Department for Transport

Climate Risk Assessment Guidance for the Transport Sector

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Introduction

Background

Accessible, safe, and reliable transport infrastructure is fundamental to day-to-day life. Climate change has the potential to disrupt operations and damage the transport network, through hazards such as flooding, subsidence, high and low temperatures, and other extreme weather.

Even if the global temperature increase can be limited to 1.5°C in line with the goals of the Paris Agreement, a level of warming is locked in and will continue to change the UK's climate. According to the Met Office, climate projections suggest the UK could experience warmer, wetter winters, hotter, drier summers, and more frequent and severe weather events. By 2070, winters could be up to 30% wetter and summers could be up to 60% drier compared to 2020.

Climate Change Risk Assessments (CCRAs) can help organisations understand the current and future effects of climate change and prioritise adaptation action. The Climate Change Act 2008 allows Defra to invite certain organisations to produce CCRAs every five years as part of the Adaptation Reporting Power. A recent review of CCRAs by the Climate Change Committee concluded that gaps remain in the quality and quantity of adaptation reports in the transport sector, particularly for ports, airports and local highways.

CCRAs may also be undertaken for a specific transport scheme to identify climate-related risks to prioritise where adaptation measures are required.

This guidance document has been developed by Mott MacDonald in collaboration with the Department for Transport and has been reviewed by the Met Office.

Aims of the guidance

This guidance provides a step-by-step approach to completing a CCRA for the UK transport sector. It is suitable for use across the sector but focusses on ports, airports and local highways where the evidence base is currently comparatively less well developed.

This guidance has been developed with input from across the transport sector. It focusses on physical climate risks (climate risks to assets, systems and organisations) and does not specifically discuss transition risks (climate risks associated with decarbonisation policies and the transition away from fossil fuels and other greenhouse gas-emitting activities).

The purpose of this work is to:

- guide infrastructure owners and operators to identify and prioritise climate risks
- increase the uptake of CCRAs
- reduce uncertainty and improve consistency across the sector

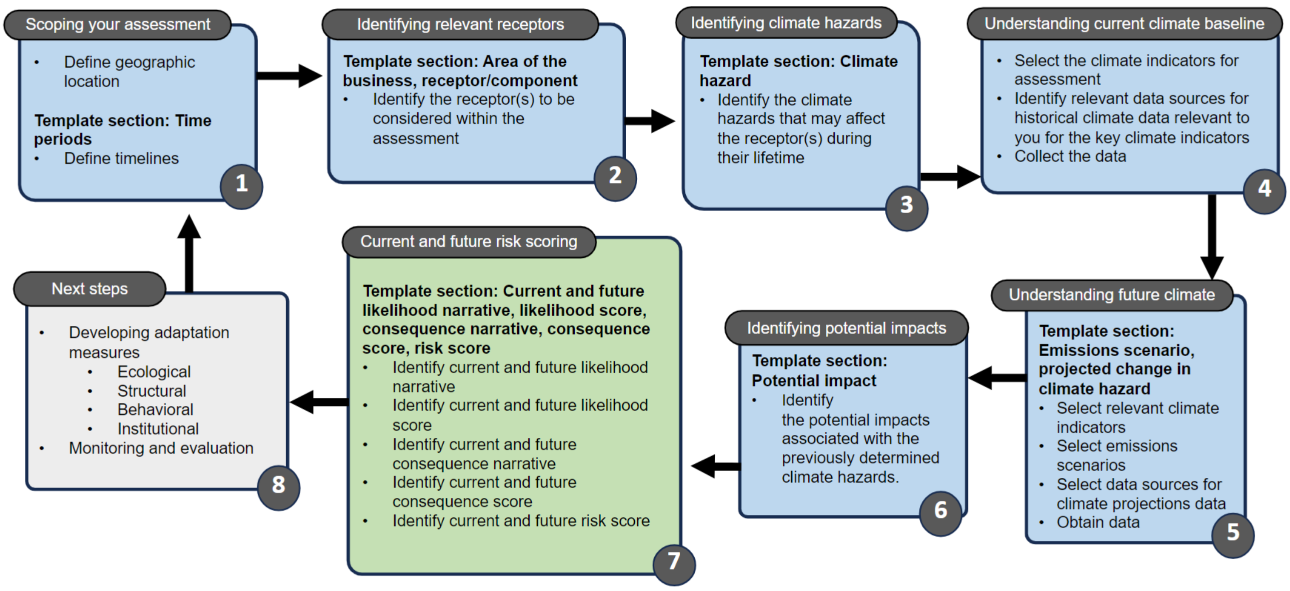
This guidance provides:

- an over-arching approach to CCRAs, identifying useful tools to complete each step
- a methodology to score climate risks
- best-practice case studies

Structure of the guidance and where to find information

The CCRA method takes the user through the steps required to carry out a CCRA. These steps are summarised as a flowchart in Figure 1. Each section includes guidance, references to supporting materials where appropriate, and a check list.

Figure 1 A flow diagram outlining the steps to undertake a CCRA



Following these steps will allow users to complete the template in Figure 2. This template should be completed for each climate risk. Risks should be assessed for both the present day and for your selected future time period(s). We also recommend that users develop a CCRA report, providing more detail about the assumptions, methodology and results.

Figure 2: CCRA Template

		Example
Scope & potential impact	Area of the business	
	Receptor / component	
	Climate hazard	
	Projected change in climate hazard	
	Potential impact	
Risk assessment Time period: Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

More detailed guidance on how to access and download UK climate projections data is available in Annex A:. Annex B:includes best practice case studies for ports, airports and local highways, and Annex C: includes a list of potential climate risks for these three subsectors.

CCRA method

CCRA method

This CCRA methodology for the transport sector draws on existing best practice from across the transport sector. It is targeted at users without a background in CCRAs or experience of using climate change projections data.

A note on terminology

This guidance and the corresponding template use the terms Likelihood and Consequence to break down the elements of scoring a climate risk. This terminology is most aligned with current best practice across the transport sector and relatable to the stakeholders targeted by this guidance.

Other assessment frameworks use different terms such as Hazard, Vulnerability and Exposure. For example, this terminology is used in ISO:14091: Adaptation to climate change: guidelines on vulnerability, impacts and risk assessment.

A CCRA can be carried out for:

- an individual asset or multiple assets in one place (e.g. an airport)
- a collection of distributed assets (e.g., a network of radar stations)
- an entire organisation

A CCRA can be qualitative, semi-quantitative or quantitative, requiring an increasing level of data, information and complexity to develop. Organisations should choose what level of CCRA will be proportionate depending on their capacity and capability and the expected significance of climate risks.

Within the assessment, organisations should consider both positive (i.e. opportunities) and negative (i.e. risks) impacts that may arise as a result of the changing climate.

Figure 3 summarises the steps in the CCRA. The arrow illustrates that a CCRA is not a one-off assessment but part of a continuous cycle. The final step on developing adaptation actions and monitoring and evaluation is not discussed in detail within this guidance but is an important step in the process.

You may wish to supplement this guidance with other sources such as the local authority Climate Adaptation Toolkit, ADEPT guidance, International Civil Aviation Organisation (ICAO) guidance or World Association for Waterborne Transport Infrastructure (PIANC) guidance.

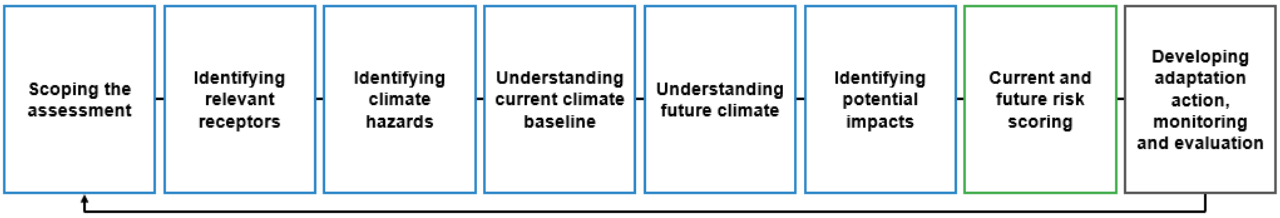


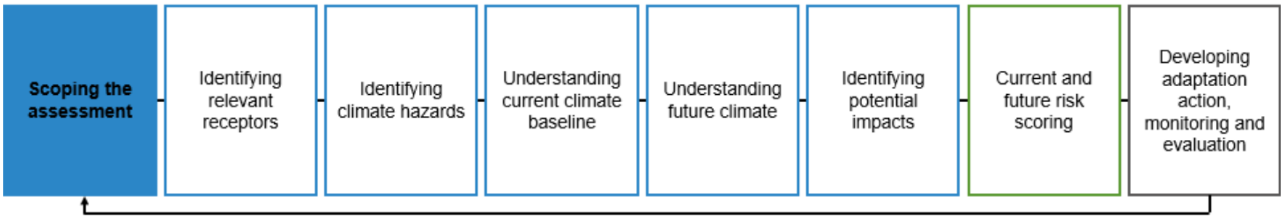
Figure 3 CCRA steps

Identifying your CCRA working group

Identify a team and create a working group specifically for the CCRA process. This group should draw on relevant internal expertise, for example on risk, assets and operations. Effective collaboration will enhance the quality and relevance of your CCRA.

This group will be responsible for overseeing the assessment process. It is important to ensure that you clearly define roles and responsibilities for each participant, for example, facilitator, technical inputs, validation team.

Step 1: Scoping the assessment



This step will identify the time periods and physical boundaries of the assessment.

Example

Scope & potential impact	**Area of the business**	**Airport infrastructure**
	Receptor / component	
	Climate hazard	
	Projected change in climate hazard	
	Potential impact	
Risk assessment **Time period:** Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

1.1 Defining the physical boundary of your assessment

The physical boundary of the assessment should be defined in relation to the asset, system or organisation which the assessment is targeting.

To define the physical boundary of the assessment, you should consider which direct and indirect impacts should be within scope of the CCRA.

- Direct impacts (or primary impacts) describe the impacts of the risks on your assets, systems or organisation arising directly due to the occurrence of climate hazards. For example, extreme weather events such as flooding, and storm events can disrupt a section of a local highway.
- Indirect impacts (or secondary impacts) describe impacts that result due to the interdependencies. Interdependencies can be either upstream (cascading failures

from other sectors impacting the receptor(s) of interest) or downstream (cascading failures from the receptor(s) of interest to other receptors). Indirect impacts may also occur because of cascade risk where assets, systems and organisations are not necessarily interdependent but are co-located - for example, disruption to water or gas supply buried underneath a highway asset.

The physical boundary of an assessment which considers direct impacts may be different than that of an assessment which considers indirect impacts. If an assessment is looking at indirect impacts as well as direct impacts, then the CCRA would include the wider systems the initial asset, system or organisation is interdependent or co-located with. Users are encouraged to consider significant upstream and downstream impacts.

Example
If assessing the direct impacts for an airport, the physical boundary could be defined to include the airport terminal, the runway and any ancillary buildings and services. If assessing the indirect impacts for an airport, the physical boundary could also include connecting local highways and public transport that allow staff and passengers to reach the airport.

The example above identifies the area of the business (i.e. the focus of the assessment) as 'airport infrastructure'.

If carrying out an organisation-level assessment, the assessment is likely to focus on risks to business functions rather than specifically to assets.

Once the physical boundary has been decided it is possible to determine the scale of the data that will be needed to obtain the current climate baseline. It is reasonable to begin an assessment with a smaller, well-defined scope to better understand the principles and risks to the asset or organisation. This assessment can then be expanded upon.

The physical boundary should be recorded and justified within the CCRA report. This could be done using maps or whichever geospatial systems the organisation is currently using.

1.2 Defining the time period for your assessment

It is important that an assessment-relevant time period is selected.

For an asset-based assessment, the time period for the CCRA should reflect the asset life. It may be desirable to also use intermediate time periods for the assessment which align with when an asset needs to be replaced or refurbished. This could allow adaptation measures to be embedded in asset maintenance cycles, if relevant (e.g. if the CCRA suggested that further adaptation measures are required).

Example

For a local highway project, the road surface may require refurbishment every eight to twelve years, whereas the underlying infrastructure, such as bridges, tunnels and drainage systems are built to last much longer.

As such, the CCRA timeframe for a local highway could include both a short-term time period for refurbishment cycles, and a longer-term time period to ensure future impacts are accounted for.

Example

Expansion of an airport terminal building. The anticipated lifespan of the terminal is 80 years, however there is a planned refurbishment period after 30 years. In this situation, it would be appropriate to consider the 2050s and 2100 as two time periods.

For an organisation-level assessment, there is no such asset-specific defined lifetime. An organisation may want to consider aligning time periods with their decision-making and investment cycles, as well as any time periods which might be regulated.

Alternatively, an organisation might choose to align with the third UK Climate Change Risk Assessment which considered the 2050s and the 2080s, or with the Intergovernmental Panel on Climate Change which define near-term as 2021 - 2040, medium-term as 2041 - 2060 and long-term as 2081 - 2100.

To provide a representation of future trends at one location, it is common practice to use a period of at least 20 years to provide average values over that period, smoothing out year-on-year variability.[1] For a CCRA, you may also want to consider variability over the 20 year period as well as the average trend.

UK Climate Projections (UKCP) for land are not currently available beyond 2100 and only a selection of marine projections datasets are available beyond 2100. Therefore, only marine hazards can be considered quantitatively for time horizons beyond 2100. These time periods can be relevant when considering long-lived coastal infrastructure such as ports or coastal airports.

Professional judgement will be required to select appropriate time periods for assessment. Justification for the choice of time period should be included within the CCRA report.

[1] It is worth noting that longer-term climate projections are typically unable to capture relatively short-term changes in climate such as those driven by El Niño / La Niña, by volcanic eruptions or by other Short-lived Climate Forcers (SLCF). Longer-term projections do try to capture the correct number and size of modes of variability such as El Niño / La Niña, but will not capture specific events in specific future years. These phenomena can drive temporary changes in global and local climate systems lasting typically between a few months to a few years. When selecting your time period you should be aware that short-term climate events are a source of uncertainty within the climate projections data you select. Refer to section 5.4 for more details on uncertainty.

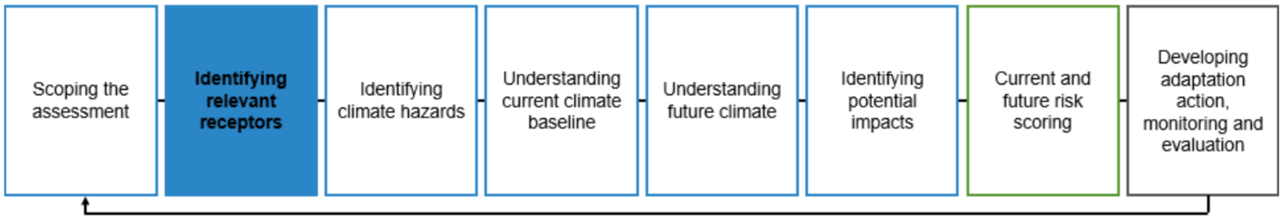
Checklist: Defining the scope of assessment

By the end of this section you will have:

☐ Defined the physical boundary of the assessment

☐ Defined the time period(s) for the assessment

Step 2: Identifying receptors



This step identifies the receptors to be considered within the assessment.

A receptor is defined as a person, physical object or asset (linear or point asset), system, or organisation which has the potential to be impacted by a climate hazard. It is important to be comprehensive in identifying all receptors within the assessment which may be impacted by a climate hazard.

Example

Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	**Airport buildings**
	Climate hazard	
	Projected change in climate hazard	
	Potential impact	
Risk assessment Time period: Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

When defining the receptors relevant to the assessment, consideration should be given to:

The specific receptor(s):

- For linear receptors such as roads and rail lines, a CCRA could be conducted at either asset-class level (e.g. considering all bridges in an area), or by breaking the linear asset into sections (e.g. considering a 2km section of road). Alternatively, a hotspot assessment may be appropriate (e.g. at a bridge).

- For organisation-level assessments, it may be appropriate to assess the impact of risks on business functions and/or organisational KPIs.

- Consideration should be given to which human receptors are in-scope e.g. construction workers, employees, end users, local residents and communities. Particular consideration should be given to impacts on people who are vulnerable (e.g. the elderly or those with health problems) and with protected characteristics.

- Other physical receptors associated with the asset(s), system(s) or organisation such as the IT systems that they rely on.

The level of detail needed for the assessment to achieve its intended outcomes:

- Can the receptors be grouped, or do they need to be assessed individually? For example, by asset category (such as structures), asset specific (such as bridges) or asset component (such as bridge deck).

Phases of a project/lifecycle:

- Are there multiple phases of a project? For example, construction, operation, decommissioning and end of life.

Table provides a non-exhaustive list of receptors for ports, airports and local highways.

Table provides further resources to help identify relevant receptors for ports, airports and local highways CCRAs.

Table 2: Non-exhaustive list of receptors for ports, airports and local highways

	Ports	Airports	Local highways[2]
Construction	Access roads, site compounds, temporary structures, materials and stockpiles, drainage, plant and machinery.		
	Workers		
	Surrounding environment		
Operation receptors	Drainage	Airport/ground staff	Bridges/structures
	Gantry cranes	Communication systems	Drainage and culverts
	Locks	Drainage	Earthworks/embankments
	Navigation systems	Electrical equipment	End users and local communities

[2] Local highways practitioners could also refer to the Chartered Institute of Public Finance and Accountancy's highway asset groups.

	Ports	Airports	Local highways[2]
	Port operators, site staff	Navigation aids	Lighting
	Containers, bulk cargo	Passengers	Barriers and restraints
	Reach stackers	Runway vehicles	Road surface
	Ship loaders and unloaders	Runway, apron, taxiway (and other hard surface)	Roadside vegetation
	Structures: bridges, radar towers, breakwaters, navigation lights, buildings	Structures: terminal, control towers, utility buildings, hangars	Signage and gantries
	Surrounding environment: flora, fauna and ecosystems around the port	Surrounding environment: flora, fauna and vegetated areas	Ducts and electrical equipment (buried cables)
	Telemetry systems	Utilities: water supply, electricity	Car parks
	Utilities: water supply, electricity	Car parks	Public Rights of Way Network
	Water channels		
	Harbour walls		
	Car parks		
Operation activity	Handling and storage of cargo	Handling and storage of baggage	Road and roadside maintenance
	Port buildings/ grounds maintenance	Terminal/grounds maintenance	
Decommissioning and end of life receptors	Materials and waste disposal		
	Heavy lifting and transportation		
	Cleaning and decontamination		
	Storage of equipment and materials		

	Ports	Airports	Local highways[2]
	Marine and onshore logistics		
	Return of site		

Table 3: Resources to help identify relevant receptors for assessment

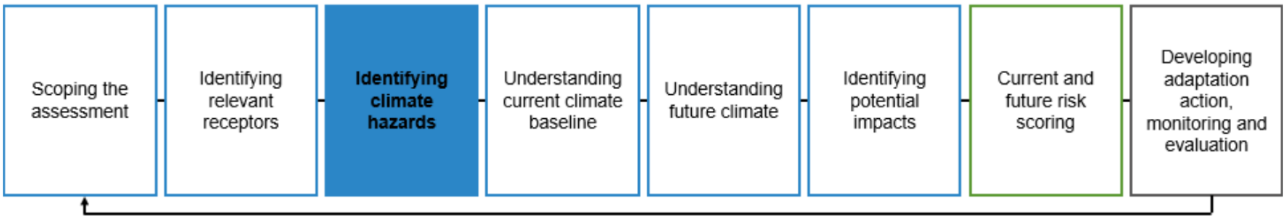
Resource	Purpose
Climate Change Committee's Independent Assessment of UK Climate Risk – Transport sector briefing	This document provides a summary of how the transport sector has been assessed within the latest UK Climate Change Risk Assessment. This is a useful document to assist you in identifying the types of receptors that are considered when undertaking a CCRA across the transport sector.
Climate change adaptation reporting: third round reports	This resource compiles reports submitted under the third round of the Adaptation Reporting Power (ARP3) from a range of organisations detailing the projected effects of climate change on their organisation. It includes reports from subsectors in transport including airports, highways and harbour authorities. This is a useful resource to assist you in identifying the types of receptors that are considered when undertaking a CCRA, with more specific examples for each subsector.
Department for Transport Rapid Evidence Assessment	This resource presents the findings from a Rapid Evidence Assessment (REA) on climate change adaptation and transport infrastructure. This is useful report to help in understanding the range of receptors that are considered within adaptation planning across the transport sector
PIANC Climate Change Adaptation Planning for Ports and Inland Waterways	This resource presents a portfolio of how assets, systems and operations could be impacted by climate change, and therefore is a useful resource for assisting in identifying relevant receptors for the ports subsector.

Checklist: Identifying relevant receptors for the assessment

By the end of this section you will have:

☐ Identified the receptors to be considered within the assessment

Step 3: Identifying climate hazards



This step identifies the climate hazards to be assessed.

Climate hazard refers to a weather or climate related event which has potential to impact receptors such as people, assets, activities or organisations.

		Example
Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	**Summer temperature**
	Projected change in climate hazard	
	Potential impact	
Risk assessment Time period: Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

The third UK Climate Change Risk Assessment identified 61 risks from climate hazards across multiple sectors. Many of these also feature in the UK National Risk Register 2023. These documents can be used to support hazard identification.

Climate hazards can be:

- acute, referring to event-driven hazards including increased severity of extreme weather events, such as storms or floods.
- chronic, referring to longer-term shifts in climate patterns, such as rising average summer temperatures.

Table provides a non-exhaustive list of climate hazards which may be relevant for the UK transport sector.

You should consider which hazards are relevant based on the location and type of receptors you identified in Step 2 and the nature of operations. You should also consider whether multiple hazards may occur concurrently or at the same time, and pre-conditions that may exacerbate a hazard e.g., a heavy rainfall event on saturated ground or following a period of drought may resulting in flooding. Each receptor can be vulnerable to one or many climate hazards.

Example

Ports and other coastal transport infrastructure may be more vulnerable to the sea/ocean related and wind related hazards.

Airports, due to their location on flat land, may be more exposed to wind related hazards and flooding.

Table 4: Examples of climate hazards on infrastructure. Source: European Commission (2022)

	Chronic	Acute
Temperature related	Change in average temperature (can be seasonal)	Heatwave Cold wave/frost Wildfire
Precipitation related	Change in average precipitation (can be seasonal) e.g., rain, hail, snow	Extreme precipitation e.g., rain, hail, snow Pluvial (surface water) flooding Fluvial (river-related) flooding Groundwater flooding Drought
Wind related	Change in wind patterns	Extreme wind event e.g., storm, hurricane
Sea/Ocean related	Sea level rise Saline intrusion Ocean acidification	Storm surge Coastal flooding

	Chronic	Acute
Ground/solid-mass related	Coastal erosion Soil erosion Soil degradation Ground-heave	Landslide/avalanche Subsidence

To determine climate hazards relevant to your assessment[3], it is useful to consider Table 4 alongside the following:

- The physical boundary you have defined
    - Has the assessment location previously experienced any climate hazards in the past?
    - Does the nature of the location mean receptors would be more exposed to certain hazards? For example, is it located in a coastal area or flood zone?
- The time period(s) you have defined
    - Could the receptor(s) experience these climate hazards over its lifetime?
- The receptor(s) you have identified
    - What are their specific vulnerabilities which could be impacted by climate hazards? For example, communication towers or tall structures would be more vulnerable to wind and storms.
    - Are assets well maintained and if not could this impact their vulnerability to climate change?
    - Are there specific thresholds over which hazards are expected to occur? For example, within infrastructure design guidance.
    - What aspect of the hazard is important for the receptor? For example, the maximum temperature of a heatwave or the duration of a heatwave.
    - What climate hazards have occurred for similar receptors elsewhere, particularly those which are already more exposed to climate change?
    - Have CCRAs been undertaken for similar receptors elsewhere?

[3] The use of the term ‘assessment’ in this context relates to the asset, process or organisation you are considering (your receptor).

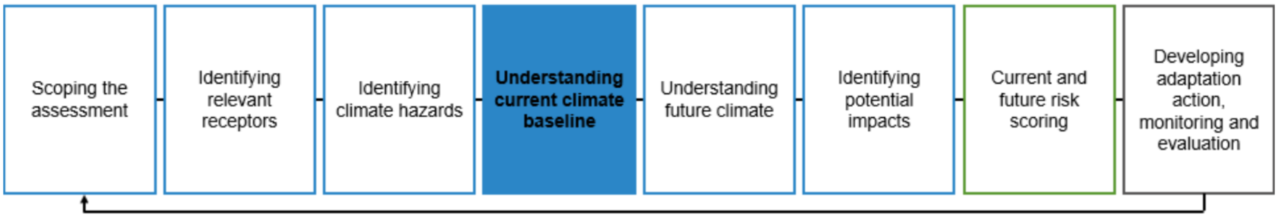
- ○ Are the receptor(s) exposed to cascading risks from other assets, systems or organisations?

Checklist: Identifying climate hazards

By the end of this section you will have:

☐ Identified the climate hazards that may affect the receptor(s) during their lifetime

Step 4: Understanding the current climate baseline



This step will build an understanding of the climate baseline. The climate baseline provides a snapshot of the current climate under which a receptor(s) operates.

It is important to understand the average conditions and variability, and nature of extreme events within the physical boundary you have defined and on your type of asset, system or infrastructure. Establishing the baseline provides essential context for assessing the level of risk under present day conditions compared to projected future conditions. It is important that the historic baseline is at least 20 years long in order to capture natural variations in climate.

The climate baseline will consist of key climate data. The first step is to identify any historical climate data, guided by the hazards identified in Step 3. This may include:

- monitoring (observations) data – daily records of weather (e.g., rainfall, wind, temperature, flow gauges) and climate averages produced from these data.
- reanalysis data – these data are created by combining past short-range weather forecasts with observations data, through a process called data assimilation. They provide a completer and more coherent picture of past weather than can be obtained from observations data alone.
- approaches such as the UNSEEN method – these provide pseudo-observations for climates that match present day conditions, but which might contain unrealised extreme events that have simply not been observed during the short observational record.
- information from attribution studies – these allow us to make statements on whether the climate change to date has changed the likelihood of particular extreme events such as heatwaves occurring.
- datasets – information on impacts from weather related events on the transport sector.
- analogous information – regarding recent extreme events and the extent of impacts they caused on the receptors (e.g., operating and capital expenditure required for repairs and upgrades, cost of downtime).

Using this data, summarise the key findings on historical climate trends, using tables to outline key findings for the key climate indicators identified.

Table 1 provides a non-exhaustive list of potential data which may be relevant for your climate baseline. Not all data will be relevant for every CCRA. For example, a CCRA for an airport located far inland from the coast will not find it relevant to obtain data about sea level rise for the assessment.

Table 1: Types of climate information to consider and potential data sources

Data sources	Types of climate information to consider
Temperature data Average temperatures of summer and winter. Extreme events (e.g. coldest recent winter day and hottest recent summer day, recent heatwaves on record). **Precipitation data** Average seasonal rainfall for summer and winter. Data on heavy rainfall events (e.g. maximum rainfall in 24 hours during recent storms). **Wind data** (if applicable) Average wind speed and direction. Recent high wind events (e.g. during recent storms). **Other data** (if applicable) Sunshine hours, cloud cover, frost days etc.	Met Office regional summaries, available here: UK regional climates - Met Office Met Office weather station records, available here: Historic station data - Met Office, Local weather station data - Met Office, and UK actual and anomaly maps showing national maps of historic climate variables HadUK Grid data (UKCP18 observed data), available here: HadUK-Grid - Met Office State of the UK Climate report updated annually. Latest report available here: State of the UK Climate - Met Office Organisation data records e.g., weather stations and sensors Reanalysis data – e.g. ERA5, available here: ECMWF Reanalysis v5 (ERA5)
Flood data (if applicable)	River flow data - UK Centre for Ecology & Hydrology, available here: National River Flow Archive Precipitation data/sea level rise and coastal flood data - Environment Agency (EA) flood maps, available here: Flood risk assessments: climate change allowances Flood risk data - The Flood Hub, available here: Flood Risk Maps Sea level rise and coastal flood data - Proudman Oceanographic Laboratory sea level records, available here: Data and

	Research Facilities | National Oceanography Centre
Further extreme event data (if applicable) Landslides, drought and water scarcity, wildfire etc.	Further extreme event data - Local press, for records of extreme weather events Event attribution data: State of the UK Climate report updated annually. Latest report available here: State of the UK Climate - Met Office. World Weather Attribution studies for Europe, which contains some studies focused on the UK – available here: World Weather Attribution - Europe

Checklist: Understanding the current climate baseline

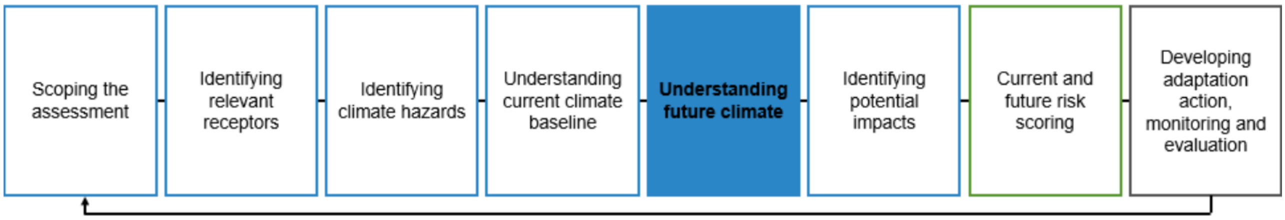
By the end of this section you will have:

☐ Selected the climate indicators for assessment (temperature, rainfall, sea level rise, and others where relevant)

☐ For each climate indicator, identified relevant historical climate data

☐ Collated the above data

Step 5: Understanding future climate



This step will identify the projected future climate over the time period(s) selected for assessment.

Once you understand the current climate baseline, the next step is to obtain data on how the climate may change over the time period of the assessment. Examining climate projection information will help you understand how the frequency and intensity of extreme weather events might change in the future.

It is important that new or emerging climate hazards are considered. Although some infrastructure and operations may not currently be affected by climate hazards you should consider whether this is likely to change over time. Climate change will also offer opportunities which may be beneficial to the transport sector, such as projected increase in average winter temperature, and it is important to identify these too.

The below example shows a light touch assessment. When undertaking a more detailed assessment, it is appropriate to indicate the climate projections obtained for the climate hazard and provide some explanation for the projections chosen.

Example

Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	Summer temperature
	Projected change in climate hazard	**Higher summer maximum temperatures**
	Potential impact	
Risk assessment Time period: Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

5.1 About climate projections data and emissions scenarios

The Met Office provides climate projections data for the UK up to 2100, known as the UK Climate Projections (UKCP). The most recent major release of the projections was the UK Climate Projections 2018 (UKCP18). Further UKCP products have also been added since 2018.

The suite of information available in UKCP18 for land include probabilistic, global, regional and local, and derived projections. The strands use 'representative concentration pathways' (RCPs) to demonstrate different greenhouse gas emission scenarios.

Table outlines the four main climate RCPs used within CCRA and the associated global warming levels.[4] Each RCP may drive a change in global average temperatures. The table provides the best-estimate (central estimate) for the average temperature change, as well as the 5-95% range in brackets.

Table 6 The four main RCPs and associated global warming. Source: Met Office

RCP	Description	Projected change in global mean surface temperature by 2081 - 2100
RCP2.6	Low emissions scenario: • Assumes significant reduction in global greenhouse gas emission.	+1.6°C (0.9-2.3°C)
RCP4.5	Medium-low emissions scenario: • Assumes moderate reduction in global greenhouse gas emissions.	+2.4°C (1.7-3.2°C)
RCP6.0	Medium-high emissions scenario: • Assumes a smaller reduction in global greenhouse gas emissions than RCP4.5.	+2.8°C (2.0-3.7°C)
RCP8.5	High emissions scenario:	+4.3°C

[4] It is worth noting that a later set of scenarios have been released by the IPCC, which are used to drive the latest global climate models, known as the Shared Socioeconomic Pathways (SSPs). RCPs and SSPs can be closely related for several of the scenarios. However, UKCP has not yet produced these models to create UK specific projections. As such, UKCP18 and the RCPs remain the most used scenarios for UK CCRAs.

Not all RCPs are available for all UKCP18 products (except for RCP8.5 which is available for all but the Derived Projections product). More information on data availability can be found in section 1 of the UK Met Office UKCP Guidance on data.

RCP	Description	Projected change in global mean surface temperature by 2081 - 2100
	• Assumes unmitigated growth in global greenhouse gas emissions.	(3.2-5.4°C)

5.2 Selecting emissions scenarios

First you should decide whether to use one or more (generally two) emissions scenarios.

- considering one emission scenario would provide a simple assessment. However, unless you are looking at near-term climate change (out to approx. 2040, when the climate response to different emissions scenarios is fairly similar), it could result in your taking an approach that is too risk-averse or too risk-tolerant, and thus could lead to over- or under-adaptation.

- considering two or more emission scenarios has the advantage of covering a wider range of eventualities and providing greater flexibility to your assessment. For example, you could choose a medium emissions scenario for your assessment and consider the high emissions scenario for worst-case scenario planning.

The choice of which emissions scenario(s) to adopt depends on your organisation's risk appetite and decision-making approach and the criticality of potential risks. It is also worth noting that projected changes in most climate indicators under the different scenarios are often relatively small in the near term.

The CCC's principles for good adaptation recommend adapting to 2°C (based on RCP4.5 or RCP6.0) and assessing the risk of 4°C (based on RCP8.5) (CCC, 2023). This approach is also taken by the third UK Climate Change Risk Assessment, which considered a two-degree and four-degree world. In this case, the four-degree world was based on the 50th to 95th percentile of the RCP6.0.

When selecting which emissions scenarios you will use for your CCRA, you may want to consider the following:

- RCP 2.6 – this scenario is below the level of emissions consistent with current policies for emission reduction globally so represents a higher level of emission reduction ambition. Some safety critical businesses may feel it does not go far enough in terms of identifying worst-case scenario events.

- RCP 4.5 and RCP 6.0 – these represent the Met Office's middle scenarios for emissions abatement and climate change. RCP4.5 is most consistent with current policies for emission reduction.

- RCP 8.5 – this scenario is helpful in providing a worst-case scenario. It may also be helpful if your business has a low risk appetite, for example a safety critical business which is highly sensitive to climate variations. However, only considering this scenario may result in an overly conservative assessment for some businesses.

When selecting emission scenarios for risk assessment, you may want to use a 'transient emission scenario' approach, considering how emissions change over time or use a 'global warming level' approach considering which level of warming you are interested in looking at rather than when that warming level is reached. Or you may wish to use a combination of both.

Industry collaboration on scenarios

Some industries are working towards an agreed set of climate scenarios to increase the consistency of climate risk assessments and adaptation planning. In 2023, the rail sector agreed a set of scenarios for CCRAs through their Climate Change Adaptation Working Group.

While these scenarios may not be appropriate for other subsectors, collaboration amongst transport industry groups on climate scenarios is encouraged.

5.3 Selecting future climate data

Once you have selected your emissions scenario(s) and future time period(s) the next step is to obtain your future climate data. Table sets out various sources for obtaining UKCP18 climate data or impacts derived from it, of which the following may be particularly helpful:

- the Climate Risk Indicators tool (CRI) is a user-friendly portal which is particularly helpful for first-time users of climate data; and
- the Met Office Climate Data Portal is the Met Office's portal for accessing and downloading climate datasets in a range of easy-to-use formats.
- the UKCP User Interface is the Met Office's portal for accessing UKCP18 data, providing a broader range of climate data.

Detailed guidance on how to obtain and interpret data from CRI and UKCP User Interface is available in Annex A:.

Table 7: Routes to access UKCP18 climate projections data

Data source	Description
UK Climate Resilience Programme Climate Risk Indicators	This is a user-friendly portal for exploring climate data, based on UKCP18.[5] Future projections data covers: • Climate indicators • Temperature extremes • Transport indicators e.g. road melt risk • Wildfire • Water Users can estimate various indicators of current and future climate risk at local to national scales. Users can also groups indicators into different types of impact - there is a ‘transport’ specific section with newly derived indicators such as ‘road melt risk’ (days above a certain temperature threshold relevant to the transport sector). Note that the data contained within the CRI is based on the UKCP18 data but includes some slight differences due to the choice of baseline (CRI uses a 1981-2010 baseline) and a smoothing that has been applied to the analysis. This should not affect the outcomes of your risk assessment but be it advised to be clear and report on your data provenance. First-time users with limited or no previous experience of using climate data/UKCP18 data may find this an accessible starting point, given that CRI is a user-friendly interface where data can be selected and accessed with relative ease.

[5] The research underpinning the data on this website was undertaken as part of the UK Climate Resilience Programme funded by UK Research and Innovation and the Met Office. It uses the UKCP18 climate projections produced by the Met Office. The research was undertaken by University of Reading and the UK Centre for Ecology and Hydrology.

Data source	Description
Met Office UKCP User Interface	This is the Met Office portal used to access UKCP18 data. Users will be required to register for a free account. Climate projections data available for various climate indicators including temperature, precipitation and marine projections, in addition to temperature and precipitation extremes. Additional guidance on use of UKCP18 climate projections is provided in Annex A: Guidance on accessing and interpreting climate projections data. More advanced users, likely with previous experience of working with UKCP18 projections data, who want to download more detailed or disaggregated data might use this interface.
CEDA archive	Archive of full set of UKCP data (including some datasets which are not available on the User Interface), managed by the Centre for Environmental Data Analysis. Advanced users and those with experience working with large datasets may use the archive but it will likely not be necessary for the majority of those wanting to carry out a CCRA.
Met Office UKCP18 Marine Report	This document provides a useful summary for the background, and use of the UKCP18 marine projections, including both the time-mean and extreme sea level projections. Particularly useful for the ports subsector and organisations with coastal receptors to understand risks to coastal areas.
Met Office Climate Data Portal	This portal contains 55 different data layers, as well as guidance and information to analyse a range of climate risks. The tool provides complex scientific climate projections in easy-to-use formats for those users with less experience in using climate projections data.
Environment Agency Climate Change Allowances	Climate change allowances to show anticipated change for: • Peak river flow • Peak rainfall intensity • Sea level rise • Offshore wind speed and extreme wave height This has been developed by the Environment Agency, based on UKCP projections. This tool is useful to understand future risk of

Data source	Description
	flooding and coastal change and is mandatory in flood risk assessments carried out as part of UK planning applications. For use in CCRAs that require climate change allowances for infrastructure design.
Environment Agency Climate Impacts Tool	The climate impacts tool provides a simple description of current and potential future challenges. It uses nationally-averaged information and shows changes to weather, climate, and environmental variables for 4 scenarios. Present day (The climate has already changed). Mid-century (+2°C by 2050). Managed transition (+2°C by 2100). Runaway change (+4°C by 2100). New users of climate data and for projects that only require high-level climate projections. Projects requiring less granular information may include strategic planning or provide climate context on wider work/policy areas which are vulnerable to climate risks or have a long lifespan.
GeoClimate UKCP18 Open	GeoClimate UKCP18 combines long-term climate projection data with geotechnical ground properties to identify projections in subsidence over the next century. This tool is useful to understand risk relating to subsidence and ground-heave. Users who need and have experience with geospatial data and for projects that need an understanding of ground movement risk
Coastal Risk Screening Tool	Coastal area maps to explore sea level rise and coastal flood risks. This tool is useful to understanding future risk of flooding and sea level rise to coastal areas.

5.4 Uncertainty within future climate projections

Climate projections are not predictions or forecasts but simulations of potential scenarios of future climate under a range of hypothetical emissions scenarios (as described above) and assumptions. The results cannot be treated as exact.

We cannot be certain about future climate change because:

- some variations in climate are inherently unpredictable (internal variability).
- the trajectory of greenhouse gas emissions is uncertain, so models are run with different trajectories or RCPs based on a set of assumptions (emissions uncertainty).
- climate models approximate some of the key processes that affect climate change (modelling uncertainty).

The relative importance of the three sources of uncertainty changes depending on the climate variable and time period being considered and granularity of projections data used.

Some hazards are less certain than others. For example, projections for how precipitation will change in the future are more uncertain than projections for how average temperatures will change. Climate hazards which arise from changes in precipitation, such as landslides, are therefore even more uncertain because they depend on a range of climatic and non-climatic factors. Short-term changes in climate, such as El Niño / La Niña events and volcanic eruptions are also hard to produce projections for.

The use of multiple emissions scenarios can help to manage some of the uncertainty within climate projections. Obtaining a range of estimates from each climate projections dataset can also help you understand some of the uncertainties associated with different forecasts and the likelihood of specific climate thresholds being exceeded. For example, the probabilistic projections may be particularly helpful as they report data for the at the 10th, 50th and 90th percentiles, representing low, medium and high estimates respectively for a given emission scenario.

Understanding climate risks often requires an element of professional judgement. It may be pragmatic to use qualitative assessments where appropriate (e.g. considering direction of change). Supplementing climate projections data with other data sources, an understanding of historic events, institutional memory and learning from other organisations and projects in the same sector can also be used to inform your assessment.

Checklist: Understanding future climate baseline

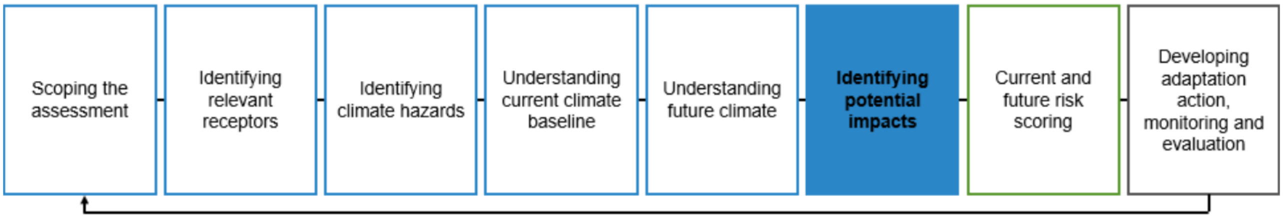
By the end of this section you will have:

☐ Selected emissions scenario(s) to represent future climate

☐ Selected sources for climate projections data, using Annex A Guidance on accessing and interpreting climate projections data

☐ Obtained and collated the above data

Step 6: Identifying potential impacts



This step will identify the potential impacts associated with the climate hazards.

		Example
Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	Summer temperature
	Projected change in climate hazard	Higher summer maximum temperatures
	Potential impact	**Decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity.**
Risk assessment Time period: Emissions scenario:	Likelihood narrative	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

6.1 Identifying climate impacts

For each of the climate hazards (identified in Step 3), the potential impacts of the hazards on each of the receptors (identified in Step 2) should be considered.

Examples of potential impacts include:

- overheating of vessel engines due to changes in average temperature and heatwaves.
- loss of ground transport links due to ground flooding on site.

- increased risk of debris obstructions in the road, including fallen trees, traffic signage, and subsequent road blockages and closures due to extreme wind gusts.

To identify potential impacts you can:

- identify past instances of climate-related impacts on the receptor(s).
- use expert judgement or forums.
- review climate risk assessments for similar receptor(s).

Some resources to help identify potential impacts can be found in Table. Each climate hazard may have one or multiple potential impacts to individual receptors. Further examples of potential impacts to ports, airports and local highways are identified in Annex C.

Table 8: Potential resources to help identify impacts

Resource	Purpose
Climate Change Committee's Independent Assessment of UK Climate Risk – Transport sector briefing	This document provides a summary of how the transport sector has been assessed within the latest UK CCRA. This is a useful document to assist you in identifying the types of risks and potential impacts associated with the climate hazards, with examples.
Climate change adaptation reporting: third round reports	This resource compiles reports from organisations detailing the current and future predicted effects of climate change on their organisation. This is a useful resource to assist you in identifying the types of risks and potential impacts associated with the climate hazards, with more specific examples for each subsector.
Design Manual for Roads and Bridges LA114	This resource provides examples of potential climate impacts for highways during both construction and operation phases for a range of climate hazards. This is a useful document to assist you in identifying types of risks and potential impacts within the local highways subsector.
Department for Transport Rapid Evidence Assessment	This document provides a summary of existing evidence that exists on how climate change is affecting and will affect transport infrastructure. This is a useful resource providing examples of potential impacts for ports, airports and local highways subsectors.

Resource	Purpose
Department for Transport Lessons learned from extreme-weather emergencies on UK highways	This review identifies the effects and impacts on the UK highway sector from extreme-weather events (2015 to 2020). This is a useful resource for providing examples of impacts for local highways.

6.2 Identifying interdependencies

Resilience to climate change goes beyond individual risks though this section will only be relevant if the scope of your assessment includes indirect impacts. Interdependent risks occur where systems depend on each other to operate. Infrastructure sectors and transport subsectors are connected meaning that risks to one sector can cause problems for others with impacts cascading across systems. For example, flooding of local highways may result in the blocking of access to users, making it difficult to access to nearby ports and airports.

There are different types of dependencies that could be considered when preparing risk assessments:

- **upstream dependencies** on other sectors i.e. impacts that occur elsewhere that could affect your assets/organisation.
- **downstream dependencies** i.e. if your services are interrupted (or assets disrupted) who will be affected and how. Ideally these risks would also form part of your risk assessment.

There are resources available to help organisations consider interdependent risks, including a series of systems maps developed to support the third UK Climate Change Risk Assessment.

Understanding and addressing interdependencies also requires collaboration. This could be done via:

- **multi-sector groups of stakeholders** such as the Infrastructure Operators Adaptation Forum or the rail industries Climate Change Adaptation Working Group.
- **local or regional level discussions** such as local climate or resilience forums. These may be more effective when collaborating on interdependencies by geography or where assets are co-located.
- **private bilateral discussions** may enable organisations to be more open about potential risks.

Organisations could:

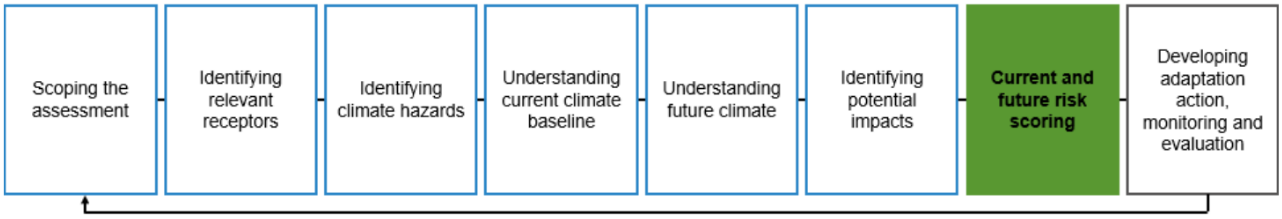
- discuss and map systemic interactions, dependencies and interdependencies, particularly those which are seen as critical. Examples of past events or near misses can help to identify interdependencies.
- discuss failure points that could lead to cascading impacts and identify/prioritise any specific failure points where increasing resilience may bring wider benefits throughout the system.
- identify common risks between organisations, overlapping or common responsibilities for risk management, and any gaps in addressing these risks. This may help identify opportunities for mutual investments in adaptation actions.

Checklist: Identifying potential impacts

By the end of this section you will have:

☐ Identified the potential impacts of climate hazards that may affect the receptor during its lifetime

Step 7: Current and future risk scoring



This step provides guidance for scoring risks for the current and future time period(s). In this guidance, the overall risk is determined by scoring and combining the likelihood and consequence of the hazard occurring.

Determining current risk is useful as it provides a baseline of comparison when assessing future risk (section 2.8.6). Information about the likelihood and consequence of each risk should be presented in the following sections of the template.

		Example
Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	Summer temperature
	Projected change in climate hazard	Higher summer maximum temperatures
	Potential impact	Decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity.
Risk assessment Time period: Emissions scenario:	**Likelihood narrative**	
	Likelihood score	
	Consequence narrative	
	Consequence score	
	Risk score	

7.1 Scoring current likelihood

Current likelihood relates to the expected frequency of risks occurring over the receptor's lifetime, based on today's climate.

This could be informed by evidence about the frequency with which this impact has occurred over the life of the asset to date or similar assets.

Example likelihood scoring and narratives are in Table assuming a 60-year design life for the receptor. Boundaries may be placed differently depending on your organisation. It is important to consider and use, where applicable, any existing corporate risk assessment thresholds as they may provide definitions specific to your organisation.

Table 9: Illustrative example of current likelihood scoring criteria for an asset with a 60-year design life

Likelihood	Definition
Very high (5)	The impact is expected to occur frequently within the receptor’s lifetime assuming today's climate persists (for example every year)
High (4)	The impact is expected to occur several times within the receptor’s lifetime assuming today's climate persists (for example approximately every five years)
Moderate (3)	The impact is expected to limited times within the receptor’s lifetime assuming today's climate persists (for example approximately every 10 years)
Low (2)	The impact is expected to occur infrequently within the receptor’s lifetime assuming today's climate persists (for example approximately every 30 years).
Very low (1)	The impact is not expected to occur over the receptor's lifetime assuming that today's climate persists.

Example

Delays and disruption to flight schedules from storms have occurred once so far within the 50-year operation of the airport therefore current likelihood is assigned a score of 2 (Low likelihood).

7.2 Scoring current consequence

Consequence is the extent to which the receptor is impacted, either positively or negatively each time the climate hazard occurs (it is independent of the likelihood with which the climate hazard occurs). Consequences can be direct or indirect and can be experienced in relation to a number of areas such as financial, health and safety, environment, performance and reputation.

To make an informed view of the current consequence level, you might use:

- evidence for the impact of this climate hazard occurring for the same or similar receptor(s)
- analysis or modelling for the impact occurring

- professional judgement

When assessing consequence, it is also important to consider the condition of the asset and the standards to which those assets were designed. Poorly maintained or deteriorated assets may experience greater damage during extreme weather and climate events, whereas regular inspection and maintenance are likely to enhance the resilience. Similarly, assets are designed based on specific standards and assumptions about their lifespan and expected conditions. If climate conditions deviate significantly from the design standards (e.g. increased rainfall, higher temperatures), consequences may be more severe.

When developing consequence criteria, you should tailor the definitions to your assessment. Example consequence scoring and narratives are in Table, assuming a medium-large organisation.

It is important to consider and use, where applicable, any existing corporate risk assessment thresholds as they may provide definitions specific to your organisation. For example, what is financially material for one organisation may not be for another. This applies to all the consequence categories defined in Table.

Table 10: Illustrative example of consequence scoring criteria for a medium-large organisation

Consequence	Definition[6]				
Catastrophic (5)	**Receptor has experienced/has the potential to experience severe or permanent damage in relation to:**				
	Financial	**Health and Safety**	**Environment**	**Reputation**	**Performance**
	>£15m impact on organisation	Fatality or life changing injury	Serious and permanent widespread environmental impact	External impact on all stakeholders, extensive media interest, extensive customer/public complaints	Significant impact with permanent damage to or loss of infrastructure, requiring complete repair or replacement. Substantial impact to service lasting more than five days.

[6] The terminology of the definitions has been phrased as 'receptor has experienced/has the potential to experience' so it is applicable to both the current and future consequence assessment.

Consequence	Definition[6]				
Significant (4)	**Receptor has experienced/has the potential to experience extensive damage in relation to:**				
	Financial	**Health and Safety**	**Environment**	**Reputation**	**Performance**
	£5m-£15m impact on organisation	Non-fatal but results in hospitalisation and life-threatening injury	Reportable, significant environmental damage or loss requiring significant remediation	External impact on multiple stakeholders, extensive media interest, extensive customer/public complaints	Extensive impact with extensive infrastructure damage, requiring major repair. Substantial impact to service lasting between a day up to five days.
Moderate (3)	**Receptor has experienced/has the potential to experience limited, measurable adverse impacts to condition in relation to:**				
	Financial	**Health and Safety**	**Environment**	**Reputation**	**Performance**
	£1m-£5m impact	Multiple injuries requiring hospital treatment	Reportable temporary environmental incident resulting in damage to and loss of environment requiring remediation	External impact on a small number of stakeholders, wider media interest, numerous customer/public complaints	Moderate impact, limited infrastructure damage requiring some repairs. Service disruption lasting between a few hours up to a day.
Limited (2)	**Receptor has experienced/has the potential to experience minor, short-term change in feature condition in relation to:**				
	Financial	**Health and Safety**	**Environment**	**Reputation**	**Performance**

Consequence	Definition[6]				
	£500k-£1m impact on organisation	Injury to up to 10 people requiring treatment by a medical practitioner	Localised impact on the environment which can be addressed using existing control measures	Internal issue with some local media interest and some customer/ public complaints.	Limited impact, minor infrastructure damage, little impact to service, disruption lasting up to few hours at most
Minor (1)	**Receptor has experienced/has the potential to experience minimal or undetectable change in condition in relation to:**				
	Financial	**Health and Safety**	**Environment**	**Reputation**	**Performance**
	<£500k impact on organisation	Minor injury requiring first aid to one individual	Localised, non-reportable and minor impact on the environment which can be addressed using existing control measures	Internal issue with minimal local media coverage, very few customer/public complaints	Very limited impact, very minor or no infrastructure damage, little impact to service with no disruption to service.

Example

Decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity have incurred the following consequences:

Financial: financial cost of providing immediate additional cooling provisions and increasing cooling capacity is estimated to be £500k to £1m.

Health & Safety: five instances of heat related illnesses experienced by passengers and staff with older passengers particularly affected.

Reputation: passenger complaints and internal minimal negative media coverage.

Performance: staff may be slower at undertaking roles with disruption lasting up to few hours at most, resulting in minor impact on services.

Therefore consequence is assigned a score of 2 (Limited consequence).

Where one impact may have multiple consequences of different severity (and scores), the overall consequence score could take the highest score or be based on the average or weighted average across the scores.

Example

You assess a climate hazard could have a high health and safety impact (4) and a low reputation impact (2). Therefore, the overall consequence score could be 4 (taking the maximum of the two scores).

7.3 Current risk scoring

The current risk score should be determined by combining the likelihood and consequence scores.

Table provides an illustrative example of how likelihood and consequence scores could be combined to determine the final risk rating. In this example the likelihood and consequence scores are multiplied to obtain an overall risk score.

It is important to consider and use, where applicable, any existing corporate risk assessment matrices as they may weigh the likelihood and consequence scores differently. For example, you may want to consider whether a low consequence event which occurs frequently is of similar concern to a high consequence event which rarely occurs.

Table 11: Illustrative example of a risk scoring matrix

		Consequence				
		Minor (1)	Limited (2)	Moderate (3)	Significant (4)	Catastrophic (5)
Likelihood	Very high (5)	5	10	15	20	25
	High (4)	4	8	12	16	20
	Moderate (3)	3	6	9	12	15
	Low (2)	2	4	6	8	10
	Very low (1)	1	2	3	4	5

Example

Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	Summer temperature
	Projected change in climate hazard	Higher summer maximum temperatures
	Potential impact	Decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity.
Risk assessment **Time period:** Current **Emission scenario:** N/A	**Likelihood narrative**	The impact has previously occurred only once
	Likelihood score	2
	Consequence narrative	Financial cost of providing immediate cooling provisions and increasing cooling capacity is estimated to be £500k to £1m, potential for heat related illnesses to be experienced by passengers and staff, passenger complaints and internal minimal negative media coverage. Staff may be slower at undertaking roles with disruption lasting up to few hours at most, resulting in minor impact on services.
	Consequence score	2
	Risk score	4

7.4 Scoring future likelihood

Future likelihood relates to the frequency of the risk occurring over the assessment period. Scoring of future risks needs to be based on professional judgement, informed by climate projections. Example likelihood scoring and narratives are in Table 12, using an assessment period of 60 years.

When establishing future likelihood it is important to consider:

- climate projections (as this will inform how exposed the receptor will be to different climate hazards over time).
- if the impact has occurred previously (if it has, this suggests the likelihood of it occurring again might be higher).
- the frequency with which this hazard has occurred for similar receptor(s), particularly where they are already more exposed to the hazard.

In some instances, there may be known climate-related thresholds above which hazards are expected to occur, for example set out in infrastructure design standards. Where this is the case, the probabilistic projections may be helpful to infer the likelihood of this threshold being exceeded in the future (see Annex A). The example below utilises the data for climate scenario RCP6.0 (medium-high emissions).[7]

Table 12: Illustrative example of future likelihood scoring criteria for an assessment period of 60 years

Likelihood	Definition
Very high (5)	Impact is expected to occur frequently during the assessment period (e.g. every year)
High (4)	Impact is expected to occur several times during the assessment period (e.g. approximately every 5 years)
Moderate (3)	Impact is expected to occur limited times during the assessment period (e.g. approximately once every 10 years)
Low (2)	Impact is expected to occur very infrequently during the assessment period (e.g. approximately once every 30 years)
Very low (1)	The impact is not expected to occur over the assessment period.

[7] Please note that data for RCP6.0 is available from the probabilistic projections product but is not available across all UKCP18 products. Depending on what data you wish to utilise, this scenario may be appropriate for your needs or an alternative may be preferable (typically RCP4.5 or RCP8.5 depending on your risk appetite and location).

Example

Projections indicate maximum summer temperature is expected to rise by 2.0°C (50th percentile, for South East England from the baseline 1981-2000) by the 2050s under RCP6.0 using the Probabilistic Projections.

Therefore, the future likelihood of a decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity from higher summer maximum temperatures may occur more frequently in the 2050s compared to the baseline period.

Future likelihood is assigned a score of 3 (Moderate likelihood).

7.5 Scoring future consequence

Consequence scoring for future risk should be undertaken using the same approach as for current risks (see step 7.2). Consideration should be given to whether the future consequence should differ from the current consequence, for example where transport usage is expected to increase over time, where there are emerging hazards not experienced currently or where outcomes could worsen due to increasingly extreme weather events.

Example

Consequence is assigned a score of 2 (Low consequence) for all time periods and emissions scenarios as airport patronage is not expected to significantly change over time.

7.6 Future risk scoring

As per the current risk score, quantifying the future risk involves combining the likelihood and consequence scores.

Example

For the 2050s, medium (RCP6.0) emissions scenario, a likelihood score of 3 multiplied by the consequence score of 2 equates to a risk score of 6 (medium risk).

Example - HIRAM tool, Local Highways

The South West Highways Alliance, the Environment Agency and others have collaborated to develop a Highways Infrastructure Resilience Assessment Modelling tool (HIRAM).

HIRAM is a web-based application designed to assist local highway authorities in identifying, qualifying and quantifying climate risks to the local highways sector. The application incorporates UKCP18 climate projections and national flood risk mapping to assess future climate changes and associated impacts.

This tool combines Likelihood and Consequence to assess and score the overall resilience risk. It also estimates whether there are likely to be cascading risks and assesses a number of other risks by type, including risks to the environment, health, heritage and local community and economy.

By way of example, we populate the template scoring the risk of discomfort for passengers and staff due to high temperatures for airport buildings in the 2050s under RCP6.0. If using multiple time periods and emissions scenarios, you should repeat the assessment and scoring of likelihood and consequence for each.

Example

Scope & potential impact	Area of the business	Airport infrastructure
	Receptor / component	Airport buildings
	Climate hazard	Summer temperature
	Projected change in climate hazard	Higher summer maximum temperatures
	Potential impact	Decrease in passenger and staff comfort in airport buildings due to insufficient cooling capacity.
Risk assessment Time period: 2050s, Emissions scenario: medium (RCP 6.0)	**Likelihood narrative**	Projections indicate summer maximum temperatures will rise by 2.0C (50th percentile, for South East England from the baseline 1981-2000), therefore the impact may occur more frequently. The impact has previously occurred once.
	Likelihood score	3
	Consequence narrative	Financial cost of providing immediate cooling provisions and increasing cooling capacity, potential for heat related illnesses to be experienced by passengers and staff, passenger complaints and internal minimal negative media coverage.
	Consequence score	2
	Risk score	6

Table 13: Potential resources for risk scoring

Resource	Purpose
ISO 14091:2021 Adaptation to Climate Change — Guidelines on Vulnerability, Impacts and Risk Assessment	This document outlines a framework for organisations to determine their risks associated with a changing climate. This is a useful resource as it aligns with this guidance document for the transport sector. Access to this resource is not free of cost.
ISO 14090:2019 Adaptation to Climate Change - Principles, requirements and guidelines	This document outlines a framework for organisations to determine their risks associated with a changing climate. This is a useful resource as it aligns with this guidance document for the transport sector. Access to this resource is not free of cost.
ISO 31000:2018 - Risk Management	This document outlines principles and guidelines for risk management. This is a useful resource as it outlines an approach to identifying, analysing, evaluating, monitoring and communicating risks across an organisation.
ISO 31010:2019 - Risk Management Techniques	This document outlines guidance on the selection and application of different risk assessment techniques to be used during decision-making in times of uncertainty. This is a useful resource as it serves as a supporting standard for ISO 31000:2018.
Climate Change Committee's Independent Assessment of UK Climate Risk – Transport sector briefing	This document provides a summary of how the transport sector has been assessed within the latest UK CCRA. This is a useful resource to assist you in risk scoring, by providing context of how risk assessments are undertaken within the transport sector.
Accounting for the Effects of Climate Change: Supplementary Green Book Guidance	This document provides guidance on ensuring projects are resilient to the effects of climate change. This is a useful resource as it provides context for the importance of considering climate risks during the appraisal of options, which can be useful in helping to determine relative risk score.

Resource	Purpose
Adaptation Scotland's Climate Change Risk Assessment Guidance & Tools	This resource provides a framework for assessing and responding to risks posed by climate change, within the context of Scotland. This is a useful resource as it offers support on how to evaluate and determine climate risk.
Climate Change Impacts and Adaptation for Coastal Transport Infrastructure: A compilation of Policies and Practices	This resource provides guidance related to the management of coastal transport infrastructure in the face of climate change. This is a useful resource for evaluating climate risks and determining risk scores if you are undertaking a CCRA within the Ports subsector.
Eurocontrol's Climate change risks for European Aviation	This resource provides guidance related to the assessment of risks within the aviation industry across Europe, as a result of climate change. This is a useful resource for evaluating climate risks and determining risk scores if you are undertaking a CCRA within the airports subsector.
Design Manual for Roads and Bridges Sustainability and Environment Appraisal – LA114: Climate	This resource provides guidance related to the assessment of climate risks within the context of highways. This is a useful resource for evaluating climate risks and determining risk scores if you are undertaking a CCRA within the local highways subsector.
Climate Change Adaptation Reporting: Third round reports (ARP3)	This resource provides reports from organisations as part of the Third Round Reporting (ARP3) for Climate Change Adaptation. This is a useful resource to understand how climate risks are assessed for similar transport bodies, and with specific examples across all ports, airports and local highways subsectors.

Checklist: Risk scoring (for current and future risk)

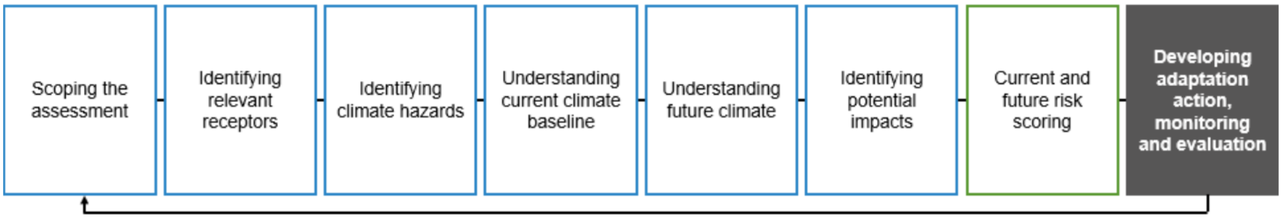
By the end of this section you will have:

☐ Determined likelihood narratives and scores for current and future climate for selected emissions scenario(s) and time period(s)

☐ Determined consequence narratives and scores for current and future climate for selected emissions scenario(s) and time period(s)

☐ Determined an overall risk score for current and future climate for selected emissions scenario(s) and time period(s)

Step 8: Developing adaptation action, monitoring and evaluation



This guidance does not cover selection of adaptation actions or monitoring and evaluation comprehensively. Rather this step is intended to signpost that CCRAs are a continuous process, not a single action or report.

Once a CCRA has been completed, it may be appropriate to consider adaptation measures to mitigate significant risks. Early adaptation priorities to address risks and opportunities in the near-term may include:

- 'no-regret' or 'low-regret' actions that reduce risks associated with current climate and build resilience for the future.
- consideration of adaptation in decision-making on major infrastructure and other decisions with long lifetimes to reduce the risk of 'locking in' a low level of resilience.

Table provides some examples of different types of adaptation measures. The UK Adaptation Inventory collates some of the different adaptation options which are available and provides examples of measures already being implemented by sector.

Table 14: Examples of adaptation measures. Adapted from IPCC

Ecological adaptation measures	Structural adaptation measures
Using nature-based solutions to mitigate risk E.g., use of swales / soakaways to reduce impact of flooding to road surfaces	Building something or modifying an asset to mitigate risk E.g., use of flood barriers or installation of air conditioning to reduce impact of heatwave events on transport users and workers

Behavioural adaptation measures	Institutional adaptation measures
Modifying people's behaviour to mitigate risk E.g., encouraging staff to exercise increased awareness of heat-related illness and to protect their health and	Modifying the capacity of an organisation or system to mitigate risk.

wellbeing during heatwaves such as through water uptake and seeking cool areas.	E.g., amending design standards, designating a senior responsible official for climate risk and adaptation

You may also find it helpful to hold a workshop exercise with relevant asset managers to develop adaptation measures. You should consider possible co-benefits of adaptation action - such as wider social or environmental benefits - and potential synergies or trade-offs with climate change mitigation.

Your CCRA should be updated to assess how adaptation measures under consideration will impact the risk scores to help decision-makers understand the benefits of adapting.

It is important to continuously monitor and evaluate climate risk, to ensure a CCRA remains relevant and up to date. You could consider reviewing your assessment:

- every 5 years, following an update to the UK Climate Change Risk Assessment
- if there are significant changes to your organisation
- if the Met Office publishes new climate change projections
- whichever of the three occurs soonest.

Your CCRA should be included within your wider risk reporting mechanisms or organisational risk management systems.

CCRA templates and report

In addition to completing the template for each climate risk, we recommend that you produce a report documenting key information about the CCRA methodology and conclusion. This should include:

- the physical boundaries of the assessment, and reasoning behind this
- the time periods and climate scenarios chosen for the assessment, and reasoning behind this
- current climate baseline information
- future climate information including climate projections data for selected indicators
- completed CCRA templates, outlining and scoring each climate risk

An example of a completed CCRA template for airports has been repeated throughout the guidance. See below examples of completed CCRA templates for the local highways and ports subsectors.

		Example
Scope & potential impact	Area of the business	Local highways
	Receptor / component	Road surface
	Climate hazard	Heavy rainfall (or surfaces water)
	Projected change in climate hazard	Increased in heavy rainfall events / intense rainfall.
	Potential impact	Surface flooding leading to interruption to connectivity, and risk to road users.
Risk assessment Time period: current	**Likelihood narrative**	The impact has previously occurred once.
	Likelihood score	2
	Consequence narrative	Interruption to travel, leading to loss to the local economy. Increased likelihood of car accidents leading to human injury or death, and damage to vehicles. Emergency services can't access – increased risk of injury or loss of life.
	Consequence score	4
	Risk score	8
Risk assessment Time period: 2050s, Emission scenario: medium (RCP6.0)	**Likelihood narrative**	Projections indicate that intense rainfall will increase by 17% in the winter. The impact has previously occurred once.
	Likelihood score	3
	Consequence narrative	As per current consequence.
	Consequence score	4
	Risk score	12

		Example
Scope & potential impact	Area of the business	Ports
	Receptor / component	Water channels
	Climate hazard	Sea level rise
	Projected change in climate hazard	Rising average sea level
	Potential impact	Episodic sedimentation infill of dredged areas such as berths and approach channels.
Risk assessment Time period: current	**Likelihood narrative**	The impact has previously never occurred.
	Likelihood score	1
	Consequence narrative	Delays to service and financial cost of maintenance requirements and dredging of water channels to restore previous conditions and allow for vessel berthing and docking.
	Consequence score	3
	Risk score	3
Risk assessment Time period: 2050s, Emission scenario: medium (RCP6.0)	**Likelihood narrative**	Projections indicate that sea level will rise by 0.3m. The impact has previously never occurred.
	Likelihood score	2
	Consequence narrative	As per current consequence.
	Consequence score	3
	Risk score	6

Annex A: Guidance on accessing and interpreting climate projections data

This section provides guidance on climate projection data in the Met Office's 2018 UK Climate Projections (UKCP18), how they can be accessed using different portals and additional sources of evidence to assess a wider range of climate risks not in UKCP18. Further background information to UKCP18 can be found here.

As stated in Step 5, there are a number of sources for accessing UKCP18 data. This section provides guidance for using the following sources:

- Climate Risk Indicators (CRI) interface is a useful tool for first-time users
- UKCP18 User Interface is the Met Office's portal for accessing UKCP18 data, providing a broader range of climate data

To understand how climate is changing it is often useful to compare projections to a baseline period. Baseline periods should ideally be the same across all analysis within a CCRA to ensure that results are comparable. For example, if one product uses 1981-2000 as baseline, and another uses 1961-1990, the projections they provide for the 2050s are not directly comparable. The standard baseline period used by UKCP18 climate projections is 1981-2000 (previous iterations of the UK climate projections had used 1961-1990).[8]

Whichever climate projections product, or combination or products, you use, it is important to be aware of their limitations. Climate projections are not predictions or forecasts, but simulations of potential scenarios of future climate under a range of hypothetical emissions scenarios and assumptions. Therefore, the results cannot be treated as exact. They represent internally consistent representations of how the climate may evolve in response to a range of potential emissions scenarios and their reliability varies between climate variables. Any scenario necessarily includes subjective elements and is open to various interpretations. Additional caveats and limitations can be found within UKCP18 guidance.

A.1 **UKCP18 land-based projections**

[8] Some advanced users might want to re-baseline the climate data to a period nearer to the present day. It is recommended that a 20 or 30 year time period is used.

This section provides a summary of the key land-based climate projections in UKCP18.

UKCP18 includes a number of products providing different land-based climate projections, including:

- probabilistic projections
- global, regional, local and derived Projections

Each set of projections have different advantages and disadvantages, and it is for the user to determine which is most appropriate.

To build an understanding of future climate within a CCRA, the probabilistic projections may be particularly relevant. These projections are available at 25km grid resolution and require less manipulation than other products. The probabilistic projections provide data for all four RCPs across a wide range of indicators and provide data on the probability of different outcomes occurring. This can help users understand some of the uncertainty range associated with projections and the likelihood of specific climate-related thresholds being exceeded.

There may be situations where the probabilistic projections are not the preferred product. The probabilistic projections do not cover marine or international projections. If you are conducting a CCRA for a portfolio of assets which are spread across an area wider than 25km x 25km, or are conducting a strategic risk assessment, then the global or regional projections may be more appropriate. If you require a higher spatial granularity (e.g., for a singe asset or scheme), then it may be preferable to use the local (2.2km) projections. Refer to UKCP18 guidance on how to use land projections datasets for further details.

The probabilistic projections provide monthly, seasonal and annual time intervals. If you require daily projections you may wish to use the global, regional and local projections. Sub-daily projections are only available in the local projections. The probabilistic projections are not spatially coherent, which means that you cannot use data from multiple grid squares to estimate the combined probability of multiple events occurring across different locations. The global, regional and local projections are spatially coherent.

UKCP18 guidance on how to use land projections provides further detail on the differences between products. There is also UKCP18 guidance on the data available for different products. It should be noted that not all climate indicators or scenarios are available within each product. It is preferable to use multiple UKCP18 tools - the Met Office recommend that analysis using the global, regional, local and derived projections is placed in the broader uncertainty context of the probabilistic projections, where information is available.

A.2 **UKCP18 marine projections**

The UKCP18 marine projections were derived from climate models informing the IPCC's Fifth Assessment report. The projections are useful to explore changes in sea level and storm surges. Other data sources or site-specific modelling may exist which can provide more detailed projections for these hazards and should be sought on a case-by-case basis.

The Marine projections provide data for the following indicators:

- mean sea level – projected change in the average sea level relative to a baseline (1981-2000 average sea level).
- storm surge trend – projected extreme sea level caused by storm's wind pushing water onshore.
- storm surge simulations – a time-series of sea water level (excluding mean sea level change).
- extreme still water return levels – projected water level to be exceeded during extreme events with a specific return period (e.g., 100 years) i.e. the highest level water may reach including tides and storm surges but excluding waves.

The marine projections are available in a 12km spatial resolution along the coast. They are available for RCP8.5 for all indicators, and RCP2.6 and RCP4.5 for two indicators. Mean sea level change and extreme still sea level can be accessed up to 2100, and there are exploratory projections up to 2300 which may be useful for those with extremely long-lived coastal assets.

Further details about UKCP18 maritime projections can be found here.

A.3 **Using the UKCP18 User Interface**

This section provides step-by-step guidance for accessing UKCP18 data from the Met Office's UKCP18 User Interface.

As stated above, the probabilistic projections may be particularly useful to inform CCRAs. The UKCP18 User Interface includes two types of probabilistic projections:

1. Probabilistic Projections 2018 (PP2018) provides estimates of monthly, seasonal and annual mean changes from a baseline.
2. Probabilistic Projections for Climate Extremes (PPCE) provides estimates of extreme daily values for several return periods. Provides absolute values.

Table 15 sets out which indicators are available for each of these products.

Table 15: Climate indicators available within the Probabilistic Projections products (PP2018 and PPCE)

PP2018	PPCE
Average maximum temperature Average minimum temperature Mean temperature Precipitation Short and long wave radiation	Maximum daily temperature Maximum daily precipitation Maximum 5-day accumulated precipitation

Specific humidity Sea level pressure Cloud cover	

Once you have accessed the UKCP18 User Interface (you will need to register for a free account) you can select the product you wish to use and select whether to obtain the raw data, produce a map, or a graph. Data obtained via the graph functions (cdf/pdf or plume plots) are a useful way to view and analyse data and are recommended. Once you have selected your product (by clicking 'submit a request' as shown in Figure 4), you will be required to fill in a range of fields. Table 1 provides an overview of the fields.

Figure 4 An overview of UKCP18 User Interface product selection

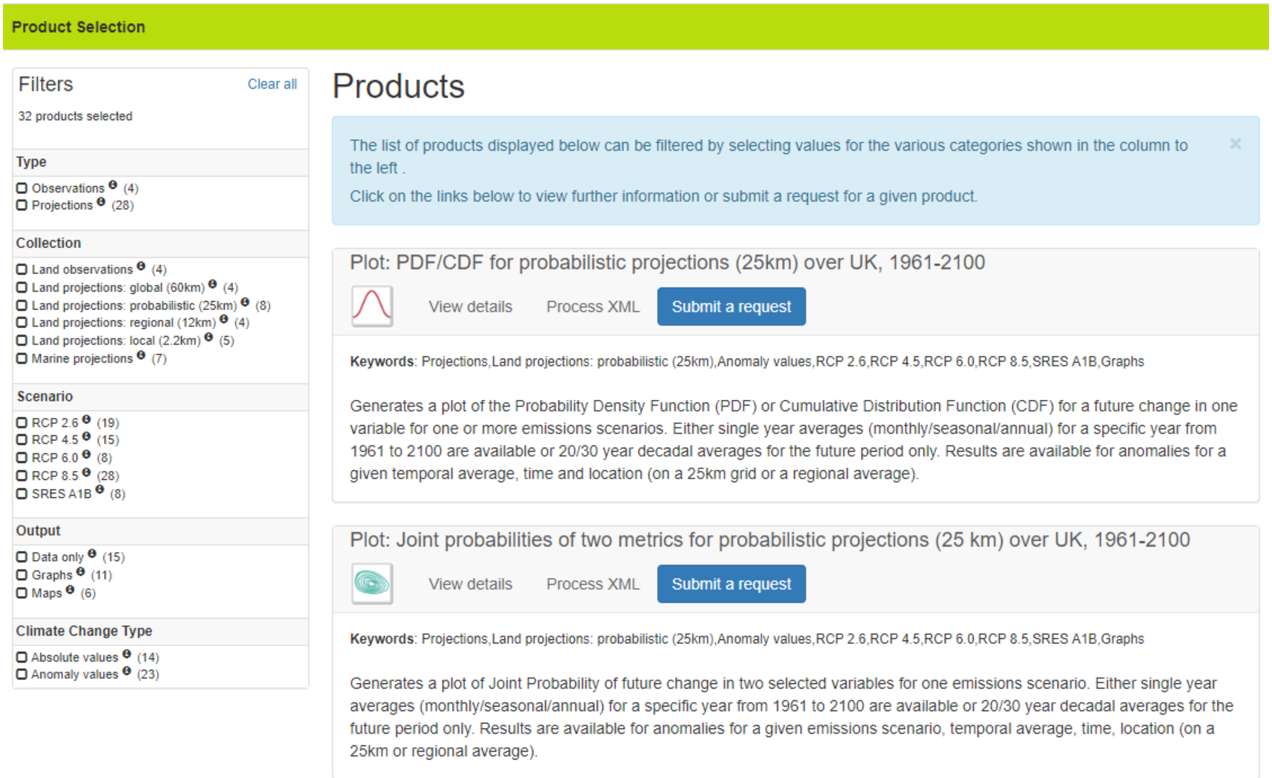


Table 16: An overview of UKCP18 User Interface fields

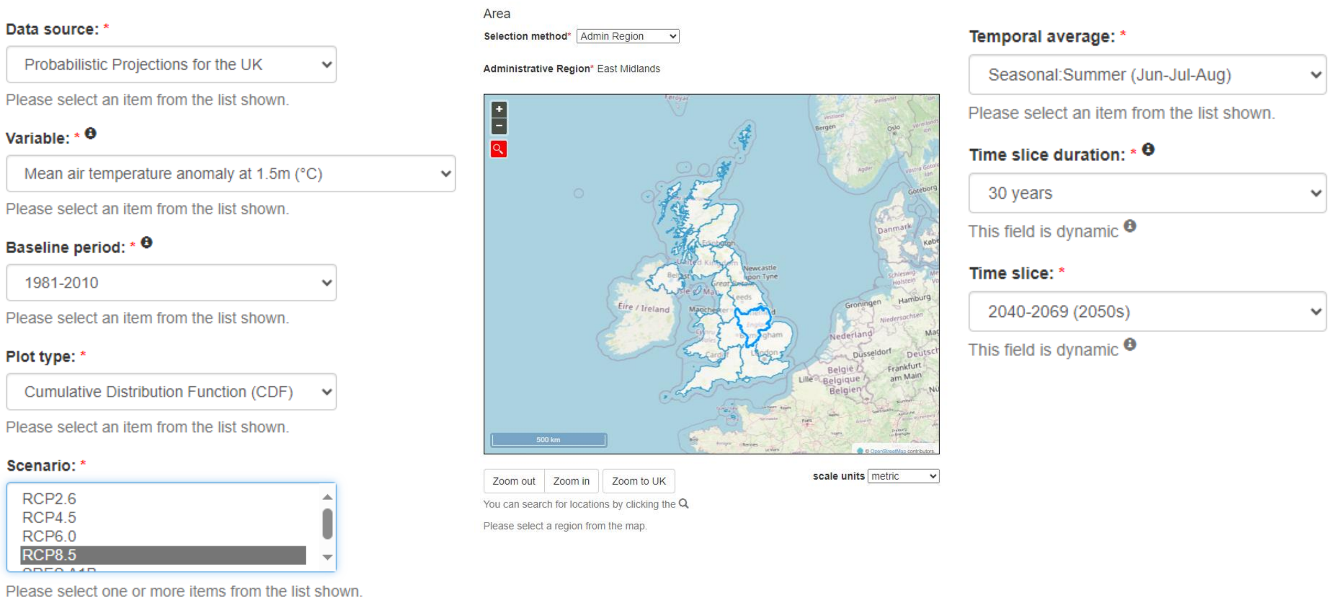
Field	Explanation
Variable	Select the climate indicator of interest
Baseline	Select the baseline of interest. 1981-2000 is the available across all UKCP18 products and is therefore typically recommended for continuity.[9]
Plot type	If using a plot to obtain the data (both raw data and a plot will be provided). Select cumulative distribution function (cdf) - which calculates the probability that indicator X is less than or equal to value x (PP2018 only). This is useful for understanding thresholds above or below which a hazard is expected to occur. For example, railway track may be more at risk of buckling where temperatures exceed 30°C. The PP2018 provide cumulative distribution plots (CDFs) which estimate the probability a given indicator will be higher or lower than the specified threshold (e.g. probability of temperature being higher than 30°C). The PPCE provide plume plots which plot the probabilities of different outcomes occurring around the central estimate. The PP2018 and PPCE projections can be obtained from the UKCP18 User Interface by selecting the following: • "Plot: PDF/CDF for probabilistic projections (25km) over UK, 1961-2100" for PP2018 • "Plot: Plume of time series of probabilistic projections of climate extremes (25km) over UK, 1961-2100" for PPCE. These options will provide you with a csv file containing the data for each percentile, as well as a plot and query file.
Scenario	Choice of RCP scenario.
Spatial selection	Chose as relevant to your purpose. Probabilistic projections were created at 25km resolution but are also available as an average over a larger area. If you are interested in multiple 25km squares, do not average them but instead select a regional or national resolution. If you want data for more than one 25km square, you will need to run separate queries using the User Interface.
Temporal average	It is often recommended to consider seasonal or monthly resolution since annual values may show smaller anomalies than interannual due to the effect of averaging different seasons.

[9] The standard baseline of the World Meteorological Organisation (WMO) is currently 1991-2020. This is not available for UKCP18 products because UKCP18 was release in 2018 prior to the adoption of this baseline.

Field	Explanation
Time slice	Typically recommended to choose the 20 year time slice, providing an average of the climate for a two-decade period to smooth out year-on-year variability. Select the future time slice you are interested in.
Return period (PPCE only)	Make your choice of return periods based on the size of event you are interested in. For example, a 100 year return period will provide you with projections for the indicator e.g., maximum temperature that represents a 'one in a hundred year event' (same as a 0.01 annual exceedance probability). The choice of return period may be driven by risk appetite, criticality of the project/asset being assessed, and any impacts from prior extreme events.
Season and time series (PPCE only)	Chose the season of interest. The PPCE will not present anomalies but absolute values for each year in the time series that you select. For example. if you want to explore the hottest it may get in 2050, then select summer season for a timeseries out to 2050, and the data will show you the simulated maximum daytime temperature in July 2050.

Figure 5 provides an overview of an example of UKCP18 User Interface field selection for Probabilistic Projections data.

Figure 5: An overview of UKCP18 User Interface field selection for Probabilistic Projections data



Once you submit a request it will become available via URL and will also be emailed to your registered email address. Data will be in csv format and include relevant graph. You should explore the data and provide a relevant summary within your risk assessment report. Each job has a link in the "job details" which takes you back to a prepopulated form for that job - if you want to do multiple locations you then only need to change the grid square, all other things will be preselected according to what was in the prior job.

A.4 Using the CRI interface

This section provides step-by-step guidance to access UKCP18 data from the CRI interface.

Once you have accessed the CRI interface there will be a range of filters on the left-hand side bar for selecting the most appropriate future climate data.

Figure 6 provides an overview of the CRI interface. The left-hand pane is where data selections are made [1]. There is an information button on the right-hand side [2]. When selecting data you can select data for multiple scenarios or regions simultaneously [3]. Once you have made your data selections, download the data [4].

Figure 6: An overview of the CRI tool.

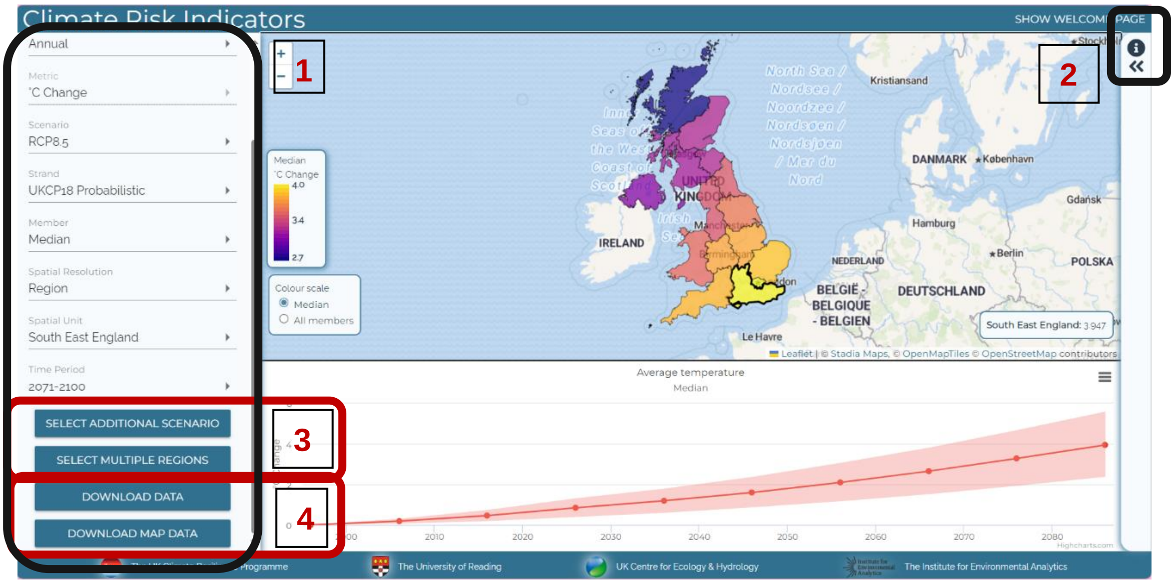


Table 17 provides an overview of each of the filter categories [1].

Table 17: An overview of CRI filter categories

Field	Explanation
Indicator category	These broad categories are to guide the user and understand which indicators are relevant for which sector. Some categories are more general and may apply to all sectors (including transport) such as the ‘climate’ and the ‘temperature extremes’ categories. Note: within the CRI interface, there is an indicator category for the health sector with indicators such as number of tropical nights. If your assessment involves a high number of staff or end-user vulnerabilities (such as night-time working, people spending significant amounts of time outside) then you may want to consider additional health-related indicators.

Field	Explanation
Indicator	The actual climate-related indicators you will use to understand the future climate, informed by the climate hazards identified in Step 3.
Variant	For some indicators you will be required to select a variant: annual or seasonal.
Metric	The units of measurement for your chosen indicator.
Scenario	Select your choice of emissions scenarios as defined in Step 5.
Strand	Select which UKCP18 product you wish to use.
Member	Select the relevant statistics from the product. For example, when using the probabilistic projections you may wish to obtain data for the 10th, 50th and 90th percentiles to understand the range of potential future climate values.
Spatial resolution	Select as relevant to your project. For example, if you are assessing a single project or location then more a granular spatial resolution such as 12km x 12km may be appropriate. If you are conducting an organisation-level assessment, you could use less granular spatial resolution.
Spatial unit	Select which areas you wish to obtain data for. If you have a portfolio of assets / projects across the UK, it may be necessary to select multiple regions.
Time period	Select as defined in Step 1.

Table 18 outlines some of the indicators in the CRI interface that might be relevant in your assessment of the future climate.

Table 18: Potential indicators from the CRI which could help inform the CCRA

Indicator Category	Indicator	Metric
Climate	Average temperature Variant: summer and winter	°C change
	Minimum temperature Variant: Winter	
	Maximum temperature	

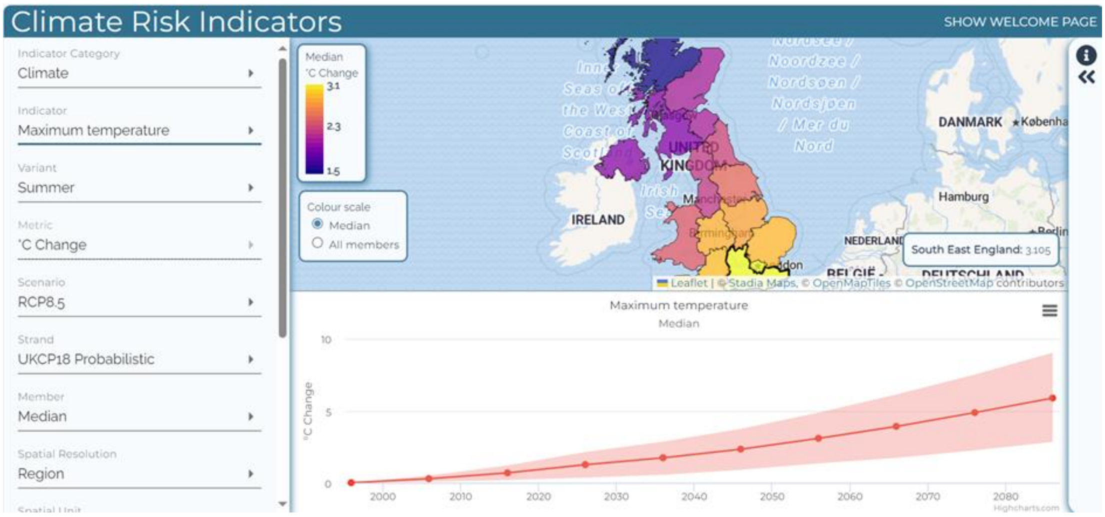
Indicator Category	Indicator	Metric
	Variant: Summer	
	Rainfall Variants: Summer, Autumn, Winter	% change
Temperature extremes	Amber heat-health alert	Events / year
	Cold weather alert	Events / year
	Very hot days (Tmax >35°C)	Days / year
Transport Consider if assessment is based on rail or local highways, or if your organisation is dependent on reliable rail or local highway connections.	Rail high temperature days Variant: >30°C Network Rail recommend there is a risk of rails buckling over 27°C	Days / year
Wildfire	Met Office Fire Danger	Days / year
Water Selection of indicators in this category will depend on proximity to a river. Consult the Environment Agency's Flood Maps to identify proximity.	River flood Variant: 10-year and 30-year	% change

Example - Interpreting percentiles of climate projections (1)

In some cases, the trend will be very clear - for example, if you consult the CRI to extract climate projections data for Maximum Temperature (under the 'Climate' Indicator Category), selecting the Summer variant, under the RCP8.5 (the high emissions scenario), selecting 'UKCP18 probabilistic' for the 2050s time period (2041-2070), at a regional spatial resolution, selecting the South East of England (Figure 7).

The projected change is a 3.1°C median increase in the maximum temperature from the baseline (1981-2000), with a 1.3°C increase in the 10th percentile, and a 4.9°C increase in the 90th percentile. It is clear the trend is for hotter summers, and this can be used later in the assessment, to score the likelihood of risks associated with high temperatures in summer occurring.

Figure 7: Interpreting percentiles of climate projections. Summertime maximum temperature, RCP8.5 for South East England



Example - Interpreting percentiles of climate projections (2)

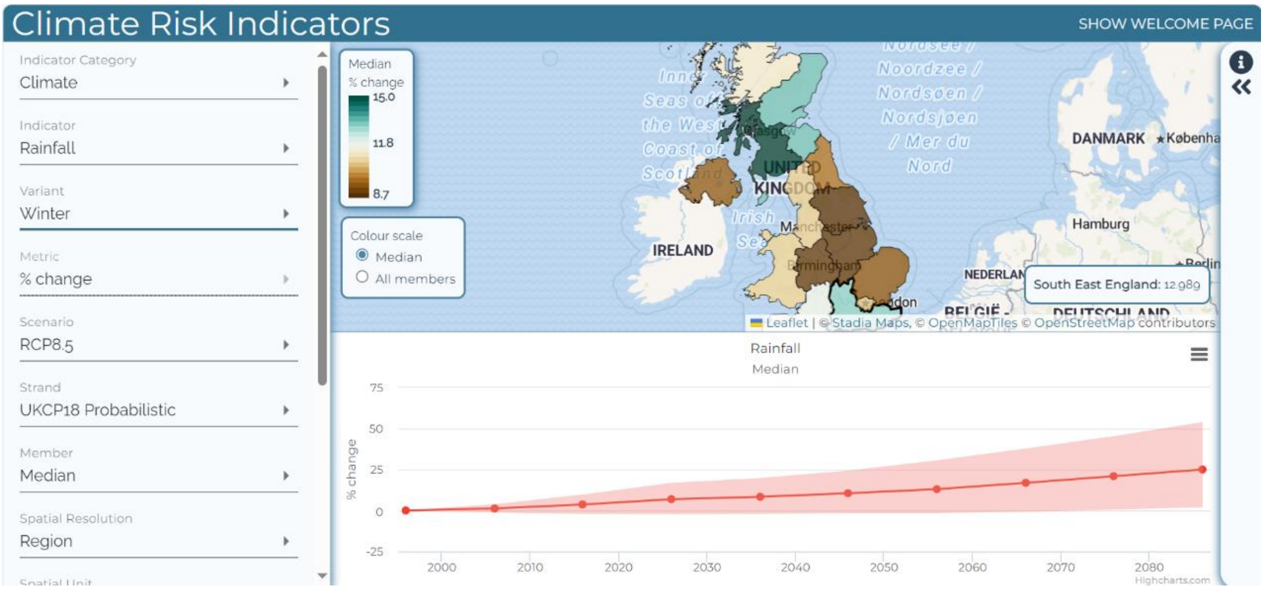
Climate projections outputs are not always as straightforward. In a second example, we consult the CRI to find out what the projected change is for Rainfall, in Winter, also under the high RCP8.5 emissions scenario, selecting 'UKCP18 probabilistic' for the 2050s time period, for the South East of England region.

The projected change indicates a 13% increase in rainfall for the median, a decrease in rainfall of 1.6% in the 10th percentile and an increase of 30.6% in the 90th percentile (Figure 8).

This may initially seem confusing, as the 10th percentile value, if taken in isolation, indicates less rain in the future. However, when assessing the trend in projections, you should take into account that the 10th percentile means only 10% of the probabilistic projections outcomes fall below that value.

Rainfall modelling is more uncertain than modelling of temperature, therefore the probabilistic projections have a greater range, which sometimes includes negative values (decrease in rainfall) as well as positive value (increase in rainfall). Overall, the temporal trend is rising, indicating that winter rainfall is likely to increase in the future. It is also important to remember that it is possible to have exceptions to a trend. For example, whilst the trend shows wetter winters, there may still be a few winters in the future which are unusually dry.

Figure 8: Interpreting percentiles of climate projections. Winter rainfall projections, RCP8.5 for South East England



A.5 Other sources of climate data

Precipitation and flood risk

Rainfall projections data alone are insufficient to accurately project flood risk. This is because flood risk modelling requires more detailed information including high-resolution (e.g. 1km and sub-hourly) rainfall data, as well as other data such as topography, land cover and drainage. Most climate change models are restricted to estimates of the mean seasonal rainfall at a relatively high spatial level within the context of flood risk modelling. There are also high levels of uncertainty and a lack of data on changes to sub-hourly rainfall. The UKCP18 local projections (2.2km) offers hourly rainfall projections but these datasets are large and can take several hours to retrieve. Ultimately, this means that precipitation projections alone are insufficient for detailed flood risk assessment.

The Environment Agency (EA) has issued guidance for peak rainfall, peak river flow and seal level rise climate change allowances for Flood Risk Assessments. These allowances are primarily aimed at developers during the planning process and refer to the uplift that should be used in drainage and flood management to mitigate a 1-in-30 year or 1-in-100 year flood event. Data is available for two time periods: the 2050s (2022 to 2060) and the 2070s (2061-2125). For CCRAs, these uplifts may be useful in illustrating the potential change in flood risk.

Other climate hazards

Changes in climate and meteorological values have impacts upon a range of other climate hazards which are commonly included in risk assessments such as lightning, adhesion, drought and water scarcity and ground movements (e.g., landslide, karstification, desiccation, heave, subsidence). However, UKCP18 does not provide quantitative data on such indicators but does have fact sheets that may contain useful information (e.g., on soil moisture and water balance).

It may be desirable to use variables from UKCP18 as a proxy for these hazards. For example, future precipitation projections may provide insight into whether drought and water scarcity risks will increase or decrease, as it is likely that water scarcity will follow a similar trend to precipitation.

Annex B: Case studies

B.1 **Ports Case Study**

Port of Felixstowe Flood Risk Assessment 2004, 2008, 2016

Hutchison Ports owns and operates a network of 53 ports across 24 countries, including the Port of Felixstowe, Harwich International and London Thamesport in the UK. The Port of Felixstowe is the largest container port in the country, situated in Suffolk, South East England, and owned by Hutchison subsidiary The Felixstowe Dock and Railway Company (FDRC). In 2003, FDRC applied for planning permission to expand the capacity of the Port of Felixstowe through a scheme known as the Felixstowe South Reconfiguration (FSR).

As part of the FSR work, Port of Felixstowe undertook a Flood Risk Assessment in 2004 to identify any flood risk that may arise during the operational lifetime in the location. This was then revised in 2008 to provide an update to risk, and then again in 2016 to consider any changes since the 2008 update.

Key findings

The 2008 Flood Risk Assessment concluded that the FSR works would significantly enhance the protection of the Port from marine risks associated with climate change. Specifically, the works would improve protection from a 1 in 100 year, to in excess of a 1 in 1000 standard of protection, in regard to the design of flood defence level set at 4.6 AOD.

In 2008, the FRA concluded that the flood defences within the remainder of the Port of Felixstowe had a standard of protection in excess of 1 in 1000 years, which was projected to decrease to approximately 1 in 200 years by 2067. This meant that any overtopping of these defences would likely be limited to localised wave action. The impact of this overtopping was identified as minimal, as the areas were contained within the Port area and so would be discharged back to the sea through the surface water drainage system.

Methodology information (what timelines, climate scenarios, which method used)

In order to ensure the Flood Risk Assessment assessed future climate change throughout the operational lifetime of the development, the lifetime was defined as 60 years.

Actions identified

Hutchison Ports (UK) are already on the Environment Agency's Flood Warning System, and has risk management plans, specifically flood management plans, in place with the aim to minimise the potential impacts and avoid disruption associated with extreme tidal conditions. However, in addition to this, further resilience has been identified through embedded mitigation within port design for new construction activity.

For example, any new fixed assets constructed in the area were planned to be suitably flood-proofed in order to minimise the damage from localised flooding due to wave overtopping. Any other structures would be required to include embedded mitigation within design such as the adjustment of threshold levels and relocation of access doorways.

The proposed reconfiguration works were considered to significantly reduce the risks associated with coastal flooding and tidal inundation to the Port of Felixstowe and the nearby town, by providing a standard of protection in excess of 1 in 1000 years. As a result, with the risk management plan in place the flood risk is considered to be negligible.

B.2 **Airports Case Study**

Manchester Airports Group ARP3 2021

Manchester Airports Group (MAG) is a leading UK airport group that owns and operates three major airports: East Midlands, London Stansted and Manchester. MAG carried out a climate change risk assessment as part of their ARP3 response. MAG had previously published Climate Change Adaptation Reports for these airports, however, this ARP3, published in 2021, was the first holistic report covering all three airports together.

Within the risk assessment, the identified receptors were categorised into two main groups: airport infrastructure and airport operations. The airport's infrastructure encompassed a range of receptors: concrete and steel building components, aircraft, runways, aprons, belowground structures, drainage systems, navigational systems, communication systems, surveillance systems, and the surrounding environment.

Similarly, the airport operations involved various critical aspects: schedule disruption including any interruptions that can impact airport efficiency, airport reputation, employees, passengers, water supplies, and electricity supplies. All of these receptors, both infrastructure and operational, collectively contribute to the effective functioning of the airports, and their selection ensured the efficient evaluation of risk due to a changing climate.

Key findings

The output of the assessment included the identification of key summary risks for each of the three airports, which represent the risks which were assessed as being the most significant.

All three airports share the same key risks, as outlined below:

- physical damage to infrastructure due to increased frequency and severity of storm events including high winds, rain, lightning and snow

- release of contaminated surface water due to increased frequency and intensity of winter rainfall events leading to overspill of balancing ponds containing de-icing chemicals

In addition to these key risks, Manchester Airport identified an additional risk of increases in serious airfield safety incidents due to more frequent and/or severe weather events such as high winds, intense rainfall and icy conditions.

Methodology information (what timelines, climate scenarios, which method used)

Consistent with MAG's previous ARP reporting, the assessment considered the likelihood and impact of potential risk consequences on a scale of 1 (minimal) to 5 (critical). The likelihood and impact scores for each risk were multiplied to calculate the risk exposure score (likelihood x impact = risk exposure). Therefore, the maximum exposure risk rating was 25.

This method was applied for both current risk and future risk and based upon the UKCP18 Probabilistic Projections for England.

While the UKCP18 Probabilistic Projections were identified as the most appropriate for the assessment, acknowledgement was made to the geographic spread of the three airports around the country. Consideration was taken as to whether supplementary information would add value to reflect these variations. Subsequent assessment of the UKCP18 Regional Projections for the North West, Central, and Eastern regions concluded that differences between the regions would not be significant to the outcomes of the risk assessment. Therefore, the UKCP18 Probabilistic Projections for England were used as the basis of assessment across all three airports.

Projections for average temperature and rainfall were obtained from RCP6.0, using data from the 50th percentile, representing the median estimates. The future timelines obtained were the 2030s (2020-2039), 2050s (2040-2059) and 2080s (2070-2089).

Actions identified

Every risk identified within the CCRA was assigned a ‘further planned action’ to be undertaken within 5 years from the date of assessment. Each of these actions was assigned to one of three categories:

- maintain a watching brief – short-term approach using the latest available information on climate projections and the situation at the airport.
- action required to mitigate or adapt to a climate change risk.
- investigate further to fully understand the risk, its associated impacts and the likelihood it leads to a risk.

Actions identified at East Midlands, London Stansted and Manchester Airport were considered separately. An example of the further planned actions identified for some of the risks are detailed below. For some of the risks, a combination of the above were assigned to help reduce the significance.

Airport	Risk	Further planned action
East Midlands Airport	Release of contaminated surface water in contravention of environmental permits as a result of storm event, including exceeding balancing pond capacity.	Watching brief: Drainage system capacity in light of updated climate projections and site developments. Action: Complete review of drainage system, identifying and implementing improvements. Action: Ensure specifications for future developments and asset renewals consider climate change predictions.

London Stansted Airport	Damage to on and off-airport infrastructure due to an increase in storm events (high winds, rain, lightning and snow)	Watching brief: On impact of wind damage to airport assets. Action: Ensure specifications for future development and asset renewals consider climate change predictions.
Manchester Airport	Damage to assets and operational disruption due to an increase in lightning events.	Investigate: Lightning detection and prediction technology. Watching brief: On impact of increased lightning events on electricity supply systems and ground handling operational performance.

B.3 **Local Highways Case Study:**

Cambridgeshire County Council 2021/22

Cambridgeshire County Council (CCC) is the local authority for Cambridgeshire, providing services to local residents and business including local highways.

The council has set out its ambitions to adapt to climate change in its Climate Change and Environmental Strategy, with the aim of improving resilience to climate change impacts. As part of the work to increase resilience of roads, the local highways team have undertaken work on a CCRA as part of a wider climate adaptation strategy.

Key findings

The risk assessment identified areas of key risks, which are the focus of future climate resilience work.

The most significant climate risks relate to changes in precipitation, including seasonal changes, increased intensity of heavy rainfall events in addition to flooding events. CCC have noted that flood events, when occurring successively, are causing issues where the groundwater levels are rising, with saturation lasting longer and the water having nowhere to go. This means after a time even less intense rainfall events have greater implications for local highways operation and maintenance.

Freeze-thaw is also an issue that has been noted, due to flooding followed by a cold spell, such as that experienced through the 2023/24 winter months. This has led to the increased rate of deterioration of the road surfaces. This issue is amplified due to the geology of Cambridgeshire, with many of the local highways sitting upon peatlands, which are subject to movement in relation to changes in precipitation. This has meant that traditional methods of road maintenance (e.g. backfilling following freeze-thaw) are not providing durable solutions. Where the expected lifespan of road surfacing is generally 12-15 years, it has recently been observed to be only 2-3 years, which has significant budget implications.

Methodology information (what timelines, climate scenarios, which method used)

Cambridgeshire County Council have taken an approach to CCRA that identifies areas under assessment as the different areas of service (business functions) which are being delivered.

Cambridgeshire have used the Highway Infrastructure Resilience Assessment Modelling (HIRAM) tool, an advanced map-based tool developed by Wilson Pym May (WMP) Solutions. HIRAM was designed to support asset management decision makers within the highways sector. This tool offers a scenario data-driven, comprehensive overview of highway infrastructure’s vulnerability to the impacts of climate change and extreme weather events.

The HIRAM tool uses a Likelihood and Impact based model to assess the severity of climate risks (risk severity of consequence is = Likelihood x Impact).

The assessment of likelihood is based on climate projections data. HIRAM holds UKCP18 climate projections and National flood risk mapping data which are used as the basis for assessment of changes in future climate and associated impacts. The following data are available on the HIRAM tool and were incorporated as part of Cambridgeshire Council’s risk assessment:

- change in Summer mean max temperature (˚C)
- change in Winter mean minimum temperature (˚C)
- change in wettest days of Summer (%)
- change in wettest days of Winter (%)
- change in the warmest day of Summer (˚C)
- change in annual mean precipitation (%)

To assess the impact of a climate risk, factors concerning the impact to community, environment, and economy are built into the tool, and included questions for the local highway authority to consider. Some examples are outlined below:

- is the road a route to transport interchange?
- how many people use the road per day/month/year?
- does the road pass through a Site of Special Scientific Interest (SSSI)?
- is there a bridge of historic structure?
- what is the economic cost to Cambridgeshire City Council for road closure and associated diversion route?

The tool then calculates a risk score for each climate risk and identifies the risks with the highest likelihood or the greatest projected impact.

B.4 **Interdependencies Case Study:**

Transport for London Interdependencies

Transport for London (TfL), along with Network Rail, National Highways, High Speed 2 (HS2), High Speed 1 (HS1), Defra, and other organisations, have been actively collaborating as part of the Transport Adaptation Steering Group (TASG). This has supported the delivery of their Adaptation Reporting Power Round 4 (ARP4) submissions, which set out the risks they face from climate change and progress in delivering adaptation actions. This has fostered a collaborative environment for sharing knowledge and best practice, as acknowledged in the London Climate Resilience Review. This project focused on the area of interdependencies and cascading risks to London's land based transport sector (LBTS).

London's LBTS is already being affected by severe weather events that are becoming more frequent and more intense. Climate hazards that impact upon one organisation's assets can then lead to cascading impacts to other organisations. The congested nature of London's infrastructure increases both the likelihood and potential magnitude of these cascading impacts. Therefore, climate interdependency risks represent a complex problem for the LBTS as these risks cascade across organisational boundaries. The project combined system mapping with a climate change risk assessment (CCRA) for London's LBTS and its upstream interdependencies (i.e. processes or organisations which if impacted by climate change will impact on the LBTS), following guidance from Defra for reporting organisations. Adopting a systems approach involved the assessment of interdependencies and cascading risks across the interconnected infrastructure systems within London. As a result, stakeholder engagement with other sectors took place throughout the project to jointly develop a comprehensive understanding of the existing interdependencies, climate hazards, and potential measures to mitigate climate-related interdependency risks.

Key findings

Figure 5 summarises the key findings from the risk assessment. Key climate hazards are presented along with the LBTS' interdependencies that are most impacted by them.

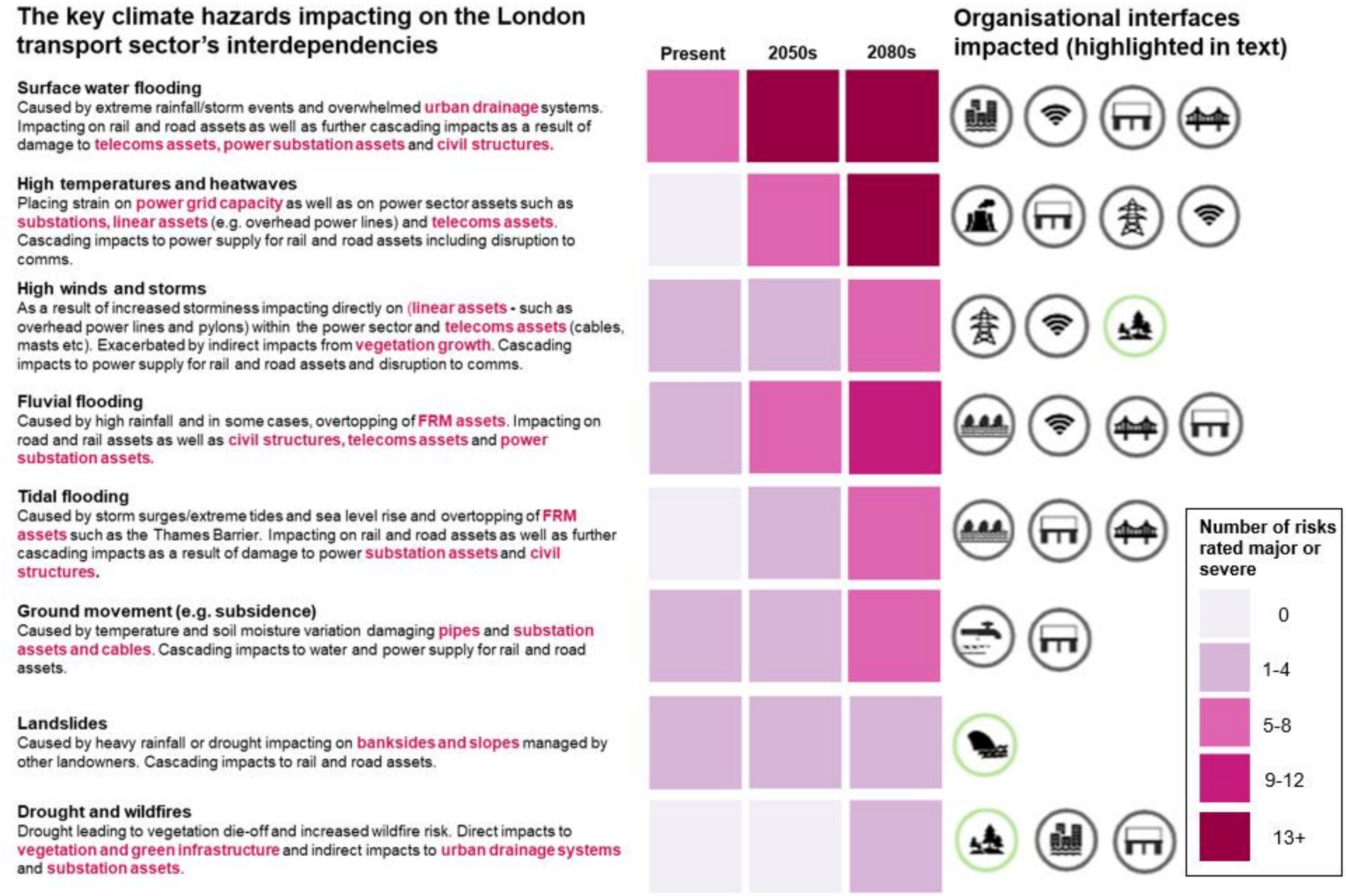


Figure 5: Key findings from TfL's interdependency risk assessment

The main findings from the climate interdependency risk assessment were that:

- the power sector interdependency is considered high-risk due to the variety of climate hazards impacting power assets and the shift towards decarbonisation and electrification which will amplify consequences for the LBTS
- urban drainage and civil infrastructure also present high risks to the LBTS, attributed to the probability of flood impacts and the severity of consequences
- the interdependency with the telecoms sector presents a medium risk, which can vary greatly based on the individual configurations of organisations. Confidence in these risk scores is limited by the scarcity of data on vulnerability from both the telecoms sectors and within the LBTS
- flood risk management (FRM) assets are an interdependency with generally lower risk scores, although this assumes a high level of adaptation, noting that these plans are not yet funded and therefore the potential for significant risks from tidal and fluvial flooding remain
- risks associated with vegetation management and pipe bursts are rated lower, reflecting the presence of adaptation measures and less severe consequences

Actions identified

In response to the findings, stakeholders collaboratively developed 52 actions to mitigate climate risks to interdependencies, across the following timeframes; short-term (1 year), medium-term (2-4 years), and long-term (5+ years). Key priorities were to:

- continue to support cross-sectoral collaboration beyond the LBTS and prioritise engagement where knowledge gaps exist, such as with the telecoms sector
- improve data sharing across organisations, with the ultimate aim of creating shared risk registers
- explore co-funding opportunities for resilience measures which deliver co-benefits, particularly for green infrastructure solutions which can reduce the risk from multiple hazards such as flood management and urban cooling
- share and develop best practice on the maintenance of green infrastructure which presents an increasingly important adaptation solution yet remains poorly understood in regard to management and maintenance

By integrating a systems approach with a traditional CCRA, the project established a thorough and innovative framework for gathering and analysing climate interdependency risks. The project also showed how taking a collaborative approach to interdependency analysis can be beneficial, strengthening cross-sectoral ties and cultivating a collective understanding of the climate interdependency risks to London's infrastructure. As all organisations and their infrastructure assets are increasingly interconnected and affected by climate change, taking a collaborative approach to assessing risk and planning action allows the most effective interventions to be identified with the greatest overall economic, social and environmental benefits.

However, the project also highlighted a need for this analysis to be convened at a multi-sector level due to the limited resources and influence of one sector alone. A co-ordinated response across all organisations would also avoid duplication of effort and ensures that stakeholder time is used as efficiently as possible.

Annex C: Examples of physical climate risks

C.1 Examples of physical climate risks to ports

This is a non-exhaustive list - it does not include all possible risks to ports.

Climate indicator	Climate hazard	Receptor	Potential impact
Temperature	Change in average temperature Heatwave	Port operators, site staff	Uncomfortable conditions and heat-related illness, workers unable to perform operation or maintenance activities.
Temperature	Change in average temperature Heatwave	Surrounding environment	Increase in leisure activity leading to greater presence of recreational users in harbour areas, increased risk of collision with small crafts.
Temperature	Change in average temperature Heatwave	Structures	Exceedance of temperature thresholds leading to overheating and failure of machinery and equipment e.g. gantry cranes
Temperature	Change in average temperature Heatwave	Vessels	Overheating of vessel engines.
Temperature	Change in average temperature	Surrounding environment	Increased presence of non-invasive species in dredged sediment can lead to lack of disposal options and future risk to navigational safety.

Climate indicator	Climate hazard	Receptor	Potential impact
Temperature	Change in average temperature	Surrounding environment	Introduction or transfer of invasive non-native species to water within harbour and watercourses, increasing threat to native species. Threat to people e.g. presence of jellyfish.
Temperature	Change in average temperature	Surrounding environment	Increasing water temperature and increased algal bloom can decrease level of dissolved oxygen in water, leading risk to biodiversity.
Temperature	Change in average temperature	Surrounding environment	Habitat migrations due to increasing air and water temperatures.
Temperature	Change in average temperature	People Operation	Increased risk of pandemics. If similar to COVID-19, could temporarily affected port trade, passenger and tourist services.
Temperature	Change in average temperature	Surrounding environment	Increased biofouling of dock or local structures, equipment, ladders can lead to increased maintenance and biodiversity impacts.
Temperature	Cold wave/frost	Port operators, site staff	Stock shortages in supplies such as grit, heating fuel can lead to increased pressure on staff availability.
Temperature	Cold wave/frost	Port operators, site staff	Risk of slips and trips.
Precipitation	Drought	Locks	Delays to lock operation due to limited number of times locks can be opened.
Precipitation	Drought	Operation	Reduction in water availability for port operation.
Precipitation	Drought	Vessel Handling, storage and transportation of cargo	Low water levels leading to reduction in maximum vessel cargo capacity.

Climate indicator	Climate hazard	Receptor	Potential impact
Precipitation	Drought	Vessel	Low water levels leading to lower maximum vessel speeds, increased fuel consumption and increased congestion.
Precipitation	Drought	Vessel	Low water levels leading to increased fuel consumption of vessels.
Precipitation	Extreme rainfall	Structures	Accelerated deterioration of structural assets e.g. radar towers, navigation lights, buildings, breakwaters.
Precipitation	Extreme rainfall	Surrounding environment	Increased runoff can lead to concentration of pollutants and nutrients in water, contamination of potable water supply.
Precipitation	Extreme rainfall	Water channels	Increased runoff can lead to litter entering watercourses and distribution of litter downstream.
Precipitation	Flooding	Surrounding environment	Increased risk of river bank erosion
Precipitation	Flooding	Structures	Accelerated deterioration of structures that lie on or over the river e.g. bridges.
Precipitation **Wind**	Flooding Storm events	Port operators, site staff Operation	Staff unable to reach the port via road networks. With ports, alternative travel options can be limited.
Precipitation **Wind**	Flooding Storm events	Operation	Supply issues for imported construction materials.
Wind	Storm event Lightning	Structures	Damage to electrical equipment.
Sea/ocean	Storm surge	Operation	Wave slam and wave overtopping can lead to disruption to operations e.g. berthing, mooring systems, navigational safety, reduced availability to board and recover pilots and for loading/unloading.

Climate indicator	Climate hazard	Receptor	Potential impact
Sea/ocean	Storm surge	Telemetry systems	Wave slam and wave overtopping can lead to damage to or failure of telemetry systems.
Sea/ocean	Storm surge	Structures	Wave slam and wave overtopping leading to structural damage e.g. bollards
Sea/ocean	Storm surge	Operation	Reduction or interruption of operation during high wind and precipitation events to maintain safety of pilots and port operators.
Sea/ocean	Storm surge	Structures	Damage to harbour authority assets e.g. buildings, breakwaters, electrical equipment.
Sea/ocean	Storm surge	Operation	Increased occurrence of ‘force majeure’ enabling contractors to cease work without contractual penalty.
Sea/ocean	Sea level rise	Surrounding environment	Habitat loss due to coastal squeeze.
Sea/ocean	Sea level rise	Surrounding environment	Rising water levels increases the distance for sunlight to reach seagrass on the seabed for process of photosynthesis. Seagrass can only survive in shallow water with depth under 4m. Seagrass is important to provide natural coastal defences, improve water quality, and to provide nursery habitats for marine life.
Sea/ocean	Sea level rise	Operation	Flooding can lead to the interruption of port operations e.g. delays, closure.
Sea/ocean	Sea level rise	Vessel	Rising water level can improve vessel under keel clearance, leading to reduction in dredging requirements.
Sea/ocean	Sea level rise	Vessel	Rising water level can prevent vessels from passing under bridges.
Sea/ocean	Sea level rise	Locks	High water levels increase the water pressure on lock gates and lead to uncontrolled opening.

Climate indicator	Climate hazard	Receptor	Potential impact
Sea/ocean	Sea level rise	Operation	Rising water levels can restrict access for maintenance.
Sea/ocean	Sea level rise	Navigation systems	Changes in ocean floors can compromise telemetry configurations and reliability of readings.
Sea/ocean	Sea level rise	Structures	Flooding of port area may damage port structures and buildings.
Sea/ocean	Sea level rise	Water channels	Sedimentation infill of dredged areas such as berths and approach channels.
Ground/solid-mass	Subsidence	Structures	Paths and patios surrounding port buildings may lift or become uneven.
Ground/solid-mass	Subsidence	Structures	Doors within port buildings may stick as their frames become misaligned due to ground movement.

C.2 Examples of physical climate risks to airports

This is a non-exhaustive list - it does not include all possible risks to airports.

Climate indicator	Climate hazard	Receptor	Risk
Temperature	Changing average temperatures	Surrounding environment	Increase in disease vectors at airport resulting from changes to their distribution, due to increasing temperatures.
Temperature	Changing average temperatures	Aircraft Surrounding environment	Changes to airfield habitats and bird populations impacts wildlife control and increasing risk of bird/aircraft impact.
Temperature	Changing average temperatures Heatwave	Utilities	Increased energy demand for cooling and ventilation, increased reliance on energy suppliers be able to supply this demand.

Temperature	Changing average temperatures Heatwave	Runway Structures	Airfield surface and sub-surface structural damage to runway and aprons caused by temperatures exceeding design standards, i.e. cracking, melting.
Temperature	Changing average temperatures Heatwave	Passengers Airline/airport staff	Decrease in passenger and staff comfort outside and within airport buildings and aircraft, and risk of heat-related illness.
Temperature	Changing average temperatures Heatwave	Surrounding environment	More nearby resident windows open, particularly during summer nights, leading to greater disturbance from airport operations.
Temperature	Changing average temperatures Heatwave	Aircraft	Increased air temperature can lead to harder, faster aircraft landings.
Temperature	Changing average temperatures Heatwave	Aircraft	Impacts on maximum weight take off (MWTO).
Temperature	Changing average temperatures Heatwave	Electrical equipment	Sensitive electronic equipment and mechanical operating mechanisms may fail to operate correctly.
Temperature	Cold wave/frost	Aircraft	Increased requirement for aircraft de-icing.
Temperature	Cold wave/frost	Airline/airport staff	Increased risk to the health and wellbeing of outside workers.
Temperature	Cold wave/frost	Utilities	Increased energy demand for heating, increased reliance on energy suppliers be able to supply this demand.
Temperature	Cold wave/frost	Operation People	Difficulties for staff and customers getting to/from the airport site.

Temperature	Heatwave	Structures	Thermal expansion of building infrastructure, e.g. concrete and steel, reducing longevity.
Temperature	Heatwave	Runway	Increased accumulation of rubber on runway leading to increased runway maintenance and closure.
Temperature	Heatwave	Aircraft	Exceedance of flashpoint of aviation fuel can lead to a fire hazard.
Temperature	Heatwave	Surrounding environment	Increase in local air pollutants due to lack of stagnant air.
Temperature	Heatwave	Aircraft	Reduced lift for departing due to ‘thin air’ and reduced engine efficiency in very hot weather.
Temperature	Heatwave	Structures	Increased expansion and contraction of pipework can damage pipes.
Temperature	Wildfire	Surrounding environment	Grass/vegetation pose as a fire risk, leading to spread of fires and smoke, leading to disruption to operation; risk of fire resulting from use of bird scaring flares.
Precipitation	Drought	Surrounding environment	Pollution of local debris can accumulate in pipework during periods of drought, which can be washed out with rainfall at later date.
Precipitation	Drought	Operation	Reduced water availability for water intensive activities.
Precipitation	Drought	Surrounding environment	Increased drought stress to plants and landscaped areas.
Precipitation	Extreme rainfall	Surrounding environment	Release of contaminated surface water brooks as a result of polluted water holding tanks exceeding capacity.
Precipitation	Extreme rainfall	Runway vehicles Airline/airport staff	Intense rainfall creates hazardous conditions for vehicles and aircraft e.g. airside and landside road vehicles, and landing aircraft due to reduced visibility.

Precipitation	Extreme rainfall	Structures	Rain ingress in roof of certain airport buildings increase the occurrence of false fire alarm activation.
Precipitation	Extreme rainfall	Structures	Changes to groundwater levels can lead to subsidence and water ingress damage to building structures.
Precipitation	Extreme rainfall	Drainage	Interceptors as pollution prevention within the drainage system can be overwhelmed during heavy rainfall events.
Precipitation	Extreme rainfall	Airline/airport staff	Increased risk to health and wellbeing of outside workers.
Precipitation **Wind**	Extreme rainfall Storm	Operation	Decrease output for UK businesses due to an increase in supply chain disruption and consequent loss of output as a result of extreme weather events.
Precipitation	Flooding	Runways Taxiways	Overflow of brooks and culverts, leading to flooding of roads, runway, taxiway, general site.
Precipitation	Flooding	Runway vehicles	Loss of ground transport links due to ground flooding on site.
Precipitation	Flooding	Navigation systems	Intrusion of water can damage instrument land system (ILS) and navigational aid systems, leading to reduced accuracy of readings, and even equipment shut down.
Wind	Changing wind patterns	Aircraft	Changes to high altitude air currents used by airlines can lead to changes to flight times. Combined impacts can lead to substantial changes to operating cost and fuel consumption.
Wind	Changing wind patterns	Aircraft	Changes to wing tip vortex effect, particularly problematic for small aircraft taking off in quick succession after large aircraft.
Wind	Changing wind patterns	Aircraft	Changes to prevailing wind direction can impact take off procedures.

Wind	Extreme gusts	Runway	Loose debris material e.g. dry soils at risk of being picked up in high winds and deposited as foreign object debris on runway, structures and buildings, leading to increased risk of schedule disruption.
Wind	Extreme gusts	Structures	Damage to high structures e.g. air traffic control tower.
Wind	Storm	Aircraft	Disruption to operation e.g. suspension to refuelling activities, changes to flight routing.
Wind	Storm	Navigation systems	Remote communications, radar and navigation sites can lose connection and cause temporary shutdown of operation.
Wind	Storm	Passengers	Longer significant weather delays and cancelled flights, increasing costs and risking company reputation.
Wind	Storm	Operation	Diverted, longer flight paths so as to avoid areas impacted by storm events, leading to delayed services and additional operation costs.
Wind	Storm	Airline/airport staff	Increased occurrence of 'force majeure' enabling contractors to cease work without contractual penalty.
Sea/ocean	Sea level rise	Runway	Erosion of surfaces such an runways, aprons and taxiways.
Sea/ocean	Sea level rise	Structures	Increased threat of flooding and infrastructure damage.
Ground/solid-mass	Subsidence	Structures Drainage	Instability of surrounding objects, buildings, trees, overground structures and sub-surface structures e.g. drainage system
Ground/solid-mass	Subsidence	Runway	Runway lights, navigation aids, and runway markings may shift or break.
Ground/solid-mass	Subsidence	Drainage	Damage to drainage systems leading to poor water runoff.

C.3 Examples of physical climate risks to local highways

This is a non-exhaustive list - it does not include all possible risks to local highways.

Climate indicator	Climate hazard	Receptor	Risk
Temperature	Changing temperatures (extreme shifts) Freeze-thaw	Bridges/structures	Structural cracking leading to failure of bridge structures.
Temperature	Changing average temperatures Heatwave	Road surface	Disruption to operation with longer road closures as freshly laid asphalt retains heat and remains soft for longer, making it more susceptible to rutting if the road is opened before it is cooled.
Temperature	Changing average temperatures Heatwave	Bridges/structures	Thermal action and failure of bridge bearings, which are designed to accommodate the movement of the bridge for a temperature range.
Temperature	Cold wave/frost	Road surface	Increased maintenance requirement for snow to be cleared and roads to be gritted.
Temperature	Cold wave/frost	Road surface	Lifespan of road surface can be shortened if asphalt is laid in cold conditions.
Temperature	Cold wave/frost	Road surface	Deterioration of older, more porous road surfaces due to freeze thaw. Increased pothole development and disruption
Temperature	Cold wave/frost	Road surface	Subsidence due to frost heave over longer periods of freezing temperature.
Temperature	Cold wave/frost	Road surface End users	Diminished surface grip leading to slippery road surfaces for users and risk of accidents, road closures/delays.

Climate indicator	Climate hazard	Receptor	Risk
Temperature	Cold wave/frost	Workers	Roadside workers at risk from uncomfortable working conditions which may cause disruption to work activity and longer road closures/delays.
Temperature	Cold wave/frost	Bridges/structures	Snow and ice build-up on overhead structures can cause risk from falling ice, leading to road closures/delays.
Temperature	Heatwave	Drainage	Prolonged hot, dry periods can cause soils to dry out and shrink, leading to destabilisation and damage to underground drainage assets.
Temperature	Heatwave	Road surface	Extreme high temperatures can cause concrete slabs to expand and ‘blow-up’. This risk is greatest for road with a concrete surface course, or concrete sub-surface layers overlain with asphalt.
Temperature	Heatwave	Road surface	Melting and deformation of asphalt surface course, leading to uneven road surface and early replacement.
Temperature	Heatwave	End users	Customers and workers travelling during peak temperatures are at risk of uncomfortable conditions and heat-related illness.
Temperature	Heatwave	Workers	Workers at risk from uncomfortable working conditions or heat-related illness and can cause disruption to work activity causing longer road closures and delays.
Temperature	Heatwave	Bridges/structures	Expansion joints may become damaged or fail if temperature exceedance threshold is passed.

Climate indicator	Climate hazard	Receptor	Risk
Temperature	Wildfires	Road surface End users	Damages to the road network, smoke can cause unsafe driving conditions.
Precipitation	Extreme rainfall	Road surface	Waterlogging of road surface due to increased percolation of water into the porous upper layers of the pavement surface, leading to weakened asphalt and formation of faults and potholes.
Precipitation	Extreme rainfall	Roadside	Waterlogging, saturation and excessive drying of slopes can affect their stability.
Precipitation	Extreme rainfall	End users	Decreased visibility can lead to unsafe driving conditions and increasing the likelihood of traffic accidents.
Precipitation	Extreme rainfall	Bridges/structures	Visible weathering of bridge structures.
Precipitation	Extreme precipitation	End users	Diminished surface grip leading to slippery road surfaces for users.
Precipitation	Flooding	Drainage	Overwhelming of drainage systems can lead to highway not draining properly and inundating the road.
Precipitation	Flooding	Drainage	Damage to structural integrity of drainage assets from an overwhelmed system.
Precipitation	Flooding	Drainage	Overwhelming of drainage system can lead to destabilisation of earthworks due to standing water.
Precipitation	Flooding	Road surface	Overwhelming of drainage can cause the road to flood.

Climate indicator	Climate hazard	Receptor	Risk
Precipitation	Flooding	End users	Road flooding can lead to road closures and disruptions to journeys.
Precipitation	Flooding	Road surface	Pavement rutting from water saturation can damage stability of granular foundation layers and lead to deformation.
Precipitation	Flooding	Bridges/structures	Structural deterioration and scouring of assets e.g. bridges.
Precipitation	Flooding	End users	Flooding of major rail lines can lead to increased road users, leading to more road congestion, resulting in delays to journey times.
Precipitation	Snow	End users	Customers driving through snowstorm or sleet events can experience decreased visibility leading to risk of accidents.
Precipitation **Wind**	Flooding Storm events	End users	Decrease output for UK businesses due to an increase in supply chain disruption and consequent loss of output as a result of extreme weather events.
Wind	Storm events	Signage Lighting and barriers	Power outages leading to communication failures and safety risks due to lack of signage. Addition risk of damage to charging infrastructure for electric vehicles.
Wind	Storm events	Workers	Increased occurrence of ‘force majeure’ enabling contractors to cease work without contractual penalty.
Wind	Extreme gusts	Road surface End users	Increased risk of debris obstructions in the road, including fallen trees, traffic signage, and subsequent road blockages and closures.

Climate indicator	Climate hazard	Receptor	Risk
Wind	Extreme gusts	Road surface	Lifespan of road surface can be shortened if asphalt is laid in windy conditions.
Wind	Extreme gusts	End users	Tall and exposed vehicles may turn over, vehicles toppled over by wind.
Wind	Extreme gusts	End users	High winds can be a risk to vehicles crossing bridges.
Sea/ocean	Sea level rise	Road surface	Road flooding and erosion
Sea/ocean	Sea level rise	Brides/structures	Structural deterioration and scouring of assets e.g. bridges.
Ground/solid mass	Subsidence	Road surface	Soil shrink-swell leading to failure of road.
Ground/solid-mass	Subsidence	Road surface	Uneven road surface, posing risks to vehicles and causing discomfort for drivers.
Ground/solid-mass	Subsidence	Road surface	Cracks and fracturs in road surfaces, affecting their stability.

Annex D: Glossary and abbreviations

The definitions referred to throughout this report have been developed for this guidance - some are based on UK Met Office and Intergovernmental Panel on Climate Change (IPCC) definitions.

Term	Definition
Absolute	Absolute values refer to the projected future climate conditions. E.g. "Summer maximum temperatures are projected to be 38 ˚C by 2100". See also “anomaly”.
Adaptive capacity	Adaptive capacity refers to the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Anomaly	Anomaly, in climate projections terms, refers to the change in a climate indicator compared to a baseline E.g. "Summer maximum temperatures are projected to be 3.5 ˚C warmer by 2100 compared to a baseline of 1981-2010". See also “absolute”.
Baseline	The state of the climate against which the change is measured. In other words, the baseline is the reference period (e.g., 1981-2000) that is used to assess the extent of change (anomaly) by the future time period (e.g., 2081-2100). The climate baseline provides a snapshot of the climate under which a system operates.
Cascading failures	One event or trend triggering others, where disruptions or failures caused by extreme weather event(s) cause a chain of impacts across multiple organisations and/or sectors.
CDF	In this context, a Cumulative Distribution Function (CDF) is a way to understand probability of a climate hazard of a certain magnitude or higher occurring. For example, a CDF graph can be examined to determine the probability that maximum temperatures meet or exceed 30°C during summers in the 2050s. The CDF differs from a PDF (see below) because the probability is

Term	Definition
	cumulative, and therefore considers probabilities up to a specified value, whereas a PDF only considers the probability of that specified value occurring.
CEDA	Centre for Environmental Data Analysis (which provides an online technical portal for accessing environmental data).
CCRA	Climate Change Risk Assessment presents the assessment of risks as a result of changes in climate.
Climate	Climate refers to the statistical description of weather over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often near-surface indicators such as temperature, precipitation, and wind. See also "weather".
Climate adaptation	Climate adaptation refers to the process of adjustment to actual or expected climate change and its effects. Adaptation seeks to reduce risks, moderate harm, and take advantage of beneficial opportunities from today's changed climate conditions, and to prepare for impacts from future changes.
Climate change	Climate change refers to long-term shifts in temperature and typical weather patterns, due to natural internal processes or external forces such as variations in solar cycles, volcanic eruptions, and persistent human-induced changes in the composition of the atmosphere or in land use.
Climate change scenario	A climate change scenario is a pathway to a future in which the climate is different from the present-day climate due to the effect of greenhouse gas emissions over time (contributing to global warming). There are globally recognised scenarios which are based on a set of assumptions about driving forces (such as demographic and socio-economic development, technological change, changes in energy and land use). The recommended climate change scenarios for UK climate change risk assessments are called the 'representative concentration pathways' (RCPs).
Climate hazard	Climate hazard refers to a weather or climate related event which has potential to impact people, assets or activities (receptors) and cause damage or a change in status such as damage, destruction, injury or a change in service provision. For example, increased winter precipitation could be a climate hazard.
Climate indicators	Otherwise known as climate variables, the Climate Risk Indicators web portal uses the term "climate indicators" to refer to available indicators from the climate projections – e.g. average temperature,

Term	Definition
	minimum temperature, maximum temperature, record-breaking weather, rainfall.
Climate projection	Climate projections describe the projected future values for climatic factors (such as temperature and rainfall) that could exist at a future point in time, for a given geographical location and for a chosen climate scenario. Climate projections are the output of climate models, which calculate possible future climate values based on a set of assumptions about how the climate will respond to future GHG emissions (which cause radiative forcing) into the future.
Consequence	Consequence refers to the extent to which a receptor is impacted, either positively or negatively by the climate hazard.
CRI	Climate Risk Indicators (CRI) is a project which provides information on future changes to indicators of climate risk across the UK. Research underpinning the data on this website was undertaken as part of the UK Climate Resilience Programme funded by UK Research and Innovation and the Met Office. It uses the UKCP18 climate projections produced by the Met Office.
Dependencies	In this context, dependencies refer to situations where systems or entities rely on each other to function.
Desiccation	In this context, desiccation refers to the drying out of topsoil resulting in extreme soil dryness and cracking, usually as a result of prolonged drought or water scarcity. Soil desiccation can lead to damage to surface or near-surface buried assets. Desiccated soil is also more susceptible to flash flooding during heavy rainfall.
Exposure	The presence of assets or activities (such as people; livelihoods; species or ecosystems; ecosystem services; infrastructure) in places and settings that could be adversely affected by climate hazards.
Fluvial flooding	Fluvial flooding occurs when the water level in a river, lake or stream rises and overflows onto the neighbouring land.
Groundwater flooding	Groundwater flooding occurs when water from beneath the ground (known as the water table) rises to the surface.
Heave	The movement of the ground upward, known as ground heave, is typically attributed to the swelling of clay soils, which expand when moist. The exposed upper surface of the ground increases as a result. Changes in the water table and resultant changes in soil

Term	Definition
	moisture can cause soils to shrink and swell and result in risks associated with heave such as damage to foundations.
Interdependencies	Interdependent risks occur where systems depend on each other to function. In the context of climate risk, interdependency risks refer to risks that assets or activities are impacted not directly due to climate hazards, but due to failures or damage to assets or services they depend upon (see also 'cascading failures'). For example, storm events may lead to loss of power at ports and lead to downtime, even though port-owned assets and may be resilient to the storm.
IPCC	Intergovernmental Panel on Climate Change.
IPCC AR5	The Intergovernmental Panel on Climate Change's Fifth Assessment Report which provides a comprehensive assessment of the state of global knowledge on climate change.
Karstification / subsidence	The process of dissolution of rock (usually limestone) due to surface or groundwater. Karstification can result in cave formation and sink holes or areas of ground subsidence, which are hollows that result of collapsed or shrinkage of underlying rock layer.
Likelihood	Likelihood relates to the probability that a given event will occur during the lifetime of the assessment. For a CCRA, likelihood may differ depending on the time period or climate scenario which is selected.
Ocean acidification	Ocean acidification refers to a decrease in the pH of the ocean over an extended period of time, which is primarily due to uptake of carbon dioxide from the atmosphere.
PDF	In this context, a Probability Distribution Function (PDF) is a way to understand probability of a climate hazard of a certain magnitude occurring. For example, a PDF graph can be examined to determine the probability that maximum temperatures are 30°C during summers in the 2050s. The PDF differs from a CDF because it considers only the probability of a specified value occurring, whereas a CDF considers the probability up to a specified value occurring.
Pluvial flooding	Pluvial flooding, also known as surface water flooding, occurs when the ground becomes oversaturated, or drainage systems overflow, preventing excess water from being absorbed or drained away.

Term	Definition
PPCE	Probabilistic Projections for Climate Extremes (a UKCP18 product).
PP2018	Probabilistic projections 2018 (a UKCP18 product).
Receptor	Receptor refers to a person, physical object or asset, business, or system which has the potential to be impacted by a climate hazard.
Representative Concentration Pathways (RCPs)	Representative Concentration Pathways (RCPs) are climate scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) and used by the UKCP18 climate projections.
Resilience	Resilience refers to the capacity of social, economic, or environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation.
Return period	In this context, a return period represents the average time or estimated average time between the occurrence of specific events (such as floods, or heatwave events). It can be based on model data of the past or future or on historical data.
Risk	Risk is the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. Within this guidance, risk is scored as a combination of consequence and likelihood.
Saline intrusion	Saline intrusion refers to the movement of saline water (which contains higher levels of dissolved salts and minerals) into an area that is not normally exposed to high salinity levels.
System	System refers to a set of interrelated or interacting elements. For example, the system of an operating airport will comprise various interrelated elements including but not limited to terminal operations, air traffic control, electricity and water supplies.
Transition risks	Transition risks are risks associated with the transition to a low-emission economy. For example, in the case of transition to zero emissions vehicles, transition risks include availability of technology, supply chain
UKCP18	The UK Climate Change Projections 2018 are the family of climate observations, projections and guidance whose release begain in 2018.

Term	Definition
Vulnerability	Vulnerability refers to the propensity or predisposition of a receptor to be adversely affected by climate change.
Weather	Weather is the atmospheric conditions (such as temperature, wind, cloud cover, and rain) that are experienced at a particular time and place. See also 'climate'.

Annex E: References

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