TRINITY HOUSE

DECEMBER 2021

Climate Change Adaptation Report

Third round

TRINITY HOUSE

Climate Change Adaptation Report Third Round

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CONTRIBUTING AUTHORS

Lead Authors	**Role**
Andrew McArthur Associate Director – WRc	Project Manager; Monitoring and Evaluation
Dr David Hodkin Assets and Infrastructure Technical Specialist, WRc	Technical Lead
Mark Kowalski Principal Consultant – Asset Resilience, WRc	Technical Review
Danielle King Principal Climate Change Consultant, RSK	CCRA and Risk Register
Charles Ffoulkes Associate Director – Climate and Sustainability, ADAS	CCRA and Risk Register
Dr Alice Johnson Coastal Infrastructure Project Engineer, Binnies	Adapting to Climate Change

Trinity House Steering Group	**Role**
Peter Hill Estates and Property Manager, Trinity House	Trinity House Project Manager
Tom Arculus Head of Legal and Risk, Trinity House	Expert Review
Steve Keddie Head of Engineering and Operations, Trinity House	Expert Review
Anthony Porter Risk Manager, Trinity House	Expert Review

1 INTRODUCTION

1.1 Trinity House

Trinity House 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 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 Trinity House in its capacity as a GLA and does not apply to Trinity House 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, Trinity House is the UK's largest-endowed maritime charity, the General Lighthouse Authority (GLA) for England, Wales, the Channel Islands and Gibraltar.

Trinity House has responsibility, subject to certain provisions, for the superintendence and management of "all lighthouses, buoys and beacons" throughout its geographical area including "the adjacent seas and islands…." within and beyond territorial waters up to the outer limit of the UK Exclusive Economic Zone (EEZ).

It provides many traditional short-range aids to navigation (AtoN) complemented by a mix of radio aids to navigation for the safety of all mariners engaged in general navigation irrespective of who pays for the service, the size or type of the vessel, her equipment fit, the competence of her crew, or flag.

The statutory authority for Trinity House 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).

Trinity House currently maintains 66 lighthouses; seven lightvessels / lightfloats; 450 buoys, and eight Differential Global Positioning System (DGPS) Reference Stations, which are due to be discontinued from March 2022.

Key dates

1514: Henry VIII grants a Royal Charter to the corporation of Trinity House.

1566: Elizabeth I Grants Trinity House the power to build lighthouses and other seamarks for the protection of seafarers.

1609: Lighthouses built to protect shipping along the East Anglian Coast.

1703: Eddystone, the first rock lighthouse in Europe, is destroyed by a storm.

1858: Electricity introduced to the first Trinity House lighthouse.

1977: Last oil burning light removed from a Trinity House lighthouse (St Mary's Bay, Tynemouth).

1982: Eddystone Lighthouse is the first Trinity House rock lighthouse to be converted to automatic operation.

1993: The conversion of Trinity House buoys to solar power is completed.

1994: Lundy North becomes the first Trinity House lighthouse to be converted to solar, reducing reliance of diesel generators.

1998: Keepers are withdrawn from North Foreland, the last manned Trinity House lighthouse.

2000: Trinity House achieves ISO 14001 certification, which leads to the establishment of:

Environmental Policy

Environmental Plan

Aspects & Impacts Register

Environmental Working Group.

2008: Development of E-navigation concepts such as AIS, eLoran, and DGPS begins.

2011: New power systems introduced to reduce CO_2 emissions and Trinity House completes first round of Climate Change Adaption Reporting.

2013: Crow Point Lighthouse damaged by winter storms.

2014: Trinity House celebrates 500 years of service to the mariner.

2016: Trinity House completes second round of Climate Change Adaption Reporting.

2020: Orfordness Lighthouse (decommissioned in 2013 due to the threat from erosion) demolished after significant erosion to its foundations.

2021: Extensive storm damage to the sea wall adjacent to Hurst Point Lighthouse prompts Environment Agency's review of the spit's future (ongoing).

2022: Trinity House completes third round of Climate Change Adaption Reporting with expert input from WRc, RSK, and Binnies to align with UKCP18 climate projections.

1.2 Trinity House's assets

Lighthouses and lightvessels

Trinity House maintains 66 lighthouses and seven lightvessels around England, Wales and the Channel Islands, including one lighthouse in Gibraltar, illustrated in Figure 1 (excluding Gibraltar). A full list of the lighthouses and lightvessels can be found in Appendix A. These aids to navigation range from isolated offshore towers exposed to the open sea to shore-based stations in some of the nation's most beautiful locations.

Navigation buoys

Trinity House maintains around 450 buoys which are designed in accordance with IALA Buoyage System. These buoys include[1]:

- Cardinal marks
- Lateral marks
- Emergency Wreck Marking buoys
- Isolated danger marks
- Safe water marks
- Special marks

Buoys can be either lighted or unlighted and many are installed with a fog signal in the form of either bells or automatic whistles and are monitored from the Harwich depot.

Depots and offices

- Trinity House, Tower Hill, London, EC3N 4DH
- Trinity House, The Quay, Harwich, Essex, CO12 3JW
- Trinity House, Kings Dock, Swansea, Glamorgan, SA1 8QT
- Trinity House, Land's End Airport, Kelynack, St Just, Penzance, TR19 7RL

1.3 Adaptive Reporting Power Aims

Trinity House 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 all issues in the Risk and Opportunity Register for each asset. The careful analysis of the Risks and Opportunities identified provides a clear framework for identifying and prioritising the investment and work over the next 5 and 20 years.

This round of reporting affords us 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. To support this, Trinity House has elected to extend its reporting beyond the United Kingdom to include our assets in the Channel Islands. Our assets in Gibraltar are not covered under this reporting as these are not covered by UKCP18.

By delivering these aims Trinity House will be able to contribute to the government's Climate Change Risk Assessment which seeks to assess the level of preparedness of critical infrastructure across the UK.

1 www.trinityhouse.co.uk/mariners-information/navigation-buoys

Figure 1: Distribution of Trinity House's assets in the British Isles

2 CLIMATE CHANGE RISK ASSESSMENT

2.1 Approach to Risk Assessment

The climate data used for the risk assessment is outlined in Table 1. Further detail can be found in Appendix B.

The UK Climate Projections (UKCP) provide a current assessment of how the UK climate may change in the future. The projections published in 2009 (UKCP09) were widely used by industry under the Defra Adaptation Reporting Power (ARP) second round of reporting. These projections were updated by the Met Office in 2018 (UKCP18).

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. 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). Our risk assessment focussed on RCP8.5, commonly known as the high-emissions scenario.

Strategic locations used to assess climate data

The resources available for this reporting meant that it was not feasible to undertake a detailed risk assessment for individual assets. Instead, assets were categorised under one of five strategic areas: North East England, South West England, South East England, North Wales, and the Channel Islands. UKCP18 climate projections were then used to provide an assessment of climate risk that was representative of the assets based on their geographical location. 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.

	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
Percentiles:	5th and 95th percentiles	5th and 95th percentiles
RCP:	RCP8.5	RCP8.5
Baseline:	1981 - 2000	1981 - 2000
Time horizons		
Short:	2025 (2015-2035)	2025 (2010-2040)
Medium:	2050 (2040-2060)	2050 (2035-2065)
Long:	2080 (2070-2090)	2080 (2065-2095)

Table 1: Climate data used for the assessment

Identification of hazards

Hazards were identified and documented in a risk register. This included hazards reported by Trinity House in previous rounds of reporting (ARP1 and ARP2). 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 new risks identified by experts in the risk assessment team, and through stakeholder engagement (i.e. with Trinity House 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 (Section 3 – Trinity House Climate Risk Register).

2.2 Risk Matrix

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

Risk Rating = Likelihood of occurrence * Magnitude of the impact

Likelihood description	Likelihood	Very Low (minimal) 1	Low (Minor) 2	Medium (moderate) 3	High (Major) 4	Very High (Catastrophic) 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)
	Impact	• 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.	• 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.	• 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.	• 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.	• 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.

Table 2. Risk matrix used for quantifying the risk of hazards (likelihood vs impact).

2.3 Observed Climate in the UK

2.3.1 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 strategic locations used in this assessment. Typical climate conditions for each of the five locations, based on observational data, are summarised in Figure 2.

Extreme weather hazards experienced in the UK are associated with acute events such as short periods of heavy rainfall and localised flooding, extreme hot temperatures and associated heat stress to plants and animals, 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.

2.3.2 Extreme weather events

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 for 2019 and 2020. For example:

- **Land temperature**: All the top 10 warmest years for the UK in the series from

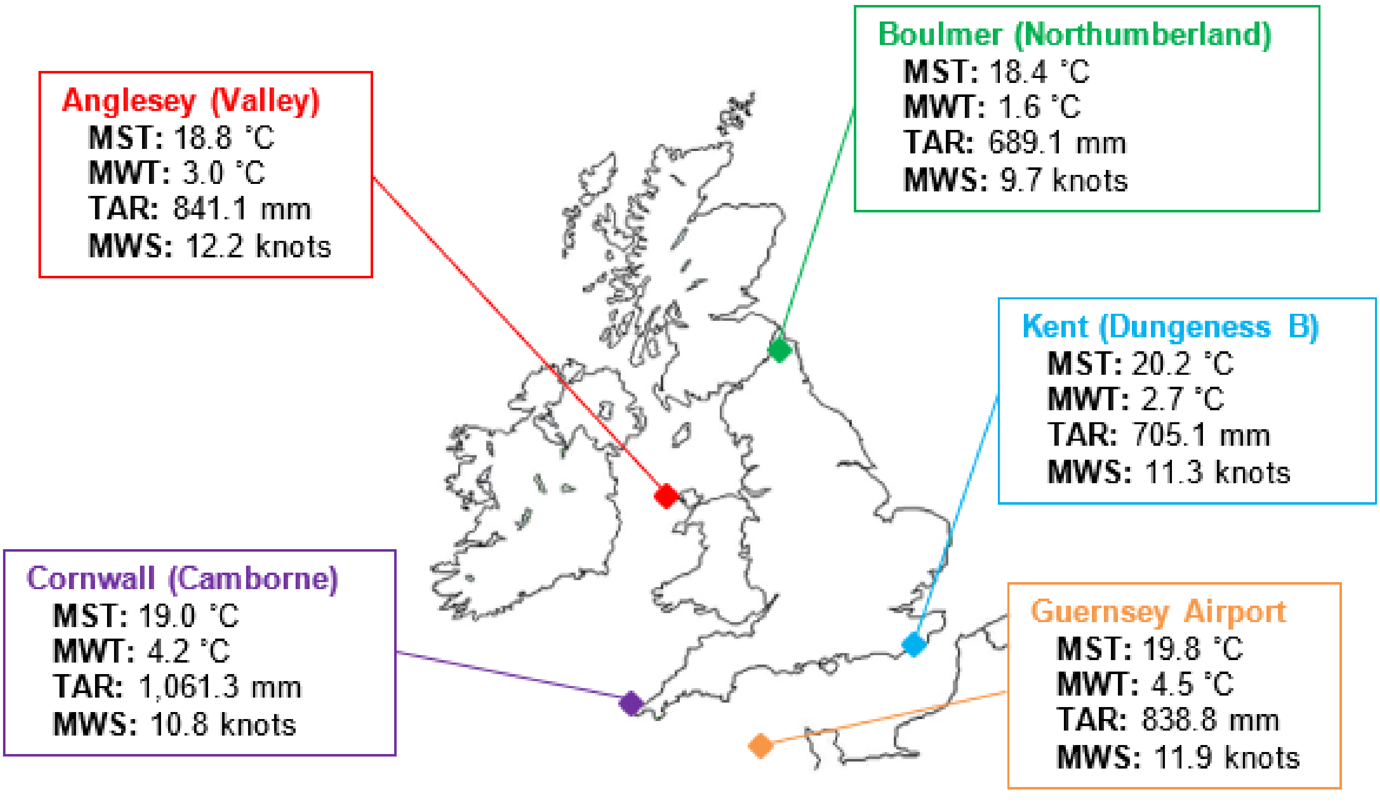


Figure 2: Shows a summary of the current climate in the UK for five locations (Anglesey, Cornwall, Kent, Boulmer and Guernsey) for key average climate variables throughout England, Wales and the Channel Islands (1981-2010) including maximum summer temperature (MST; ˚C), minimum winter temperature (MWT; ˚C), total annual rainfall (TAR; mm), and mean wind speed at 10m (MWS; knots). Data extracted from UKCP18

1884 have occurred since 2002.

- **Land temperature extremes**: Four national UK high temperature records were set in 2019, including a new all-time record (38.7°C), a new winter record (21.2°C), a new December record (18.7°C) and a new February minimum temperature record (13.9°C).
- **Near-coast sea-surface temperature**: Nine of the 10 warmest years for near-coast SST for the UK have occurred since 2002.
- **Precipitation**: Six of the ten wettest years for the UK in a series from 1862 have occurred since 1998.
- **Precipitation extremes**: February 2020 was the UK's wettest February and fourth wettest calendar month on record in a series from 1862.
- **Snowfall**: 2020 was one of the least snowy years on record.
- **Sunshine**: Spring 2020 was the UK's sunniest spring on record, and also sunnier than most UK summers.
- **Sea level change**: UK sea-level has risen by 16.5cm since the start of the 20th century.

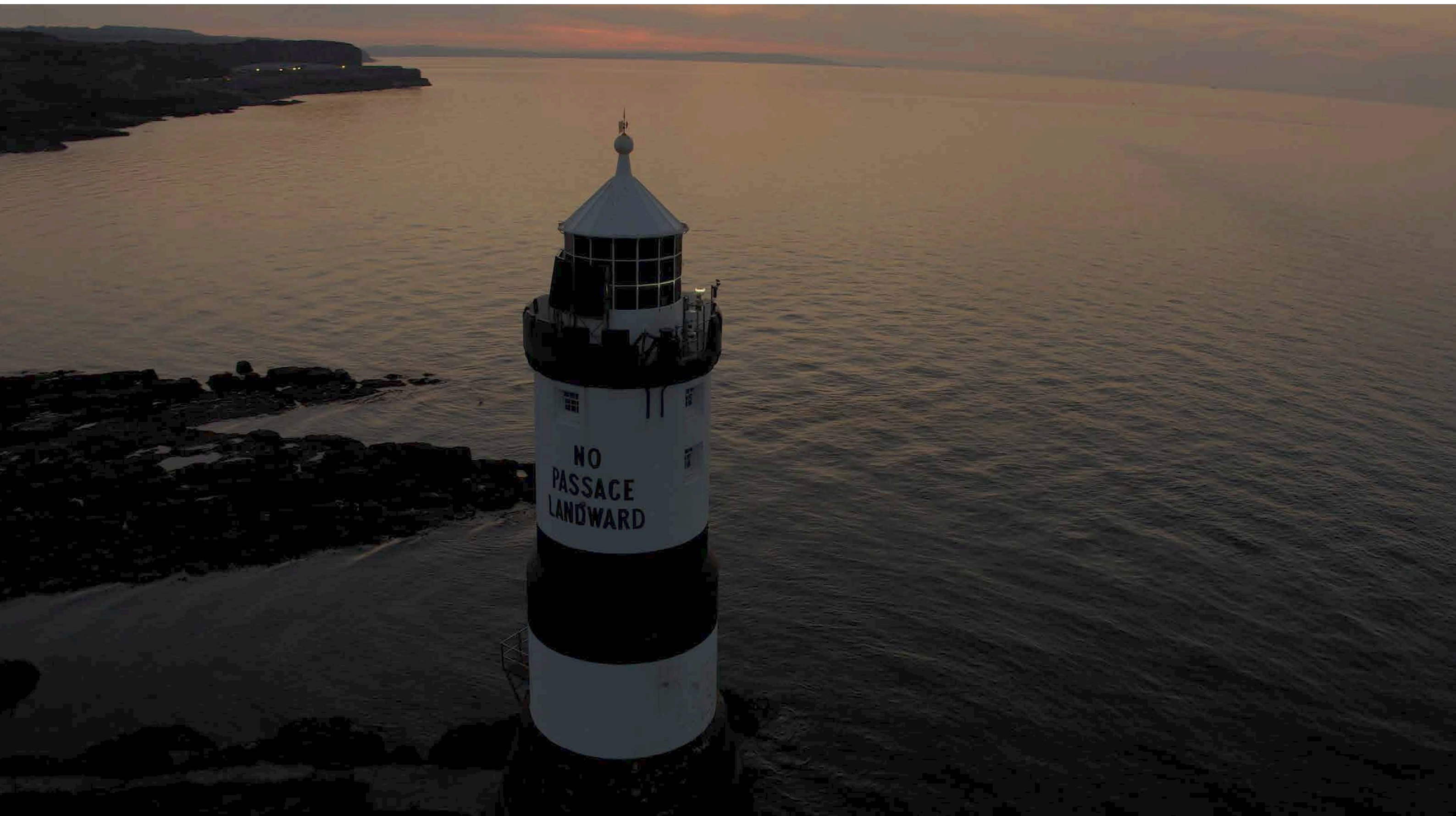
2.4 Climate Projections for the UK

The 2018 UK Climate Projections (UKCP18) provide the most up-to-date assessment of how the UK climate may change in the future. Overall, the probabilistic projections in UKCP18 show ranges that have a large overlap with those from UKCP09, but with some notable differences in the tails of the projected distributions. UKCP18 headline projections for the UK are outlined in sections 2.4.1 (land projections) and 2.4.2 (marine projections).

2.4.1 Land projections for the UK

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

By 2070, under the RCP8.5 high emission scenario, the low and high estimates (corresponding to 10% and 90% probability levels) show a temperature change of 0.7°C to 4.2°C (increasingly warmer) in winter, and 0.9°C to 5.4°C, in summer (increasingly hotter).



For precipitation, corresponding ranges of UK average changes are -1% to +35% for winter (increasingly wetter), and -47% to +2% for summer (increasingly drier).

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 low (<10%). The probability has already increased due to climate change and is now estimated to be between 10-20%. With future warming, hot summers by mid-century could become as common as one in every two years.

2.4.2 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 at 2100 under RCP8.5, relative to the 1981-2000 baseline, are estimated at 0.53-1.15m around London and 0.51-1.13m around Cardiff, with smaller increases expected in the north; 0.30-0.90m around Edinburgh.

Projections of average wave height in the 21st century suggest changes in the order 10-20% and a general tendency towards lower wave heights. Changes in extreme waves are also of order 10-20%, but there is little agreement in the sign of change among the model projections.

2.4.3 Local projections

Local climate projections were extracted for the five sites of focus in this risk assessment.

Figure 3 outlines the summary data for these locations. The data provided show the 50th percentile estimates.

Figure 3: 2080 Climate Change Projections for England and Wales (50th percentile)

Summer Mean Air Temperature (˚C)
+4.4

Winter Precipitation Rate (%)
+15.2

Summer Precipitation Rate (%)
-32.0

Min Winter Air Temperature (˚C)
+2.8

Max Summer Air Temperature (˚C)
+4.9

Winter Mean Air Temperature (˚C)
+2.8

3 TRINITY HOUSE CLIMATE RISK REGISTER

3.1 Overview of Trinity House Climate Risk Register

This section provides an overview of climate hazards that pose a risk to Trinity House. In total, 32 hazards were identified in the climate change risk assessment, affecting both physical assets and operational activities.

Risks (R#) were considered across four broad categories, which are detailed in sections 3.2 to 3.5 respectively: Sea Level Change (R01 to R07), Temperature Change (R08 to R15) and Multiple Variables (R16), Changing Precipitation Patterns (R17 to R24), and Storm Events (R25 to R32).

Each hazard was quantified to provide a risk score (likelihood vs impact) for each of the time horizons of focus (2025, 2050s and 2080s), which considered how the climate is projected to change under the RCP8.5 high emissions scenario.

The climate change risk assessment found that the inherent risk to Trinity House from a changing climate is expected to result in increasingly severe and costly impacts, with the risk severity of hazards becoming more pronounced in the latter part of the century, illustrated in Figure 4.

The assessment indicates that, under an extreme climate scenario (RCP8.5), and without new adaptation measures, the number of major and severe risks to Trinity House will double from 8 in 2025 to 16 in the 2050s, increasing to 20 major and severe risks projected in the 2080s.

Table 3 illustrates the distribution of hazards across the risk matrix for each time horizon. The tables show a general movement towards increasingly more severe risk ratings, associated with an increased likelihood and impact from each hazardous event.

This suggests that climate change and extreme weather events are exacerbating the scale of damage or disruption to Trinity House assets and operations from current conditions and will continue to worsen unless adaptive measures are taken.

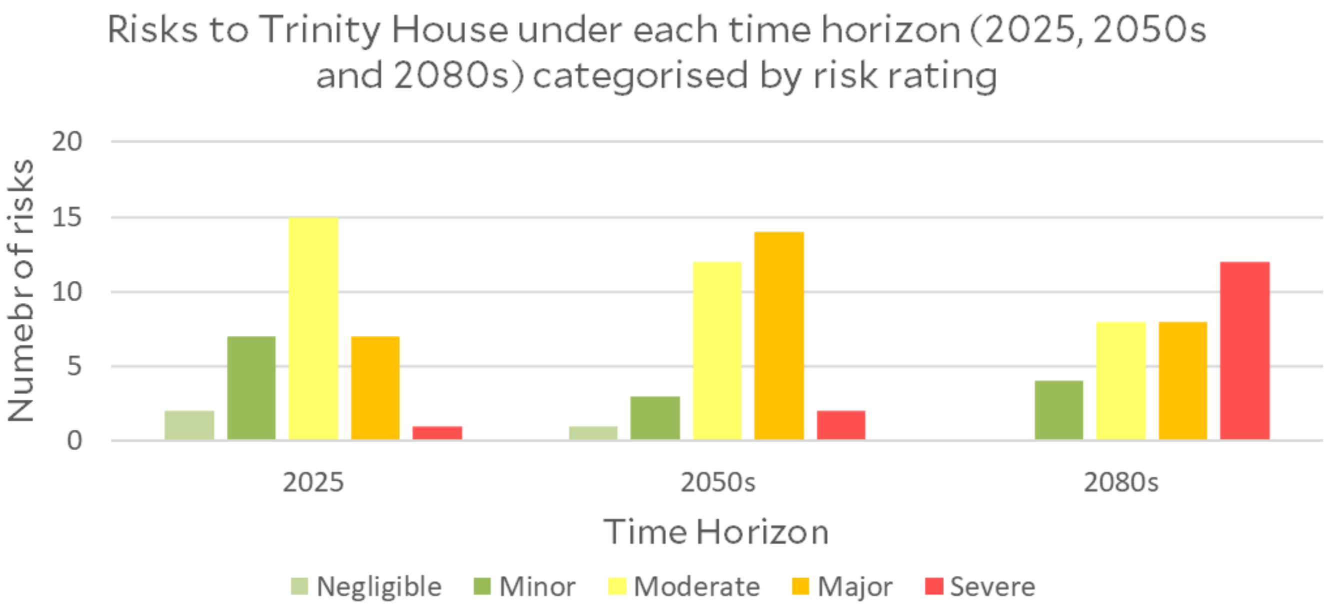


Figure 4: Risks to Trinity House, categorised by risk severity in 2025 and the 2050s and 2080s.

Table 3. Distribution of hazards across the risk matrix in 2025 and the 2050s and 2080s.

2025

Likelihood \ Impact	Very Low (minimal)	Low (Minor)	Medium (moderate)	High (Major)	Very High (Catastrophic)
Very High (Almost Certain)					
High (Likely)	R09	R30	R06, R32		R26
Medium (Possible)	R10, R15, R28	R23, R25, R31	R16, R18, R19, R29	R03, R05, R17, R27	R04
Low (Unlikely)	R08	R12, R22	R01, R02, R11, R20	R07, R13	R24
Very Low (Highly Unlikely)	R14			R21	

2050s

Likelihood \ Impact	Very Low (minimal)	Low (Minor)	Medium (moderate)	High (Major)	Very High (Catastrophic)
Very High (Almost Certain)			R06		
High (Likely)		R08, R09, R10, R30	R18, R19, R32	R03, R17, R27	R04, R26
Medium (Possible)	R15, R28	R12, R23, R25, R31	R16, R29	R01, R02, R05, R07, R11, R13, R20	
Low (Unlikely)	R14	R22		R21	R24
Very Low (Highly Unlikely)					

2080s

Likelihood \ Impact	Very Low (minimal)	Low (Minor)	Medium (moderate)	High (Major)	Very High (Catastrophic)
Very High (Almost Certain)			R09, R10, R32	R06, R18, R19	R03, R17
High (Likely)		R30, R31	R08	R20, R27	R01, R02, R04, R05, R07, R11, R26
Medium (Possible)	R15, R28	R12, R25	R16, R29	R13, R21	
Low (Unlikely)		R14, R23	R22		R24
Very Low (Highly Unlikely)					

3.2 Risks associated with Sea Level Change

There are a number of risks presented to Trinity House as a result of sea level rise, outlined in Table 4. 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 Trinity House 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 Trinity House services including asset maintenance and recovery (in the absence of power it would not be possible to charge electric boats), wreck location and marking, towing, buoy handling and surveying.

A further potential consequence of sea level rise is an increased risk of erosion to Trinity House 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 (as a result of 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.

ID	Risk Descriptor	2025	2050s	2080s
R01	Risk of damage to lighthouse assets or disruption to operations from coastal flooding.	Moderate	Major	Severe
R02	Risk of flooding or damage to lighthouse utilities infrastructure from coastal flooding.	Moderate	Major	Severe
R03	Risk of damage or flooding to depots/ offices from high tides and coastal flooding, particularly at Harwich.	Major	Major	Severe
R04	Risk of damage to, or loss of, Trinity pier and buoy yard from coastal flooding.	Major	Severe	Severe
R05	Risk of damage to lighthouse assets and infrastructure, including undermining of assets, from coastal erosion.	Major	Major	Severe
R06	Risk of damage to, or loss of, hard and soft sea defences around lighthouse assets from coastal erosion.	Major	Major	Severe
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

Table 4: Risks to Trinity House associated with sea level change (R01-R07)

3.3 Risks associated with Temperature Change

The risks identified as a result of temperature increase (outlined in Table 5) include the temporary potential for diminished staff health and wellbeing. This is likely to be brought about through increased heat and/or sun exposure resulting in human discomfort, heat stress, heat stroke, heat exhaustion, sunburn, and dehydration. In some offices, this risk is mitigated against through the use of air conditioning and the provision of drinking water, for example, however in other offices, and in lighthouses, this is not the case. The consequence of this is the potential for diminished efficiency and/or disruptions to service delivery.

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 Trinity House.

A further risk identified as a result of temperature increase includes the potential destabilisation of lighthouse asset foundations as a result of the shrink and swell of foundation soils. This is unlikely to significantly impact Trinity House assets, however there are a small number of lighthouses which may be at increased risk as a result of their position on shallow, cohesive, or shrinkable geology. In either case, the shrink and swell of building components is 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, giving false information to the mariner. 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).

Multiple variables

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.

ID	Risk Descriptor	2025	2050s	2080s
R08	Risk of overheating in offices/depots during summer hot days and heatwaves, potentially causing heat stress for employees in non-cooled environments.	Negligible	Moderate	Major
R09	Risk of overheating in lighthouses during summer hot days and heatwaves, potentially causing uncomfortable conditions for maintenance operators.	Minor	Moderate	Major
R10	Risk of overheating or uncomfortable working conditions during summer hot days and heatwaves for employees working in non-cooled environments at residential properties.	Minor	Moderate	Major
R11	Risk of power, electricity, IT and Comms disruption on summer hot days and heatwaves associated with overheating of infrastructure.	Moderate	Major	Severe
R12	Risk of damage to lighthouse assets associated with the destabilisation of asset foundations due to the shrink and swell of soils in extreme temperatures.	Minor	Moderate	Moderate
R13	Risk of shrink and swell of building infrastructure during extreme temperatures, causing the expansion and contraction of building components.	Moderate	Major	Major
R14	Risk of increased maintenance requirements associated with warmer marine temperatures increasing marine growth on buoys, landing slips and piers.	Negligible	Negligible	Minor
R15	Risk of increased maintenance requirements associated with increased plant/weed growth during a longer growing season.	Minor	Minor	Minor
R16	Risk of international supply chain issues associated with interacting and cascading risks resulting from global extreme weather events.	Moderate	Moderate	Moderate

Table 5: Risks to Trinity House associated with temperature change (R08-R15) and multiple variables (R16)

3 .4 Risks associated with Changing Precipitation Patterns

The risks to Trinity House as a result of changing rates of precipitation are outlined in Table 6.

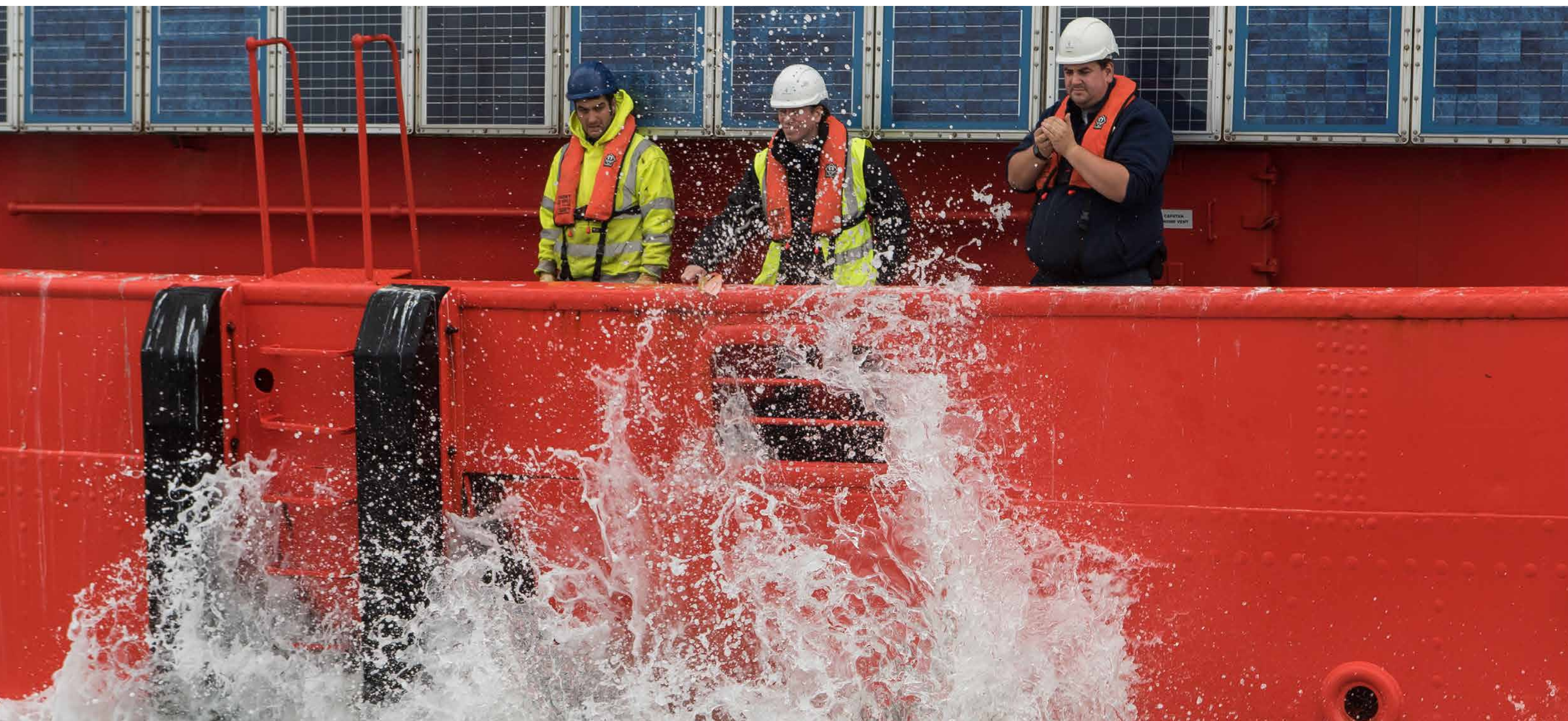
Trinity House has four main offices/depots: London, Harwich, St Just, and Swansea. Current flood maps indicate that the risk of flooding from 'rivers and the sea' is very low risk at Trinity House's London, St Just and Swansea sites (each year these areas have a chance of flooding of less than 0.1%, or 1 in a 1000), and low risk at Harwich risk (each year this area has a chance of flooding of between 0.1% and 1%). It is noted that these risk values consider the effect of flood defences that 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 Trinity House Harwich office is at the most risk of fluvial flooding. Sited on the edge of an estuary with the River Stour to the West 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 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 Trinity House 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 severe by 2080.

Again, this also has the potential for indirect



risks to Trinity House as a result of power and communications failures.

In addition to the risk of fluvial and pluvial flooding to Trinity House assets, changing rates of precipitation are also projected to contribute towards other extreme events including blizzard conditions. Such conditions have the potential to temporarily limit lighthouse visibility and result in increased risk to human health (both on land and at sea). Limited visibility may hinder access to landing infrastructure and increase the rate of collisions at sea. One of the consequences of this includes the additional operational requirements which may be necessary, including those relating to the marking of wrecks etc.

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 result in the failure of some AtoN. The risk of accidents and/or damage or disruption to equipment brought about by cold events including snowfall is likely to decrease.

ID	Risk Descriptor	2025	2050s	2080s
R17	Risk of damage to depots/offices from fluvial (river) flooding associated with heavy rainfall events and high river flows, particularly at Harwich.	Major	Major	Severe
R18	Risk of damage to depots/offices from pluvial (surface water) flooding associated with heavy rainfall events.	Moderate	Major	Severe
R19	Risk of damage to lighthouses from pluvial (surface water) flooding associated with heavy rainfall events.	Moderate	Major	Severe
R20	Risk of flooding or damage to utilities infrastructure from pluvial and fluvial flood events, causing power, IT and Comms disruption.	Moderate	Major	Major
R21	Risk of damage to lighthouse from erosion and slope or embankment failure associated with heavy rainfall events and high winds.	Minor	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	Minor	Moderate
R23	Risk of accidents to staff and damage or disruption to equipment associated with cold events and snowfall.	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

Table 6: Risks to Trinity House associated with changing precipitation patterns (R17-R24)

3.5 Risks associated with Storm Events

The risks to Trinity House from storm events (outlined in Table 7) 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. Storm surges are likely to occur relatively infrequently but have significant impact when they do 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, including the failure of AtoN due to damage or loss. Other disruptions to service include a potentially diminished 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 Trinity House 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 panels which are critically important to the function of Trinity House, particularly during extreme weather events.

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 the helicopter with other GLAs.

Subsequently, when storms do occur during a time in which the helicopter is scheduled for use by Trinity House then this can present significant logistical and cost challenges (particularly in such instances as when alignment is required with a Trinity House vessel).

3.6 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 5 outlines a system map for the key

Photo by Ryan Palmer

risks to Trinity House and how these interact, considering climate drivers, hazardous events, impacts and consequence to Trinity House. Key interacting risks include 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 Trinity House, one key cascading risk influenced by a range of risk pathways relates to the failure of national infrastructure. In particular, the risk to power and thus telecommunications infrastructure from sea level rise, temperature, and precipitation change, which has the potential to significantly limit awareness of lighthouse faults and remote connections, as well as cause temporary disruption to services (potentially arising from the inability to charge electric vessels, for example).

ID	Risk Descriptor	2025	2050s	2080s
R25	Risk of damage to lighthouses, lightvessels and buoys associated with storm surges and coastal flooding.	Moderate	Moderate	Moderate
R26	Risk of damage to depots/offices associated with storm surges and coastal flooding.	Severe	Severe	Severe
R27	Risk of disruption to services and AtoN failure associated with storm events.	Major	Major	Major
R28	Risk of disruption to services (e.g. surveys and maintenance of assets) associated with high winds and rough seas.	Minor	Minor	Minor
R29	Risk of damage to lighthouse assets and infrastructure due to erosion and damage from high winds and rough seas.	Moderate	Moderate	Moderate
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	Moderate	Moderate
R31	Risk of structural damage to lighthouses and depots (e.g. roofing materials) from high winds.	Moderate	Moderate	Moderate
R32	Risk of disruption to air services where strong winds prevent use of helicopters to access sites.	Major	Major	Major

Table 7: Risks to Trinity House associated with storm events (R25-R32)

Interacting and Cascading Risks

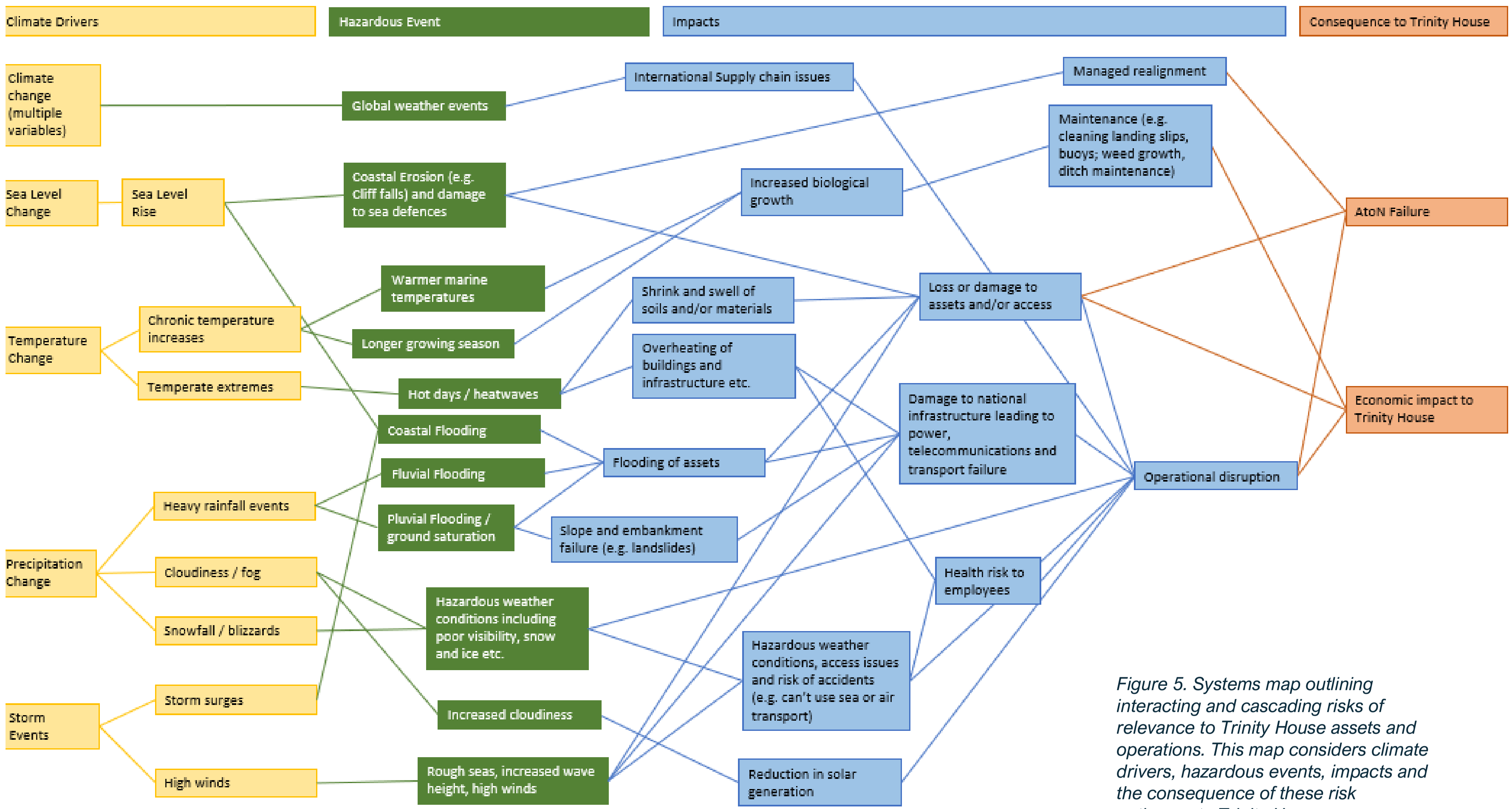


Figure 5. Systems map outlining interacting and cascading risks of relevance to Trinity House assets and operations. This map considers climate drivers, hazardous events, impacts and the consequence of these risk pathways to Trinity House.

4 ADAPTING TO CLIMATE CHANGE

4.1 Approach to adaptation

The Independent Assessment of UK Climate Risk Advice to Government for the UK's Third Climate Change Risk Assessment (CCRA3) (Climate Change Committee June 2021) provides key principles for good adaptation. Of particular relevance for Trinity House are:

- Integrate adaptation into other policies
- Adapt for 2ºC; assessing risk for 4ºC rise in global temperature
- Prepare for unpredictable extremes
- Assess interdependencies
- Consider opportunities
- Consider funding and resourcing.

This is the approach taken when examining each of the key climate hazard risks:

- sea level change
- temperature change
- precipitation change
- change in storminess.

Key commitments from Trinity House's Health, Safety and Environmental Objectives Policy include:

- Protect the environment including prevention of pollution.
- Heighten environmental consciousness among employees, 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 its operations on climate change.
- Ensure that its operations and estate are able to adapt to climate change, where possible, and that, the need for adaptation to climate change is built into its 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.

Natural, human, and engineering systems are fundamentally interlinked in delivering infrastructure adaptation. Considering assets as systems is essential to achieve appropriate resilience.

Adaptation must consider changes in navigation needs and continuing developments in technology.

4.2 Proposals and policies for adapting to climate change

Trinity House holds a detailed risk register for each asset. This register is used to identify and rank site specific risks, which are then put into the broader context of the site's operational requirements, and any planned obsolescence. Through this process Trinity House is able to identify which trends pose a critical risk to our operation and develop adaptation pathways to mitigate these risks.

4.2.1 Sea Level Change

Lighthouses must be positioned in such a way as to provide AtoN in often challenging terrain. As a result of this, lighthouses are situated in a diverse range of locations - cliff tops, river inlets, sand spits. Indeed, some of Trinity House's stations are situated at sea level, fully exposed to significant wave action.

The diverse nature of Trinity House's asset profile requires a site-specific assessment of asset specific risks.

For assets at sea level there is a structural risk to the asset as it could be undermined, flooded, or damaged by wave action. Some Trinity House assets, e.g. Hurst point lighthouse section 5.2, are reliant on coastal defences maintained by third parties. If these are altered or fail, there is potential for accelerated change.

Geological issues also need to be considered. The rate of cliff erosion is likely to increase due to more extreme conditions. Therefore, the examination of cliff top structures is important and should include assessment of all system assets including utilities and communications.

Detailed planning is then undertaken to understand vulnerabilities at each site and to inform site by site adaptation requirements. This would be carried out in conjunction with a budget plan for additional adaption trials and investment to avoid reactive responses which would likely incur greater expense.

4.2.2 Temperature Change

The cooling/heating of assets needs to be considered with extreme temperatures more likely. Improvements to ventilation and heating should be considered to reduce the extremes that may impact the operative in the case of a manned assets, such as depots and offices. For unmanned assets, the effectiveness of the components should be considered.

For a manned asset, or one where the temperature changes could make maintenance periods insufficient in the summer or winter, further automation and improvements to remote monitoring may be explored e.g. new and improved sensors to improve efficiency of site visits and maintenance.

Within glass structures, temperature extremes are likely and may result in damage to assets. In these situations, active or passive cooling systems may be explored on a site-by-site basis e.g. reflective coatings, shutters, or cladding, to reduce the temperatures within the building. In terms of utilities, it is necessary to plan for redundancy and resilience including appropriate power backup, communications, and monitoring.

4.2.3 Precipitation Change

Increased precipitation may cause flooding of assets including offices, workshops, and buoy depots. The risk of pluvial and fluvial flooding on these assets should be assessed and adaptation works built where necessary.

Some remote assets rely on rainwater harvesting. If there is a persistent reduction in precipitation long term, this may lead to a lack of water resources and so it is important to plan for redundancy and resilience.

4.2.4 Change in Storminess

Changes in storminess may have an impact on the condition of assets due to the increase in asset deterioration. It is important, therefore, that the frequency, data attributes and process for asset inspection is well defined and recorded. The capture and analysis of work order information is also important to assist quantification of risk and support the formation of risk-based maintenance and asset design.

Increased storminess may also impact on the available maintenance periods and this should be kept under review.

Increased frequency and intensity of storms could impact on the structural integrity of some assets. Whilst many assets will include considerable redundancy, these risks should be kept under review. Indeed, mitigation is already underway at many of Trinity House's sites, including the fitment of lightning suppression components and lightning tapes.

4.2.5 Other

There are also a variety of other risk areas to consider including:

- Consider reliability and resilience of third-party systems e.g. communications etc. and potential implications of failure.
- Understand any critical supply chains. Store any items which could be in high demand and/or reduced availability in extreme events or longer periods.
- Consider the impact on the workforce and ability to respond in severe events.
- Consider interaction with other events e.g. pandemics, staff availability.
- Other uncertain or indirect impacts such as increased accelerated low water corrosion due to higher sea water temperatures.
- Given the severe natural environment for many assets introduce new technology carefully ensuring that appropriate testing has been undertaken.
- Generally, these risks can be managed through additional system redundancy and appropriate monitoring.

4.2.6 Opportunities

The following opportunities will be considered:

1. Improving efficiency

- Reduce energy demands through efficient lighting.
- Opportunity for increased use of solar power.

2. Benefit to utilising property to encourage diversification e.g. holiday cottages, camping due to warmer UK summers.

Communication and connection

Further develop links into other organisations such as Environment Agency and the Met Office to inform risks. Seek to better understand cascade risks associated with telecommunicates failure and develop a strategy to ensure resilient communications provision.

Monitoring

Set up system of monitoring objectives to assess the impact and adaptation of climate change aspects. Use the monitoring to feed back in to review and improve adaptation plans.

4.3 Uncertainties and assumptions

There are many uncertainties relating to the impact of climate change. The most applicable to Trinity House being the impact of climate change on offshore environmental conditions.

The confidence in the effect of climate change on offshore environmental conditions, including wave heights, is low according to the UKCP18 Marine Report[1] (Palmer et al., 2018). Therefore, planning for offshore structures would need to take this into consideration, with asset management plans identifying longer range risks that go beyond our current 20-year horizon.

4.4 Barriers and interdependencies

4.4.1 Barriers to Adaption

Funding

Implementing adaptation activity in which significant capital expenditure will be needed, requires Department for Transport approval. This would be sought as part of the agreed corporate planning process and the development of the 5-year Corporate Plan. The impact in terms of planning will be mitigated as far as reasonably possible through the

1 www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Marine-report.pdf

arrangements described in Section 3.1 above.

The AtoN estate is in robust order and it is not considered that significant adaptation funding will be required in the short term. Longer term, it is not currently possible to provide a realistic estimate of the cost of implementing adaptation measures required as a result of climate change. This will however be kept under review and the DfT will be kept informed as part of the normal corporate planning process.

Consents

For certain assets, the land on which they lie is leased and any demolition/reconstruction would be subject to the consent of the landlord (public or private) to discharge appropriate duties. In addition to this, where an asset lies within the jurisdiction of another Authority, it may also be applicable to work with them to ensure any proposed works do not adversely affect the other assets or result in maladaptation.

The approach of public bodies such as the Environment Agency, Historic England/CADW, Natural Resources Wales, Natural England, and Local Planning Authorities, have a significant potential to impact upon the ability of Trinity House to adapt to Climate Change.

Similarly, the environmental, planning, listed building and conservation law, directives, and policy that these bodies interpret and implement and enforce also has a significant potential to impact upon the ability of Trinity House to adapt to Climate Change. Most of the Lighthouses are listed buildings in designated habitats and the designations of further areas is currently under consideration. Any adaptation works would need to meet the requirements of the relevant regulatory bodies. Early consultation with relevant organisations on proposals will be essential to overcome any such potential barriers. Consultation already takes place with these bodies.

4.4.2 Management

Effective adaptation to climate change risk is achieved through proactive management and detailed planning. Taking a systems approach ensures that the complexity and interdependencies are understood, and appropriate plans put in place to mitigate risk

Navigational needs, technological developments and climate change will continue to evolve, and the assessments will be updated to reflect this process.

5 CASE STUDIES

5.1 Crow Point Lighthouse, Devon

Crow Point Lighthouse was built as an unmanned structure in 1954 as a guide to vessels navigating the Taw and Torridge estuary in North Devon.

Crow Point Lighthouse is a small lattice steel structure with the light just 7.6 metres above Mean High Water. Originally powered by acetylene gas, Crow Point Lighthouse was converted to electrical operation in 1978 and then solar power operation in 1987.

The lighthouse is situated on a sand spit which is moving and eroding quickly. This has resulted in the lighthouse and the rock armour, on which it sits, becoming an island at high tide, which makes completing appropriate maintenance challenging.

The Environment Agency is exploring the viability of future maintenance of the rock armour along the spit. This was part of an annual process of re-positioning rocks that had moved, the spit was breached soon after this. Continued breaches at this site are likely to occur, this increases the risk of further spit erosion and places the future of this site at risk. As a result of this Trinity House is actively considering alternative arrangements to ensure continuous aid to navigation provision in the Taw and Torridge estuaries.

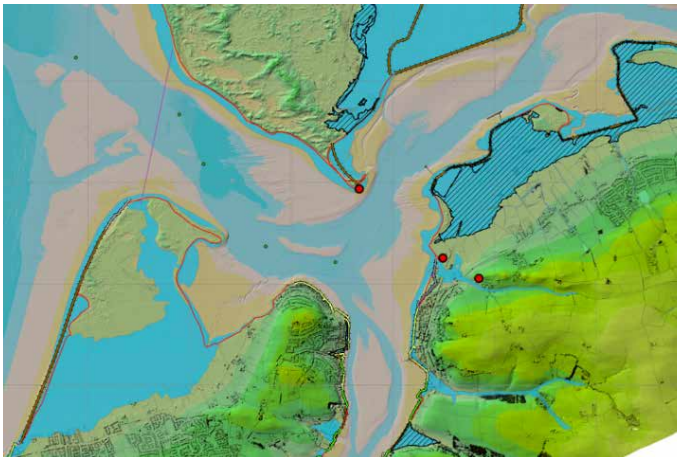
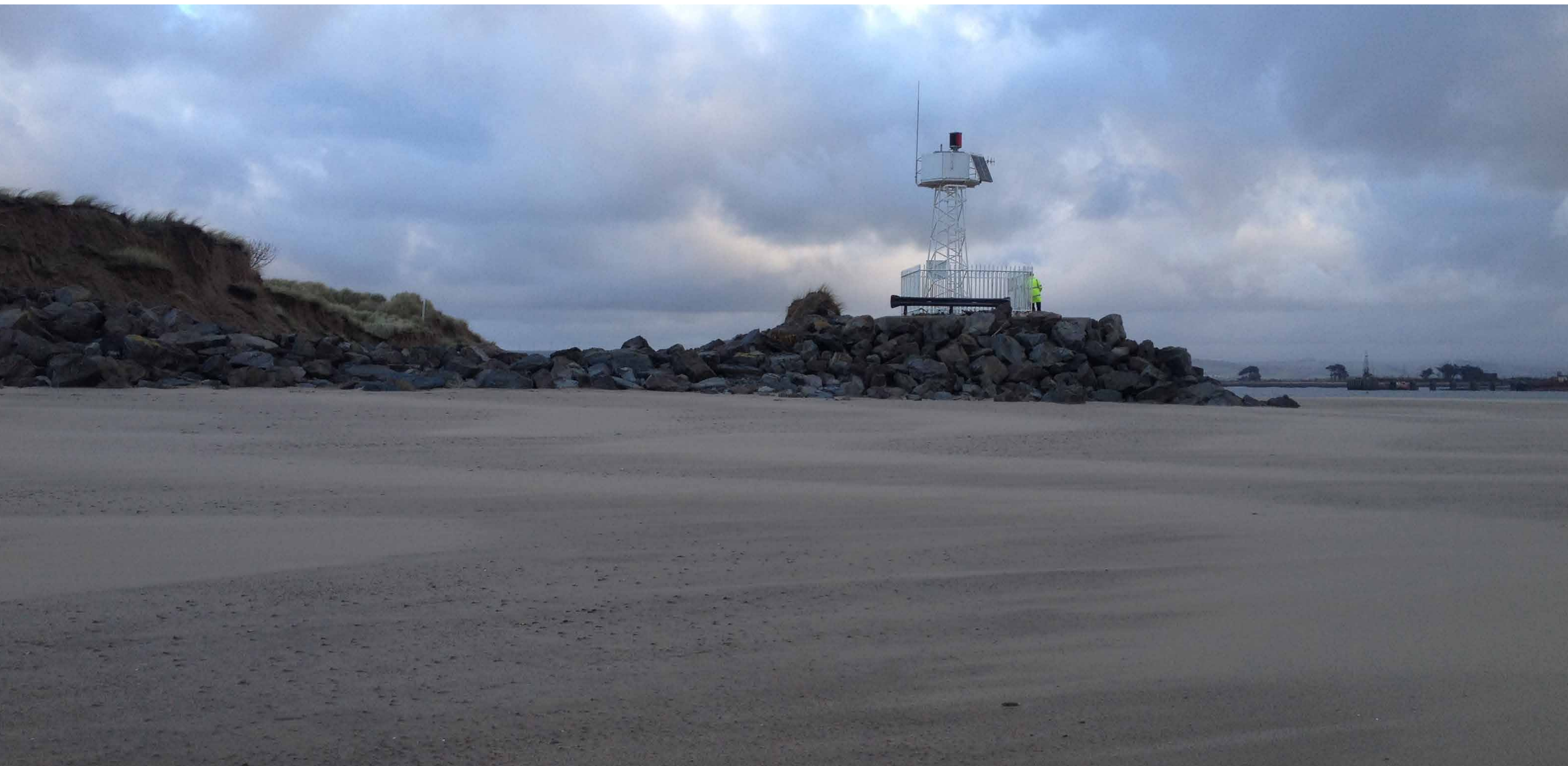


Figure 6: Topographic map showing flood risk (blue) and coastal defences (coloured lines) and areas benefitting of the defences (hatched).



5.2 Hurst Point Lighthouse, Solent

Hurst Point Lighthouse was built by Trinity House in 1867 to guide vessels through the hazardous western approaches to the Solent.

Following a growth in the volume and diversity of traffic using the Needles Channel, a major modernisation of Hurst Point High Lighthouse was completed in July 1997. After extensive consultation with the maritime community, high-intensity projectors (port entry light) were installed which are exhibited day and night to mark the channel between the Needles and the Shingles Bank. The projectors, sited in the service room below the lantern of the lighthouse, provide an accurate system of red, green, and white directional lights giving precise cut offs over narrow arcs of. The lighthouse is now monitored and controlled from Trinity House's Planning Centre in Harwich, Essex.

Both Hurst Point Lighthouse and the nearby Hurst Castle are protected by a series of coastal defences arranged along a spit. Storm activity recently overwhelmed these defences, resulting in significant damage to the nearby Hurst Castle (Figure 7).

The Environment Agency is currently carrying out a review of the future of flood defences at Hurst spit. The results of this review are likely to have far-reaching implications for Trinity House and the way Hurst Point Lighthouse is managed.

Figure 7: Impact of storm events of Hurst Castle.

5.3 South Stack Lighthouse, N. Wales

South Stack Lighthouse was built by Trinity House in 1809, marking an islet off Holy Island, itself off Anglesey, at the northwest tip of Wales.

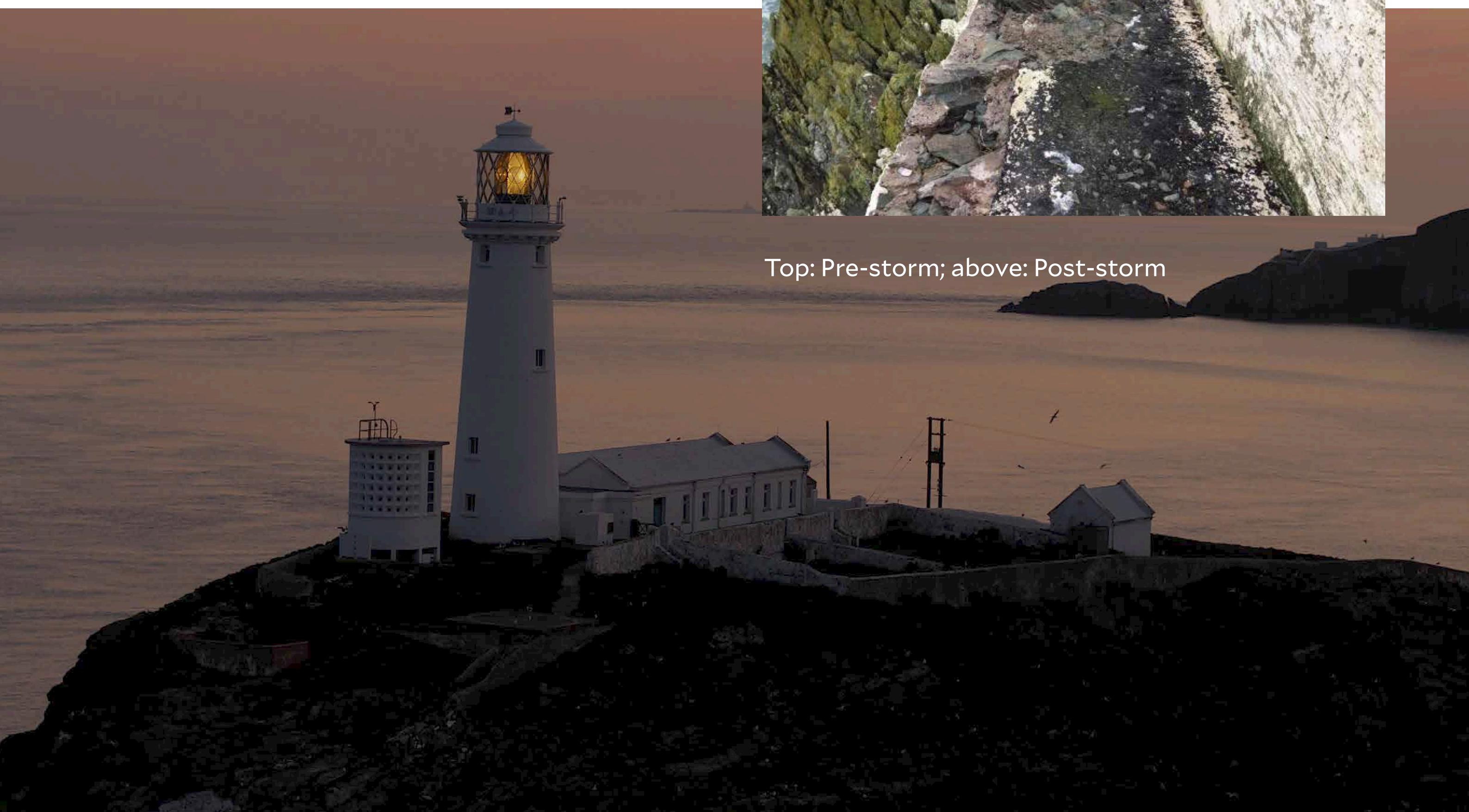
South Stack Rock lies separated from Holy Island by 30 metres of turbulent sea, surging to-and-fro in continuous motion. The coastline from the breakwater and around the southwestern shore is made of large granite cliffs rising sheer from the sea to 60 metres.

The station was electrified in 1938 and automated in 1984 when the keepers were withdrawn. The lighthouse is now monitored and controlled from Trinity House's Planning Centre in Harwich, Essex.

In 2017 South Stack Lighthouse was impacted by winter storms which resulted in damage to an listed structure. This site had remained largely untouched by storms throughout the site's history however, the unpresented severity of the 2017 storms led to significant damage to this site.

We anticipate that damage of this nature is likely to increase into the future and Trinity House is integrating this into its asset planning process.

Top: Pre-storm; above: Post-storm



6 MONITORING AND EVALUATION

6.1 Overview

Whilst the risks from climate change remain sufficiently mitigated at present, the impact will become more significant in the future. The production of this Round 3 report has refreshed the focus on the possible areas of impact in the years ahead, together with those areas where a greater degree of monitoring will be required. These will be woven into the asset planning and investment process to support delivery of the Trinity House 20-year strategy.

6.2 Approach to Monitoring, Evaluation & Intervention

Trinity House maintains a robust risk framework which provides the mechanism to identify, evaluate, own, control, mitigate and monitor risks. This includes a series of risk registers that conflates identified departmental risks into organisational risk and finally into corporate risk. Within this process, a league table of prioritised interventions is created to inform the 20-year strategy. The rolling 20-year strategy is reviewed annually and updated to reflect any changes to risk levels and associated interventions.

6.3 Drivers

The Trinity House Environmental Working Group (EWG) considers and reviews the aspects and impacts (the 'Drivers') affecting the organisation. These are added to the Aspects and Impacts Register (A&IR) where they are assigned a risk rating based on likelihood and impact. We are exploring how we can reshape our A&IR to better include climate change risks. The most significant aspects and impacts are then identified based on this scoring and are communicated to staff. This is the stage at which they are added to the departmental risk registers.

In this way the risks and objectives set out in this Climate Change Adaptation report, including the accompanying Climate Change Risk Assessment, will be reviewed at various levels and, ultimately, by the Executive Committee.

6.4 Objectives

Under the 2008 Climate Change Act, the UK Government is required to complete a climate change risk assessment (CCRA) every five years, with the third CCRA due in 2022. The outputs from the ARP form a vital component of this CCRA, allowing the Government to assess the preparedness of the reporting organisation.

To allow Defra to assess Trinity House's position and commitment to adaptation, Trinity House has developed a series of SMART performance indicators to measure its resilience against the identified major and severe hazardous events.

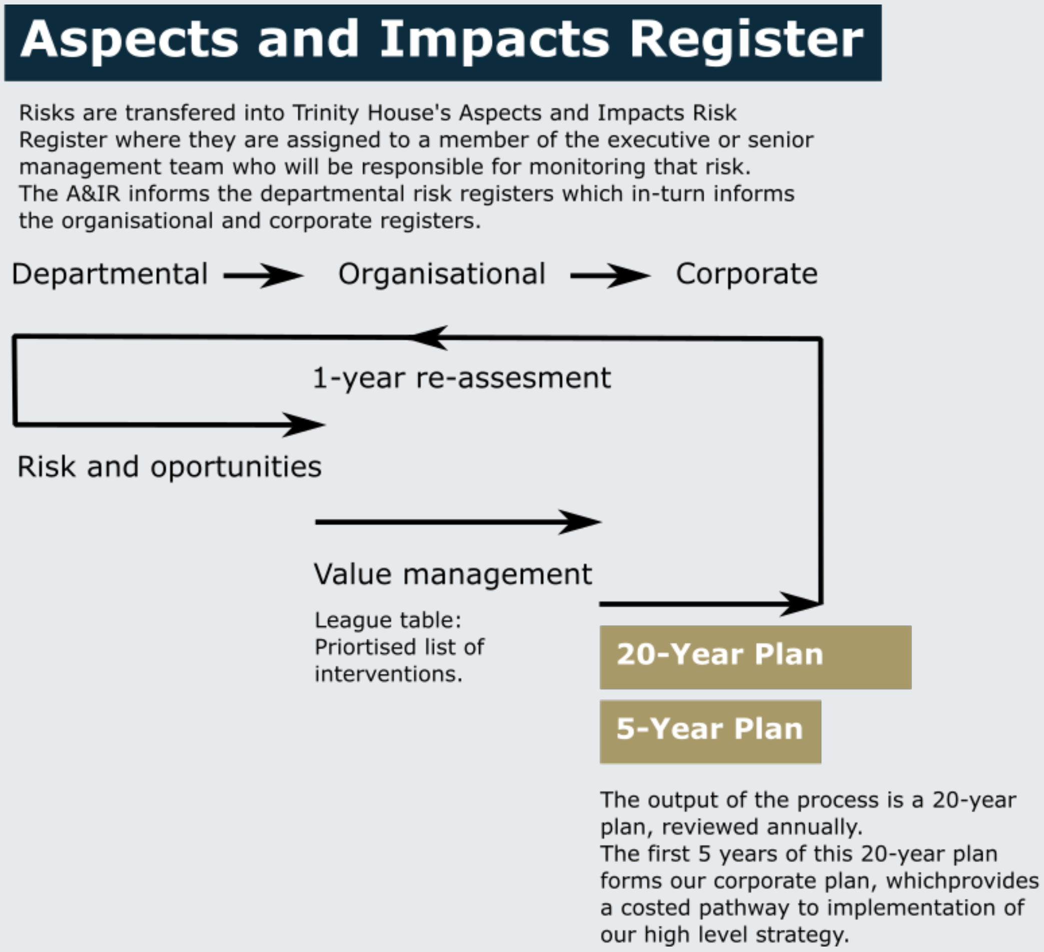


Figure 7: Trinity House Investment Planning Process

TRINITY HOUSE CLIMATE CHANGE ADAPTATION OBJECTIVES

Risk	Codes	Objective	Owned / Monitored by
Coastal flooding	R01, R02, R03, R04, R07, R26	Trinity House 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, Trinity House will take action to mitigate this as appropriate. e.g. Trinity House will carry out routine inspections to assess the condition and long-term viability of Harwich Pier.	Board Executive O&M by Director of Operations.
Fluvial (river) flooding	R17	Trinity House 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 Trinity House will take action to mitigate this as appropriate to the site in question.	Board Executive O&M by Director of Operations.
Pluvial (surface water) flooding	R18, R19	Trinity House 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 Trinity House will take action to mitigate this as appropriate to the site in question.	Board Executive O&M by Director of Operations.
Coastal erosion	R05, R06, R07	Adaptation options will be evaluated through Trinity House'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.	Board Executive O&M by Director of Operations & Director of Navigational Requirements.
Extreme hot days and heatwaves	R11, R08, R09, R10	Our internal analysis suggests that circa 90% of work force located in coastal locations or on-board ship where conditions are more temperate. Trinity House will continue to monitor climate change predictions and implement additional measure as necessary, including revised working patterns, cooling systems, and reflective coatings.	Board Executive O&M by Director of Operations & Director of Business Services.
Poor conditions on land and/or sea	R30	To ensure continuity of service Trinity House will explore enhanced long-term storm forecasting to enable us to better schedule maintenance works around adverse weather conditions.	Board Executive O&M by Director of Operations.
Wind damage to assets	R31	Updated climate projections from this report will feed into our asset planning cycle which will ensure that our sites are appropriately adapted, and that Trinity House have appropriate funds and insurance to enable these works.	Board Executive O&M by Director of Operations.
Shrink and swell of infrastructure and assets.	R13	Monitoring of individual sites and assets will be explored where this poses a significant risk. This will be identified through Trinity House's asset planning cycle.	Board Executive O&M by Director of Operations.
Strong winds preventing use of helicopters	R32	Through TH's existing business planning systems, we aim to schedule our major maintenance in periods where historic weather conditions have been favourable. Moving forward we are working to understand the potential for long-term storm forecasting is being explored to enable us to better schedule maintenance works around adverse weather conditions.	Board Executive O&M by Director of Operations.

Strong winds, heavy rain, and rough seas	R27	Through Trinity House's asset management process, Trinity House assess 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.	Board Executive O&M by Director of Operations.
Fluvial and pluvial flood events	R20	Trinity House potential for fluvial and pluvial flooding events to impact utilities providers, causing interacting and cascading risks for Trinity House is currently managed through site back-up power supplies, and appropriate stocks of strategic/critical items.	Board Executive O&M by Director of Operations.
Erosion and slope or embankment failure	R21	Cliff and beach monitoring will be implemented, where a short-medium term risk is identified, Trinity House will review how to meet the navigational requirement locally through existing floating and fixed AtoN and/or additional floating or fixed AtoN.	Board Executive O&M by Director of Operations & Director of Navigational Requirements.

7 CONCLUSIONS

This round of climate change adaption reporting has afforded Trinity House a greater insight into its understanding of the magnitude of our climate related risks and how they propagate towards the 2080-time horizon used in this work.

From Figure 8 it is clear that the overall severity of the risks Trinity House faces as an organisation are set to increase into the future.

To ensure that Trinity House has adaptation pathways to manage these risks and ensure continuation of service to its end users, Trinity House aims to further embed this information into its corporate risk register and continue to assign ownership of these risks to individuals with the appropriate authority and experience to act on them.

With respect to the variables which contribute towards the risks to which Trinity House may be subject, sea level rise contributes towards a variety of significant risks. Indeed, all risks (R01-R07) associated with sea level rise are categorised as being severe under the 2080-time horizon, with R04 reaching this category under the 2050-time horizon.

Temperature change presents, broadly speaking, less significant direct risk, although the general trend over time continues to increase in terms of significance. However, R11 (the risk of power, electricity, IT and Comms disruption on summer hot days and heatwaves associated with overheating of infrastructure) is categorised as 'severe' under the 2080-time horizon, with R08-R10 and R13 being categorised as 'major' for the same period.

Regarding precipitation rates, an increase during the winter months presents a significant challenge to Trinity House, with the greatest risks being R17, R18 and R19 which are categorised as 'severe' under the 2080-time horizon. There were no significant risks identified with respect to reduced rates of precipitation during the summer months and the only major opportunity identified (where the risk level decreases from its current category) is that associated with accidents to staff and damage or disruption to equipment associated with cold events and snowfall, which are projected to become less frequent in the future.

The evidence-base for whether UK storminess will change remains weak and has been identified by the Climate Change Committee as a priority area for future research. With that said, it should be acknowledged that whilst the evidence for storminess remains weak, the risks associated with changes in regional

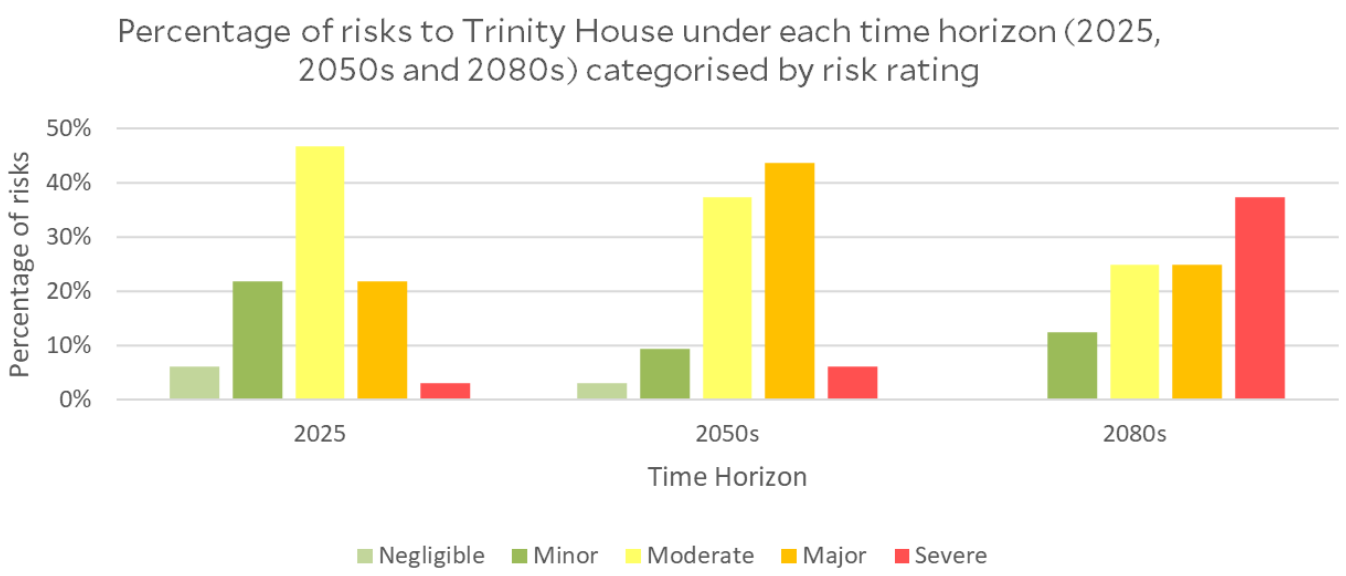


Figure 8: Changing distribution of climate risks from 2025 - 2080

atmospheric pressure, when combined with other hazards/variables, may lead to an increase in the intensity of individual storm events. An example of this would be the combination of sea level rise and regional atmospheric pressure at sea level which may result in more extensive coastal flooding.

Interacting risks are included within the systems map of interacting and cascading risks outlined in Figure 5. As this figure shows, risks are rarely the result of a single variable and can frequently be the consequence of multiple and/or interacting risk pathways.

APPENDIX A: TRINITY HOUSE ASSETS

Region		Lighthouses	Lightvessels
England	North West	St. Bees Lighthouse Hilbre Island Lighthouse	
	North East	Heugh Hill Lighthouse Guile Point Lighthouse Bamburgh Lighthouse Farne Island Lighthouse Longstone Lighthouse Coquet Lighthouse Whitby Lighthouse Flamborough Head 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 Lighthouse Instow Front Lighthouse Instow Rear Lighthouse Hartland Point Lighthouse Trevose Head Lighthouse Godrevy Lighthouse Pendeen 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 Longships Lighthouse	Sevenstones Lightvessel
	South East	North Foreland Lighthouse Dungeness Lighthouse Royal Sovereign 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	

APPENDIX B: METHODOLOGY FOR RISK ASSESSMENT

Climate data

This climate change risk assessment employed the findings of the Inter-Governmental Panel on Climate Change Sixth Assessment Climate Change 2021: The Physical Science Basis report, and the UK Climate Change Risk Assessment 2017 Evidence Report, together with the climate projections extracted from the 2018 UK Climate Projections (UKCP18) climate analysis tool, part of the Met Office Hadley Centre Climate Programme.

The UK Climate Projections (UKCP) provide a current assessment of how the UK climate may change in the future. The projections published in 2009, UKCP09, were extensively used by organisations to assess climate impacts on their assets and operations and formed the basis of previous risk assessment and adaptation reporting under Defra's first and second round of ARP. UKCP09 used the SRES (Special Report on Emissions Scenarios) emissions scenarios from the IPCC's fourth assessment report (AR4). In 2018, the climate projections were updated by the Met Office.

Probabilistic climate projections

UKCP18 specifically employed the future probabilistic (25km) projections which are constructed using three perturbed parameter ensembles and provide conditional probability density functions to express the relative strength of the evidence from models and observations which support future climate outcomes (scenarios).

The probability distributions provide information on ranges of outcomes and the relative likelihood of alternative outcomes within these ranges. For the purpose of this assessment the 50th percentile was used as the basis for the scenario chosen, though values were extracted also for the 5th and 95th percentile to provide for an indication of probability distribution in recognition of relevant guidance (e.g. coastal flood risk guidance).

Representative Concentration Pathways

UKCP18 uses new emissions scenarios based upon those used in the IPCC's latest assessment report (AR5). These Representative Concentration Pathways (RCPs) specify GHG concentrations that would result in target amounts of radiative forcing at the top of the atmosphere by 2100, relative to pre-industrial levels. 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). The global mean temperature increase associated with each RCP is shown in Table 8.

While many impacts remain similar in terms of the direction of change (e.g. it is still expected that the UK will experience warmer, wetter winters), the magnitude of change is projected to be more significant for some climate variables, including sea level rise. For example, UKCP18 provides new projections of mean sea-level rise and extreme water levels for the UK coastline. Under the high emissions scenario (RCP8.5), sea level change in 2100

RCP	Increase in GMST (°C) by 2081-2100	Most similar SRES scenario (in terms of temperature) in UKCP09
RCP2.6	1.6 (0.9-2.3)	None
RCP4.5	2.4 (1.7-3.2)	SRES B1 (low emissions scenario)
RCP6.0	2.8 (2.0-3.7)	SRES B2 (between the low and medium emission scenarios)
RCP8.5	4.3 (3.2-5.4)	SRES A1F1 (high emissions scenario)

Table 8: Increase in global mean surface temperature (GMST) averaged over 2081-2100 compared to preindustrial period (1850-1900 avg) for the RCPs (best estimate, 5-95% range) and the most similar SRES scenario in terms of global mean temperature. Based on Table 12.3 of IPCC (2013).

relative to a 1981-2000 baseline is expected to increase between 0.53m and 1.14m in London, and 0.51m and 1.13m in Cardiff (based on 5th to 95th percentiles). Local differences in coastal features may experience smaller or greater changes, particularly when high tides are factored

This data provides the latest climate projections for the UK based on new evidence and modelling, which supersede the 2009 UK Climate Projections (UKCP09) that were used in Trinity House's previous reports to Defra under the ARP.

Time horizons considered

Climate change is typically considered over periods of at least twenty years (minimum of twenty years for land-based projections and thirty years for marine projections). The scenarios chosen for this assessment broadly align with Defra's ARP guidance and considered climate change within three periods representing short, medium and long-term time horizons at strategic locations (+/-25km):

Short-term land horizon: 2025 (2015-2035)

Medium-term land horizon: 2050 (2040-2060)

Long-term land horizon: 2080 (2070-2090)

Short-term marine horizon: 2025 (2010-2040)

Medium-term marine horizon: 2050 (2035-2065)

Long-term marine horizon: 2080 (2065-2095)

Strategic locations used to assess climate data

To assess local climate projections at all of Trinity House's assets would be an enormous task. Consequently, five strategic locations were identified to provide projections that were representative for groups of assets based on their geographical locations.

These land-based locations and their UKCP18 25km grid cells were:

Northeast England (412500.00, 612500.00)

Southwest England (612500.00, 137500.00)

Southeast England (162500.00, 37500.00)

North Wales, Anglesey (237500.00, 387500.00)

Channel Islands Guernsey (362500.00, -62500.00)

Their corresponding marine-based locations and their UKCP18 12km grid cells defined by the

Table 9 Risk Evaluation Matrix (1-2 score = negligible risk; 3-4 score = minor risk; 5-10 score = moderate risk; 12-16 score = major risk; 20-25 score = severe risk)

Likelihood	**Very High** (Almost Certain)	Moderate (5)	Moderate (10)	Major (15)	Severe (20)	Severe (25)
	High (Likely)	Minor (4)	Moderate (8)	Major (12)	Major (16)	Severe (20)
	Medium (Possible)	Minor (3)	Moderate (6)	Moderate (9)	Major (12)	Major (15)
	Low (Unlikely)	Negligible (2)	Minor (4)	Moderate (6)	Moderate (8)	Moderate (10)
	Very Low (Highly Unlikely)	Negligible (1)	Negligible (2)	Minor (3)	Minor (4)	Moderate (5)
		Very Low (Minimal)	**Low** (Minor)	**Medium** (Moderate)	**High** (Major)	**Very High** (Catastrophic)
				Impact		

latitude and longitude in decimal degrees at their centres are:

North East England: 55.39, -1.58

South West England: 51.06, 1.08

South East England: 50.06, -5.42

North Wales, Anglesey: 53.39, -4.58

Channel Islands, Guernsey: 49.50, -2.58

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. For further information regarding model limitations, uncertainty, and bias, please see UKCP18 Guidance[1]. Beyond this, limitations also

1 www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---caveats-and-limitations.pdf

Very High (Catastrophic)	5	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.
High (Major)	4	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.
Medium (Moderate)	3	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.
Low (Minor)	2	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.
Very Low (Minimal)	1	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.

Table 10: Magnitude of Impact rating (score of 1-5; very low to very high)

exist with respect to the use of set scenarios, and their embodied assumptions, as well as the particular methodologies employed by the UKCP18.

Evaluation of risk

Upon identification of future climatic conditions, the potential magnitude of impact (Table 10) and likelihood of occurrence (Table 11) was evaluated to provide a significance score. These values are then multiplied to provide a risk rating (Table 9). The details of each risk and their subsequent significance rating are included in the risk register (Section 3.1).

The likelihood of effects is premised upon both the probability and frequency of the projected occurrence. The criteria for likelihood is thus defined in Table 11.

Very High (Almost Certain)	5	Very likely to occur within 1 year or more than 80% chance of occurrence. Has occurred within last 1 to 2 years.
High (Likely)	4	Likely to occur every 1 to 2 years or 50% to 80% chance of occurrence. Potential of it occurring within 5 years. Has occurred.
Medium (Possible)	3	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.
Low (Unlikely)	2	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.
Very Low (Highly unlikely)	1	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.

Table 11: Likelihood of occurrence rating (score of 1-5; very low to very high)