are 27 research initiatives in risks N1 and N2. Five cover worldwide spatially, and one focuses on regions of critical interest to the UK (the Arctic, Africa, Antarctica). Four cover a set of countries including the UK. Landscape restoration, woodland biodiversity, landscape regeneration, and projects focusing on ecology overall are covered.

3.3.1.4 Summary of findings

Temperature, rainfall and landslide hazard information is provided. Information on multiple pathogens such as rabies, malaria and foulbrood is also present and information on INNS from the NBN Atlas. Risks from pests are present but pathogens and INNS are not present in the models. Presence/abundance of terrestrial species is also covered by the NBN Atlas and specific survey data, with around 150 datasets identified for exposure risks. There are models for changes in species ranges due to climatic factors covering: moths, vascular plants, bees, bryophytes, carabid beetles, spiders, badgers, two butterfly species and three bird species. Measures of adaptation for habitat preservation are covered by research initiatives such as the Transferable Ecology for a changing world (TREE) and Restoring Resilient Ecosystems (RestREco).

Table 21 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N1 + N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))	Current and forecast temperatures, wildfire, rainfall and timing of seasons in different climate scenarios. Pests, pathogens and invasive non-native species (INNS) current and forecast presence/abundance.	Terrestrial species presence/abundance, terrestrial habitat coverage and designated site coverage	Sensitivity of species' ranges to changes in temperature, rainfall and seasons. Measures of adaptation for habitat preservation

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.2 N4 Risk to soils from changing conditions, including seasonal aridity and wetness

Changing climate conditions, land use changes and seasonal aridity and wetness pose an increasing risk to the ecosystems provided by soils. These include soil fertility, regulation of water flows and water quality, nutrient recycling, carbon storage and cultural value. Climate-related processes together with socioeconomic factors are major risks to soil degradation. Peatlands are particularly vulnerable. By the 2080s most peatlands in the UK could be modified or highly modified.

3.3.2.1 Spatial models

There is a total of 14 models within risk N4 Risk to soils from changing conditions, including seasonal aridity and wetness. The majority of models cover risks to soil (in terms of organic carbon, pH, or soil moisture) from changing climate conditions or land use. Risks of soil erosion by water are also covered. Models include: Land Use and Management (LANDUM), Soil and Water Assessment Tool (SWAT), the Land Surface Data Assimilation (LSDA) model and CENTURY model.

3.3.2.2 Datasets

The five datasets that cover hazard data concern evapotranspiration, rainfall and evaporation, surface soil wetness and soil moisture data. UKCP18 has projections of rainfall and temperature under different climate scenarios.

There are five exposure datasets which include measured data, satellite data and modelled data on soil moisture. UKCP18 also has projections of soil moisture under different climate scenarios although it should be used with caution[9].

16 datasets cover vulnerability which include data on: soil type, soil organic carbon and current and future land use and land use intensity.

3.3.2.3 Research initiatives

There are 9 research initiatives within risk N4. Two are worldwide, one covers Wales and six are UK-research focused. Soils in general, but also peatlands and shrink-swell in clay soils specifically are covered. Two address peaty soils and issues surrounding water scarcity and drought.

3.3.2.4 Summary of findings

There is sufficient hazard information on temperature and rainfall information and sufficient exposure information on soil aridity and moisture levels. There is some vulnerability information on soil type and land use but less information on adaptations or methods to conserve soils.

Table 22 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N4 Risk to soils from changing conditions, including seasonal aridity and wetness	Current and forecast rainfall, temperature, evaporation and evapotranspiration in different climate scenarios	Soil aridity and moisture levels	Characteristics of soils with respect to rainfall, temperature, evaporation and evapotranspiration (e.g. soil type, condition, land use). Measures of adaptation to conserve soils (e.g. maintain minimum soil cover, take measures to prevent erosion, and maintain soil organic matter levels).

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.3 N5 Risks to natural carbon stores and carbon sequestration

For the UK's Net Zero plans, it is important to understand how changing climatic conditions change the carbon sequestration/emissions potential of soils, peatlands, forests and coastal and marine environments such as saltmarshes. In GHG inventories, interactions between soil types, soil processes, land use management and climate are some of the biggest uncertainties as they are often considered in isolation.

3.3.3.1 Spatial models

There are a total of 9 models within risk N5 Risks to natural carbon stores and carbon sequestration which include Forest Research CSORT model, N14CP plant-soil biogeochemical model and several Scottish models such as the Blanket Bog Tree model. The risks of climate change, sea level rise, soil erosion, land use and management, and nutrient cycles on terrestrial carbon sequestration are covered. Distribution models of bog trees and other woodland species under climate change scenarios are included for Scotland. Carbon storage and sequestration rates for UK trees and soil are also covered.

3.3.3.2 Datasets

10 datasets cover hazard which include current and forecast rainfall, temperatures and sea level, but no datasets were found on soil erosion.

[9] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-factsheet-local-2.2km.pdf

Two datasets cover terrain models, one for greenhouse gas exchange, one for soil carbon, one for soil organic carbon, one climate data and lastly one for NDVI estimates. 14 datasets cover exposure including woodland carbon code statistics, soil organic carbon and normalised difference vegetation indices (NDVI). Other datasets include information on the National Tree Map, soil CO_2 exchange, aerial photography, CO_2 exchange, evaporation and heat flux and urbanisation based on projected population growth.

There are three datasets for vulnerability covering lidar data which could be used to determine slope indicating soils that are vulnerable to soil erosion. However, overall vulnerability data is very limited.

3.3.3.3 Research initiatives

There are 21 research initiative within risk N5. Trees, soils, peatlands, aquatic ecosystems, sea sediments, and seagrass are some specific areas covered. Especially the six worldwide operating initiatives are focusing on climate change impacts and resilience overall.

3.3.3.4 Summary of findings

There is sufficient information on hazards. There is sufficient exposure information on carbon stocks and carbon sequestration. Soil organic carbon is mainly featured in relation to forests but a small number of more generalised datasets and models are present. The N14CP plant-soil biogeochemical model focuses on the potential effects of climate change, land use and management, and nutrient cycles on terrestrial carbon sequestration. There is little information is available on carbon sequestration sensitivity, especially to flooding or coastal erosion.

Table 23 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N5 Risks to natural carbon stores and carbon sequestration	Current and forecast rainfall, temperatures, soil erosion and sea level rise in different climate scenarios	Carbon stocks in soil and different habitats and carbon sequestration	Sensitivity of carbon stocks to changing temperatures, rainfall coastal erosion and sea level rise. Measures of adaptation to enhance soil carbon stocks (e.g. Green and Pleasant Land scenario)

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.4 N6 + N7 + N8 Risks to agricultural and forestry productivity (including from pests, pathogens and INNS)

Heat stress, drought, wetness-related risks such as soil moisture variations, frost frequency, wind exposure, variations in solar radiation, and land management activities can enhance the degradation of biodiversity, water and soils, lead to changes in the growing season, and have plant phenology effects. These can affect inherent socioeconomic factors such as changes in domestic food supply and other commodities, the viability of livestock and different crops, milk, timber and other fibres. Pests, pathogens and INNS which are increasingly introduced and surviving due to climatic variations enhance the impacts on food security and forest productivity. The uncertainty is still high but integrated pest management and surveillance are necessary to maintain ecosystem services provided by forests.

3.3.4.1 Spatial models

There are a total of 8 models within N6, N7 and N8 Risks to agricultural and forestry productivity (including from pests, pathogens and INNS). An OpenCLIM model looks into the impacts of flooding, heat stress and changing temperature and precipitation on agriculture. Three models cover wildfire risks. Risks from pests, pathogens and INNS are not covered. Risks to forestry productivity are also not covered.

3.3.4.2 Datasets

There are around 570 datasets covering hazard data. Current and forecast heat stress in different climate scenarios are covered by the UKCP18 dataset which includes data on hot summer days, hot spells and summer mean precipitation. Current and forecast water scarcity is covered by eFlag which used UKCP18 data to make hydrological projections of river flow, groundwater level and groundwater recharge for UK catchments from 1981 to 2080. Surface water, coastal and river flooding in different climate scenarios are covered.

There is data from 2010 onwards on pests, pathogens and invasive non-native species (INNS) presence including: apiary inspections, avian influenza testing, BSE cases and Bovine Tuberculosis testing. There is no forecast data on pests, pathogens and invasive non-native species (INNS).

There are almost 3000 spatial datasets covering exposure risks which cover topics such as land cover, agricultural land classification, cattle data and forestry statistics. Agricultural land classification and agricultural datasets dominate most of the data covered.

Seven datasets cover vulnerability, three covering environmentally sensitive areas. Other data covers convergence areas, countryside stewardships schemes, flood and coastal risk management and land use intensity.

3.3.4.3 Research initiatives

There is a total of 13 research initiatives within risks N6, N7 and N8. Two initiatives operate worldwide, whereas the rest are UK-research focused. Agricultural landscapes, landscape demands, and ecological research and monitoring are themes covered. The CS-N0W project 'Climate Impacts at a Global, Regional and Country Scale' has developed several useful models:

- UKCEH and Ecocrop agricultural models at 1 km resolution providing changes in crop yield, water requirements, debt, suitability and productivity with a full range of climate change outcomes.
- Future Flood Explorer (FFE) enabling changes in flood flow, intense rainfall and sea level rise to be translated to spatially disaggregated risk to quantify crop/natural area exposed to fluvial/coastal flooding and direct/indirect economic losses.
- Wallace Initiative database providing risks to biodiversity and natural capital at 1×1 km resolution (Wallace initiative 3HR3), including quantifying risks to pollination.

3.3.4.4 Summary of findings

There is sufficient hazard information on current and forecast heat stress, water scarcity and flooding in different climate scenarios. For pests, pathogens and INNS, multiple sources relate to farm animal pathogens and crop pathogens, and tree health is also covered.

For exposure there is sufficient information on agricultural land and forest. The majority of datasets are related to agricultural land classification data, with other datasets such as Crop Map of England (CROME) 2021 providing further information on crop types and locations. OS Mastermap and CORINE data can also be used for mapping and identifying agricultural areas.

For vulnerability two UKCEH models provide data on current and predicted crop yields based on climate. There is some coverage of environmentally sensitive areas and the effects of coastal flooding through three Defra datasets but little mention of forest productivity sensitivity or adaptation measures.

Table 24 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N6 + N7 + N8 Risks to agricultural and forestry productivity (including from	Current and forecast heat stress, water scarcity and flooding in different climate scenarios. Pests, pathogens and invasive non-native	Agricultural land and forest	Sensitivity of agricultural and forest productivity to water scarcity and flooding, pests, pathogens and INNS. Measures of adaptation to improve

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
pests, pathogens and INNS)	species (INNS) current and forecast presence/abundance.		agricultural and forestry resilience.

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.5 N11+ N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS)

Reduced water availability, higher temperatures, and extreme weather events, for example, floods are major risks to freshwater species, ecological processes, and habitats. These provide important ecosystem services such as water supply, pollution removal, peat extraction and recreation to the UK population. Changing thermal regimes are favourable on pest, pathogens and INNS distribution and spread especially in England.

3.3.5.1 Spatial models

There are nine models within risks N11 and N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS). Water availability, flooding and water quality is covered. Pests, pathogens and INNS are not covered.

3.3.5.2 Datasets

40 datasets cover hazard information on current and forecast temperatures, rainfall, water quality and availability in different climate scenarios. 36 exposure datasets cover freshwater habitats and freshwater species data mainly from Water Framework Directive (WFD) datasets. Over 150 datasets cover vulnerability information mainly related to water quality, sensitive areas and WFD status. Factors contributing to sensitivity is covered but not species-specific sensitivity.

3.3.5.3 Research initiatives

There is a total of 15 research initiatives within risks N11 and N12. Three initiatives are worldwide programs, the others are UK-research focused. Rivers, freshwater ecosystems, and modelling are detailed areas covered.

3.3.5.4 Summary of findings

Temperature and rainfall information is provided by UKCP18. Freshwater species distributions, abundances and habitat data are included within the NBN Atlas in addition to substantial freshwater survey data. The sensitivities of their ranges to temperature, rainfall, seasons, pests, pathogens and INNS are less prevalent within the available dataset, models or research initiatives. One Defra dataset does include a bundle of datasets relating to sensitive areas however. Sensitivity of freshwater species is not covered.

Table 25 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N11+ N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS)	Current and forecast temperatures, rainfall, water availability, flooding and extreme weather events in different climate scenarios. Pests, pathogens and invasive non-native	Freshwater species presence/abundance and freshwater habitat coverage/location	Sensitivity of freshwater species' ranges and habitats to changes in temperature, rainfall, seasons,

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
	species (INNS) current and forecast presence/abundance.		pests, pathogens and INNS

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.6 N14 + N16 Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS)

The marine environment is at risk through changes in ocean acidification, stratification, oxygenation, variability in salinity and changes in ocean currents caused by increased carbon dioxide. Both direct and indirect effects on the oceans have implications for marine species in moving poleward, spawning time, and predator-prey interactions, for example. Fisheries put further pressure on fish populations. Declines have also been observed in seabird and marine mammal populations in the past, and risks from pests, pathogens and INNS mainly transported via ships through international trade are known but their risks to the marine environment are still uncertain.

3.3.6.1 Spatial models

There is a total of 9 models within risks N14 and N16 Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS). Risks to fisheries species under different climate change scenarios and effects (including ocean acidification) are covered. In the majority of cases, the commercial impacts of the changes in fisheries' distribution are analysed. Population management models under changing climate scenarios are also covered. Risks from pests, pathogen, and INNS are only covered for shellfish farming. Risks to seabird and marine mammal populations are not covered.

3.3.6.2 Datasets

There are 12 datasets relating to hazard. There is data on temperature, salinity, dissolved oxygen, chlorophyll, fluorescence, turbidity and photosynthetic active radiation (PAR) from the CEFAS data. However, there are no data on changes in ocean acidification, stratification, changes in ocean currents or pests, pathogens and INNS. There are also no data on forecast hazards.

243 datasets cover exposure components of risks covering various topics such as species occurrence, fisheries statistics and condition assessment.

Seven datasets provide indicators of vulnerability, including marine designated sites, protected shellfish water, native oyster bed potential and global biodiversity information.

3.3.6.3 Research initiatives

There is a total of 15 research initiatives within risks N14 and N16. Five initiatives are operating worldwide, and the rest focus on the UK only. Some research initiatives will address hazards such as: Climate consequences of rapid ocean changes (CCROC) which will determine the heat and freshwater budgets of the North Atlantic Ocean and the global partnership to understand the fate of native, invasive and hybrid mussels in a warming ocean.

3.3.6.4 Summary of findings

CEDA Archive sources provide data on temperatures, rainfall and season timings. Marine species biodiversity data is provided through numerous sources via studies and survey data. Most models regarding sensitivities and ranges are related to molluscs, with some research initiatives also focussing on seagrass. Less in-depth data is provided on other taxonomic groups.

Table 26 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N14 + N16 Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS)	Current and forecast changes in ocean acidification, stratification, oxygenation, variability in salinity and changes in ocean currents. Pests, pathogens and invasive non-native species (INNS) current and forecast presence/abundance.	Marine species presence/abundance, marine habitat, fisheries coverage/location	Sensitivity of marine species' ranges, habitats and fisheries to changes in ocean acidification, stratification, oxygenation, variability in salinity, changes in ocean currents and pests, pathogens and INNS

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.3.7 N17 Risks to coastal species and habitats due to coastal flooding, erosion and climate factors

Sea level rise is a major risk to coastal species, and intertidal and supratidal marine environments. Where there is some potential for habitat creation and species gain for some habitats, negative risks of species and habitat loss are predominant.

3.3.7.1 Spatial models

There are five models within risk N17 Risks to coastal species and habitats due to coastal flooding, erosion and climate factors. Coastal flooding and coastal erosion risks are covered. Storms and risks to coastal species and intertidal and supratidal marine environments are not explicitly covered.

3.3.7.2 Datasets

13 datasets cover hazard information. Current and forecast sea levels, coastal flooding, coastal erosion and storms notably by UKCP-18 which covered time mean sea level, storm surge trend and storm surge simulations, Fathom UK coastal flooding and EA and NRW coastal erosion risk datasets.

There are 77 exposure datasets in total with the majority being monitoring datasets sourced from Natural, England other datasets include habitat maps, special protection areas, sediments, surf zone modelling, sensitive area maps, fish surveys and heritage coast data. Four datasets cover vulnerability data all datasets are water framework directive covering transitional and coastal waterbodies and river basin management plans risk assessments.

3.3.7.3 Research initiatives

There is a total of 14 research initiatives within risk N17. There are four initiatives which operate worldwide, nine are UK-focused and of which one is including learnings from Japan. Biodiversity, storm surge barriers and sea level rise risks to coastal species and habitats are covered.

3.3.7.4 Summary of findings

Hazard information is sufficiently available. Coastal species abundance data is in multiple datasets from a variety of survey sources, and present in the NBN Atlas. Datasets on coastal habitat or species sensitivity are not considered although the models included do focus on coastal erosion susceptibility. A small number of research initiatives do focus on measures of adaptation, e.g., UPSURGE: Helping storm surge barriers prepare for climate change although the focus is on protecting human property.

Table 27 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
N17 Risks to coastal species and habitats due to coastal flooding, erosion and climate factors	Current and forecast sea levels, coastal flooding, coastal erosion and storms	Coastal species presence/abundance and coastal habitat coverage	Sensitivity of coastal habitats and natural flood protection to sea level rise and erosion. Measures of adaptation to improve resilience of coastal habitats and natural flood protection

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.4 BUSINESS AND INDUSTRY

3.4.1 B1 Risk to business sites from flooding

Across the UK, flooding is a major current and future risk to businesses leading to damaged sites, production losses, business interruption and profitability losses.

3.4.1.1 Spatial models

There is a total of 7 models within risk B1 Risk to business sites from flooding. Direct risks to business due to flooding and electricity failures are covered in the 'Business Disruption and Economic Losses Due to Electricity Failures and Flooding' model. In other models, flooding risks to catchment basins are captured in relation to rainfall events and they could be used to assess the impact on businesses.

3.4.1.2 Datasets

One dataset includes modelled data under different climate scenarios. Three other datasets cover flood hazard, flood risk from surface water and aerial photography. There are four exposure datasets which cover status of corporate & residual property and population estimates based on census data. Four datasets were categorised as potential indicators of vulnerability, albeit loose ones. Spatial data on internal drainage boards could be used as indicators of adaptive capacity as they describe governing body responsible for addressing flooding risks. Data on Gross Value Added (GVA) and Produced capital could also be used as indicators of adaptive capacity. Data on urbanisation could potentially be used as indicator of sensitivity to flooding risks.

3.4.1.3 Research initiatives

There is a total of 10 research initiatives within risk B1. Two initiatives are worldwide, the rest focus on the UK specifically. Climate change resilience, weather extremes in the UK and societal impacts are addressed.

3.4.1.4 Summary of findings

Flooding hazards are covered thoroughly within models, datasets and research initiatives. There is exposure information for existing business sites but not forecast ones. For vulnerability there are specifications of current business sites built into the Fathom UK CAT model (described in more detail in the subsequent section). Similarly, adaptation scenarios are not covered specifically.

Table 28 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
B1 Risk to business sites from flooding	Current and future flood zones in different climate scenarios	Existing and forecast business sites	Specifications of current and future business sites with regard to drainage/flooding. Adaptation scenarios of future location of business sites and/or drainage

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

3.4.2 B2 Risks to business locations and infrastructure from coastal change

Sea level change, coastline geomorphology, coastal processes, the nature of the hazard, human interventions along the coast, and coastal protection determine the risk exposure of business locations and infrastructure from coastal change. Extreme weather events and coastal flooding are key risks to chemical processing plants, food processing facilities, pharmaceutical manufacturing, train stations, railways, roads, power stations, landfill sites and farmland in the UK.

3.4.2.1 Spatial models

There are five models within risk B2 Risks to business locations and infrastructure from coastal change. These are: Fathom-UK CAT model, JBA UK Flood Model, Coastal Erosion Susceptibility Model (for Scotland), XBeach and XBeach-G for sand and gravel beach wave hazard, overwashing or overtopping volumes for hard defences and Adaptation and Resilience of Coastal Energy Supply (ARCoES) project Decision Support Tool (DST). Fathom-UK CAT is a probabilistic model which uniquely characterises the relationship between flood depth and damage in a variety of contexts. It is underpinned by the Fathom UK Coastal Flood model which accounts for multiple coastal scenarios including sea level rise, high tides and storm surge. The CAT model outputs probabilities on the damage to non-residential buildings with an accurate determination of damages based on a property's characteristics in three time horizons for present day, 2030 and 2050.

3.4.2.2 Datasets

Sea-level rise and coastal erosion hazard datasets cover information on the network of wave buoys in flood risk areas, LiDAR data, coastal erosion vulnerability and coastal flood risk and historic datasets mainly from the Environment Agency. Data regarding storm surges, astronomical tides under different climate scenarios are not covered. Exposure data covers train stations, railways, roads, power stations, landfill sites, airports, farmland and non-residential buildings.

Data that could potentially be used as indicators of vulnerability, such as produced capital, is available. However, vulnerability data specifically relevant to retreating shoreline/coastal erosion and other coastal hazards was not found.

3.4.2.3 Research initiatives

There is a total of 11 research initiatives within risk B2. Three worldwide initiatives are included, all others are covering risks within the UK. Landslides coastal surges and climate change resilience overall are addressed.

3.4.2.4 Summary of findings

Coastal flooding and sea level hazard is sufficiently covered by the Fathom coastal flood models. However, coastal erosion hazard is only covered in Scotland. For exposure, existing business locations and infrastructure is covered by the datasets, however planned locations are not covered. There is building vulnerability data built into the Fathom UK CAT model, but not for infrastructure. There is also a lack of adaptation information.

Table 29 RAG analysis of the models, datasets and research initiative indicating where there are gaps for each risk component

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
B2 Risks to business locations and infrastructure from coastal change	Coastal change, including coastal erosion, flooding from waves, astronomical tides, storm surges and relative mean sea level rise, in different climate scenarios	Existing and forecast business locations and infrastructure	Specifications of current and future business sites with regard to retreating shoreline/coastal erosion, and other coastal hazards including flooding, storms and sea level rise. Adaptation scenarios of future location of coastal businesses

RAG colouring: Red – Significant gaps; Amber – Some minor gaps; Green – No gaps.

4. CONCLUSIONS

This study surveyed the spatial models, datasets and research initiatives that can be used to assess the spatial distribution of climate risks across the economy and the natural environment in the UK. Each of the identified models, datasets and research initiatives are summarised in greater detail in the accompanying Excel document.

There are likely numerous datasets and models that are not in the public domain (for example owned by water companies or energy companies) that have not been captured in this study. In addition, data on planned/future assets for exposure was often lacking. Spatial coverage was generally uniform across the UK although certain models were country specific.

A summary of our findings, based on the models, datasets and projects that we were able to identify, is presented in Table 30. Across the climate risks that received the highest urgency score in CCRA3, there is significant spatial evidence available on the evolving hazards and some information available on the exposure of the systems and assets at risk. However, there are significant evidence gaps on the vulnerability of those systems and assets to the hazard. It is advised that further research is conducted into all three specifically on cascading effects and cross-sectoral interactions.

A key conclusion from this research is that further spatial research is required on the sensitivity and adaptive capacity of UK infrastructure; health systems, communities and the built environment; the natural environment; and business and industry. Beyond providing a stock take of the existing spatial evidence available, this analysis will hopefully guide future research in the UK in the lead up to CCRA4.

Table 30 RAG rating of risk component for each CCRA3 risk indicating where there are data gaps

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
Infrastructure			
I1 Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures	Cascading failures under current and future climate change scenarios (from changing temperatures and rainfall regimes)	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned water, energy, transport and ICT infrastructure networks with respect to cascading failures
I2 Risks to infrastructure services from river, surface water and groundwater flooding	Spatial data on current flood zones and future ones in different climate scenarios	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned power, transport, ICT and water infrastructure with respect to flooding
I3 Risks to infrastructure services from coastal flooding and erosion	Current and forecast coastal flood zones and coastal erosion in different climate scenarios	Existing and planned location of water, energy, transport and ICT infrastructure	Specifications of existing and planned coastal energy, transport, telecommunications and water infrastructure with respect to flooding and coastal erosion
I5 Risks to transport networks from slope and embankment failure caused by heavy rainfall events	Current and forecast summer temperatures, summer mean rainfall, winter rainfall events and winter mean rainfall under different climate scenarios	Existing and planned engineered cuttings and embankments supporting transport infrastructure	Specifications of existing and planned slope and embankment supporting transport infrastructure e.g. older, less compacted earthworks not built to modern construction standards
I8 Risks to public water supplies from drought and low river flows	Spatial data on current drought and river flows, and future forecasts in different climate scenarios	Existing and planned abstraction locations and public water infrastructure such as reservoirs, overflow structures and spillways constructions or valves and draw off towers	Specifications of existing and planned public water infrastructure such as reservoirs, overflow structures and spillways or valve and draw off towers with respect to drought and low river flows

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
I9 Risks to energy generation from reduced water availability	Spatial data on current drought and river flows, and future forecasts in different climate scenarios	Existing and planned energy infrastructure of operational thermal power plants	Specifications of existing and planned energy infrastructure of thermal power plants and electrolysis derived hydrogen plants with respect to water scarcity
I10 Risks to energy from high and low temperatures, high winds, lightning	Current and forecast high and low temperatures, high winds, snow, fire outbreaks and lightning and in different climate scenarios	Existing and planned energy infrastructure	Specifications of existing and planned energy infrastructure with respect to extreme temperatures (high and low), as well as high winds and lightning
I12 Risks to transport from high and low temperatures, high winds, lightning	Current and forecast high and low temperatures, high winds and lightning in different climate scenarios	Existing and planned transport networks	Specifications of existing and planned transport infrastructure with respect to extreme temperatures (high and low), as well as high winds and lightning
Health, communities and the built environment			
H1 Risks to health and wellbeing from high temperatures	Current and forecast temperatures, fire outbreaks, air pollution and drought in different climate scenarios	Existing and planned buildings and population density	Characteristics of existing and planned buildings with regard to heatwaves. Current and forecast demographics (age, income level, etc.) and other indicators of sensitivity to high temperatures (e.g. availability of healthcare, quality of healthcare for temperature related illnesses such heat stress, heat stroke, etc.)
H3 Risks to people, communities and rivers from river, surface and coastal flooding	Current and future flood zones	Existing and planned buildings	Characteristics of existing and planned buildings with regard to flooding. Current and forecast demographics (age, income level, etc.) and other indicators of sensitivity to flooding and potential water-borne diseases or health problems exacerbated by exposure to water/flooding (e.g. availability of healthcare, including mental health support, quality of healthcare for potential water-related illnesses, etc.)

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H4 Risks to people, communities and buildings from sea level rise	Areas at risk from sea level rise and sediment erosion	Existing and planned buildings, housing and community infrastructure	Characteristics of existing and planned coastal buildings and community infrastructure with regard to sea level rise
H6 Risks from summer and winter household energy demand	Current and future seasonal temperature changes (hotter summers and winters) in different climate scenarios	Spatial data on energy consumption correlated with temperature	Characteristics of existing and planned buildings with regard to insulation to retain heat/cool down efficiently in extreme temperatures. Current and forecast demographics (age, income level etc.) and other indicators of sensitivity to higher temperatures and to potential inflation of energy prices due to higher demand (for mechanical cooling). Availability of regulations and governance structures to provide financial support for low-income communities to aid in the uptake of mechanical cooling
H8 Risks to health from vector-borne diseases	Current distribution/risk of vector-borne diseases and forecast under different climate scenarios	Current and projected population data in the zones where vector-borne diseases are expected to spread to	Characteristics of populations (including demographic, recreation, workplace data which might indicate populations that are sensitive) and other indicators of sensitivity to potential vector-borne diseases (e.g. availability and quality of healthcare for vector-borne diseases, etc.)
H12 Risks to health and social care delivery	Current and forecast floods, heatwaves, other weather extremes and landslide risk in different climate scenarios	Existing and planned health and social care buildings and infrastructure (e.g. laboratory services) and transport infrastructure	Characteristics of existing and planned health and social care buildings and transport infrastructure with regard to extreme weather events including floods, heatwaves, landslides etc. Characteristics of health and social care workers, such as age, that may indicate the sensitivity of staff delivering care

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
H13 Risks to education and prison services	Current and forecast floods, heatwaves, other weather extremes and landslide risk in different climate scenarios	Existing and planned education and prison services	Characteristics of existing and education and prison infrastructure with regard to extreme weather events including floods, heatwaves, landslides etc. Characteristics of education and prison workers, such as age, that may indicate the sensitivity of staff delivering the services
The natural environment			
N1 + N2 Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))	Current and forecast temperatures, rainfall and timing of seasons in different climate scenarios. Pests, pathogens and invasive non-native species (INNS) current and forecast presence/abundance.	Terrestrial species presence/abundance, terrestrial habitat coverage and designated site coverage	Sensitivity of species' ranges to changes in temperature, rainfall and seasons. Measures of adaptation for habitat preservation
N4 Risk to soils from changing conditions, including seasonal aridity and wetness	Current and forecast rainfall, temperature, evaporation and evapotranspiration in different climate scenarios	Soil aridity and moisture levels	Characteristics of soils with respect to rainfall, temperature, evaporation and evapotranspiration (e.g. soil type, condition, land use). Measures of adaptation to conserve soils (e.g. maintain minimum soil cover, take measures to prevent erosion, and maintain soil organic matter levels).
N5 Risks to natural carbon stores and carbon sequestration	Current and forecast rainfall, temperatures, soil erosion and sea level rise in different climate scenarios	Carbon stocks in soil and different habitats and carbon sequestration	Sensitivity of carbon stocks to changing temperatures, rainfall coastal erosion and sea level rise. Measures of adaptation to enhance soil carbon stocks (e.g. Green and Pleasant Land scenario)
N6 + N7 + N8 Risks to agricultural and forestry productivity (including from pests, pathogens and INNS)	Current and forecast heat stress, water scarcity and flooding in different climate scenarios. Pests, pathogens and invasive	Agricultural land and forest	Sensitivity of agricultural and forest productivity to water scarcity and flooding, pests, pathogens and INNS. Measures of adaptation to improve agricultural and forestry resilience.

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
	non-native species (INNS) current and forecast presence/abundance.		
N11+ N12 Risks to freshwater species and habitats (including from pests, pathogens and INNS)	Current and forecast temperatures, rainfall, water availability, flooding and extreme weather events in different climate scenarios. Pests, pathogens and invasive non-native species (INNS) current and forecast presence/abundance.	Freshwater species presence/abundance and freshwater habitat coverage/location	Sensitivity of freshwater species' ranges and habitats to changes in temperature, rainfall, seasons, pests, pathogens and INNS
N14 + N16 Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS)	Current and forecast changes in ocean acidification, stratification, oxygenation, variability in salinity and changes in ocean currents. Pests, pathogens and invasive non-native species (INNS) current and forecast presence/abundance.	Marine species presence/abundance, marine habitat, fisheries coverage/location	Sensitivity of marine species' ranges, habitats and fisheries to changes in ocean acidification, stratification, oxygenation, variability in salinity, changes in ocean currents and pests, pathogens and INNS
N17 Risks to coastal species and habitats due to coastal flooding, erosion and climate factors	Current and forecast sea levels, coastal flooding, coastal erosion and storms	Coastal species presence/abundance and coastal habitat coverage	Sensitivity of coastal habitats and natural flood protection to sea level rise and erosion. Measures of adaptation to improve resilience of coastal habitats and natural flood protection
Business and industry			
B1 Risk to business sites from flooding	Current and future flood zones in different climate scenarios	Existing and forecast business sites	Specifications of current and future business sites with regard to drainage/flooding. Adaptation scenarios of future location of business sites and/or drainage
B2 Risks to business locations and infrastructure from coastal change	Coastal change, including coastal erosion, flooding from waves, astronomical tides, storm surges and	Existing and forecast business locations and infrastructure	Specifications of current and future business sites with regard to retreating shoreline/coastal erosion, and other coastal hazards including

Climate risks from CCRA3	Risk component		
	Hazard	Exposure	Vulnerability
	relative mean sea level rise, in different climate scenarios		flooding, storms and sea level rise. Adaptation scenarios of future location of coastal businesses

APPENDICES

Appendix 1 Survey Questionnaire

Description of the Questionnaire

Thank you for taking part in this survey, which aims to obtain information on the evidence landscape for the Fourth Climate Change Risk Assessment (CCRA4), developed by the Climate Change Committee (CCC) at the request of Defra.

The CCRA4 aims to provide a greater level of spatial granularity in its assessment of the climate risks across the UK and present a more localised view of adaptation needs than previous CCRAs.

The CCC has commissioned independent research institutions Ricardo Energy & Environment and Tyndall Centre for Climate Change Research to assess the current and upcoming evidence landscape for the UK-focused spatial climate risks as part of the scoping of the CCRA4. By taking part in this survey, you are helping with this assessment and the scoping of the CCRA4.

The questionnaire will take approximately 15-30 minutes to answer.

The questionnaire will consist of the following:

1. Firstly, you will be given the option to provide your name and email address, so that we can follow up with you if we require more information to help inform the CCRA4. If you wish for your answers to be anonymous, leave this blank. Read the privacy policy for more information.
2. Then, it will ask what areas of climate change risk you have expertise in, e.g. (a) infrastructure (b) health, communities and the built environment (c) the natural environment etc.
3. You will then be asked to select what are risks, within these areas, that you are knowledgeable on (from a list of specified risks).
4. For each risk you select, you will be asked about your knowledge of the following:

(i) Spatial models
(ii) Spatial datasets
(iii) Research initiatives

1) If you are happy for us to follow up with you, please provide your name and email address:

Name: _____

Email Address: _____

Climate Change Risks

2) Which sector or risk area do you have expertise in?

[ ] Infrastructure

[ ] Health, communities and the built environment

[ ] The natural environment

[ ] Business and industry

3) Within infrastructure, which risks do you have expertise in?

[ ] I1) Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures

[ ] I2) Risks to infrastructure services from river and surface water flooding

[ ] I3) Risks to infrastructure services from coastal flooding and erosion

[ ] I5) Risks to transport networks from slope and embankment failure caused by heavy rainfall events

[ ] I8) Risks to public water supplies from drought and low river flows

[ ] I9) Risks to energy generation from reduced water availability

[ ] I10) Risks to energy from high and low temperatures, high winds, lightning

[ ] I12) Risks to transport from high and low temperatures, high winds, lightning

4) Within health, communities and the built environment, which risks do you have expertise in?

[ ] H1) Risks to health and wellbeing from high temperatures

[ ] H3) Risks to people, communities and rivers from river, surface and coastal flooding

[ ] H4) Risks to people, communities and buildings from sea level rise

[ ] H6) Risks from summer and winter household energy demand

[ ] H8) Risks to health from vector-borne diseases

[ ] H12) Risks to health and social care delivery

[ ] H13) Risks to education and prison services

5) Within the natural environment, which risks do you have expertise in?

[ ] N1-2) Risks to terrestrial species and habitats (including from pests, pathogens and invasive non-native species (INNS))

[ ] N4) Risk to soils from changing conditions, including seasonal aridity and wetness

[ ] N5) Risks to natural carbon stores and carbon sequestration

[ ] N6-8) Risks to agricultural and forestry productivity (including from pests, pathogens and INNS)

[ ] N11-12) Risks to freshwater species and habitats (including from pests, pathogens and INNS)

[ ] N14+16) Risks to marine species, habitats and fisheries (including from pests, pathogens and INNS)

[ ] N17) Risks to coastal species and habitats due to coastal flooding, erosion and climate factors

6) Within business and industry, which risks do you have expertise in?

[ ] B1) Risk to business sites from flooding

[ ] B2) Risks to business locations and infrastructure from coastal change

For each risk, the following questions were asked:

7) Within this risk, are you aware of any spatial models?

[ ] Yes

[ ] No

8) What spatial models are you aware of?

Spatial model 1: _____

Spatial model 2: _____

Spatial model 3: _____

9) Model details.

Please provide the link of the model and as much additional information as your time allows.

	Spatial model 1	Spatial model 2	Spatial model 3
Link			
Short Description			
Ownership			
Open source or proprietary			
Spatial coverage, i.e. country, county, local authority etc.			
Spatial resolution			
Year			
Input 1			
Input 2			
Input 3			
Input 4			
Uncertainty			

10) Are there any other spatial models that you are aware of?

_____

_____

_____

_____

11) Within this risk, are you aware of any spatial datasets?

[ ] Yes

[ ] No

12) What spatial datasets are you aware of?

Spatial dataset 1: _____

Spatial dataset 2: _____

Spatial dataset 3: _____

13) Spatial dataset details.

Please provide the link where the dataset can be found and list as many details in the table below as your time allows.

	Spatial dataset 1	Spatial dataset 2	Spatial dataset 3
Link			
Ownership			
Open source or proprietary			
Spatial coverage, i.e. country, county, local authority etc.			
Spatial resolution			
Time period (years)			
Time intervals			
Method			
Limitations			

14) Are there any other spatial datasets that you are aware of?

_____

_____

_____

_____

15) Are you aware of any research initiatives within the risk?

[ ] Yes

[ ] No

16) If yes, which research initiatives are you aware of?

Research initiative 1: _____

Research initiative 2: _____

Research initiative 3: _____

17) Information on the research initiative you mentioned in the previous question.

Please provide the link of the research initiative and give as much additional information as your time allows.

	Research initiative 1	Research initiative 2	Research initiative 3
Link			
Participating organisations			
Project timeframe			
Spatial coverage			
Methodology			

	Research initiative 1	Research initiative 2	Research initiative 3
Outputs			
Limitations			

*18**)** Are there any other research initiatives / lead organisations that you are aware of?)*

_____

_____

_____

_____

Thank You!

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