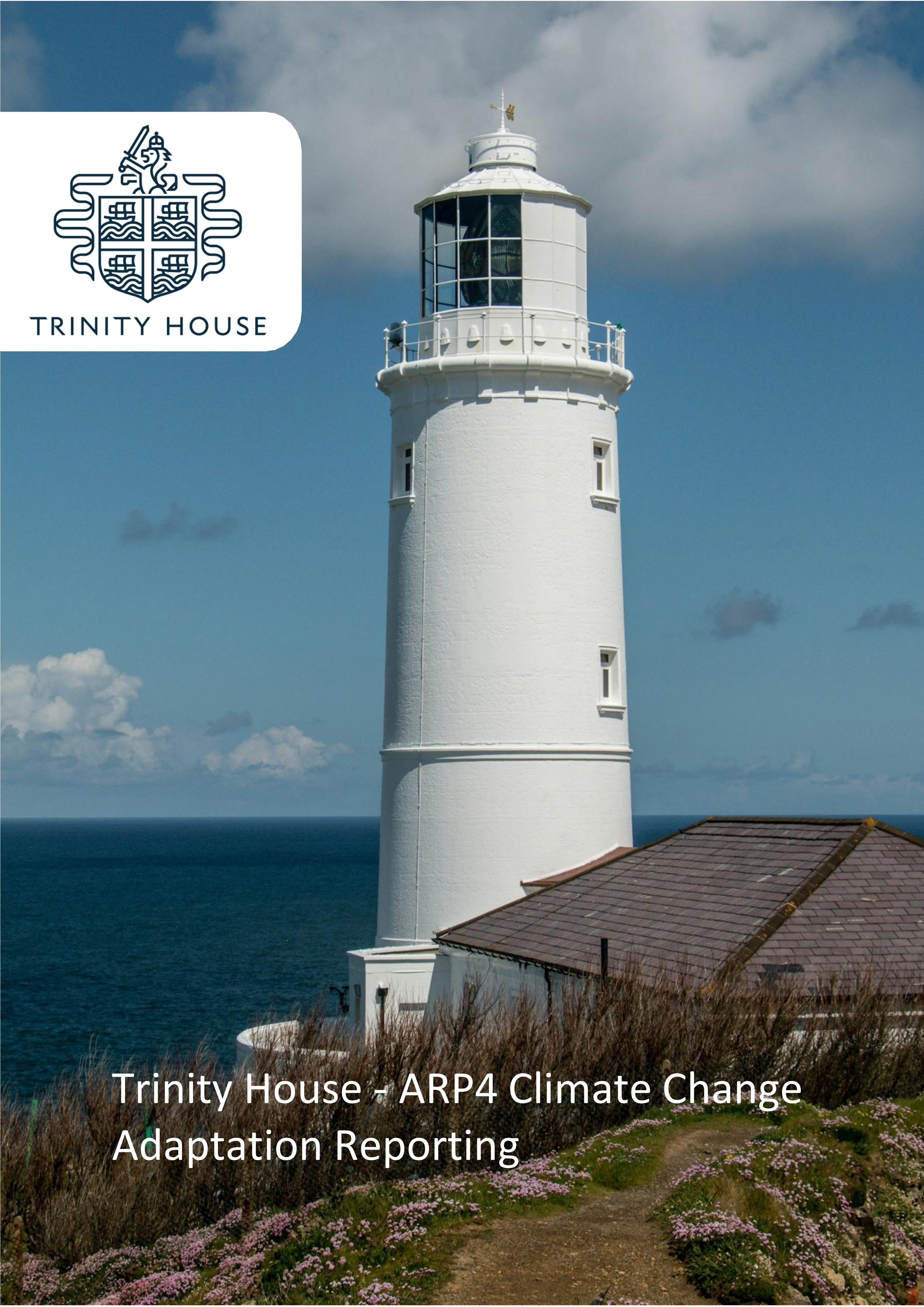

TRINITY HOUSE

Trinity House - ARP4 Climate Change Adaptation Reporting

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Citation: Trinity House**,** Anderson, B., Ffoulkes, C., Oliver, H., Rushnaiwala, F., and McArthur, A. (2024)

1 EXECUTIVE SUMMARY

Reporting

This is the fourth submission Trinity House has made to the Department for the Environment, Food and Rural Affairs (Defra) under the Adaptation Reporting Power (ARP) of the UK Climate Change Act (2008). This round of reporting affords Trinity House (TH) an opportunity to align our adaptation plans with the latest UKCP18 climate projections and take a broader view of the interdependencies between emerging climate risks.

The scope of assessment covers TH's assets, operations and staff across the United Kingdom and the Channel Islands. This report and action plan provides insight into the risks and opportunities facing TH and the work both planned and underway to build resilience.

This report is voluntary, and while it provides TH with a very valuable snapshot of adaptation options and management frameworks, the primary reason for the report is to expand the available evidence-base within Government. This evidence can be considered within the National Climate Change Risk Assessment that seeks to assess the level of preparedness of critical infrastructure across the UK.

Projections

The previous TH ARP3 report was predicated on only the RCP8.5 worst case scenario, aligned with global warming of 4˚C+ by the end of the century. For ARP4, two scenarios have been considered: a mid- level scenario aligned with a 2˚C warming scenario, and the high RCP8.5, in line with DEFRA best practice guidance.

Projected climate change trends for the UK show a move towards warmer and wetter winters, and hotter and drier summers, with increasing intensity and frequency of extreme weather events, and sea level change.

The risk of coastal flooding in the UK is expected to increase over the 21st century and beyond due to a growth in the frequency and in the magnitude of extreme water levels. These levels are expected to predominantly result from the effects of time-mean sea level rise[1], rather than changes in atmospheric storminess. Changes in the volume of water may also lead to changes in tidal characteristics.

Impacts

TH's assets (that include vessels at sea and offices/depots ashore) are situated in locations across England and Wales. This wide distribution of sites and operating environments increases the exposure of TH to climate risks. Many sites are in remote locations and so are exposed to a greater number of risks. Similarly, due to the nature and often remote location of the sites there is a high reliance on multiple infrastructures such as various routes of transportation. These sectoral interdependencies, including TH's reliance on communications networks and utilities provision to service these remote locations further increases the exposure of assets and infrastructure to cascading or interacting climate risks.

Risk Assessment

Underpinning this report is a climate change risk and opportunity assessment that has considered the impacts, both positive (opportunities) and threats (risks), on TH's assets, operations and staff. The impacts have been considered under five broad themes, aligned to climate hazards:

- Sea Level Change
- Temperature Change
- Precipitation Change

[1] Projected mean sea level measured over a given period.

- Storm Events
- Multiple Climate Variables

Each hazard was quantified for both the 2˚C + aligned (RCP2.6) and the 4˚C+ (RCP8.5) scenarios to provide a risk score for each of the time horizons of focus (2025, 2050s and 2080s).

Using a precautionary approach, the resulting assessments indicate that under the 4˚C+ scenario for global warming, and without new adaptation measures, the proportion risks that will change from major to severe for TH will increase from 12% in 2025 to 29% in the 2050s; and rise to 61% of all risks in the 2080s.

Adaptation Planning

TH's understanding of the most significant climate-related risks has developed over the previous reporting periods as more data becomes available. TH has incorporated these challenges within risk management processes and this process of assessment and review which continues with each annual review.

Adaptation capacity improvements continue through ongoing discussions with key stakeholders and the General Lighthouse Authorities (GLAs) of the United Kingdom and Ireland with which TH work collaboratively, sharing best practice and resources to increase their resilience to these changes. For example, as part of ARP4 reporting, TH and consultants RSK set up a maritime working group so that similar reporting organisations could share their learnings and best practice.

Our work on ARP4 has tracked multiple existing actions to reduce vulnerability and improve resilience alongside a shortlist of potential actions for the highest risk short to medium term impacts.

Key Findings

- The climate change risk assessment found that the inherent risk to TH from a changing climate is expected to result in increasingly severe and costly impacts. The risk severity of the hazards is expected to become more pronounced in the latter part of the century and increase under greater levels of global warming, as illustrated by Figure 5.

- The assessment indicates that under 4˚C+ of global warming (RCP8.5), and without new adaptation measures, the proportion of major and severe risks to TH will increase from 12% in 2025 to 29% in the 2050s; and rise to 61% of all risks in the 2080s. Under the 2˚C aligned scenario in the 2080s 37% of risks to TH are expected to be major or severe.
- Key risks remain to building structure and staff health from extreme heat and storm events, whilst some offices and facilities (in particular in Harwich) are exposed to flood risk.
- Improved mapping of our interdependencies and interactions with other key service providers will lead to improved resilience planning.
- A clear plan to improve data collection and understanding of risk, particularly around engineering and asset management is being developed.

2 INTRODUCTION

2.1 Trinity House

TH is a charity dedicated to safeguarding shipping and seafarers, providing education, support, and welfare to the seafaring community with a statutory duty as a General Lighthouse Authority (GLA) to deliver a reliable, efficient, and cost-effective aids to navigation service for the benefit and safety of all mariners. This report has been commissioned by TH in its capacity as a GLA and does not apply to TH in its capacity as a charity, nor any of its charitable estates.

The Corporation of Trinity House was incorporated by Royal Charter in 1514 to regulate pilotage on the River Thames and provide for aged mariners. With a mandate that has expanded considerably since then, TH is now the UK’s largest-endowed maritime charity and the GLA for England, Wales, the Channel Islands and Gibraltar.

TH has responsibility, subject to certain provisions, for the superintendence and management of “all lighthouses, buoys and beacons” throughout its geographical area. It provides many traditional short-range Aids to Navigation (AtoN) complemented by a mix of radio navigation aids for the safety of all mariners engaged in general navigation. The funding source for the GLA role is a hypothecated tax, levied on certain types of vessels using ports in England and Wales. As a result, TH operates at no expense to UK taxpayers. The statutory authority for TH in terms of AtoN is Part VIII of the Merchant Shipping Act (MSA) 1995 as amended by the Marine Navigation Act 2013 and other statutes. There is a separate GLA for Scotland & the Isle of Man (the Northern Lighthouse Board) and another for the geographical island of Ireland (the Commissioners of Irish Lights).

2.2 Trinity House’s Assets

Lighthouses and Light Vessels

TH maintains 64 lighthouses and beacons around England, Wales, and the Channel Islands, and Gibraltar, illustrated in Figure 1 (excluding Gibraltar). A full list of the lighthouses can be found in Appendix A – TH AtoN range from isolated offshore towers exposed to the open sea to shore-based stations with a range of ancillary cottages, boat landings, helipads, visitor centres, hazard warning signals and outbuildings sited in some of the nation's most beautiful locations.

Floating AtoN

TH also maintains 7 lightvessels and some 450 buoys which are designed in accordance with IALA Buoyage System. These buoys include:

- Cardinal marks
- Lateral marks
- Emergency Wreck Marking buoys
- Isolated danger marks

- Safe water marks
- Special marks

Buoys can be either lighted or unlighted. Some include audible warnings, some are augmented with AIS or RACON and some are remotely monitored from an operations centre in the main operational office in Harwich.

Depots and Offices

- Trinity House Head Office, Tower Hill, London, EC3N 4DH.
- Trinity House, Operations Centre, The Quay, Harwich, Essex, CO12 3JW (Main office and buoy yard).
- Trinity House, Kings Dock, Swansea, SA1 8QT (Office space and buoy yard).
- Trinity House, Land's End Airport, Kelynack, St Just, Penzance, TR19 7RL.

TH are also responsible for a number of smaller sites/storage facilities such as Holy Island Stores, Seahouses and Penlee Point.

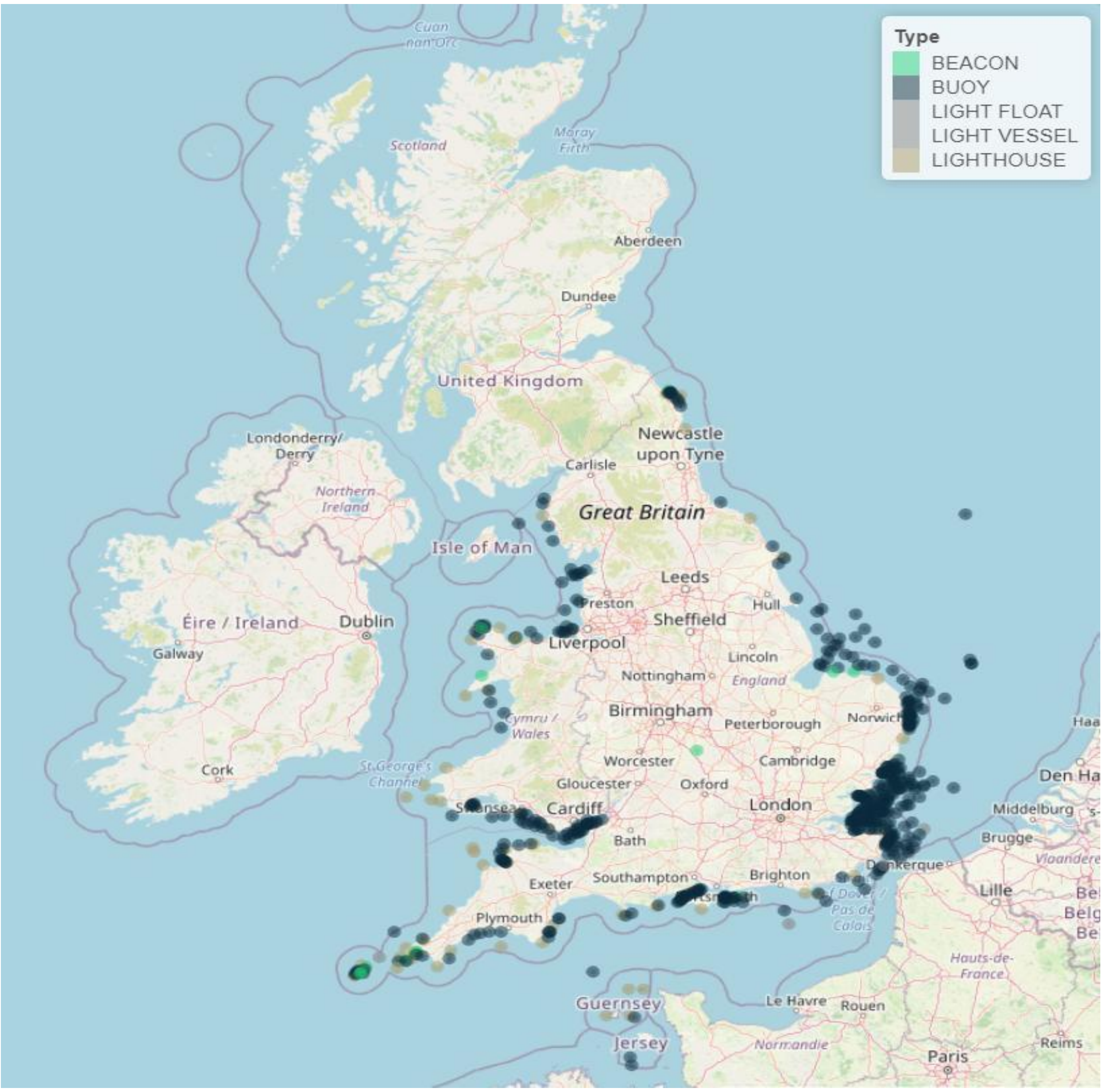


Figure 1. Distribution of TH's assets in the British Isles

2.2.1 Adaptation Reporting Power Aims [2]

TH has embedded climate change adaptation into its operations through its 20-year asset plan which informs its overall Engineering Strategy.

The Strategy is informed by through-life management of all assets, principally through the capture of issues in the Risk and Opportunity Register for each asset. Careful analysis of the risks and opportunities identified provides a clear framework for identifying and prioritising the required investment and work over the next 5 and 20 years. ARP4 affords TH the opportunity to align its adaptation plans with the latest UKCP18 climate projections and take a broader view of the interdependencies between emerging climate risks. To support this, TH has elected to extend its reporting beyond the United Kingdom to include our assets in the Channel Islands. TH assets in Gibraltar are not covered under this reporting as these are not covered by UKCP18.

By delivering these aims TH will be able to contribute to the government's Climate Change Risk Assessment.

[2] Under the Climate Change Act 2008, the Secretary of State has the power to direct reporting authorities like TH to produce reports on measures undertaken to adapt to climate change

3 CLIMATE CHANGE RISK ASSESSMENT

3.1 Approach to risk assessment

The UK Climate Projections (UKCP) provide a current assessment of how the UK climate may change in the future. The latest set of projections, which were released by the Met Office in 2018 (UKCP18), were used in this analysis, in keeping with TH's ARP3 report. Further methodological updates were made in 2022 to improve the consistency of variables within the UKCP18 projections, resulting in some modifications to the data used in this report compared with ARP3. The climate data used for the risk assessment is outlined in Table 1.

UKCP18 uses new and updated emissions scenarios based upon those used in the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (AR5). These representative concentration pathways (RCPs) specify greenhouse gas (GHG) concentrations that would result in target amounts of radiative forcing at the top of the atmosphere by 2100, relative to pre-industrial levels.[3] Four RCPs are used in UKCP18: RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (the numbers denote radiative forcing levels in W/m^2).

ARP3 focused on just the RCP8.5 worst case scenario. For ARP4, two scenarios have been used in line with Defra best practice guidance. These are a 2˚C aligned scenario (RCP2.6) and a 4˚C+ aligned scenario (RCP8.5). RCP2.6 represents strong reductions in global greenhouse gas emissions whilst RCP8.5 depicts a scenario where global emissions remain high and grow unmitigated. The more conservative RCP2.6 was included in this assessment to illustrate the avoided impacts associated with emission reductions compared to the impacts from continued high emissions.

Table 1. Climate data used for the assessment

		Land Projections	Marine Projections	
Dataset:		2018 UK Climate Projections (UKCP18)		
Collection:		Land projections: probabilistic	Marine projections	
Product:		Plot: Plume of time series anomalies for probabilistic projections (25km) over UK, 1961-2100	Plot: Plume of time series anomalies for marine projections around UK coastline, 2007-2100	Data: Future extreme sea levels around the UK coastline using standard method, 2020-2100
Percentiles:		5th, 50th and 95th percentiles	5th, 50th and 95th percentiles	5th, 70th and 95th percentiles
RCP:		RCP2.6 and RCP8.5	RCP2.6 and RCP8.5	RCP2.6 and RCP8.5
Baseline:		1981 - 2000	1981 - 2000	Present day extremes
Time horizons	**Short:**	2025 (2015-2035)	2025 (2010-2040)	2030
	Medium:	2050s (2040-2060)	2050s (2035-2065)	2050
	Long:	2080s (2070-2090)	2080s (2065-2095)	2080 and 2100

<u>Strategic locations used to assess climate data</u>

Asset-level risk assessments are being conducted within TH and it is anticipated that this information will be available for ARP5.

[3] Radiative forcing occurs when the amount of energy entering the atmosphere is different from the amount that leaves, if more enters than leaves then the atmosphere will warm. This is observed today as Global Warming.

Five locations were chosen across five representative areas (North East England, South West England, South East England, North Wales, and the Channel Islands) to provide insight into the range of climate projections that might be expected. UKCP18 climate projections were then used to provide an assessment of climate risk that was representative of the assets within these geographical locations. The land-based locations use the associated UKCP18 25km grid cells, and their corresponding marine-based locations use the relevant UKCP18 12km grid cells.

Uncertainty within model projections

As with all climate models, there are inherent limitations to the models used. In particular, the estimated ranges for future climate variability are conditional on a number of assumptions with expert judgement playing a role in the various methodological and data choices.

Identification of hazards

Hazards were identified and documented in a risk register, including both negative (hazards) and positive (opportunities) impacts. The risk register included hazards reported by TH in previous reporting rounds (ARP1, ARP2 and ARP3). These were supplemented with a new analysis that identified key risks identified by other organisations in the sector (e.g., the Northern Lighthouse Board, and port authorities) and new risks identified through a series of stakeholder workshops (i.e. TH experts).

Evaluation of risk

The potential magnitude of impact and likelihood of occurrence were evaluated for each hazard using a risk matrix (Table 2) to provide a significance score from very low [1] to very high [5]. These scores were then multiplied to provide a risk significance rating (Negligible, Minor, Moderate, Major, Severe). The details of each risk and their subsequent significance rating are included in the risk register (Chapter 3 – Trinity House Climate Risk Register). The opportunities were not scored, as these were considered negligible relative to the risks posed but are instead acknowledged within this report.

3.2 Risk Matrix

The scoring system for the quantification of risk used in this assessment is outlined in Table 2.

Table 2. Risk matrix used for quantifying the risk of hazards.

Risk Rating = Likelihood of occurrence * Magnitude of the impact

Likelihood description	Likelihood	Very Low 1	Low 2	Medium 3	High 4	Very High 5
• Very likely to occur within 1 year or more than 80% chance of occurrence. • Has occurred within last 1 to 2 years.	**Very High** (Almost Certain) **5**	Moderate (5)	Moderate (10)	Major (15)	Severe (20)	Severe (25)
• Likely to occur every 1 to 2 years or 50% to 80% chance of occurrence. • Potential of it occurring within 5 years. • Has occurred.	**High** (Likely) **4**	Minor (4)	Moderate (8)	Major (12)	Major (16)	Severe (20)
• Possibility of occurrence in 10-year period or 20% to 50% chance of occurrence. • Has occurred, to varying degrees, within last 10 years • History of some occurrence.	**Medium** (Possible) **3**	Minor (3)	Moderate (6)	Moderate (9)	Major (12)	Major (15)
• Unlikely to occur in a 10-year period or 10% to 20% chance of occurrence. • Has not occurred in last 10 years • Low history of occurrence.	**Low** (Unlikely) **2**	Negligible (2)	Minor (4)	Moderate (6)	Moderate (8)	Moderate (10)
• Highly unlikely to occur in a 20-year period or less than 10% chance of occurrence. • Has not occurred • Occurrence more than 20 years ago.	**Very Low** (Highly Unlikely) **1**	Negligible (1)	Negligible (2)	Minor (3)	Minor (4)	Moderate (5)

Magnitude

Very Low (minimal) **1**	**Low** (Minor) **2**	**Medium** (moderate) **3**	**High** (Major) **4**	**Very High** (Catastrophic) **5**
• Financial impact on TH/GLF likely to be below £50K. • Very low (if any) impact on TH strategic plans and delivery of operational services. • Little (if any) stakeholder concern/impact. • Excellent prospect of defensibility of realisation of risk. • Reinstatement to pre-risk condition very likely to be achieved. • Very low impact on health of TH staff (office based and operational).	• Financial impact of TH/GLF likely to be in the region of £50K to £250K. • Low impact on TH strategic plans and delivery of operational services. • Low stakeholder impact/concern. • Defensibility of realisation of risk likely. • Reinstatement to pre-risk condition likely to be achieved with the minimum commitment of resources. • Low impact on health of TH staff (office based and operational).	• Financial impact on TH/GLF likely to be in region of £250K to £1M. • Moderate impact on TH strategic plans and delivery of operational services. • Moderate stakeholder impact/concern. • Some defensibility of realisation of risk probable. • Reinstatement to pre-risk condition possible with the commitment of a moderate level of resources. • Moderate impact on health of TH staff (office based and operational).	• Financial impact on TH/GLF likely to be in region of £1M to £5M. • Significant impact on TH strategic plans and delivery of operational services. • Significant political and stakeholder concern. • Low defensibility of realisation of risk. • Reinstatement to pre-risk condition requiring commitment of a high level of resources. • High impact on health of TH staff (office based and operational).	• Financial impact on TH/GLF likely to exceed £5M. • Major impact on TH strategic plans and delivery of operational services. • Major political and stakeholder concern. • Very low defensibility of realisation of risk. • Reinstatement to pre-risk condition extremely difficult requiring. considerable resources and possible additional sanction from DfT. • Very high impact on health of TH staff (office based and operational).

3.3 Observed climate in the UK

3.3.1 Typical climate conditions

Due to its location on the eastern edge of the Atlantic Ocean and the proximity of the warming North Atlantic Drift Ocean current, the UK and Channel Islands experience a temperate climate with considerable day-to-day variability in weather conditions; caused by changes to wind direction, air mass and the relative position of the polar jet stream.

Local weather and climatic conditions within the UK are influenced by topography and land use.

Key meteorological data and climate statistics for the period 1981-2010, were assessed for the five representative locations used in this assessment. This period was used to indicate the climate in the 30-year period (i.e. 1995) preceding the first set of projections used in the assessment for 2025 (i.e. 2011-2040. Observed climate conditions from the closest Met Office climate station for each of the five locations are summarised in Figure 2.

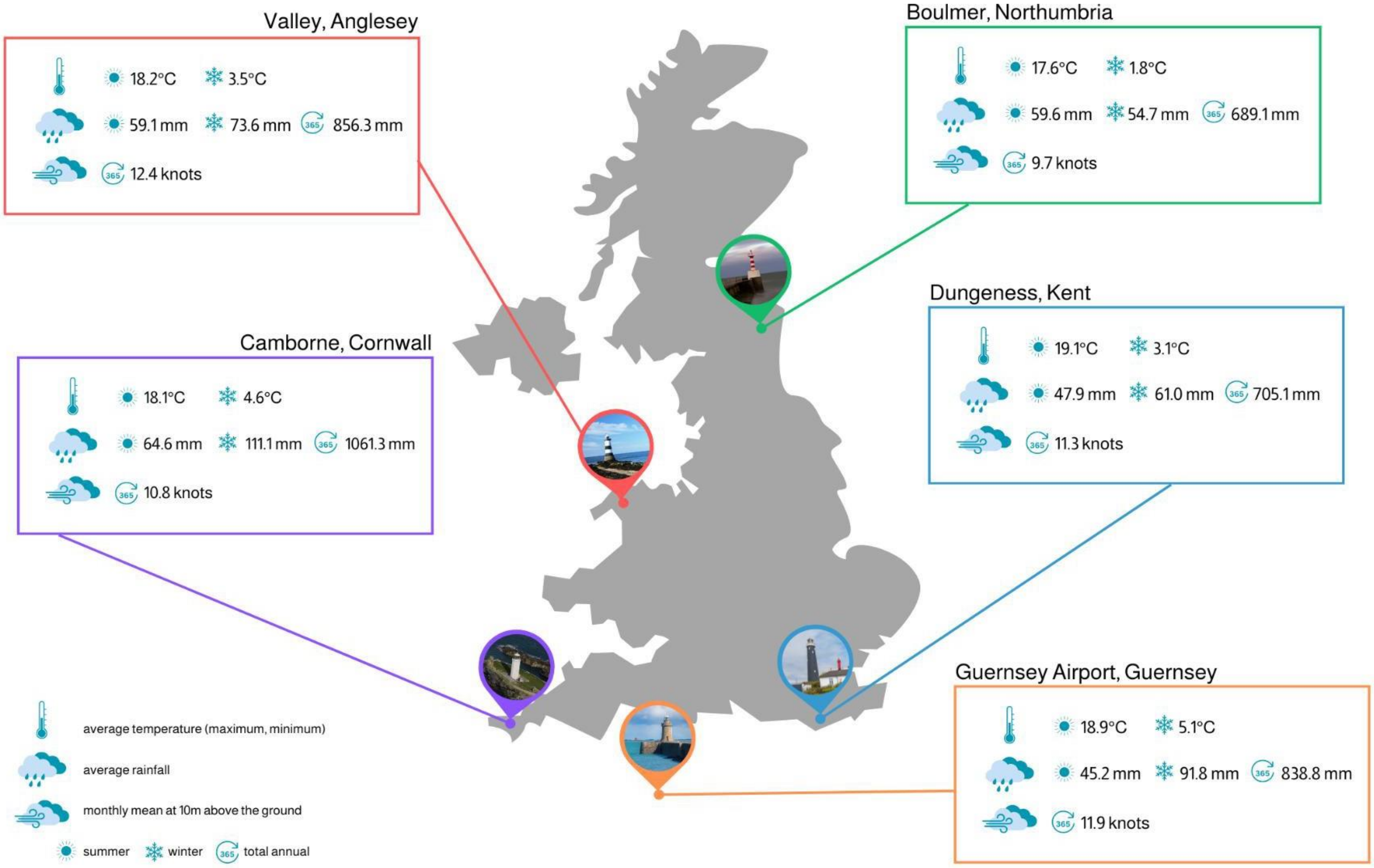


Figure 2. Summary of the observed climate at five locations around England, Wales and the Channel Islands for core climate variables between 1981 and 2010. Variables shown are average maximum summer temperature (°C) and average minimum winter temperature (°C); average total rainfall in summer (June, July, August), winter (December, January, February) and annually (mm); and monthly mean wind speed at 10m above the ground (knots). Data source: Met Office.

3.3.2 Extreme weather events

Extreme weather hazards experienced in the UK are typically associated with acute events such as short periods of heavy rainfall and localised flooding, storms and high winds, extreme hot temperatures and associated heat stress, and periods of low rainfall associated with drought. These events are expected to continue occurring in the future and are projected to increase in frequency and intensity as our climate continues to warm.

The UK has always experienced extreme weather events, however, in recent years these have become more frequent and more intense, as shown in the State of the UK Climate reports. Figure 3 shows a timeline of record weather events and incidences of weather-related damage to lighthouses and TH assets.

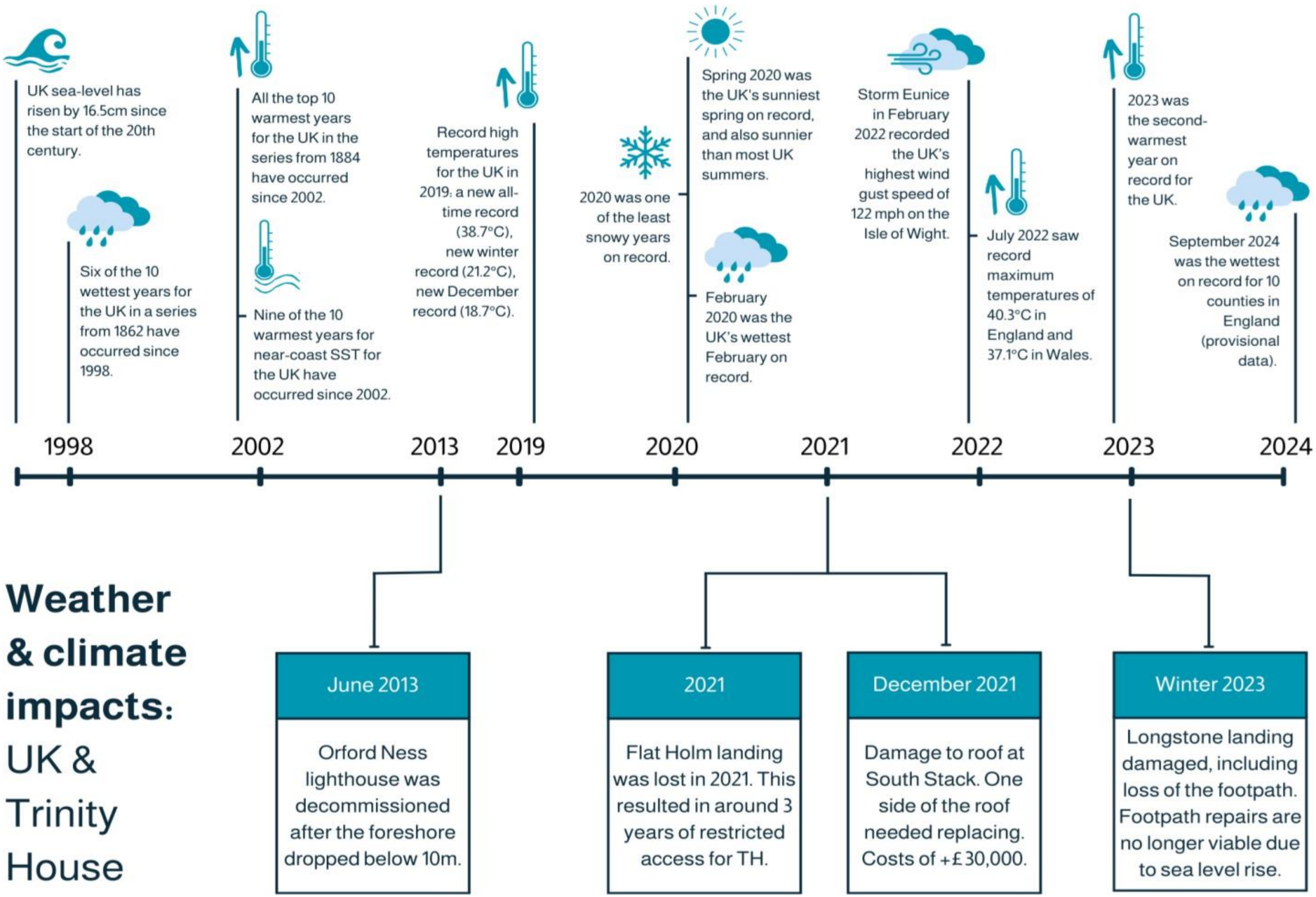


Figure 3. Timeline of key climate and weather records in the UK above and examples of weather-related events affecting TH assets below.

3.4 Climate Projections for the UK

The 2018 UK Climate Projections (UKCP18) provide the most up-to-date assessment of how the UK climate may change in the future. UKCP18 headline projections for the UK are outlined in sections 2.4.1 (land projections) and 2.4.2 (marine projections).

3.4.1 Land projections for the UK

Over land, the projected general climate change trends in the 21st century show a move towards warmer and wetter winters, and hotter and drier summers. However, natural variations mean that some cold winters, some dry winters, some cool summers, and some wet summers will still occur.

By 2080 in the UK, under the RCP8.5 high emission scenario, the central (and low and high estimates corresponding to 5% and 95% probability levels) show:

- A temperature change of 2.4°C (-0.4°C to 6.3°C) – becoming increasingly warmer – in winter; and 3.6°C (0.2°C to 6.1°C) – increasingly hotter – in summer.
- For precipitation, corresponding changes of UK average rainfall are +19.5% (-37.3% to +98.9%) – increasingly wetter – for winter; and -34.3% (-85.9% to +74.4%) – increasingly drier – for summer.
- Hot summers are expected to become more common. For example, in the recent past (1981-2000) the probability of seeing a summer as hot as 2018 was less than 10%. The probability has already increased due to climate change and is now estimated to be between 10-15%.[4] With future warming, hot summers by mid-century could become as common as once in every two years.

3.4.2 Marine projections for the UK

UK coastal flood risk is expected to increase over the 21st century and beyond, resulting in both an increase in the frequency and magnitude of extreme water levels around the UK coastline. This increased future flood risk will be dominated by the effects of time-mean sea level rise, rather than changes in atmospheric storminess associated with extreme coastal sea level events. There may also be changes in tidal characteristics.

21st century projections of time-mean sea level change around the UK vary substantially by emissions scenario and geographic location. Sea level change in 2080 under RCP8.5, relative to the 1981-2000 baseline, is estimated at 0.40 to 0.80m in Kent, Guernsey and Cornwall, with smaller increases expected in the north; 0.30 to 0.70m around Alnwick and Anglesey.

Projections of average wave height in the 21st century suggest changes in the order 10-20% and a general tendency towards lower wave heights. Extreme wave height is projected to change by +/- 1m (20%), however uncertainty in these models is high. [5] Raw projection data from UKCP18 indicates that future extreme sea levels will increase with time and emissions, with greater increases in extreme sea levels later into the 21st century under the higher emissions scenario.

[4] Met Office (2020). Available at: https://www.metoffice.gov.uk/research/news/2020/what-are-the-chances-of-another-hot-summer-like-2018 [Accessed 18/10/2024]

[5] UKCP18 Science Overview report (2018). Available at: https://www.abpmer.co.uk/blog/ukcp18-five-key-points-from-a-coastal-perspective/ [Accessed 18/10/2024]

3.4.3 Local projections

Local climate projections were extracted for the five sites of focus in this risk assessment. Figure 4 outlines the summary data for these locations. The data provided shows the 50th percentile (central) estimates and the 5th (lower) and 95th percentile (upper) estimates.

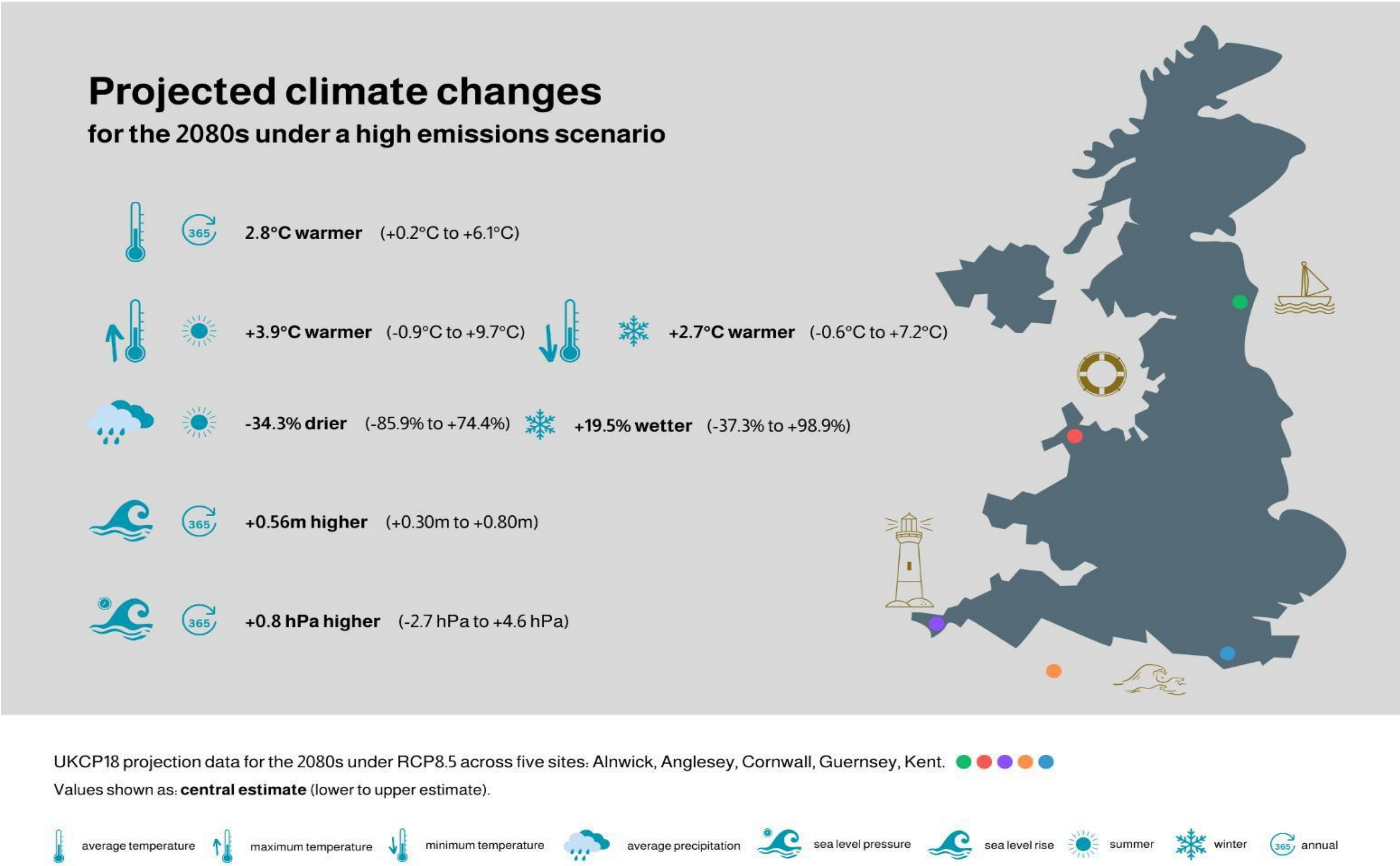


Figure 4. Summary of projected climate for the five locations in England and Wales in the 2080s under RCP8.5.

Climate projections were also assessed for the four TH offices, as shown in Table 3.

Table 3. Summary of key climate projections for TH offices under a high emissions scenario (4°C by 2100) (Met Office data).

	London	Harwich	Swansea	St. Just
Hottest summer day (°C)	42.6	40.8	38.3	33.3
Warmest winter day (°C)	21.7	20.4	18.8	17.7
Wettest summer day (mm)	52	57	76	69
Wettest winter day (mm)	51	43	85	57

Whilst hotter days are likely to become more frequent and/or intense, current adaptation measures (i.e. air conditioning) will mitigate the impacts of extreme heat for 87% of the office-based workforce (255 out of 293), as outlined in Table 4.

Table 4. Staff based in offices and status of air conditioning availability

	London	Harwich	Swansea	St. Just
Number of staff	32	155	26	11
Is the office air conditioned?	Yes	Yes	No	No

The long-term flood risk for each office has been indicated using the Environment Agency ‘Check the long-term flood risk for an area in England’ service, which provides an estimation of flood risk from different flood types, as shown in Table 5. These ratings provide a broad indication of the area’s flood risk, produced using modelling to assess an area’s long term flood risk. Flood risk from sources such as blocked drains and burst pipes are not included in the modelling. The Environment Agency do not state as to whether the models account for climate projections, or if they do, which emission scenarios.

Table 5. Summary of yearly flood risk levels (Environment Agency data). Other flood risks in the EA data cover flooding from groundwater and reservoirs. Flood risk rating system: 'High' means more than 3.3% chance of a flood each year. 'Medium' means between 1% and 3.3% chance of a flood each year. 'Low' means between 0.1% and 1% chance of a flood each year. 'Very low' means less than 0.1% chance of a flood each year.

	London	Harwich	Swansea	St. Just
Risk of surface water flooding	Very low	Low	Very low	Very low
Risk of river flooding	Very low	Low	Very low	Very low
Risk of sea flooding	Very low	Low	Low	Very low

	London	Harwich	Swansea	St. Just
Other flood risks	Unlikely	Unlikely	N/A	Unlikely

TH is also associated with a number of other services provided, including six visitor centres, and twelve sites with holiday cottages. These assets have not been included within this round of reporting, but it is recommended that these are considered further within ARP5 reporting. The assets associated with these services include:

Lighthouse visitor centres at:

- Portland Bill Lighthouse
- Flamborough Head Lighthouse
- South Stack Lighthouse
- Southwold Lighthouse
- Longstone Lighthouse
- Start Point Lighthouse

Sites/stations with cottages (amenity dwellings, holidays cottages, and assured shorthold tenancies (AST) included):

- Alderney – 1 AST
- Anvil Point – 2 holiday cottages
- Bull Point – 4 holiday cottages
- Cromer – 1 AST, 2 holiday cottages
- Flamborough – 2 AST, 1 amenity dwelling
- Harwich – 4 AST
- Lizard – 1 AST, 6 holiday cottages
- Lowestoft – 2 AST
- Nash Point – 2 AST, 2 holiday cottages
- North Foreland – 2 holiday cottages
- Pendeen – 2 AST, 2 holiday cottages
- Portland Bill – 1 amenity dwelling
- Sark – 1 AST
- Start Point – 2 holiday cottages
- St. Anthony – 1 holiday cottage
- St. Catherines – 1 AST, 3 holiday cottages
- Trevose Head – 4 holiday cottages
- Whitby – 2 holiday cottages

4 TRINITY HOUSE CLIMATE RISK REGISTER

4.1 Vulnerability

Climate vulnerability considers the exposure; sensitivity of a system, asset or related populations to climate risks; and their capacity to adapt to these risks. Climate vulnerability describes the degree to which natural, built and human systems are at risk of exposure to climate change impacts. Vulnerability to risks will vary between assets (and systems and populations) depending on various factors. An assets exposure and sensitivity to climate risks influence their vulnerability, as does adaptive capacity. The higher a system's adaptive capacity, the lower its vulnerability.

Whilst a detailed vulnerability assessment of TH was not undertaken as part of this ARP4 assessment, a high-level assessment was undertaken to provide useful consideration and context when assessing TH's climate risk.

Sensitivity

TH's assets include lighthouses and beacons, lightvessels and ships, buoys, and four main offices. Whilst lighthouses are highly exposed to coastal changes such as sea level rise, coastal flooding and erosion, and these risks are projected to increase with climate change, they are inherently robust structures designed to withstand severe weather. Beacons are similarly resilient structures, used largely in nearshore, low-lying areas where foundations for a lighthouse would be unsuitable and non-cost effective. A beacon is more likely to be affected by collisions from ships than weather or climate related stresses. Therefore, lighthouses and beacons are considered to have a lower sensitivity to some hazards compared with many conventional buildings. Table 6 provides a high-level indication of the sensitivity of assets to various hazards.

Table 6. Sensitivity of TH's assets to climate hazards

Hazard	Lighthouses / Beacons	Lightvessels / Ships	Buoys	Offices
Extreme heat	Medium	Low	Very low	High
Extreme cold	Low	Low	Medium	Low
Low rainfall / drought	Low	Very low	Very low	Low
High rainfall / flooding	Medium	Very low	Very low	High
Storms / wind / lightning	Medium	High	Very high	Medium
Storm surge / coastal flooding	Medium	High	Very high	High
Sea level rise	Very high	Low	Medium	High
Coastal erosion	High	Low	Low	High
Wildfire	Low	Very low	Very low	Medium

Exposure

TH's operational sites, AtoN, buoy yards and offices are situated in locations across England and Wales. This wide distribution of sites increases the exposure of TH to climate risks. Many sites are in remote locations and so are exposed to a greater number of risks.

Similarly, due to the nature and often remote location of the sites there is a high reliance on multiple infrastructures. These sectoral interdependencies further increase the exposure of assets to cascading or interacting climate risks. The main risks to TH offices are the impacts on building structure and staff health from extreme heat and storm events, whilst some, including the office and buoy yard in Harwich, are also exposed to flood risk. Table 7 provides a high-level indication of the exposure of assets to various hazards.

Table 7. Exposure of TH's assets to climate hazards

EXPOSURE of assets	Lighthouses / Beacons	Lightvessels / Ships	Buoys	Offices
Extreme heat	High	High	High	Very high
Extreme cold	High	Medium	Medium	High
Low rainfall / drought	Medium	Very low	Very low	Medium
High rainfall / flooding	Medium	Very low	Very low	Medium
Storms / wind / lightning	Very high	Very high	Very high	Very high
Storm surge / coastal flooding	High	High	Very high	Low
Sea level rise	High	Low	Very high	Low
Coastal erosion	Very high	Low	Medium	High
Wildfire	Low	Very low	Very low	Medium

Adaptive capacity

Adaptive capacity (AC) refers to the ability of TH to adjust to climate change and its effects, and to reduce the potential for harm (e.g. to people, assets and operations) while taking advantage of opportunities. Table 8 provides a high-level assessment of the adaptive capacity of TH across different criteria.

Table 8. High-level adaptive capacity assessment for TH

Criteria	AC score	Comment
Governance	High	The Corporation of Trinity House is a private corporation established by Royal Charter with a statutory function as a General Lighthouse Authority (GLA). The Court of TH has overall responsibility for conduct of the Corporation's business and has delegated the

Criteria	AC score	Comment
		responsibility for effective day to day control of its GLA function and finances to the Trinity House Lighthouse Board
Leadership	High	TH has a strong leadership team which supports building resilience within the business to the impacts of climate change, thus ensuring climate is considered alongside other risks.
Access to sites	Medium	Some sites are challenging to access, both physically due to remote locations, and through restrictions (e.g. biodiversity/wildlife protection zones)
Funds / resources	Medium	Financial resources for TH are secured through the General Lighthouse Authority Fund under the responsibility of the Secretary of State of the Department for Transport. The projected funding requirement is currently forecasted to cover a set number of demands / investment requirements within 10-15yrs. Some of the climate change adaptation investment is outside this planning horizon and therefore funding availability will be considered at a later stage.
Regulatory Framework & Consenting Authorities	Medium	TH has permitted rights for development necessary for the purposes of its function as a GLA. There are exceptions and some of TH's activity falls outside of these functions. Within the TH estate there are multiple heritage assets that fall within the Listed Building Consent and Habitats Conservation regimes.
Ownership of assets	High	TH has control and ownership over many of its assets, either directly or through contracted maintenance programs. However, some assets are rented or leased which means the ability to adapt these assets may be more challenging.
Technical know-how	High	TH has a large team of in-house technical experts that have the capability to monitor, measure and innovate adaptations to climate impacts.

Many of TH's assets are highly exposed to hazards, however, the sensitivity of the assets themselves is relatively low compared with other conventional structures. Combined with a moderate organisational adaptive capacity, there factors reduce the vulnerability and impact to a small degree and are reflected in the risk ratings in the TH Risk Register, which may, therefore, appear lower for some risks when compared to some other critical infrastructure assets.

4.2 Impacts associated with key climate hazards

4.2.1 Risks associated with Sea Level Change

There are a number of risks presented to TH as a result of sea level rise, outlined in Table 9. These include coastal flood risk and coastal erosion. The first of these hazards include the potential inundation of assets including lighthouses and offices (specifically the office located at Harwich). Such inundation would be likely to result in damage to these assets, which also include piers and buoy yards. This has the potential to prove costly and time-consuming to repair or replace. It is also likely to result in disruption to services where staff are required to evacuate as a result of flooding or are unable to gain access to assets such as lighthouses. In some cases, as is the case with some boat landing infrastructure, there is potential for the loss of assets completely, particularly in the latter part of the century where sea level has the potential to increase by up to 80cm (95th percentile) under RCP8.5.

Such an increase, in the long term, has the potential to also impact upon TH indirectly as a result of damage or disruption to national infrastructure (including as a result of coastal erosion, as well as flooding). Specifically, the risk to power, water, telecommunications, and transport infrastructure is likely to severely disrupt the delivery of TH services including asset maintenance and recovery (in the absence of power it would not be possible to connect ships to shore side power), wreck location and marking, towing, buoy handling and surveying.

Table 9. Risks to TH associated with sea level change

ID	Risk Descriptor	2025	4˚C 2050s	2˚C 2080s	4˚C 2080s
R01	Risk of damage to lighthouse assets or disruption to operations from coastal flooding	Minor	Moderate	Moderate	Major
R02	Risk of flooding or damage to lighthouse utilities infrastructure from coastal flooding	Negligible	Negligible	Moderate	Moderate
R03	Risk of damage or flooding to TH Harwich office from coastal flooding	Major	Major	Major	Severe
R04	Risk of damage to, or loss of, Trinity pier and buoy yard from coastal flooding	Major	Severe	Severe	Severe
R05	Risk of damage to lighthouse assets and infrastructure, including undermining of assets, from coastal erosion	Minor	Major	Major	Severe
R06	Risk of damage to, or loss of, hard and soft sea defences around lighthouse assets from coastal erosion	Moderate	Moderate	Major	Major
R07	Risk of asset loss or relocation, including a potential need to reconsider AtoN in view of coastal realignment and coastal erosion	Moderate	Major	Severe	Severe

A further potential consequence of sea level rise is an increased risk of erosion to TH assets and their supporting foundations. In some cases, this could result in the loss of some access infrastructure including boat landing infrastructure and bridges. Prolonged periods of disruption to some local services (due to a lack of access to assets) and increased maintenance and repair costs are also a risk. Such increased maintenance and repair costs (generally speaking) may further be exacerbated in some cases by the erosion of natural flood defences and supply chain disruptions brought about by heightened climate change risks outside of the UK.

4.2.2 Risks associated with Temperature Change

The risks identified as a result of temperature increase (outlined in Table 10) include the potential destabilisation of lighthouse asset foundations as a result of the shrink and swell of foundation soils. Eight lighthouses are under active monitoring due to increased risk as a result of their position on shallow, cohesive, or shrinkable geology. The shrink and swell of building components are likely to have greater impact. This may lead to disruption of the AtoN, either through alteration to the focal plane of the light, making the light less effective, or through the disruption of light sectors. Further impact may arise through potential cracking of concrete or mortar, again resulting in increased maintenance time and cost.

Warmer marine temperatures are likely to result in increased maintenance time and costs as ocean acidification, warming and extreme heat exposure is projected to result in a shift towards algae dominated habitats. This will result in increased maintenance requirements of ‘dirty’ buoys, lightvessels, landing slips and piers etc. Increases to the length of the growing season is likely to have a similar impact on land where vegetation clearance is required around fixed assets. Also, changes in breeding patterns of birds or other wildlife may affect engineering works (e.g. due to the risk of helicopter activities disrupting sensitive nesting sites).

Staff health and wellbeing will also be affected. This is likely to be brought about through increased heat and/or sun exposure resulting in discomfort, sunburn, dehydration, heat stress, heat stroke and

Table 10. Risks to TH associated with temperature change

ID	Risk Descriptor	2025	4˚C 2050s	2˚C 2080s	4˚C 2080s
R08	Risk of overheating in offices/depots during summer hot days and heatwaves, potentially causing heat stress for employees in non-cooled	Negligible	Moderate	Moderate	Major
R09	Risk of overheating in lighthouses during summer hot days and heatwaves, potentially causing uncomfortable conditions for maintenance operators.	Minor	Moderate	Moderate	Major
R10	Risk of overheating or uncomfortable working conditions during summer hot days and heatwaves for employees working in non-cooled	Minor	Major	Moderate	Severe
R11	Risk of power, electricity, IT and Comms disruption on summer hot days and heatwaves associated with overheating of infrastructure.	Moderate	Major	Major	Major
R12	Risk of damage to lighthouse assets associated with the destabilisation of asset foundations due to the shrink and swell of soils in extreme	Minor	Major	Major	Major
R13	Risk of shrink and swell of building infrastructure during extreme temperatures, causing the expansion and contraction of building	Negligible	Minor	Minor	Moderate
R14	Risk of increased maintenance requirements associated with warmer marine temperatures increasing marine growth on buoys, landing slips	Negligible	Negligible	Minor	Minor
R15	Risk of increased maintenance requirements associated with increased plant/weed growth during a longer growing season.	Negligible	Negligible	Negligible	Negligible
R35	Risk of possible vandalism from increased water leisure activity (e.g. canoes) in the vicinity of TH assets, particularly lighthouses	Negligible	Negligible	Negligible	Negligible
R41	Risk of increased navigational needs and pressure on TH operations from increased water leisure activities and more vessels on the water	Negligible	Negligible	Negligible	Negligible

heat exhaustion. In the Harwich and London offices, this risk is mitigated against through the use of air conditioning, however in the offices at Penzance and Swansea, and in lighthouses, there is no air conditioning. The operational consequence of this is the potential for diminished efficiency and/or disruptions to service delivery. For context, the average hottest summer day in the Swansea office was 31.6°C between 1991 and 2019. Projection data indicates that under 4˚C of global warming by 2100 this could rise to 38.3°C.

The potential for overheating of national infrastructure, specifically with respect to power, may also result in disruptions to service delivery, particularly where local power supplies are dependent upon fresh water supplies for cooling (increasingly likely in view of the transition towards a low carbon economy). One of the cascading effects of this is further disruption to local telecommunications infrastructure which cannot be mitigated against through on-site back-up power generators owned by TH.

4.2.3 Risks associated with Changing Precipitation Patterns

The risks to TH as a result of changing rates of precipitation are outlined in Table 11. TH has four main offices: London, Harwich, Penzance, and Swansea. Current flood maps indicate that the risk of flooding from 'rivers and the sea' is very low risk at TH's London and Penzance offices (each year these areas have a chance of flooding of less than 0.1%, or 1 in a 1000), and low risk at Harwich (each year this area has a chance of flooding of between 0.1% (1 in a 1000) and 1% (1 in 100)). In Swansea there is a very low risk of flooding from rivers and a low risk from the sea.

The risk values consider the effect of flood defences that are in place and maintained by the Environment Agency (in England) and Natural Resource Wales. Whilst flood defences reduce the risk, the flood defences do not completely stop the chance of flooding as they can be overtopped or fail. Additionally, managed realignment may occur, where authorities deem the upkeep of defences to be too costly.

Of the four sites, the TH Harwich office is at the most risk of flooding. Sited on the edge of an estuary with the River Stour to the West, the River Orwell to the North, and the North Sea to the East, the combined risk from high river flows and high tides presents an exacerbated risk. Furthermore, the sea defences currently in place are in a poor state of repair and will become increasingly at risk of failing unless upgrades are made. It is expected that the risk of fluvial and pluvial flooding will be further exacerbated by more frequent and/or intense rainfall events, although the risk will be subject to the maintenance and upgrading of flood defences over the next few decades to be resilient to projected precipitation changes.

The risk of fluvial flooding to infrastructure upon which TH depends is also considered to be significant, as a result of the cascading risks associated with power and communications outages. The consequences of these indirect risks include a lack of awareness of lighthouse faults and remote reconnections, as well as temporary disruption to services (potentially arising from the inability to charge electric vessels for example).

The risk of pluvial (surface water) flooding to assets is also considered increasingly significant in view of the projected increase in precipitation rates, the current issues which have been experienced in the Harwich office and the limited capacity of existing public infrastructure to cope with such change. Assuming these issues are not addressed, then it is anticipated that the risk of pluvial flooding to assets will reach a level considered to be major by 2080 under the high emissions scenario.

Other extreme events (e.g. blizzard conditions) have the potential to temporarily limit lighthouse visibility and/or hinder access to landing infrastructure. The risk of accidents and/or damage or disruption to equipment brought about by cold events including snowfall is likely to decrease as the climate warms but will still happen from time to time.

An additional consequence may be the diminished power generation capability from on-site solar PV infrastructure. This poses a threat to those assets reliant upon such infrastructure insofar as demand for energy is increased during such times (e.g., increased use of hazard warning signals). The same issue of prolonged diminished sun exposure has the potential to force some AtoN into emergency state.

4.2.4 Risks associated with Storm Events

The risks to TH from storm events (outlined in Table 12) include direct damage from high winds and rough seas, as well as indirect disruption to services and operations.

Rising sea levels increase the risk of coastal erosion and flooding from high tides and storm surges. Whilst storm surges occur relatively infrequently, they can have a significant impact when they do

Table 11. Risks to TH associated with precipitation change

ID	Risk Descriptor	2025	4˚C 2050s	2˚C 2080s	4˚C 2080s
R17	Risk of damage to depots/offices from fluvial (river) flooding associated with heavy rainfall events and high river flows	Minor	Moderate	Moderate	Major
R18	Risk of damage to depots/offices from pluvial (surface water) flooding associated with heavy rainfall events	Moderate	Moderate	Moderate	Major
R19	Risk of damage (or increased maintenance) to lighthouses from pluvial (surface water) flooding associated with heavy rainfall events	Moderate	Moderate	Moderate	Major
R20	Risk of flooding or damage to utilities infrastructure from pluvial, fluvial and coastal flood events, causing power, IT and Comms disruption	Major	Major	Major	Major
R21	Risk of damage to lighthouses from erosion and slope or embankment failure associated with heavy rainfall events and high winds	Moderate	Moderate	Moderate	Major
R22	Risk of incidents at sea due to lighthouse operations (e.g. visibility of light beam) being affected by poor weather conditions (e.g. fog/blizzards)	Minor	Moderate	Moderate	Moderate
R23	Risk of accidents to staff and damage or disruption to equipment associated with cold events and snowfall	Moderate	Moderate	Moderate	Minor
R24	Risk of reduced outputs from solar energy generation, potentially causing AtoN to fail due to changes in cloud cover	Moderate	Moderate	Moderate	Moderate

take place. Climate models (including those used for UKCP18) do not generally represent storms very well, indicating only a small, non-linear change.

Nevertheless, risk associated with storm surges include disruptions to service through a reduction in the number of days during which access to floating assets can be checked, maintained, or replaced and a potential temporary loss of access to sites during storm conditions due to the health and safety risks which they present to TH personnel.

Other key risks associated with storm events (and their interaction with rising sea levels) include potential damage to lighthouse assets, and their associated access routes, as a result of wave impact and (subsequent) erosion. Damage might also occur as a result of high winds, the strength of which has the potential to impact assets by way of airborne debris, or from lightning strikes, where an entire station can be affected and require significant rework to repair. Such assets potentially include solar

Table 12. Risks to Trinity House associated with storm events

ID	Risk Descriptor	2025	4˚C 2050s	2˚C 2080s	4˚C 2080s
R25	Risk of damage to lighthouses, lightvessels and dragging buoys associated with storm surges and coastal flooding	Moderate	Moderate	Major	Major
R26	Risk of damage to depots/offices associated with storm surges and coastal flooding	Severe	Severe	Severe	Severe
R27	Risk of disruption to services and AtoN casualty (buoys dragged out of position) associated with storm events	Moderate	Moderate	Major	Major
R28	Risk of disruption to services (e.g. surveys and maintenance of assets) associated with high winds and rough seas	Moderate	Moderate	Moderate	Major
R29	Risk of damage to lighthouse assets and infrastructure due to erosion and damage from high winds and rough seas	Moderate	Major	Major	Major
R30	Risk of disruption to operations and services, including an inability to access sites at sea, due to high winds and poor weather conditions	Moderate	Major	Major	Major
R31	Risk of structural damage to lighthouses and depots (e.g. roofing materials) from high winds	Moderate	Moderate	Moderate	Major
R32	Risk of disruption to air services where strong winds and/or sea swells prevent use of helicopters to access sites	Major	Major	Major	Major

panels which are critically important to the function of TH, particularly during extreme weather events.

Storm conditions can drag buoys out of position, which has implications for navigational safety and requires sending a ship out to reposition them, which has an operational cost.

Also, of critical importance are the ship and helicopter operations which take place regularly throughout the year. These are scheduled in light of shared rental of helicopter services with other GLAs. Subsequently, when storms do occur during a time in which the helicopter is scheduled for use by TH then this can present significant logistical and cost challenges (particularly in such instances as when alignment is required with a TH vessel or as part of the wider planning schedule incorporating Northern Lighthouse Board).

4.2.5 Risks from interactions of Multiple Climate Variables

A changing climate presents multiple hazards that can affect people, assets and operations within TH. The key risks from multiple climate variables identified in the risk register, and how the scale of risk is expected to change under the assessed climate scenarios, are set out in Table 13.

Multiple climate variables from global extreme weather events (e.g., heatwaves, floods events, storms etc.) pose a risk of international supply chain issues where sourcing regions are affected, subsequently having cascading risks.

TH insures some but not all of their assets. Increasing incidence of climate related damage across the UK may cause increases in insurance premiums and this may affect TH assets and financial planning. This was identified as a major risk in the 2080s under the 4˚C+ scenario, due to the greater certainty in climate related damaging events occurring.

TH has around 224 staff working across the TH offices and sites.[6] Through this reporting process, risks to TH staff were identified.

Climate-driven disease pandemics (e.g. COVID-19) can affect the health and wellbeing of TH staff and disrupt operations. The core links between climate change and pandemics lie in the drivers of climate change. Land use change (e.g. deforestation) is a key driver of climate change and often causes habitat loss, which at the global scale is increasing the proximity of humans and animals. This increasing migration of wildlife into urban areas is increasing the potential for interaction and crossover of disease between human and animal, which can be a source of pandemic diseases. Further, a warmer climate drives the spread of disease and may contribute to amplifying disease outbreaks.

Risks of physical injury to staff, both office based and operational, from extreme weather such as flash

Table 13. Risks to TH staff from multiple climate variables

ID	Risk Descriptor	2025	4˚C 2050s	2˚C 2080s	4˚C 2080s
R16	Risk of supply chain issues associated with interacting and cascading risks resulting from global extreme weather events	Moderate	Moderate	Moderate	Moderate
R33	Health risks to staff from pandemics and risk of disruption to all manned services	Moderate	Moderate	Moderate	Moderate
R34	Risks of increased insurance premiums	Moderate	Moderate	Moderate	Major
R36	Risk of injury to TH office-based staff from damaged buildings or debris	Negligible	Minor	Minor	Minor
R37	Risk to operations from extreme weather affecting all TH staff travel and commuting	Minor	Moderate	Moderate	Moderate
R38	Risk of injury to operational/ non-office-based staff from extreme weather conditions	Moderate	Moderate	Moderate	Moderate
R39	Risk of poor mental health to all TH staff (desk based and operational) from the impacts of climate change	Minor	Minor	Minor	Minor
R40	Risk of restricted or prevented access to sites due to increased regulation relating to the consequences of a changing climate	Negligible	Moderate	Moderate	Moderate

flooding, windblown debris, landslides and dangerous travelling conditions were considered in this round of reporting. For operational staff this risk was thought to be greater than that to office or home-based staff and it was expected to increase to a moderate risk for operational staff from the 2050s onwards under both climate scenarios.

The impacts of a changing climate on staff's mental wellbeing were also considered. The consequences of experiencing climate related traumatic events and the more chronic impacts of climate-anxiety are captured by this risk.

4.3 Overview of Trinity House climate risk register

This section provides an overview of climate hazards that pose a risk to TH. In total, 41 hazards were identified in the climate change risk assessment, affecting both physical assets and operational activities.

Risks were considered across five broad categories, which were detailed in sections 4.2.1 to 4.2.5

respectively:

- Sea level change (seven risks)
- Temperature change (ten risks)
- Precipitation change (eight risks),
- Storm events (eight risks)
- And those affected by Multiple Climate Variables (eight risks).

Each hazard was quantified to provide a risk score (likelihood of occurrence vs magnitude of impact) for each of the time horizons of focus (2025, 2050s and 2080s), considering how the climate is projected to change under the 2˚C aligned (RCP2.6) and the 4˚C+ (RCP8.5) scenarios.

The climate change risk assessment found that the inherent risk to TH from a changing climate is expected to result in increasingly severe and costly impacts. The risk severity of the hazards is expected to become more pronounced in the latter part of the century and increase under greater levels of global warming, as illustrated by Figure 5.

The assessment indicates that under 4˚C+ of global warming (RCP8.5), and without new adaptation measures, the proportion of major and severe risks to TH will increase from 12% in 2025 to 29% in the 2050s; and rise to 61% of all risks in the 2080s. Under the 2˚C aligned scenario in the 2080s 37% of risks to TH are expected to be major or severe.

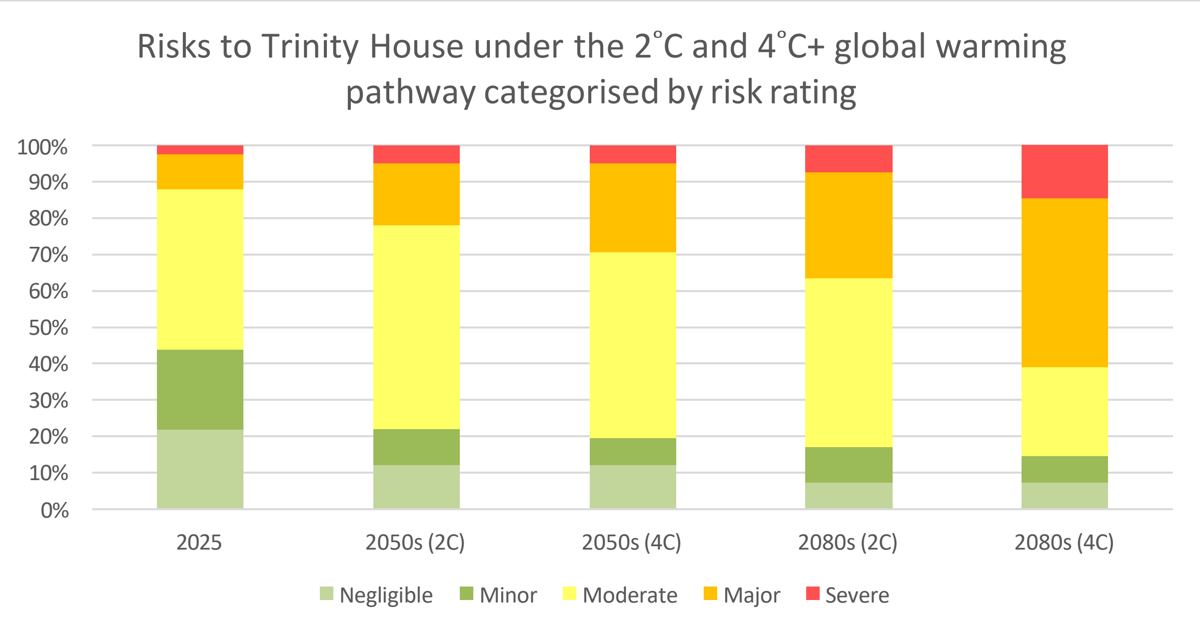


Figure 5. Risks to TH under the 2˚C and 4˚C+ global warming pathways (RCP2.6 and RCP8.5 respectively), categorised by risk severity in 2025 and the 2050s and 2080s.

Figure 6 illustrates the distribution of hazards across the risk matrix for each time horizon under 4˚C+ of global warming. For the 2050s there was a high level of similarity in risk ratings between 2˚C and 4˚C+ scenarios. The matrix tables show a general movement towards increasingly more severe risk ratings, associated with an increased likelihood and magnitude of impact from each hazardous event. In the 2080s there is a clear difference between the climate scenarios. Under the high emissions scenario (4˚C+) there is a notable further increase in the number of major and severe risks to TH, compared to the 2˚C scenario. The number of major and severe risks increases from five in the 2025s to 12 in the 2050s under 4˚C+. The difference in the scale of change between the two scenarios is most notable in the 2080s where the number of major or severe risks rises from 15 under 2˚C global warming to 25 under 4˚C+. Suggesting that climate change and extreme weather events are exacerbating the scale of damage or disruption to TH assets and operations and that existing risks will continue to worsen, and new risks emerge, unless adaptive measures are taken.

2025

Likelihood / Magnitude	Minimal	Minor	Moderate	Major	Catastrophic
Almost Certain					
Likely		R30, R34	R32		R26
Possible	R09, R10, R37, R39	R18, R23, R25, R28, R33, R38	R06, R16, R21, R27, R29, R31	R03, R20	R04
Unlikely	R08, R40	R05, R22	R19, R24	R11	
Highly Unlikely	R02, R14, R15, R35, R41	R13, R36	R01	R12, R17	R07

2050s

Likelihood / Magnitude	Minimal	Minor	Moderate	Major	Catastrophic
Almost Certain					
Likely		R08, R09, R28, R34	R10, R30, R32	R03, R29	R04, R26
Possible	R39	R18, R23, R33, R37, R38, R40	R06, R16, R19, R21, R22, R25, R27, R31	R05, R11, R12, R20	R07
Unlikely	R02	R13, R36	R01	R17, R24	
Highly Unlikely	R14, R15, R35, R41				

2080s

Likelihood / Magnitude	Minimal	Minor	Moderate	Major	Catastrophic
Almost Certain			R08, R09, R32	R10	R03, R04, R05, R07, R26
Likely		R37	R01, R18, R19, R28, R30, R31, R34	R06, R11, R12, R20, R21, R25, R27, R29	
Possible	R39	R02, R13, R33, R36, R38, R40	R16, R22	R17	
Unlikely	R15, R25, R41	R14, R23			R24
Highly Unlikely					

Figure 6. Distribution of risk scores for TH in the 2025s, 2050s and 2080s under the high emissions, 4˚C+, scenario.

4.4 Interacting and Cascading Risks

Interacting risk refers to hazardous events, impacts or interdependencies in a system that compound or interact to create a new hazard or increased level of risk within the system, which may not be prevalent in a single pathway. Figure 8 systems map outlines interacting and cascading risks of relevance to TH assets and operations. This map considers climate drivers, hazardous events, impacts and the consequence of these risk pathways to TH.

Key interacting risks include, for example, coastal flooding, which may be exacerbated by the combination of sea level rise, storm surges and high river flows (from heavy rainfall events), exacerbating flood risk and severity. Similarly, hazardous conditions (e.g., a combination of pluvial flooding; high winds, including airborne debris; damaged assets or access; high waves; and poor visibility) may pose a threat to staff.

Cascading risk refers to one or more hazards or impacts within the system occurring that then have knock-on consequences. For instance, where one impact has the potential to bring about the failure of another element of the overall system. For example, a heavy rainfall event in one location could cause flooding of a substation, which induces a power outage in another location, which then causes disruption to businesses and operations that were not directly affected by the weather event or hazard.

With respect to TH, one key cascading risk influenced by a range of risk pathways relates to the failure of national infrastructure. The risk of weather-related disruption to transport infrastructure, in particular national road networks, may impact access to TH's operational sites and so disrupt operations. Risk of power failure and thus loss of telecommunications infrastructure from weather-related impacts is also a notable risk, this has the potential to cause temporary disruption to services. The key interdependencies upstream (i.e. where weather-related loss of service would have a consequence on TH) and downstream (i.e. where operational disruption or failure within TH to provide AtoN would have consequences for others) are shown in Figure 7.

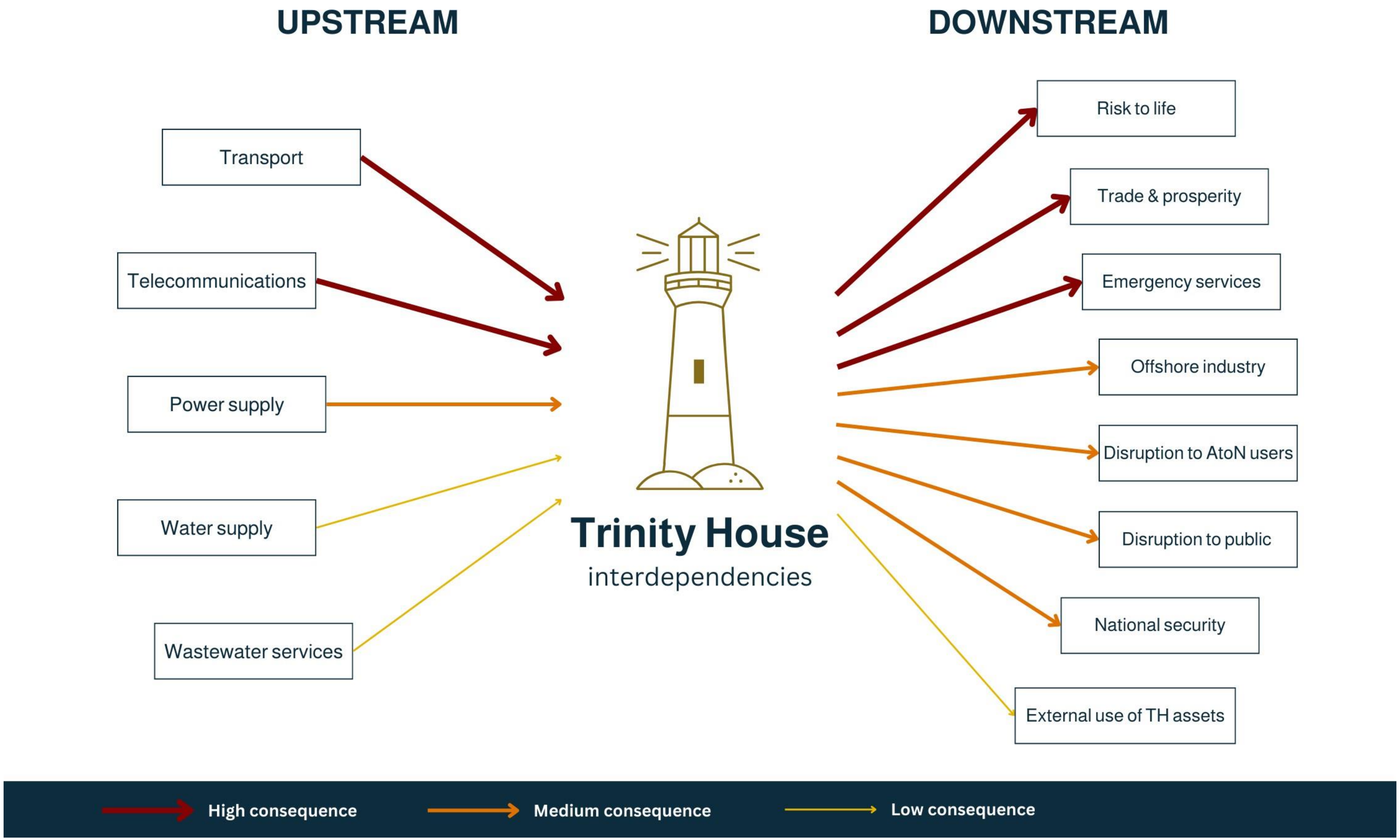
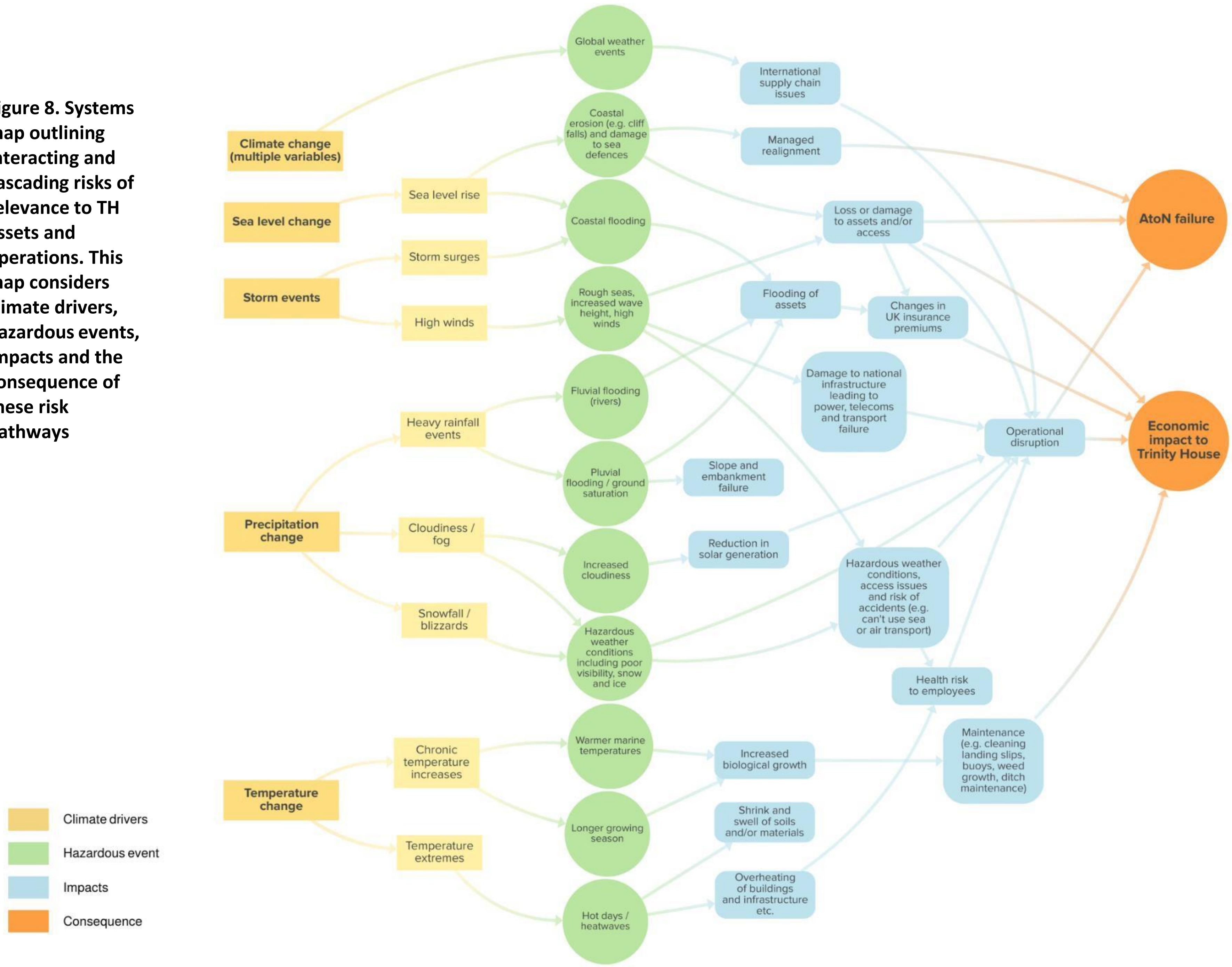


Figure 7. Headline upstream and downstream interdependencies for TH. Strength of the consequence of the interdependencies is indicated by arrow thickness and colour.

Figure 8. Systems map outlining interacting and cascading risks of relevance to TH assets and operations. This map considers climate drivers, hazardous events, impacts and the consequence of these risk pathways



4.5 Opportunities

Climate change presents numerous risks to TH; however, it may also present some opportunities that can be realised. Whilst the significance of opportunities is likely much less than other sectors (e.g. agriculture), five opportunities were identified for TH's people, assets and operations.

Milder winters including fewer and/or less severe cold, frost and snowfall events:

1. Warmer winters and fewer cold events may reduce heating energy demand in TH depots and offices resulting in reduced heating costs and lower energy use.
2. Fewer severe cold and frost events will reduce incidence of pipe freeze and freeze-thaw action, which may result in reduced building maintenance costs.
3. Fewer snowfall events would reduce the requirement for grounds maintenance, potentially resulting in reduced grounds maintenance costs.
4. Fewer frost and/or snowfall days may result in reduced incidence of dangerous road conditions.

Changing precipitation patterns and cloudiness:

5. There is the possibility for changes in cloud cover, with the potential for increased solar radiation and thus output of solar PV, although gains in some months may be offset by increased cloudiness in other months.

4.6 Monitoring and evaluation metrics and indicators

Metrics and indicators support the management, monitoring and evaluation of risks, as well as measure the effectiveness of adaptation measures. Trigger points are used to identify thresholds where a revision of risk scores or adaptation action is needed.

A range of potential metrics and indicators have been identified, which could support ongoing monitoring and evaluation of risk management and adaptation action. These are broadly classified under five metric/indicator types:

Organisational indicators: These describe and quantify key organisational metrics about TH's assets, staff and operations. These allow for key performance measures of the organisation to be used. For example:

- Number of assets (lighthouses, lightvessels, buoys, offices etc.)
- Number of staff (office-based, home-based, hybrid, site-based etc.)
- Number of vehicles (fleet cars/vans, boat/ships etc.)

Climate indicators: These describe the number of events (e.g. associated with extreme weather), across the area of operation. These indicate the exposure of TH to potential events that could cause an impact. For example:

- Number of heatwaves per year
- Number of storms per year
- Rate of sea level change

Climate change impact indicators: These describe hazards attributed to climate change. They indicate changes in the trend for climate impacts, which may result from changes in the frequency or magnitude of impacts. For example:

- Recorded instances of weather-related delays associated with accessing stations
- Recorded instances, extent and magnitude of assets suffering storm (wind) damage

- Number of weather-related helicopter delay days
- Number of buoys needing repositioning due to high winds/storms
- Recorded instances of vessels unable to survey buoys due to poor weather conditions
- Recorded instances, extent and magnitude of assets affected by coastal flooding
- Recorded damage to / solar output from buoy Solar photovoltaic panels
- Rate and loss of shoreline to asset base

Output indicators: These describe products or services created by adaptation interventions. They indicate whether actions have been implemented but do not indicate whether adaptation has been successful. For example:

- Number of assets with air conditioning installed
- Total expenditure on adaptation/resilience measures

Outcome indicators: These describe results of outputs. They indicate whether actions have increased resilience or lowered climate risks, climate impacts, economic damages or negative effects in human health. For example:

- AtoN availability / AtoN outage minutes associated with extreme weather events
- Grading of assets and changes in grade condition
- Number of insurance claims raised
- Staff days lost due to overheating incidents
- Unplanned expenditure or repairs (result of an unforeseen weather event)

The focus of this analysis was on indicators that would be suitable and insightful for managing risk and adaptation within TH. It is recognised that many of the trigger points will need to be defined at the asset level, as local conditions will be critical in determining when adaptation action will need to take place. Site-level risk assessments are currently being undertaken for individual assets (expected to be complete by ARP Fifth Round), which will support risk management and adaptation at the local level.

5 ADAPTING TO CLIMATE CHANGE

5.1 Current Adaptation Planning

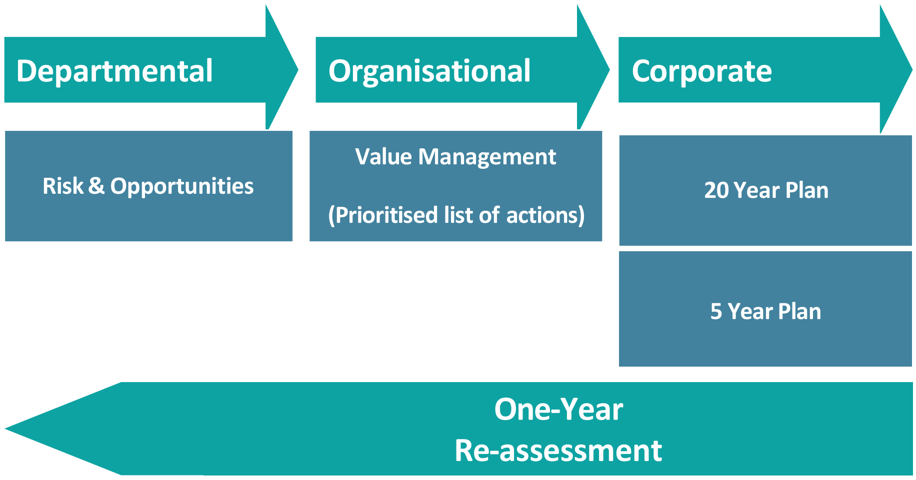
TH understands the importance of risk management in adapting to climate change. Through ongoing discussions with key stakeholders and the GLAs of the United Kingdom and Ireland TH work collaboratively sharing best practice and resources to increase their resilience to these changes.

5.1.1 Climate Impact Risk Assessment and Planning

ARP4 represents TH' fourth review of adaptation reporting first submitted in 2011 to DEFRA. Previous reports were scoped at assessment of RCP8.5 worst case scenario with the intention to provide a high level of protection to critical TH assets. While not looking to reduce TH's efforts in resilience-building the high impacts modelled add additional cost to all asset planning decisions, acting as a blocker to further action in some case. For the TH ARP4 risk assessment, two scenarios (RCP2.6 and RCP8.5) have been used in line with DEFRA best practice guidance which provide a wider view to the TH management team of the key impacts and potential pathways.

5.1.2 Asset Resilience / Adaptation Implementation

A mature asset management system is in place at TH. Records on damage to assets / service interruption (e.g. buoys) and reason behind such damage has built up a picture of risk and impact. TH's risk management process flags up the major assets identified at risk and prioritises these for investment.



TH asset risk management system has been under annual review since 2011 the register includes identified and projected risks and mirrors the climate change adaptation cycle. Risks for major assets are tracked and tipping points / actions applied e.g. Orfordness Lighthouse decommissioned in 2013 and eventual demolition in 2020 due to coastal erosion. This key register is currently being expanded to identify and rank site specific climate risks for all TH assets with predicted rate of sea level rise, rates of erosion and mitigation measures already in place e.g. status of shoreline management plans, flood defences in planning etc. Work to collect the data at individual asset level is ongoing. It is anticipated that this information is likely to be available for ARP5.

Objectives and policies set out within ARP3 have been implemented and commitments on adaptation to climate impacts remain embedded within TH key commitments:

- Protect the environment including prevention of pollution.
- Heighten environmental consciousness among colleagues, marine users, and the public so as to create a preventive culture in respect of harm to the environment.
- Be aware of the impact of our operations on climate change.
- Ensure that operations and estate are able to adapt to climate change, where possible, and that, the need for adaptation to climate change is built into planning and decision making where necessary.
- Design systems and procure products/services to consider whole-life environmental issues, in the consumption of raw materials, process pollution, and end-of-life disposal of products where reasonably practicable.

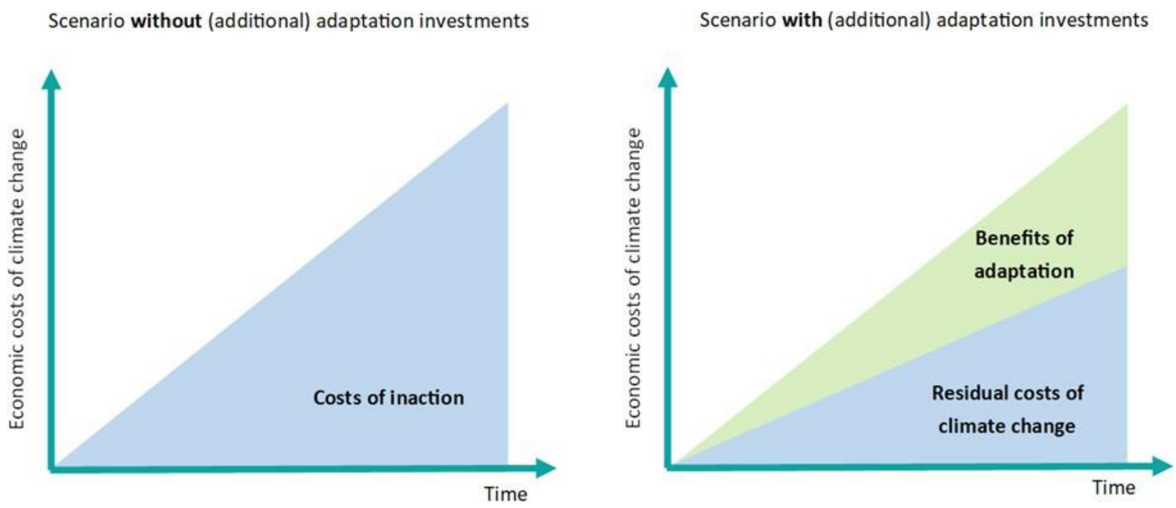
5.2 Approach to adaptation

Adapting to climate change involves adjusting systems, policies, and practices to reduce vulnerability to the current and anticipated impacts of climate change. When developing a process of adjustment to actual or existing models of climate change it is not always possible, or necessary, to deal with every identified risk. As such, in the development of the adaptation options for TH, only those risks identified as having a severe or high impact upon the organisation were considered.

Actions to adapt to specific risks were identified through collation of existing measures, relevant case studies, research papers and grey literature to identify those which may be feasible for TH to undertake.

5.2.1 Benefits of adaptation

The CCRA identifies potential threats (and opportunities) to TH, from the impacts of a changing climate. These threats relate to the assets, people, and services provided. This provides a framework for building greater organisational resilience with the capability of an effective service that safeguards our key stakeholders whilst maintaining the reputation of TH in responding to future impacts. It is important to note that not all the climate change impacts identified within this CCRA can be eliminated through adaptation and that there will be increasing damages and service interruptions due to the increased frequency of extreme weather, flooding events etc. Decisions will need to be made about which economic impacts can and will be managed. To assess the cost- effectiveness and efficiency of the various adaptation measures we need to understand the possible avoided losses see below.



Section 5.3 sets out the general objectives and specific tasks required to mitigate the direct and indirect risk / damages due to climate change impacts.

5.3 Adaptation Options

Integrating adaptation measures in a holistic approach to operational, asset and risk planning will be key. Expenditure designed to fulfil other primary objectives (such as operational development, facilities management and meeting our sustainability goals) can result in adaptation co-benefits reducing the vulnerability and overall economic impact. The following tables set out the timeline of potential actions for the impacts associated with key climate hazards in the CCRA.

5.3.1 Changing Precipitation Patterns

Objective: TH will continue to monitor the flood risk to sensitive sites as part of our asset planning process on a yearly basis. Where a site-specific risk is identified, TH will take action to mitigate this as appropriate to the site in question.

Ownership: Board Executive O&M by Director of Operations.

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
Present Day	N/A	Flood damage to critical infrastructure may disrupt power, communications, and IT systems (R20).	Backup power systems (UPS, generators & microgrids) (A12) can help maintain operational resilience in floods. Elevating (A64) & waterproofing (A05) critical power infrastructure can also protect it from flooding.
2080	RCP 8.5	Heavy rainfall and strong winds can cause fluvial and pluvial flooding, damaging depots, offices, and lighthouses (R17 &	Key adaptation options include implementing sustainable urban drainage systems (A43), sump pumps (A44), and retention basins (A45) to manage floodwaters, along with silt traps (A47) to ensure drainage efficiency.

		R18). Subsequently this will also increase the need for maintenance (R19).	Routine inspections and maintenance can also identify early signs of cracks/gaps and prevent further damage (A46).
2080	RCP 8.5	Heavy rainfall can cause erosion (R21) which could weaken lighthouse foundations.	Soil stabilisation methods, such as lime and cement treatment (A21), soil bioengineering (A62), and deep foundations like piles and rafts (A22), help mitigate erosion and enhance structural resilience in vulnerable areas.

5.3.2 Rising Sea Levels

Objectives: TH will continue to monitor the flood risk to sensitive sites as part of our asset planning process on a yearly basis. Where a site-specific risk is identified TH will take action to mitigate this as appropriate to the site in question.

Ownership: Board Executive O&M by Director of Operations.

Coastal erosion: Adaptation options will be evaluated through TH's 20-year asset management programme, supported by ongoing monitoring, measurement and evaluation of data that will inform alternative safe and cost-effective interventions where applicable.

Ownership: Board Executive O&M by Director of Operations

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
Present Day	**N/A**	Rising sea levels can result in flooding that damages, the Harwich office (R03), Trinity Pier, and buoy yards (R04).	Property flood resilience measures, such as flood gates (A03), temporary barriers (A02), and flood-resistant materials (A05), can safeguard critical facilities during extreme weather events. Effective watershed management (A32) complements these efforts by controlling upstream water flow and reducing downstream flooding. Structural reinforcements, breakwaters (A11), seawalls (A14), rock armouring (A19), provide added protection against flooding.
2050	RCP 8.5	Coastal erosion, driven by changing sea levels, undermines lighthouse foundations (R05) and	Natural defences - Restore natural coastal buffers e.g. marshes/wetland or beaches (A31), and soil bioengineering (A62) offer sustainable solutions that enhance biodiversity while mitigating flood risks.

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
		compromises hard and soft sea defences (R06).	Structural reinforcements, like geotextiles (A19) provide added protection against erosion.
2080	RCP 2.6	Flooding and Erosion may necessitate asset relocation (R07) due to the threat of asset loss or operation failure.	Adaptive Site Selection, (A37) scenario-based planning (A36) and future proofing (A35) new asset designs help protect them from future challenges. Managed Realignment (A69) of assets and operations that become uneconomic to maintain under predicted impacts.
2080	RCP 8.5	Rising sea levels can result in flooding that damages lighthouses and asset loss disrupting critical operations (R01).	Strategic approaches, including dedicated budgets (A33) for maintenance, upgrades, and emergency repairs, ensure readiness for future challenges. On-call repair teams (A34) further bolster preparedness, enabling swift responses to minimize disruptions and damage from rising sea levels.

5.3.3 Temperature Changes

Objective: Our internal analysis suggests that circa 90% of our work force is in coastal locations or on-board ship where conditions are more temperate. TH will continue to monitor climate change predictions and implement additional measure as necessary, including revised working patterns, cooling systems, and reflective coatings.

Ownership: Board Executive O&M by Director of Operations & Director of Business Services.

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
2050	RCP 8.5	Overheating can lead to uncomfortable living conditions during summer hot days and heatwaves in non-cooled offices / depots (R10)	Ventilation (A38) systems are vital for regulating air circulation and temperature indoors, creating a safer and more comfortable environment. Green roofs (A60) add an additional layer of insulation and contribute to thermal regulation offering sustainable cooling benefits in hot temperatures.
2050	RCP 2.6	Infrastructure such as power, IT, and communication systems may fail due to overheating (R11).	Backup power systems (A12), such as UPS, generators, and microgrids, are essential for ensuring uninterrupted energy supply during heat-induced outages, safeguarding critical infrastructure and operations. Reflective coatings (A15) and heat-resistant materials (A17) play a significant

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
			role in minimising heat absorption enhancing their durability in high-temperature conditions.
2050	RCP 8.5	Extreme temperatures can destabilise lighthouse foundations through soil shrinkage and swelling (R12), particularly in clay soils, leading to structural damage	Geotextiles (A19) and soil stabilisation techniques (A21), such as lime and cement treatments, improve the resilience of soil against heat-induced instability, preventing issues like ground shifting or weakening. Pile foundations and underpinning (A22) provide extra structural stability, making buildings and infrastructure more resistant to the impacts of prolonged high temperatures and shifting ground conditions.
2080	RCP 8.5	Extreme heat poses significant risks to TH's operations and assets. Overheating in offices (R08), lighthouses, depots (R09), can lead to heat stress for employees and uncomfortable working conditions.	To safeguard workers in high-temperature environments, rest break policies (A41), Heat avoidance scheduling (A20), cooling garments (A42), and hydration stations (A66) are essential in reducing heat stress and promoting well-being. Emergency training (A40) equips individuals with the knowledge and skills needed to respond effectively to heat-related incidents, ensuring safety and preparedness in increasingly challenging climates. For outdoor settings, passive cooling solutions (A39), such as outdoor fans and portable cooling units, provide much-needed relief during extreme heat.

5.3.4 Storms

Objective: Through TH's asset management process, TH assesses each site individually to ensure continuation of service. The updated climate projections from this work will feed into this cycle and, where necessary, additional measure will be implemented.

Ownership: Board Executive O&M by Director of Operations.

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
Present Day	N/A	Storm surges and coastal flooding present a significant threat to TH assets, including the potential damage to depots and	TH can adopt a wide range of adaptation measures to protect its assets and ensure operational continuity. Property Flood Resilience (PFR) solutions (A01), including flood gates (A03), temporary flood barriers (A02), and breakwaters(A11) safeguard

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
		offices such as the Harwich Operational Centre (R26).	lighthouses, depots, and other critical infrastructure from flooding.
Present Day	N/A	Strong winds (R32) and sea swells may disrupt helicopter operations, causing delays or interruptions to air services and planned site access.	Adaptive maintenance frameworks (A08) combined with drone-assisted surveys (A59), enable real-time damage assessment. Establishing a contingency fund (A09) and deploying modular maintenance units (A10) enhance the ability to respond rapidly to emergencies, ensuring the protection of critical operations during extreme weather events.
2050	RCP 2.6	Rough seas, high winds, and poor weather conditions pose risks of erosion and damage to lighthouse infrastructure (R29) and disrupt operations and site access at sea (R30).	Structural reinforcements (A04) and waterproofing (A05) combined with advanced drainage systems enhance resilience against water damage.
2080	RCP 2.6	Storm surges and coastal flooding pose a risk of damage to lighthouses, lightvessels, and buoys (R25), potentially leading to partial or complete failure in delivering lighthouse services and impacting access infrastructure.	Wind-resistant designs, such as impact-absorbing cladding (A55), storm shutters (A57), and replacing glass with acrylic or polycarbonate (A54), protect facilities and equipment from high winds. Installing windbreaks (A56) further reduce vulnerability to harsh conditions.
2080	RCP 2.6	Storm events pose a risk of disruption to services and AtoN casualties, including buoys being dragged out of position (R27), potentially impacting TH operations and safety at sea of marine traffic.	Storm-resistant mooring systems (A26), dual anchoring setups (A27), Increased sinker weights on buoys (A65) and gyroscopic stabilizers (A48) provide stability for lightvessels and buoys in rough seas. Modular buoy systems (A29) and real-time GPS (A28) buoy tracking enable efficient asset monitoring and reduce risks during extreme conditions.
2080	RCP 8.5	High winds and rough seas pose significant risks to TH assets and operations.	For renewable energy assets, wind-resistant mounting systems (A53) and floating solar panels (A67) enhance resilience.

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
		These include structural damage to lighthouses, depots, and solar panels caused by high winds and airborne debris (R31), as well as disruptions to services like asset surveys and maintenance due to limited access to floating assets (R28).	Drone-assisted surveys (A59) allow real-time damage assessment. pre-storm asset relocation protocols (A61) ensure preparedness. Integrating a digital twin (A70) enables continuous monitoring and proactive response to extreme weather events.

5.3.5 Multi Climate Variable Risks

Objective: Through TH's asset management process, TH assesses each site individually to ensure continuation of service. The updated climate projections from this work will feed into this cycle and, where necessary, additional measure will be implemented.

Ownership: Board Executive O&M by Director of Operations

Criticality Timeline	RCP	Risk Description	Potential Adaptation Options
2080	RCP 2.6	As extreme weather events become more frequent and severe, the overall cost to insurers will escalate (R34), leading to higher premiums for policyholders.	Group insurance (A24) programs and climate risk pooling initiatives are effective adaptation options for managing financial risks associated with climate change. By pooling resources and sharing risks among multiple stakeholders, these programs reduce individual exposure to catastrophic losses from extreme weather events. Climate risk pooling initiatives (A25), often supported by governments or international organisations, provide collective coverage for infrastructure and operations vulnerable to climate hazards, offering a cost-effective solution.

5.4 Barriers to Adaptation

5.4.1 Funding

Continued funding for adaptation activities resulting in significant capital expenditure, will require approval from the Department for Transport (DfT). Such funding requests will need to align with the 5-year Corporate Plan. While the AtoN estate is in overall good condition and does not currently need major adaptation funding, long-term costs for climate change- related adaptations are uncertain. Generally, this uncertainty can be reduced via the collation of data on current impacts and costs to view trends and monitor incurred costs. As the metrics in 4.6 develop these costs will be monitored, and updates will be provided to the DfT as part of regular planning.

5.4.2 Consents

TH faces constraints in adapting to climate change due to regulatory and land use requirements. Key issues include:

- **Land Lease and Permissions**: Adaptations may require landlord (public or private) consent, and coordination with relevant authorities to avoid adverse impacts on neighbouring assets.
- **Regulatory and Policy Impacts**: Public bodies (e.g., Environment Agency, Historic England, Natural Resources Wales, Cadw) and their enforcement of environmental, planning, and conservation laws can significantly influence adaptation efforts.
- **Listed Buildings and Designated Habitats**: Many lighthouses are listed buildings in protected areas, and further designations may increase regulatory scrutiny. Adaptation works required must also comply with these regulations.
- **Consultation Requirement**: Early engagement with relevant organisations is essential to navigate these challenges, with ongoing consultations already occurring.

Appendix A – Trinity House Lighthouses

Region		Lighthouses/Beacons	Lightvessels
England	North West	• St. Bees Lighthouse • Hilbre Island Beacon	
	North East	• Heugh Hill Beacon • Guile Point Beacon • Bamburgh Lighthouse • Farne Island Lighthouse • Longstone Lighthouse • Coquet Lighthouse • Whitby Lighthouse • Flamborough Lighthouse	
	East	• Cromer Lighthouse • Lowestoft Lighthouse • Southwold Lighthouse	• Sunk Inner Lightvessel
	South West	• Lynmouth Foreland Lighthouse • Bull Point Lighthouse • Lundy North Lighthouse • Lundy South Lighthouse • Crow Point Beacon • Instow Front Transit • Instow Rear Transit • Hartland Point Lighthouse • Trevose Head Lighthouse • Godrevy Lighthouse • Pendeen Lighthouse • Longships Lighthouse • Wolf Rock Lighthouse • Tater Du Lighthouse • Round Island Lighthouse • Peninnis Lighthouse • Bishop Rock Lighthouse • Lizard Lighthouse • St. Anthony Lighthouse • Eddystone Lighthouse • Start Point Lighthouse • Berry Head Lighthouse • Portland Bill Lighthouse • Anvil Point Lighthouse	• Sevenstones Lightvessel
	South East	• North Foreland Lighthouse • Dungeness Lighthouse • Beachy Head Lighthouse • St. Catherine's Lighthouse • Needles Lighthouse • Hurst Point Lighthouse • Nab Tower Lighthouse	• Foxtrot 3 Lightvessel • East Goodwin Lightvessel • Sandettie Lightvessel • Varne Lightvessel • Greenwich Lightvessel
Wales	North	• Trwyn Du Lighthouse • Point Lynas Lighthouse • Skerries Lighthouse • South Stack Lighthouse • Bardsey Lighthouse • St. Tudwal's Lighthouse	

	South	• Strumble Head Lighthouse • South Bishop Lighthouse • Smalls Lighthouse • Skokholm Lighthouse • St. Ann’s Head Lighthouse	• Caldey Island Lighthouse • Mumbles Lighthouse • Nash Point Lighthouse • Flatholm Lighthouse • Monkstone Lighthouse	
Channel Islands		• Casquets Lighthouse • Alderney Lighthouse	• Les Hanois Lighthouse • Sark Lighthouse	
Gibraltar		• Europa Point Lighthouse		