Climate Change Adaptation Report
Third Round Update
From
Port of London Authority

Update Report to the Secretary of State

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LIST OF ABBREVIATIONS

ARP	Adaptation Reporting Power
AQS	Air Quality Strategy
BNG	Biodiversity Net Gain
CCC	Committee on Climate Change
DEFRA	UK Department for Environment, Food and Rural Affairs
DRA	Direct River Abstraction
EA	Environment Agency
EMS	Environmental Management System
ESI	Environmental Ship Index
HVO	Hydrotreated Vegetable Oil
IPCC	Intergovernmental Panel on Climate Change
LRQA	Lloyds Register Quality Assurance
LCCP	London Climate Change Partnership
MHWS	Mean High Water Springs
Net Zero PLA	Net Zero Programme for the PLA as an organisation
Net Zero Port	Net Zero Programme for the Port of London
NO_x	Nitrogen oxides
NGO	Non-governmental organisation
PM	Particulate matter
PDC	Passive debris collectors
PPE	Personal protective equipment
PLA	Port of London Authority
RCP	Representative Concentration Pathway
RCP4.5	UKCP18 medium emission scenario
RCP8.5	UKCP18 high emission scenario
RNLI	Royal National Lifeboat Institution
SRES A1B	UKCP09 medium emission scenario
SSSI	Site of Special Scientific Interest
TE2100	Thames Estuary 2100 Plan
TTT	Thames Tideway Tunnel
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018
VTS	Vessel Traffic Services

EXECUTIVE SUMMARY

This report provides a review of the climate risks on Port of London Authority's (PLA) operations based on the latest UK Climate Projections 2018 (UKCP18) by the Met Office and the current actions by the PLA to adapt to and mitigate climate change. The projections by UKCP18 are consistent with the projections by UK Climate Projections 2009 (UKCP09), which were used in the previous assessment. Despite differences between the two projections, these are marginal and therefore the previous climate risk assessments and adaptation measures are still valid.

The decarbonisation of transportation sectors to mitigate climate change will also change the demand in petroleum products and alternative fuels and influence the port trade and electricity demand. Good progress has been made in the actions identified in previous report to Government. Through the continued improving monitoring and analysis since the first submission in 2011, the PLA has been able to identify resulting benefits and risk mitigation.

In the preparation of this report, new climate risks have been identified, including the increased chance of pandemics which affect port trade, inland freight and passenger transport; posed risks on the delivery of the Net Zero commitments of the organisation; and an increased risk on port trade by climate change-induced disruption in the international supply chain. New adaptation measures had been developed to address these new risks.

Climate impacts are expected to be felt over many years to come. Therefore, the PLA will continue to monitor the climate risks on PLA's operations and regularly review climate projections, climate risk assessment, and the resultant action plan.

1. INTRODUCTION

The Port of London Authority (PLA) produced the report in response to the UK Department for Environment, Food and Rural Affairs (DEFRA) under the Climate Change Act (2008). The PLA submitted its Climate Change Adaptation Report and Risk Assessments in the first and second rounds in 2011 [1] and 2015 [2], respectively. This progress report has been produced under the third round of voluntary reporting under the Adaptation Reporting Power (ARP). It included assessing current and future impacts of climate change on PLA's activities and proposal for, and progress made towards, adapting and mitigating climate change.

The organisation also undertook an interim review of the risk matrix in 2018, and in 2019, reviewed the released UKCP18 projections [3] as well as evaluating the impact of climate change on habitat, in particularly enhancements created on the tidal Thames [4].

2. INFORMATION ON THE ORGANISATION

2.1. ORGANISATIONAL CHANGES

Since the submission of PLA's Climate Change Adaptation report in 2015 and its subsequent acceptance by Government, there have been a number of changes within the PLA and new initiatives.

2.1.1. THAMES VISION

The Thames Vision, a framework for the development of the tidal Thames to set out the collective ambition for the river over 20 years, was launched in 2016 [5]. The Vision is underpinned by climate change and sets out six goals and priority actions to promote Port Trade, Inland Freight, Passenger Transport, Sport and Recreation, Environment and Heritage, and Community and Culture. The Vision is currently under review to reflect progress, changes on the river and more widely.

The Thames Litter Strategy for the tidal Thames was developed to support the Thames Vision of seeing improve water quality by a range of measures including reduced litter in the river [6]. Produced by the Thames Litter Forum, which is a group of non-governmental organisations (NGOs), university, researchers, river operators, businesses, and industry bodies, convened by the PLA. The Strategy identified a range of measures to reduce litter in the river and improve water quality, actions are framed around four strategic themes, developing data baseline, identify the entry pathways, removal of existing litter, and encouraging behavioural changes through education and outreach. The key ongoing actions include bi-annual assessments of litter foreshore conditions, driftwood collection by the PLA's afloat staff, passive debris collectors (PDCs) to collect litter in central London, as well as new actions; designing a new PDC that suitable for use in the outer estuary, and the "Cleaning the Thames" website, which is an interactive online map for organising litter pick events, launched in 2020 and providing a central hub for storage of data collected.

In order to achieve improved biodiversity of sites recognised for their wildlife interest, and the connections between them, the PLA had convened the Thames Vision Biodiversity Working Group and the Thames Invasive Non-Native Species Group, which has representatives from NGOs, landowners, and regulatory bodies. This group is now combined into one to avoid duplication. The highlights of the work include the launch of

the “Estuary Edges” website, which contains guidance for river wall owners and developers to enhance biodiversity, improved the habitats of a number of RSPB reserves in North Kent and South Essex through the PLA’s Investment Plan. The technical team has also investigated the potential impact of climate changes on habitat viability and enhancements, as well as developing a saltmarsh enhancement on a Site of Special Scientific Interest (SSSI) within the PLA jurisdiction to return the site to 1990 levels, if not beyond.

2.1.2. AIR QUALITY STRATEGY FOR THE TIDAL THAMES

Air quality is the largest environmental risk to public health in the UK [7]. The PLA was the first UK port to have an evidence-based Air Quality Strategy (AQS) published in 2018 [8]. The river activities, within London, contribute a small percentage of the 2016 London Atmospheric Emission Inventory, accounting for 1.59% of nitrogen oxides (NO_x) emissions and 0.51% of fine particulate matter ($PM_{2.5}$) emissions in London up to the M25 motorway [9]. The AQS set out air emission reduction targets and actions to further understand and reduce the impacts of river activities on air quality.

The PLA has been evaluating the impacts of river activities on air quality by establishing a river wider air emission inventory and dispersion model. The results are further validated by real-time ambient air quality monitoring in Greenwich and a NO_x diffusion tube network along the Thames. To encourage the reduction in emissions beyond current legislation and standards, the PLA has been applying incentives where feasible. The Green Tariff was first introduced in 2017 for international vessels that are visiting the Port of London and was the first such scheme introduced in the UK. The tariff is based on the Environmental Ship Index (ESI), an environmental indicator managed by the World Port Sustainability Program. In 2020, the PLA launched the Thames Green Scheme, an environmental indicator scheme designed specifically for inland waterway, and in 2021 will be investigating the feasibility of a River Low Emission Zone scheme.

To break down some of the barriers in investing green technologies, the PLA had undertaken trials on alternative fuel and post-combustion retrofit, operates the UK’s first hybrid pilot boat, *Leader*, and is adopting a Hydrotreated Vegetable Oil (HVO) for its marine fuel from 2021. Working with river stakeholders, a decarbonisation roadmap has been established for inland vessel, and energy feasibility studies.

The targets and actions set within the AQS were reviewed and updated in July 2020 to reflect the changes in policies, regulations, and progress [10]. At a port level, the AQS

reduction targets relative to 2016 baseline for NO_x and PM are 20% by 2026, 40% by 2031, 50% by 2041, and 77-78% by 2051. A more ambitious set of goals has been set for the PLA's emissions, of which the emission of NO_x and PM are targeted to reduce by 30%, 60% and 90% by 2026, 2041 and 2051, respectively. To achieve the long-term port wide targets, the PLA will continue to invest in new technologies, and work in partnership with stakeholders to investigate energy infrastructures, alternative fuels, and port call optimisation. The actions to achieve the internal targets are aligned with carbon reduction under the PLA Net Zero commitments (See Section 2.1.3).

2.1.3. NET ZERO PROGRAMME

To meet the UK Government commitment to reach Net Zero emissions by 2050 under the Climate Change Act 2008 (as amended), the PLA has developed a Net Zero Programme to reduce the organisation's carbon emissions and appraise the way the Port of London can facilitate and support the UK, regional and local economy reaching Net Zero [11].

As an organisation, the PLA has committed to halve the internal carbon emissions relative to the 2014 baseline by 2025 and achieve Net Zero by 2040, or sooner. Over 80% of PLA's carbon emissions are from vessels performing essential duties, including pilot transfer, river patrols, channel and mooring maintenance. Over the next five years, the action plan includes the adoption of HVO across the fleet, replacing two vessels with low emission alternatives, retrofitting existing vessels, and using low emission vehicles for transporting pilots along the banks of the Thames.

The longer-term plan includes further vessel and vehicles replacements with low/zero emissions alternatives, additional renewable energy sources and installation of sub-stations to cope with the increased electrical demand. The PLA's plan has also considered Biodiversity Net Gain (BNG), alongside which the PLA will be looking added benefit of carbon sequestration on PLA's land.

For the Net Zero Port, the PLA will consider the consequences and opportunities of the port and river moving to a decarbonised economy, especially regarding climate impacts likely to affect the environment for operations within the port. The detailed plan is still under development, pending trade forecasting work and climate impact work underpinning this Adaption Report. It is expected to be completed by mid-2021 and will continue within the context of the Thames Vision update.

2.1.4. CULTURAL CHANGE

Recognising cultural change is key to building resilience and achieving various environmental goals, the PLA has been promoting and encouraging cultural and behavioural change across the organisation. The PLA has an Environmental Management

System (EMS) certified to the requirements of ISO 14001:2015 by Lloyds Register Quality Assurance (LRQA), which allows the PLA to manage the environmental responsibilities systematically. To maintain and improve the organisation's environmental credentials, the PLA has commenced the Environment Group that includes members from all PLA departments. Sub-task groups have been formed from the Environment Group to focus on waste reduction/single-use plastics, energy efficiency, carbon footprint, travel plans, and communicating environmental issues.

The PLA has also been publishing the annual Environment Reports on the website since 2018 to better engage with the stakeholders and the PLA's environmental performance and progress [12] [13].

2.1.5. INVESTMENT IN PERSONNEL

Besides taking initiatives to support sustainable growth, the PLA has been investing in personnel to deliver the goals set in those initiatives. The PLA's Environment team plays a key role in supporting sustainability growth for the organisation and the Port of London. The team has been restructured and expanded in 2019 to provide a better advisory service related to protecting and improving the environment on the Thames to internal and external stakeholders. The restructuring of the team was based on the key environmental priorities highlighted in the Government's 25 Year Environment Plan, which includes clean air, clean water, thriving plants and wildlife, enhancing the natural environment, mitigating and adapting to climate change, and minimising waste.

Departments, such as Corporate Affairs, Harbour Masters, Procurement, Health & Safety, Civil Engineering, and Pilotage, have also expanded to improve communication with internal and external stakeholders and to meet the growing demand in the port activities.

2.1.6. WORKPLACE DEVELOPMENT

A major refurbishment was carried out at London River House, the PLA head office in Gravesend, Kent between 2019-2020. The refurbishment provides a modern workspace for staff and improved the energy efficiency of the building. The energy-saving features included an upgrade of insulation in the loft void, various water-saving devices, energy-saving light and motion activation system, energy-efficient appliances, and the installation of a solar tiled roof.

An extension to the berth at Barrier Gardens Pier in Woolwich is currently under development. The work will enable larger vessels, such as PLA flagship, *London Titan*, to dock directly at the pier and to plug-in to the onshore electric charging facilities, while increasing crew safety. The capability to connect to shore power at berth rather than running diesel generators or engines can reduce the emissions.

2.2. RIVER CHANGES

2.2.1. PORT PROFILE

The profile of volume, values and types of traffic using the Port of London has changed significantly over the past five years, in the following activities

- The Port of London handles the second-largest volume of freight traffic of any UK port. In 2019, it handled 54 million tonnes of freight traffic, equivalent to 11% of the UK total.
- Around 10 million passenger journeys were made and 4.8 million tonnes of inland freight were carried on the tidal Thames in 2019.
- Decarbonisation, digitalisation and the way the UK respond to both Brexit and COVID-19 will be important in shaping the future of the Port of London.
- The completion of the third berth at London Gateway in 2019 which increased the inwards lift-on lift-off traffic by 47%.
- Investment at Tilbury2, a new port terminal and associated facilities on the site of the former Tilbury Power Station. It is an extension to the operations at the existing Port of Tilbury and was completed in 2020.
- Re-opening of Royal Primrose and Peruvian wharves, safeguarded wharves in East London. Peruvian Wharf is expected to handle up to 600,000 tonnes of materials annually.

2.2.2. POLICIES, LEGISLATION AND TARGETS

The Paris Agreement, an agreement within the United Nations Framework Convention on Climate Change signed in 2016, set a long-term goal to keep the global average temperature increase to "well below" 2˚C relative to the pre-industrial level and the aspiration to limit this increase to 1.5˚C [14]. The Intergovernmental Panel on Climate Change (IPCC) concluded the global emission needs to peak as soon as possible and reach a balance of emission and removal before 2050 to meet the 1.5˚C target [15]. Supporting the Paris Agreement's implementation, the UK government has committed a legally binding target of net zero emissions by 2050, by amending the Climate Change Act. The targets are legally binding all sectors except international shipping and aviation, to accelerate emissions reductions to achieve neutrality of emissions by 2050. In addition, the revised targets within the AQS for the Thames had also offered more relevance to operators within the port.

2.2.3. THAMES ESTUARY 2100 PLAN (TE2100)

The Thames Estuary 2100 Plan (TE2100) was published by the Environment Agency (EA) in 2012 to understand and develop a plan to manage the flood risk on the Thames estuary until the year 2100 [16]. In 2019 TE2100 team began a 10-Year full Review and update of the plan [17]. The 10-Year Review has 3 main phases and will be completed in 2022; 1) monitoring changes of the estuary over the past 10 years, including the rate of sea level rise, the condition of flood defences and the rate of growth and development in the estuary; 2) economic case review to check if the plan is still fit for purpose; and 3) updating the TE2100 Plan that is fit for the future.

The PLA had responded to an online survey 'Thames Estuary 2100: Updating the Plan' as part of the 10-Year Review process, in summer 2020 and had expressed an interest in joining a sustainability working group in the future. The PLA will continue the engagement with the EA in the future to ensure the risk of flooding and the associated impacts on the tidal Thames are minimised. The Adaption Reports for the PLA in 2011 and refer to TE2100 and all future work will have consideration of the plan.

2.2.4. THAMES TIDEWAY TUNNEL (TTT)

The Thames Tideway Tunnel is a 25 km sewage system constructed under the Thames to remove pressure from London's Victorian sewerage infrastructure and prevent the Thames from being polluted during heavy rainfall when combined sewers overflow into the estuary. The water quality within the Thames in London will be improved by the opening of the TTT.

The Interim Operational Review published by Bazalgette Holdings Group for TTT in November 2020 has estimated a circa nine months delay due to the essential COVID-safe measures on site that slow down productivity (based on the assumption that these measures continue to impact until May 2021) [18]. Despite the disruptions caused by the pandemic, the Tideway has been making good progress on the target of commencing commissioning in 2023. The construction activity of the project is forecasted to be 65% complete by the end of the financial year, only 5% behind the original expectation.

The TTT has continued to use the river to transport 95% of materials to and from the construction sites to reduce traffic on land, reducing both carbon and air emissions. The total volume of materials moved on the river exceeded 4 million tonnes in late 2020.

2.2.5. COVID-19

Passenger and tourist services have been put under serious strain due to the collapse of tourism during the pandemic and with many office-based employees working from home during the lockdown. To help these operators service the current crisis, the PLA has refunded the Port Dues paid in 2020 by Class V passenger boat operators and will not be invoicing 2021 Port Dues until the second half of 2021. The cruise ship industry has also been suspended since March 2020 due to the ongoing travel restrictions.

The port trade topped 22 million tonnes in the first half of 2020. Even though the movement of foodstuffs remained robust, the overall volumes have been depressed temporarily by 15%. During the first national lockdown in Spring 2020, the pandemic had hit the oil derived fuels trade the hardest due to the restrictions of road and air travel. The transport of building materials was also significantly impacted during the same period with many construction projects in London suspended, but has since recovered as construction operations reopened.

3. REVIEW OF CLIMATE PROJECTIONS

3.1. BACKGROUND TO CLIMATE CHANGE ASSESSMENT

Future climate projections have been used to assess the likely impact on the PLA's duties, responsibilities, and activities as Statutory Navigation and Pilotage Authority to the tidal Thames, and the extent to which these activities would be affected. The assessments in the previous Adaptation reports submitted to DEFRA were mainly based on the climate projections by UKCP09 and the TE2100 project [16] [19]. In 2018, the Met Office released a new set of climate change projections for the UK, the UK Climate Projection 2018 (UKCP18) [20]. The UKCP18 projections cover changes in temperature, rainfall, wind speed, sea level rise, and still water level return. However, to the PLA's knowledge, no projections for fog based on the UKCP18 projections are available. Therefore, assessments related to fog are based on the UKCP09 projections. As there are no projections of river water temperature publicly available for the tidal Thames, the assessments are based on value for the North Sea.

This report uses UKCP18 projections whenever it is applicable. Other sources include UKCP09, TE2100, reports from the Committee on Climate Change (CCC) [21], Met Office historical meteorological data, and publications, with internal expert judgement to assess the impacts of climate change on the port operations.

3.2. CHOICE OF EMISSIONS SCENARIO

The previous assessments were based on the UKCP09 medium emissions scenario (SRES A1B). Therefore, following the precautionary approach, this report uses the projections under the medium emissions scenario (RCP4.5) and under the high emissions scenario (RCP8.5) when no medium emission projections are available.

3.3. CLIMATE PROJECTIONS UNCERTAINTIES

There are caveats and limitations in the projections that have to be considered when interpreting results from climate models. The level of confidence in the climate projections that most relevant to the PLA are listed in Table 1 Summary of the Climate Projections for the tidal Thames by 2050, with winter defines as December, January, and February (DJF) and Summer defines as June, July, and August (JJA), and the consideration taken of their use is detailed in

Appendix A – Climate PROJECTIONS.

3.4. LONDON & TIDAL THAMES FUTURE CLIMATE PROJECTION

The climate projections in London and the tidal Thames catchment by 2050s are summarised in Table 1 (projections details are listed in

Appendix A – Climate PROJECTION). For the most relevant parameters to PLA's activities, the UKCP18 projections are consistent with UKCP09, showing an increased chance of milder, wetter winters and hotter, drier summers. As expected, there are differences between the two projections. The UKCP18 shows less winter warming and less increases in winter rainfall, it also shows both bigger magnitude of sea level rise and larger reduction in summer rainfall [22]. The differences are marginal, so the previous climate risk assessments remain valid.

To better represent the recent climate and be aligned with the standard baseline of World Meteorological Organisation, the UKCP18 projection anomalies listed in Table 1 Summary of the Climate Projections for the tidal Thames by 2050, with winter defines as December, January, and February (DJF) and Summer defines as June, July, and August (JJA)are relative to the 1981-2000 baseline, while the UKCP09 projections used a 1961-1999 baseline.

Table 1 Summary of the Climate Projections for the tidal Thames by 2050, with winter defines as December, January, and February (DJF) and Summer defines as June, July, and August (JJA). The estimated anomalies are relative to the 1981-2000 baseline unless it is specified.

Weather Parameter	Medium Emission by 2050	High Emission by 2050	Compared with values used in previous assessments	Level of confidence
Annual Mean Air Temperature Anomaly (°C) [20]	0.9-2.0 (25th – 75th percentile)	1.2–2.5 (25th – 75th percentile)	Slightly less warming in winter [22]	High
Max Air Temp 20yr return (°C) [20][1]	35.6–37.0 (33rd – 67th percentile)	36.2–37.5 (33rd – 67th percentile)		High
Water Temperature (°C/ decade)[2] [23]	0.2-0.3 °C/decade			Medium
Sea level Anomaly (m) [20]	0.22–0.27 (30th – 70th percentile)	0.26–0.31 (30th – 70th percentile)	Slightly larger increase [22]	High
Seasonal Rainfall Anomaly (%) [20]	DJF:-10.7–22.7 (25th – 75th percentile) JJA:-45.8–6.3 (25th – 75th percentile)	DJF:-9.0–26.6 (25th – 75th percentile) JJA:-50.3–2.8 (25th – 75th percentile)	Slightly smaller increase in winter [22] Slightly larger reductions in summer [22]	Medium

[1] N yr-return period: events with return periods of 1 in N years

[2] The rate of water temperature increases for South East England, not specific to the Thames

Intense rainfall [20]	Most likely 1-day rainfall for a 1-5 year event in DJF: 37 mm (+2 mm relative to 2020 value) Most likely 5-day rainfall for a 1-5 year event in DJF: 110 mm (+3 mm relative to 2020 value)			Medium
River Flow	Ann: Decrease [24] DJF: Increase [24] JJA: Decrease [24] Peak: Increase [25]		Slightly larger reductions in the annual average, and summer flow but slightly smaller increase in winter flow [24]	Medium
Wind Speed Anomaly (m/s)[3] [20]	N/A	DJF: 0.15 (-0.73 - 0.88) JJA: -0.19 (-0.66 - 0.17)		Low
Still Water level 50 yr-return (m above CD at Sheerness [4]) [20]	7.35 – 7.56 (5^{th} – 95^{th} percentile)			Medium
Wave height [26]	Ann: Increase Seasonal: Increase			Low
Flooding	Increase frequency			Medium
Drought Severity (%) [27][5]	-	14% (50^{th} percentile, 1970-99 baseline)		Medium
Fog[6]	Ann: Decrease [28] DJA: Increase [28]			Low

[3] Displaced as "mean (min – max)" is the mean, min and max of the 11 members of HadGEM3-GC3.05
[4] Still water level (SWL) is the level that the water surface at a given point and time would be in the absence of wind waves. The UKCP18 SWL return level are given in meters Ordnance Datum Newlyn (ODN) and being converted to Chart Datum (CD) by adding 2.9 m, the different between ODN and CD at Sheerness [50].
[5] Drought severity is the duration (length of time in deficit) multiplied by mean standardise drought intensity (the deficit)
[6] Based on the UKCP09 medium emissions scenario, the fog will increase by 20% in the winter while the annual average will decrease by 19% in London by 2080.

4. PROGRESS ON CLIMATE CHANGE ADAPTATION

4.1. GENERAL

The impacts of climate change on PLA's operations had been identified and considered through the production of adaptation reporting 2011. Following the first submission, the PLA has been reviewing the risks regularly, undertaking appropriate adaptation measures, and collecting monitoring data of the changes. These have helped the PLA better understand the extent of the impacts and enable the evaluation of the action's effectiveness.

Acknowledging the high level of interdependence of EA's work and PLA climate resilience, the PLA has been collaborating and interacting with the EA, including data sharing with regard to river flow level, monitoring the changes and managing the foreshores, liaising the operation and maintenance of flood defences, engaging with the 10-year full review of the TE2100 plan, and the River Basin Management Plan for the Thames catchment.

The PLA has also been working closely with local water companies, such as Thames Water Ltd, on their Water Management Plans in respective cycles, to avoid water levels, flow rate, water quality, and ecology on the Thames being compromised by any future water source schemes. As a result of the previous consultations, the Teddington Direct River Abstraction (DRA) has been removed from Thames Water's Water Management Plan 2019 [29]. Thames Water has agreed in principle to take the PLA's requirement into accounts if re-considering the Teddington DRA option in the future [29].

The PLA had set the Thames Resilience Panel in 2016 to undertake the process of risk assessments and share experiences on lessons learned, good practice and challenges ahead for those working on, over or adjacent to the River Thames. The panel is responsible directly to the London Resilience Forum but also feed into the Kent and Essex Resilience Forum. The PLA has also become one of the partners of the London Climate Change Partnership (LCCP) [30]. This working group comprises public, private and community organisations that have a role to play in preparing London for extreme weather today and climate change in the future. Being part of the forums and working group helped the PLA understand the interdependencies with other stakeholders and the role of PLA in ensuring London is well adapted and resilient to extreme weather and future climate change.

4.2. NAVIGATION

Navigation on the tidal Thames can be affected by various meteorological parameters, including river flow, wind, wave, and fog as identified in the previous reports. Both high and low flow can cause restrictions on navigation. The combination of strong wind, tide,

and increased in wave height can pose a greater risk for any river activities, including navigation and port operation. During low flow period, the river users might be affected by inadequate operational depth and/or restricted by the limited operation of locks, to help retain water in the channel upstream [31].

In the last couple of years, the PLA has recorded some near misses and minor incidents related to weather or tidal conditions. Some of the cases were directly caused by the unfavourable conditions, such as disoriented in dense fog, while for some, the weather/tidal conditions were one of the contributing factors, such as being grounded at low water, drifted off the centre of the navigation channel, having difficulty at departing the berth and resulted in a minor collision. These are investigated by the Harbour Masters under the Port's Marine Safety Management System. Various actions have been taken as the result of the investigations, including updated pilots guide for berths and terminals, developed procedures for pilotage operations in a different stage of restricted visibility, reviewed risk assessment, and reviewed the Vessel Traffic Services (VTS) communication procedure. With the investigations and actions in place, the risks of climate change on navigational safety are minimised.

The rising sea level and the increased chance of fluvial flooding can affect the navigation through bridges. The higher water level can minimise the overhead clearance under the arches of the bridges and shorten the window of passage. Bridges in the upper tidal Thames, such as the Snapper Bridge to Eel Pie Island, Lots Ait Footbridge, and Hammersmith Bridge, have the highest risk of being affected by the rising sea level. The main navigational arch of these bridges has an existing overhead clearance of fewer than 4 m above Mean High Water Springs (MHWS). A sea level rise of 0.31 m (i.e. by 2050 under the high emissions scenario) and 1.15 m (i.e. by 2100 under the high emissions scenario) can reduce the window of safe passage through these bridges significantly (Appendix B – Thames Bridge Clearances).

London's flood risk is increasing, and the Thames Barrier as associated creek barriers have been used more regularly to prevent flooding upriver. As the Thames Barrier system is deteriorating with age and being used more frequently, maintenance becomes more frequent to maintain standards [16]. During inspection and maintenance, the flood protection gates between the spans would be raised in turn, which limits the number of spans available for use and could potentially slow down the river traffic. As highlighted in 2015, there are uncertainties associated with the closure of the Thames Barrier and its

effect on river trade and transport. The PLA will continue to evaluate the impacts and work with the EA to liaison with the river users to minimise the impact where possible.

Visibility also impacts on the navigation through the Thames Barrier, which vessels of a certain size and under certain visibility would have to remain at their berths, anchor in a designated anchorage area or anchor as directed by London VTS. The heavier fog in the future might lead to more delays in the Thames Barrier Control Zone; however, there is uncertainty associated with the projection of fog. Overall, the window of safe operation is likely to be shortened as the results of climate change. The PLA will remain active in reviewing projections, collecting and analysing relevant data, and undertake adaptation measures to reduce associated risk uncertainties.

The degree of disruption due to the shorter window of safe operation is not yet quantified. However, it is likely to impact the hydrographical survey on the river, which is crucial for the maintenance of the navigation channels and monitoring the depth alongside the berth. The PLA is investigating the use of autonomous survey vessels and aerial drones to assist the surveying process, which could improve the data collection efficiency.

4.3. PILOTAGE OPERATIONS

The PLA has been collecting relevant data to quantify better the climate impacts on the pilotage service since it was identified as a risk in the previous assessment. During a storm or under high wind speed conditions, the pilotage stations might be off service or operate under restriction, e.g. only certain size vessels are allowed to embark or disembark pilots. When a pilot station is off or under restriction, vessels would have to either anchor in one of the designated anchorages and wait for the station to be fully re-opened, be rerouted to another pilotage station, or carry the pilots to other continental or distant UK ports to disembark, which is known as “overcarry”.

The boarding and landing of PLA’s pilots are mainly taking place from Sunk, Northeast Spit, Warps, and Gravesend. The Sunk pilot station, the furthest away from land and the least sheltered station, is affected by strong wind from all directions while the Northeast Spit station is more vulnerable to strong Northerly wind. Both Warp and Gravesend stations are located further inland and are less likely to be affected by the strong wind. The dominant direction of the wind reaching the Thames Estuary is from the southwest. The higher than average disruption to the pilotage service in 2018, in terms of the number of vessel delays and the number of pilots being overcarried, was linked to the more frequent strong Northerly wind and caused the Northeast Spit and Sunk station to be off

at the same time. The PLA will continue to collect and analyse data to evaluate the extent of the impact, focusing on the changes in the Northerly wind in the far future.

To maintain a satisfactory pilotage service to the increasing port trade and vessel calls, the PLA has been investing in new IT system to manage the allocation of pilots to ships in the most efficient, upgraded the ship's bridge simulator that integrates the latest hydrographic modelling, and recruiting trainee pilots. The pilotage charges had been updated recently to reflect the continued and substantial investment in improving service performance as well as minimising the frequency of overcarry by charging detention for hours that the pilots spend outside the port limits.

4.4. LEISURE AND RECREATIONAL ACTIVITIES

Consistent with the previous analysis, the higher river flow in the winter and lower water level in the summer can pose a greater risk for recreational users, especially for swimmers and human-powered crafts. The Ebb Tide Flag, a warning system for the fluvial flow condition in the upper Thames, was developed in 2011 [2]. Future summers and autumns are expected to have an even higher number of black flags than the previous prediction due to the larger reduction in summer rainfall. In contrast, future winters are expected to increase the number of red flags, but the increase is likely to be slightly less than predicted previously due to the slightly less increase in winter rainfall.

To further minimise the risk and raise awareness of the issue to the public, the PLA has recently published the "The Tideway Code – a Code of Practice for Rowing and Paddling on the Tidal Thames" for recreational users. The PLA has also been proactive on various social media channels to make access to essential safety information easier.

4.5. OPERATIONAL HEALTH AND SAFETY

The PLA's Occupational Hygienist has undertaken formal reviews of work activities and the health impacts on the staff. As a result of the previous climate risk assessment, a review of the workwear and personal protective equipment (PPE) was completed in 2019. Breathable male and female clothing brought into the new catalogue to reduce the risk

associated with extreme temperature. The PLA has also been raising the awareness of UV exposure during any outdoor work and made sunblock available to all staff that work outdoors.

The staff exposed to hot indoor working environments are also at risk for climate change impacts such as extreme heat exposure and indoor air pollution. Sea-going staff will be exposed to a hotter working environment in the summer and a more hazardous environment in the winter due to the wetter and windier weather. Specific training programmes have been provided to staff to improve safety and their awareness. Recognising that risk, the PLA is assessing the working conditions at the wheelhouse in the summer months as a part of the Occupational Hygienist review in 2021-2. The PLA will also be investigating installing green roofs/walls on the PLA's buildings for Net Zero 2040. Green walls/roofs can cool the building in the summer and act as an insulator in the winter, reducing energy consumption all year round [32].

4.6. PORT TRADE

The Port of London handled 54 million tonnes of goods in 2019, increased by more than 18% compared to 2015 [33]. Oil products and gases are the largest single category of cargo handled at the Port of London, which accountable for 24% of the overall tonnage in 2019. The switch from fossil fuels to alternative fuels in the transport sector is expected to impact the volume of fuel passing through the port. The changes and transition to new cargoes could provide a marked financial challenge. However, the demand for alternative fuels, such as biofuels, hydrogen, ammonia, methanol etc. might create a new market in carriage, storage, and production of these new fuels.

As one of the most significant UK ports, the Port of London deals with freight traffic from around the world. The non-EU traffic at the Port of London has increased from 29% of the total traffic in 2015 to 38% in 2018, of which 10% of the traffic was from Asia, 9% to/from America, and 3% to/from Africa [34]. Therefore, the port trade can also be affected by the impacts of climate change abroad. Risks associated with the international supply chain interruptions include disruption in the early stages of product manufacture and damage of the transport network, such as roads, ports, harbours, and onshore infrastructures [21]. Supply chains that involve more vulnerable countries, such as South and South East Asia, and sub-Saharan Africa, may increase the risk of weather-related disruptions. However, global trade market can fluctuate rapidly [35], which create a high level of uncertainties when assessing the associated risk.

4.7. STRUCTURES AND INFRASTRUCTURE

In the previous assessments, the identified climate risks to structures and infrastructures were mainly related to increased flooding. However, there have been a number of incidents. In Winter 2018, Storm Emma brought freezing cold weather and snow with high winds creating 2 m waves in Gravesend Reach, resulting in two piers breaking free of their tethers, requiring an emergency response from the PLA and Royal National Lifeboat Institution (RNLI) assets in the area at the time, damaging third party structures, assets and vessels. The PLA spent considerable time and assets in following days to secure them safely and prevent further damage in the continuing storm. The events were attributed to poor maintenance of both sites and therefore their ability to withstand the weather.

In summer 2020, the 133-year-old Hammersmith Bridge was closed to pedestrians and all river traffic under the bridge due to urgent safety concerns. The combination of poor maintenance and consecutive days of hot weather led to a sudden deterioration in the key parts of the suspension structure, despite measures taken to mitigate the heat [36]. The closure of the bridge is having an adverse effect on all forms of river users in the Port of London where commercial vessels cannot ply their trade or operate, such as re-fuelling, sporting and recreational activities are significantly restricted, national sporting events being prevented, and impacting emergency services response, including RNLI lifeboats, fireboat, marine policing boat, as well as PLA Harbour Service.

These have highlighted the climate risks to structures and infrastructures are not only limited to the increase chance of flood but the extreme weather conditions. The prolonged heatwave, intense rainfall, increased frequency of strong wind, and higher energy waves can accelerate the deterioration of buildings and structures, especially when it is poorly maintained [37]. The extent of the impacts is uncertain and will vary significantly between buildings to buildings, depending on the age and maintenance of the structure [38].

The changing patterns of extreme weather events may imply more rebuilding and repair work. The PLA's Asset Management Plan facilitates an effective way to maintain and operate all assets, which will minimise the consequences of climate change upon them. For third parties' structures, PLA will continue to engage with local authorities and asset holders to minimise the impacts on the navigation on the Thames, and enforce maintenance required under the river works licence if found to be insufficient.

4.8. ENVIRONMENT & THAMES VISION

As mentioned in Section 2.1, in the last couple of years, the PLA has been working to minimise the environmental impacts of operations, as well as improving the environment

on and by the tidal Thames by initiating various environmental commitments. The progress and achievements of PLA's environmental works in the last two years are presented in an annual Environment Report [12] [13].

4.8.1. PLA Mitigation and Resilience

The first five year plan to enable the PLA to reach Net Zero by 2040 will be investigating the feasibility of renewable energy generation on land and installing green walls/roofs on buildings. Increasing the energy generation capacity on-site can reduce the dependency on energy provider and increase supply security, contributing toward the predicted increase in energy demand by decarbonising the fleet. The installation of green walls/roofs can act as carbon sequestration and better regulate the building's temperature [32]. A green roof can also improve local air quality and absorb excess water, which reduces the rate of deterioration of the building's fabric.

However, the changing climate can also increase the risk of executing some of the actions within the plan. The larger range of soil moisture due to the changes in rainfall patterns can affect vegetation growth, and hence imposes risks on delivering biodiversity enhancements. By undertaking the climate change assessment that this report is based on, the mitigation measures were identified including planting climate resilience species, adopting green engineering techniques and promoting ecological resilience by increasing the size, number, condition and complexity of sites for wildlife. The design of any new infrastructure will consider the impact of increased heavy rainfall, storms and stronger winds.

4.8.2. River Wide Environmental Resilience & Thames Vision Goals

Climate risks on ecology and biodiversity have been identified in the previous assessments, such as habitat loss resulting from coastal squeeze, shifts in habitat due to change in air and water temperature, and increased opportunities for invasive species to colonise. The PLA has been undertaking habitat enhancement to compensate for the decline in habitat. In 2019 the environment team appraised the impact on enhancements continued viability and concluded with careful management of sites and planning, the habitat enhancement at PLA's site can reduce the effects of climate change [4]. The habitat enhancement can support migration of species, overwintering species, provide breeding ground, and also improve the stability of the riverbank.

The Biodiversity and Invasive Non-Native Species Working Groups have now combined to develop an improvement strategy for the tidal Thames. Implementing the actions within the strategy and plans can mitigate some of the risks associated with climate change.

The hotter, sunnier, drier and less windy summers can worsen the air quality, especially in central London, although these risks can be minimised by implementing actions with the AQS to reduce the pollution sources, and continued development of goals and performance.

In terms of water quality, the proposed new PLA byelaw prohibiting the discharge of untreated sewage into the river from vessels can minimise eutrophication risk, once the byelaw has been approved by the Department for Transport. Sewage from vessels is insignificant compared to discharges from sewer overflows; this is largely, being dealt with by the construction of the Thames Tideway Tunnel (Section 2.2.4). The heavier rainfall can increase the risk of an oil spill when spilt oil on land gets washed to the river. The existing Oil Spill and Emergency Plan and the PLA internal spill procedure and training can reduce resulting impact of the climate change associated events.

The increase in run-off could increase the influx of litter into the river, especially microplastic particles that are less than 5 mm, via surface water drains. The Thames Litter Strategy can alleviate the issue by identifying the litter pathways, improving infrastructure around the Thames, and encourage behaviour change.

At the same time, however, climate change can also impose risk to the ability of delivering some of the goals and targets set within The Thames Vision, and the PLA's own strategies. New energy infrastructure for charging electric vessels and for storing/bunkering alternative fuels are required to reduce air emissions and decarbonise in the future. The changing climate will be considered in design on PLA property. Climate change can also degrade water quality, in terms of water temperature, salinity, chemical and nutrients concentrations, these changes can pose risks to the delivery of water management objectives, such as the Water Framework Directive (WFD). The PLA will continue to work with the EA and water companies to minimise the impacts on water quality.

5. SUMMARY OF ACTIONS AND RISK ASSESSMENT

5.1. CLIMATE CHANGE ADAPTATION MATRIX

Following the previous risk assessment approach for assessing the risk associated with each climate change impact, the same evaluation matrix is used with slightly modification regarding the "Longer Term" time period (Table 2 Five-by-five matrix for 2021 review). The Overall Risk is defined as the multiplication of the score on Severity and Probability after mitigation measures. The Overall Risk is ranked between 1 to 25, with 1-5 as Low risk, 6 – 10 as Medium risk, and 12 – 15 as High risk. The PLA has been making good progress in developing and implementing climate adaptation and mitigation actions. Therefore, new evaluation matrices are now presented in a different way to the ARP 2015, to demonstrate better the impacts, ongoing actions, new or planned actions to minimise or mitigate the risks in various area (See APPENDIX C – RISK ASSESSMENT METHODOLOGY for the details)

Table 2 Five-by-five matrix for 2021 review

Climate Change Adaptation Matrix

Severity or consequence of impact	Likely to threaten the survival or effectiveness of the organisation, likely to have major impact of whole operation	5	5 Low	10 Medium	15 High	20 High	25 High
	Significant impact on the organisational strategy or operational activities, likely to have major impact on many areas of business	4	4 Low	8 Medium	12 High	16 High	20 High
	Moderate Impact on organisational strategy or operational activities	3	3 Low	6 Medium	9 Medium	12 High	15 High
	Primary impact on the internal business, likely to have minor effect on many areas	2	2 Low	4 Low	6 Medium	8 Medium	10 Medium
	No Significant Impact on business as a whole	1	1 Low	2 Low	3 Low	4 Low	5 Low
			1	2	3	4	5
			Longer Term (till 2090)	Long Term (20-50 Years)	Medium Term (10-20 Years)	Short Term (5-10years)	Very Short Term (Now-5 years)
			Probability short or long term impact				

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5.2. GENERAL

Impact	Ongoing Actions Existing adaptation to reduce the associated risk	New / Planned Actions (from 2020) New adaptation to reduce risk/ new actions to mitigate climate change	Future Actions Potential actions in the future if the risk increases	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Maintenance of a sustainable operation	Comprehensive risk register with standing committees chaired by an Executive Board Member to oversee the risks that are relevant to Operational, Internal and External Risks. Climate risks are part of the External Risk assessment. Review climate projections, relevant publications and update risk assessment & report. Collect data to monitor the climate impacts on all PLA's operations As a partner of the "London Climate Change Partnership" to ensure London climate resilience by sharing knowledge, developing solutions and influencing policy in London. Being part of the partnership also helps the PLA to better understand the interdependencies. Regularly attend Resilience Forums that has helped to develop emergency plans that are practicable and necessary. Proactive on various social media channels and public meeting to help delivering targets and goals and raising awareness of the risk related to climate change.	All PLA's major projects, will require a sustainability assessment at the initial stage of the project, which include assessing the risks related to climate change Improve data management to minimise data redundancy across departments and allow useful and effective data analysis Regular updates on all the news about the Tidal Thames through the Tidal Thames News, an online publication, and annual Environment reports to improve the communication with all stakeholders. It helps delivering PLA's targets and goals and raising awareness of the risk related to climate change		All	a) Education and communication b) Corporate responsibility for climate change adaptation	a) P:2; S: 2; R: 4 b) P:2; S: 2; R: 4	P:2; S: 2; **R: 4**

5.3. NAVIGATION

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Shorten the window of safe navigation Rules and regulations are in place to avoid operating under certain weather conditions. Therefore, the increased in average and peak flow in the winter,	To minimise navigation risk: • Incidents investigation and agreed actions as part of Marine Safety Management System • Regular updates of information, such as tide tables, depths on tiers, bridges heights, critical depth etc., online			Harbour Master, Hydrographic, VTS, Corporate	a) Greater variation in water depths b) Extremes in Flow	a) P: 3; S: 3; R: 9 b) P: 3; S: 3; R: 9 c) P: 1; S: 4; R: 4	P: 3; S: 3; **R: 9**

decreased in average flow and water level in summer, increased chance of flooding, stronger wind, increased in wave height, increased in number of fog days, and decreased in overhead clearance under bridges can shorten the time period that allows safe navigation.	• Communication between river users and VTS to minimise disruption • Increased patrol requirement To maintain water level: • Ongoing monitoring of shoals and link with EA fluvial flow as cumulative effects impact flood defences • Liaise with water companies to agree upon on their water management plans.			reputation, 3rd party	c) Air draught issues d) Increased risk to navigational safety e) Increases in upriver abstraction f) Increased fog g) Increased wind Items listed above all contributed the shorter window of safe navigation	d) P: 1; S: 2; R: 2 e) P: 3; S: 5; R: 15 f) P: 2; S: 2; R: 8 g) P: 2; S: 4; R: 8	
Increased the chance of bank erosion Changed rainfall patterns can lead to larger range of soil moisture, increased mean water level and stronger wind can lead to higher energy wave reaching the shore. Therefore, increase the chance of erosion and supply of sediment due to the changings rainfall patterns that leads to larger range of soil moisture, and higher energy wave reaching the shore.	Regularly review Tree and Bank Management to minimise erosion the PLA banks (between Kew and Putney) Regular hydrographic surveying to monitor the changes. Collaboration with EA to investigate foreshore changes and management.	Restoration of marshes at West Thurrock as natural flood defence. The PLA had appointed a designated bank maintenance team to maintain the bank between Kew and Putney.	Bring the bank maintenance team up to full strength.	Hydrographic, Planning, Marine Services, Civil, 3rd party	Increasing bank erosion	P: 2; S: 3; R: 6	P: 2; S: 3; **R: 6**
Affected depth on berths The low water level can affect the depth on berths, especially in summer. The changes in river flow can affect the rate of sediment transport in rivers, and hence, the depth on berth.	Monitor operator's requirements to manage access to own berths under byelaw Estuary Morphology Study & continuing review of patterns in sediment			Harbour Master, Hydrographic, Planning, Marine Services, 3rd party	a) Depth on berth b) Changed siltation patterns Items listed above both contributed to the depth on berth	a) P:3; S: 3; R: 9 b) P: 2; S: 3; R: 6	P:3; S: 3; **R: 9**
Affected depth of the navigation channel Increased bank erosion and changes in river flow can affect the rate of sediment supply and movement.	Estuary Morphology Study & continuing review of patterns in sediment		If there is significant increase in the rate of change, then will have to increase surveying frequency	Harbour Master, Hydrographic, Planning, Corporate reputation,	a) Changed siltation patterns It can lead to change of depth of the navigation channel	aa) P: 2; S: 3; R: 6	P: 2; S: 3; **R: 6**

				Corporate financial			
Increased uncertainty of the river depth The change in sediment supply and movement can increase the uncertainty in the range of water depth.	Improved tide gauges coverage to minimise uncertainties			Harbour Master, Hydrographic, Planning	a) Requirements to modify tide gauges coverage Further explained why the tide gauges coverage required to be modified	P:1; S: 1; R: 1	P:1; S: 1; **R: 1**
Air draught issue Higher water level can minimise the overhead clearance under the arches of the bridges			Consider design of bridge to accommodate the additional requirements of the overhead space.	Harbour Master, Hydrographic, VTS, Planning, Corporate reputation, 3rd party	a) Air draught issues	P: 1; S: 4; R: 4	P: 1; S: 4; **R: 4**
Disruption to river traffic Increased frequency of barrier closure for flood prevention and for maintenance and increase the number of fog days can cause disruption to river traffic, especially around the Thames Barrier Control Zone	Liaise EA regarding the closure of flood defence barriers to minimise disruption.			Harbour Master, VTS, Corporate reputation, Corporate financial	a) Increased fog b) Increased wind Items listed above can lead to disruption in traffic	a) P: 2; S: 4; R: 8 b) P: 2; S: 4; R: 8	P: 2; S: 4; **R: 8**
Affected operation of Richmond Lock and Weir Reduction in summer rainfall can limit the number of times Richmond Lock being open for traffic to maintain the water level upstream, which can cause delay when vessels are crossing the lock. The increase frequency in use might also increase the needs of maintenance and increase the energy consumption for operating the Lock	Monitor the impact on Lock and users over time. Liaise with water companies to agree upon on their water management plans to address concerns regarding the locations and the magnitudes of the water abstraction and discharge. Regular maintenance of the Lock to ensure safe and reliable operations.			Harbour Master, Hydrographic, VTS, Corporate reputation, Corporate financial	a) Richmond Lock and Weir b) Increases in upriver abstraction Items listed above can lead to disruption in operation of Richmond Lock and Weir	a) P:3; S: 3; R: 9 b) P:3; S: 5; R: 15	P:3; S: 3; **R: 9**

Affected hydrographic surveying The shorter window of safe operation can affect the hydrographic surveying and monitoring, which is critical to ensure safe navigation on the river.		Investigating the use of autonomous vessel technology afloat and aerial drones to undertake survey that can improve the efficiency of the data collection.		Hydrographic Corporate financial	New identified risk after specifying the combined risk of shorter window of safe navigation (see above)	NA	P:2; S: 2; **R: 4**

5.4. PILOTAGE

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Disruption of the pilotage service Increased the disruption to the pilotage service due to strong wind, bigger wave, and increased number of fog days in the winter.	Data collection to quantify impacts of bad weather conditions. Invested in recruiting trainee pilots, introduced new IT system, and upgraded the ship's bridge simulator.	Change of pilotage charges to minimise the number of overcarry, e.g. by charging detention for hours that the pilots spend outside the port limits.	If future data suggest the disruption by poor weather conditions has increased significantly, then might have to investigate new pilotage stations that are less likely to be affected by strong wind and poor weather	Pilotage, VTS, Corporate reputation, Corporate financial	a) Increased fog b) Increased wind Items listed above can lead to disruption in pilotage operation	a) P: 2; S: 4; R: 8 b) P: 2; S: 4; R: 8	P: 2; S: 4; **R: 8**

5.5. RECREATIONAL

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Increased the recreational usage of the river The hotter and drier summer is also likely to draw the public to the river and increased the recreational usage of the river; however the increasing unfavourable river conditions is likely to increase the	Ebb flag warning system help raise public awareness of the conditions of the river. Working collaboratively with the Thames Regional Rowing Council to enable effective communications with the recreational users.			Harbour Master, Corporate reputation, Corporate financial	a) Change in use of River & Estuary - Increasing tourist & commuting traffic in upper river	a) P: 2; S: 3; R: 6 b) P:1; S: 2; R: 2 c) P:1; S: 2; R: 2	P: 2; S: 3; **R: 6**

risk for recreational users, especially for man-powered craft and swimmers.	Publications, such as the "Tideway Code, Guide for Rowers and Paddlers", to make access to essential safety information easier Increased patrol requirement Consider adequacy of existing speed limits				b) Increased desire to use the Thames for swimming c) Increased risk to navigational safety Items listed above are all related to recreational usage		

5.6. ENVIRONMENT

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Carbon & Energy							
Increased uncertainties in PLA's energy usage and carbon emissions The PLA Energy Policy and Net Zero PLA set out the energy and carbon reduction targets. Increase air temperature has an impact on energy consumption in the summer (due to increased demand for air conditioning) but possibly less energy consumption in the winter (due to less demand for heating).	Renewable energy generation through solar panels, rainwater harvesting for flushing toilet on one of PLA's sites, use of low energy lighting and appliances. Some 3rd party piers on the river have installed renewable energy.	Investigate the feasibility of installing green wall/roof that will insulate the buildings in winter but cooling in the summer, and hence reduce energy consumption. Investigate installing additional renewable energy infrastructures across PLA's sites. Employed Building Management System, an overall integrated system that provides better level of control.		Environment, Corporate reputation, Corporate financial	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P: 3; S: 2; **R: 6**
Increased fuel/energy consumption of vessels Increased flow rate can lead to higher fuel consumption to overcome the increased resistance	Design of any new vessels has to be optimised to achieve maximum vessel efficiency			Environment, Marine Engineering, Corporate reputation, Corporate financial	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P: 2; S: 3; **R: 6**
Increased uncertainties in the supply of HVO		Supply chain has been taken into consideration when selecting the biofuel and will review regularly on the suppliers.	Transition the PLA fleet to alternative fuels when technologies mature	Environment, Marine Engineering,	New identified risk, associated with the Net	NA	P: 3; S: 2; **R: 6**

As an action within Net Zero PLA and AQS, the entire vessel fleet is switching to HVO that generated from waste. The general demand of HVO is likely to increase as the entire transport sector is in the process of decarbonising and moving toward lower emissions fuel, which might affect the supply. HVO is seen as an interim transitional fuel only.				Corporate reputation, Corporate financial	Zero programme that launched in late 2020		
Higher the interdependency to energy providers The Five-Year Action Plan for the Net Zero PLA and the short-medium term actions with the AQS, includes replace two PLA's vessels with lower emission options and moving towards hybrid pilot taxis. The actions will increase the energy demand from the grid.	The back-up generators and Uninterrupted Power Supplies (UPS) allows the PLA to operate for a short period without grid electricity. Renewable energy generation through solar panels at some of the PLA's sites.	As part of Net Zero, investigate installing additional renewable energy infrastructures, sub grid, and energy storage system across PLA's sites, which will improve the independence. All new infrastructures will undertake a climate risk assessment at the initial stage.		Environment, Marine Engineering, Civil, 3rd party	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P: 2; S: 3; **R: 6**
Increased cost of electricity Decarbonisation across all sectors will increase the electricity demand, which is likely to increase the energy cost, i.e. require installation of substation as the existing infrastructure has reached full capacity The cost of renewable infrastructures might increase with higher specifications, i.e. able to operate at higher wind speed.		Analysis decarbonisation roadmap to understand better the energy demand in future Liaise with energy and technology providers to discuss future energy provision		Environment, Corporate financial	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P:3; S: 3; **R: 9**
Increased internal water demand Hotter summers are likely to increase water consumption. Decreased in summer rainfall might reduce the effectiveness of the rainwater harvesting system that have been installed at one of the PLA's site.	Rainwater harvesting system at one of the PLA's sites to flush toilet.	Investigate the opportunities to install rainwater harvesting system on other PLA's sites		Environment, Civil, Corporate financial	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P: 3; S: 2; **R: 6**
Increased risk when developing new energy infrastructures Achieving long term targets within the Net Zero Programme and AQS requires energy infrastructures.	New structures in the river must assess the feasibility for installing green technologies (including renewable energy) as part of their application for a PLA River Works Licence [39].	All new PLA's infrastructure will undertake a climate risk assessment at the initial stage. The future climate must be considered when developing those infrastructures. The PLA will work in partnership with stakeholders to facilitate the provision of appropriate planning, infrastructure, and alternative fuels.		Environment, Civil, Corporate financial, Corporate reputation	New identified risk, associated with the Net Zero programme that launched in late 2020	NA	P:2; S: 4; **R: 8**

Air Quality							
<u>Exacerbated poor air quality</u> Increased in air temperature especially in summer can increase in natural VOCs, hence production of O_3. Less rainfall and lower wind speed, which reduced wet deposition and dispersion of pollutants.	Implementing actions within the AQS. Ongoing actions for river wide & internal activities in the short to medium terms includes • International and inland green tariff to incentivise "greener" vessels • River wide emission inventory and air dispersion modelling • NO_x diffusion tube network. • Ambient air quality monitoring. • Trial on alternative drop-in fuels, post combustion abatement technology, and hybrid vessel.	River wide: • Launched the "Thames Green Scheme", an incentive scheme for inland operators, which encourage inland operators to continue to reduce air emissions and as an initial step toward the development of river low emissions zone in central London. • Investigate the energy infrastructure along the river to support decarbonation of the maritime sector as part of the long term plan. • Investigate port call optimisation as part of the long term plan Internal: Aligned with Net Zero PLA		Environment, Corporate reputation	New identified risk, associated with the Air Quality Strategy launched in 2018	NA	P: 3; S: 2; **<u>R: 6</u>**
Water Quality							
<u>Enhanced pollutants concentration and nutrients enrichment in water</u> Increased in runoff in winter and reduction in flow and increased in water abstraction in summer can concentrate the pollutants and nutrients in water. Nutrients enrichment can increase the chance of algal bloom.	Proposed improvement to PLA Byelaw 49, prohibiting the discharge of untreated sewage into the river from vessels and investigate the need for additional sewage pump out service. Collaboration with Tideway on Thames Tideway Tunnel to minimise the sewage and litter overspill from land sauces. Collaborate with water companies and contribute on their Water Management Plans Liaison with EA & water companies on water availability studies as developed.			Environment, Harbour Master, Corporate reputation, 3rd party	a) Increases in Algal blooms causing incidents b) Increases in upriver abstraction Items listed above are all related to enhanced pollutants and nutrients concentration	a) P: 2; S: 2; R: 4 b) 3 x 5 =15	P:3; S: 3; **<u>R: 9</u>**
<u>Increased water temperature and decreased dissolved oxygen</u> Increased water temperature is linked to the increase in air temperature Increased water temperature and increased chance of algal bloom can decrease the level of dissolved oxygen in water	Liaison with EA & water companies on water availability studies as developed.			Environment, Harbour Master, Corporate reputation, 3rd party	a) Increased turbidity, reduced 02, impacts on marine life	a) P: 3; S: 2; R: 6	P: 3; S: 2; **<u>R: 6</u>**

Wider range of salinity of the water Water abstraction and discharge, amount of run off after the intense rainfall, and sea level rise can increase the range of salinity in the tidal Thames	Collaborate with water companies and contribute on their Water Management Plans Liaison with EA & water companies on water availability studies as developed.			Environment, Harbour Master, Corporate reputation, 3rd party	New identified risk, from literature research and stakeholder engagement		P:2; S: 2; **R: 4**
Increased chance of spilt oil running off from land Increased winter rainfall can increase the chance of oil spill on land to get wash off into the river.	Regular review of oil spill and emergency plan, alongside PLA internal spill procedure and training can minimise the consequences of an oil spill on the river			Environment, Harbour Master, Corporate reputation, 3rd party	a) Modify responses to pollution incidents Better justify the reason for modifying responses to pollution incidents	a) P: 2; S: 4; R: 8	P: 2; S: 4; **R: 8**
Increased chance of litter entering from run-off Increased winter rainfall can increase the transport of litter.	Implementing actions with the Thames Litter Strategy, which includes establishing baseline and evidence, combating pathways of litter into the Thames, removal of existing litter, and behavioural change through education and outreach.			Environment, Harbour Master, Corporate reputation, 3rd party	a) Modify responses to pollution incidents b) Driftwood collection Further specification of the issues	a) P: 2; S: 4; R: 8 b) P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Redistributing litter Increased in flooding, higher wave height, and change in flow rate can lead to redistribute litter on the bankside to further downstream.	Driftwood Services and passive debris collectors (PDCs) throughout London.	Designing a new PDC which is suitable for the lower estuary. Launched the "Cleaning the Thames" website, which encourage public to organise litter pick and as a tool for data collection. Investigate 2-minutes litter pick stations and water fountains on PLA landholdings.	If data suggest the effectiveness of the PDC reduced significantly by the change in river flow, then will have to review the design of the PDC in central London.	Environment, Harbour Master, Corporate reputation, 3rd party	a) Driftwood collection Further specification of the issue	P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Increased uncertainties in the type of chemical incidents As the marine sector decarbonise to mitigate climate change, alternative fuels, including ammonia, might be used in the future.	Current Emergency procedure covers respond to chemical spill.		Review and update the regulations over activities of the alternative fuels, e.g. restriction zone, transport, when the certainties in the type and quantity of fuel require advanced. Review the emergency manual and oil spill manual to include specific procedure for handling hazardous substances.	Environment, Harbour Master, Corporate reputation, 3rd party	Modify responses to pollution incidents Better justify the reason for modifying responses to pollution incidents	P: 2; S: 4; R: 8	P: 2; S: 4; **R: 8**

Biodiversity							
Increased chance of invasive species to colonise Increased air & water temperature can provide opportunities for invasive species to colonise.	Convened the Thames Invasive Non-Native Species Group to maximise work already undertaken by the partnering organisations and networks through providing opportunities to share ideas and information.	Launched the Environmental Fund to fund invasive species research projects. Building partnership to develop a biodiversity strategy for the tidal Thames.		Environment, Corporate reputation, 3rd party	a) Invasive plants b) Change in marine fauna Items listed above are both related to invasive species to colonise	a) P: 2; S: 2; R: 4 b) P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Habitat loss Increased habitat loss due to coastal squeeze and change in water quality and vegetations.	Undertaken vessel wash assessment to understand the impacts of vessel wash and climate change on erosion on 3 of the Sites of Special Scientific Interest (SSSIs). PLA funded habitat improvement works for 4 RSPB reserves to restore wetlands, provide habitat for breeding birds and invertebrates. The work had improved the condition of 386 hectares of priority habitat in South Essex and North Kent and 10 kilometres of enhanced wetland ditches to support water voles.	Undertaking - West Thurrock Saltmarsh Improvement works increase the extent of saltmarsh, which can increase the habitat available for fish nurseries, overwintering bird roosts, increases carbon storage and provides flood protection. Ecology surveys to be undertaken at Oliver's Ait to inform an updated management plan.		Environment, Corporate reputation, 3rd party	a) More frequent beneficial flooding of marshland, supporting migrating birds/wildlife b) Encroachment due to upgrading flood defences Items listed above are both related to habitat loss	a) P: 2; S: 2; R: 4 b) P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Habitat migration Increased air and water temperature causing habitat to move further North.	Undertaken Ecological surveys of Cliffe and Allhallows to monitor habitat extent through a Phase I survey, water vole presence and bat roosts. A management plan for these sites was developed in 2019 based on the ecological survey results. Liaise with Natural England on evaluation of land in PLA ownership and value according to protection. Calculating the Natural Capital to value the losses and gains	A monitoring programme allowing targeted and more regular monitoring of species and habitats on the Thames and on PLA landholdings.		Environment, Corporate reputation, 3rd party	a) Shift in habitat b) Change in marine fauna Items listed above are both related to habitat migration	a P: 3; S: 2; R: 6 b) P: 2; S: 2; R: 4	P: 3; S: 2; **R: 6**
Affected the growth of vegetations The Five-Year Action Plan for the PLA Net Zero Plan also includes the feasibility study on green roofs, aquaculture, and woodland development. Increased winter rainfall and decreased summer rainfall lead to		Potential mitigation measures include planting climate resilient species, adopting green engineering techniques and promoting ecological resilience through increasing the size, number, condition and complexity of sites for wildlife. Specific measures will be identified in details climate risk assessment that specific to the project.	Undertake or invest in further intertidal /subtidal habitat restoration projects within the river area where a biodiversity benefit can be demonstrated.	Environment, Corporate reputation, 3rd party	a) Change in marine fauna Item listed above is related to the growth of vegetations	a) P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**

wilder range of soil moisture can affect growth of vegetation.							
Seagrasses are particularly vulnerable to climate change. A high level of sunlight is required for seagrass to photosynthesise that they can only survive in shallow water with depth under 4 m. The seagrass bed can be submerged if the increase sea level is at a great depth than the tolerable range.			Investigating methods of improving seagrass condition and/or extent within the tidal Thames. Providing increases in fish nursery habitats, natural flood defence, water quality and carbon sequestration benefits.	Environment, Corporate reputation, 3rd party	a) Change in marine fauna Item listed above is related to seagrass survival	P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Increased chance of tree fall The stronger wind and larger range of soil moisture is likely to increase the chance of tree fall.	Regular review of the tree management system for maintaining bankside tree between Kew and Putney, which includes tree survey and removal of mature trees at risk to minimise the risk of tree fall. Where replanting, ensure species chosen are tolerant of climate change.			Environment, Civil, Corporate reputation, 3rd party	Increased tree fall	P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**

5.7. Occupational Health & Safety

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Extreme heat exposure Increase the risk associated with extreme heat exposure for outdoor staff. Increase the risk associated with hot indoor working environment and indoor air pollution for office staff.	Formal review of work activities and the health impacts on the staff has been undertaken by the Occupational Hygienist. Breathable and male and female personal protective equipment (PPE) brought into the new catalogue as a result of Occupational Hygienist review. Running hot and cold water available on most of the PLA's vessels, depending upon its size. The cold water is potable and can be drunk whilst on board.	Working conditions in the wheelhouse will be reviewed in 2021 as part of the Occupational Hygienist review to improve air conditioning. As part of Net Zero PLA, investigate the feasibility of green roofs/walls, which can insulate the building in winter and reduce the temperature in summer.		Corporate reputation, Corporate financial, Civil, Corporate operational	a) Health issues of staff Further specification of the issue	a) P: 2; S: 3; R: 6	P: 2; S: 3; **R: 6**
UV radiation exposure	Sunblock available to all staff that work outdoor as a result of Occupational Hygienist review.			Corporate reputation,	a) Health issues of staff	a) P: 2; S: 3; R: 6	P: 2; S: 2; **R: 4**

Increase exposure to UV radiation for outdoor working staff due to the higher number of sunny days.				Corporate operational	Further specification of the issue		
Increased risk for sea-going staff Increase in extreme weather impose risk for sea-going staff when onboard and during boarding and disembarking.	Training programme to improve safety, e.g. the PLA has established a pioneering on-land pilot ladder training facility in Denton for staff to learn the safe and proper way to board or disembark a ship via ladder in the estuary. New vessels operated by Estuary Services Ltd (ESL), joint partnership between the PLA and Medway Ports to provide pilot cutter to cover operation in the outer estuary, have optimised hull design which improved the stability and conformability	New pier at Thames Barrier Gardens to allows bigger vessels to dock at the pier and enhanced safety when boarding and disembarking.	Future vessels design will optimise between energy efficiency, stability, and conformability	Corporate reputation, Marine Engineering, Corporate financial, Corporate operational	a) Change in infrastructure needs Further specification of the issue	a) P: 1; S: 2; R: 2	P: 1; S: 2; **R: 2**

5.8. Port Operational & Trade

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Increased risks in cargos handling Extreme weather will impose larger risks when handling cargos, such as operating cranes	Considered the impact and raise awareness with stakeholders. Incidents investigation and agreed actions as part of Marine Safety Management System			Harbour Master, Corporate financial	a) Increased wind Item listed above can increase the risk in cargos handling	a) P: 2; S: 4; R: 8	P: 2; S: 4; **R: 8**
Shift in cargo type a) Decarbonisation in transport sector will reduce the volume of petroleum products but might create a new market for alternative fuels b) Change in consumer behaviour, e.g. plastic products	Incorporated within the Thames Vision, which two of the goals are promote Port Trade and Inland Freight.	Net Zero Port considers the consequences and opportunities of the port and river moving to a Net Zero economy, especially regarding climate impacts likely to affect the environment for operations within the port. It will be incorporated into all aspects the Thames Vision update.		Corporate financial	New identified risk, associated with the Thames Vision launched in 2016		P: 2; S: 4; **R: 8**
Increased risks associated with the international supply chain interruptions Include Increased risks associated with the international supply chain interruptions include disruption in the early stages of product	Considered the impact and raise awareness to stakeholders.	Net Zero Port considers the consequences and opportunities of the port and river moving to a Net Zero economy, especially regarding climate impacts likely to affect the environment for		Corporate financial, Corporate reputation, pilotage	New identified risk, from literature research		P: 2; S: 2; **R: 4**

manufacturing process, damage of the transport network, such as roads, ports, harbours, and onshore infrastructures, increased chance of incident at sea during transit that linked to climate change **[21]**.		operations within the port. It will be incorporated into all aspects the Thames Vision update.					
Increased risks in interdependence Risk of a) damaging energy infrastructures b) transportation infrastructures c) telecoms infrastructures by severe weather might have knock-on impacts on the operation of the port, in terms of running equipment, communications, and short of staff	a) The back-up generators and Uninterrupted Power Supplies (UPS) allows the PLA to operate for a short period without grid electricity. Renewable energy generation through solar panels at some of the PLA's sites. c) Monitor impact on the interdependence on telecom infrastructures; Servers to support both internal and external communications are located at Gravesend and Thames Barrier Garden	a) As part of Net Zero, investigate installing additional renewable energy infrastructures, sub grid, and energy storage system across PLA's sites, which will improve the independence. b) Improved the capability for remote working as a result of COVID-19 measures. c) Additional independent route connection has been planned to improve resilience.		Corporate reputation, Corporate operational	a) Effective PLA communications system Further specification of the issue	a) P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**

5.9. ASSETS AND STRUCTURES

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Accelerated the deterioration of PLA's structures and increased maintenance frequency and cost a) Increase in maximum temperature and rainfall can accelerated the deterioration of PLA's structures, such as radar towers and navigation lights, and buildings **[37]** b) Increase winter rainfall can lead to nutrients enrichment and increase the rate of biofouling which impose damage to vessels, pontoons, and buoys c) increased wind loading can put stress on the radar towers	a) Regular survey and maintenance for all PLA's structures and infrastructures through Asset Management System. b) Applied anti-fouling paint on vessels and buoys regularly to prevent biofouling. c) Regular review of the UK National Annex to Eurocode 1. Actions on structures. General actions. Wind actions (BS EN 1991-1-4:2005+A1:2010) to ensure the radar tower (and any other tall structures) can withstand the wind loading		b) Investigate advance anti-fouling paint if biofouling is worsened in future c) Strengthen the structure if the standard has been updated and the current configuration do not meet the updated standard	Civil, Corporate reputation, Corporate financial, Corporate operational	New identified risk, from literature research and stakeholder engagement		P: 2; S: 3; **R: 6**

Damage of coastal/bankside assets Increase the chance of flood and increased frequency of storm can cause damage of office buildings, wharves, pontoons, and piers, which can affect the efficiency at work.	For PLA's asset: • Current pile design allows a metre extra height over the current Highest Recorded Tide level. • The pumped surface water system at Denton removes all surface water from the site. High flows during storm events are accommodated by storage within oversized pipes providing attenuated pumped discharge from the site. For 3rd parties: • Flood defence maintained by the EA. • Collaboration with EA on foreshore conditions & flood defence through contributing the TE2100. • Enforcement of maintenance regimes on licencing		Review and investigate the need of extending the pile moorings at all PLA's mooring sites and Review and investigate the need of increasing the capacity of the drainage pump at Denton.	Civil, Planning, Corporate reputation, Corporate financial, Corporate operational	a) Flooding/ overtopping pontoons, pile moorings b) More Frequent flooding at Denton Wharf Items listed above are related to damage of coastal/bankside assets	a) P:1; S:1; R: 1 b) P:1; S:2; R: 2	P:1; S:2; **R: 2**
Increased risk of overheating vessel's engines Increased extreme temperature might cause vessel's engines to overheat	All PLA vessels were over engineered such that they can withstand a larger range of environmental conditions and avoid over stressing the engines	Future extreme temperature will be considered when purchasing/designing new vessels for the PLA		Corporate reputation, Marine Engineering, Corporate financial, Corporate operational	New identified risk, from literature research and stakeholder engagement		P:1; S:4; **R: 4**
Affected the accessibility to premises for maintenance and repair Increased frequency of extreme weather and flooding can impact on the ability to access premises for regular maintenance and emergency repair, i.e. light house and radar tower	Regular monitoring, surveying, and maintenance of PLA's premises through the Asset Management System. The bridge connecting to one of the PLA's lighthouses (Broadness lighthouse) had been elevated in 2005 to minimise the chance of flooding and disruption.			Civil, Corporate reputation, Marine Engineering, Corporate financial, Corporate operational	a) Bank and wall repair/flood risk	a) P: 2; S: 2; R: 4	P: 2; S: 4; **R: 8**

Increased risk in energy infrastructures development The increasing energy demand will increase the urge to expand existing windfarms in the Thames Estuary and develop new renewable energy generators across PLA's land. Storage and bunkering infrastructures of alternative fuels, e.g. hydrogen, ammonia, methanol etc., or other form of energy storage required in the future to support decarbonisation of the maritime sector.	Liaise with the developers and operators for an optimal solution such that the structures do not compromise navigation safety and are climate resilient.	Sustainability assessment, which include assessing the risk associated with climate change, is required for all new PLA's major projects. For example, all new solar panels and wind turbines have to consider increased heavy rainfall, storms, and stronger winds. PLA will work in partnership with stakeholders to facilitate the provision of appropriate planning, infrastructure, and alternative fuels.		Civil, Corporate reputation, Marine Engineering, Corporate financial,	New identified risk, associated with the Net Zero programme that launched in late 2020		P: 2; S: 3; **R: 6**
Accelerate the deterioration of river walls. Increase in sea level, extreme weather and wave height can accelerate the deterioration of river walls.	Wall and gate repaired by the EA.	Collaboration with EA to investigate foreshore changes and management		Civil, Corporate operational, 3rd party	a) Bank and wall repair/flood risk	P: 2; S: 2; R: 4	P: 2; S: 2; **R: 4**
Accelerate the deterioration of structures that are over/on the river Increase in maximum temperature can accelerate the deterioration of structures that are over/on the river, e.g. bridges, and buildings that are on the bankside. The damage on these structures can causes disruption on the river traffic	Liaise with local authorities and asset owners to prioritise their maintenance. Enforce maintenance required under the river works licence if found to be insufficient.			Planning, 3rd party, Harbour Master, Corporate operational	New identified risk, from literature research and stakeholder engagement		P:5; S: 3; **R: 15**
Towpath Management between Kew and Putney Increased rainfall intensity in the winter can increase the frequency of flooding of the towpath or longer section of the towpath will be flooded. The increased chance of tree fall can impact on the public safety.	The towpath is maintained by the London Borough of Richmond upon Thames. The PLA's tree and bankside management to maintain public safety on the towpath.			Civil, 3rd party	a)Towpath Management	a)P: 4; S: 1; R: 4	P: 4; S: 1; **R: 4**

5.10. PANDEMIC

Impact	Ongoing Actions	New / Planned Actions (from 2020)	Future Actions	Interest Dept	Corresponding issue as listed in Evaluation Matrix 2015	2015 Probability (P), Severity (S), Risk (R)	Current Probability (P), Severity (S), Risk (R)
Increased risk for pandemics Climate change may increase the risk for pandemics like COVID-19. The loss of habitat due to deforestation and as a consequences of climate change is bringing wild animals in contact with humans more often, which increase the chance of passing diseases between animals and humans. COVID-19 had temporarily affected port trade, passenger and tourist services, as well as inland freight		Developed a policy and risk assessment to protect the core operational staff. Facilitated remote working, includes IT security upgrade, raising awareness to all staff to minimise the risk to cyber-attack, and mental support. Refunded the Port Dues paid in 2020 by Class V passenger boat operators and will not be invoicing 2021 Port Dues till the second half of 2021.		All	New identified risk	NA	P: 5; S: 2; **R: 10**

6. OPPORTUNITIES AND BENEFITS

- Estimated doubling of international trade by 2031 linked to the growing economic dominance of China and India, and the potential emergence of new Arctic shipping lanes resulting from climate change [34].

- If feasible, develop renewable energy assets on PLA land to increase energy resilience and security of supply.

- The windier, less cloudy conditions, and higher energy wave might benefit the renewable energy generation from wind turbines, solar panel, and wave turbine [40].

- A longer period of warm weather can mean a longer growing season for the vegetation and provide benefits, but only if water and soils are managed sustainability [40].

- Consider the opportunities for investment in decarbonisation technologies and innovations for the port and the PLA's use moving forward

- Continue to liaise with the Environment Agency for their 2022 publication of the TE2100 review of the previous projections and development of the update TE2100 plan.

There are also additional opportunities that may come from the PLAs continued work on developing a Net Zero commitment for the Port. These are;

- Collaboration with the boroughs to reach their own goals of carbon neutrality by 2025-30.

- Investigation and creation of new green growth as a service for transporting or production of alternative fuels, such as hydrogen, ammonia, methanol etc.

- Collaborate and cooperate with businesses and organisations along the river to act together to achieve the Net Zero target and respond to climate impacts that will still occur.

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APPENDIX A – CLIMATE PROJECTIONS

A1. MEAN AIR TEMPERATURE

All the top ten warmest years have occurred since 1990, with nine of those years having occurred since 2002. The annual mean air temperature is projected to rise between 0.9 to 2 ºC (25th -75th percentile) under the medium emissions scenario. The latest UKCP18 projections show that by mid-century hot summer could come more common. The mean air temperature in the summer is most likely to rise about 1.1 ºC by 2040 under the medium emissions scenario and rise to about 1.5 ºC by 2040 under the high emissions scenario (Figure A1).

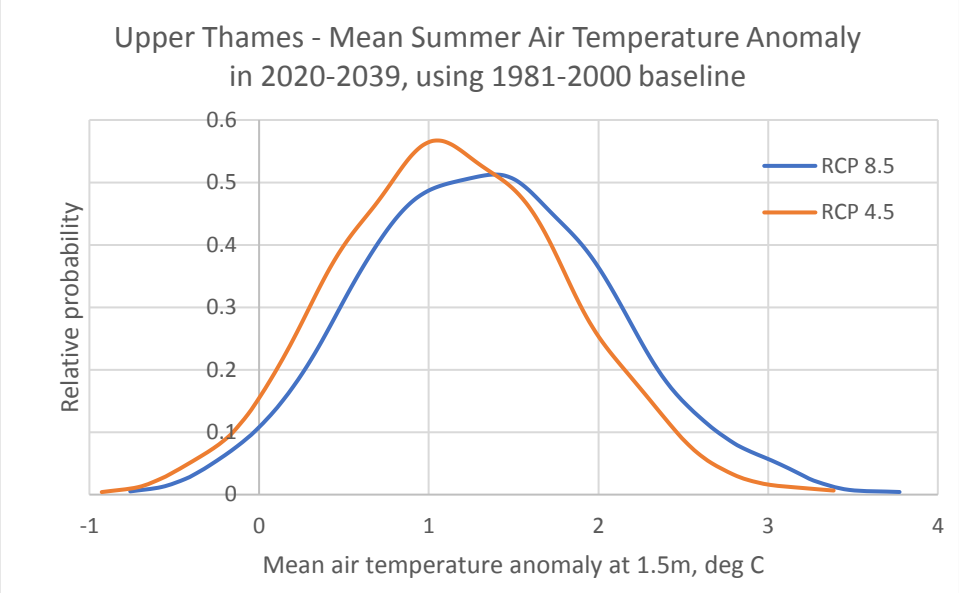

Figure A1 The relative probability of the mean summer air temperature anomaly in 2020 to 2039 under medium and high emissions scenario.

A2. MAXIMUM AIR TEMPERATURE

The combination of the urban heat island effect, which the air temperature is significantly higher than in suburban areas due to the absorption of heat by buildings, road and other infrastructure, and the diversity of residents within London, the impacts of extreme weather events can be far reaching. The maximum summer air temperature is projected to be 35.6 – 37.0 °C (33rd – 67th) by 2050 with a 20-year return period under the medium emissions scenario.

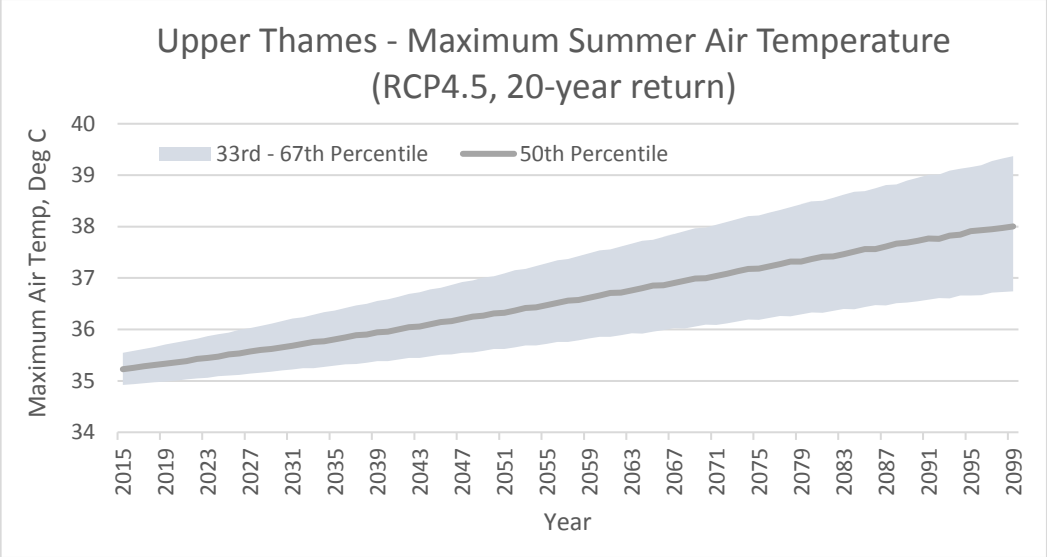

Figure A2 The maximum summer air temperature with a 20-year return period under the medium emissions scenario.

A3. SEA LEVEL RISE

Under all emissions scenarios, the sea level will continue to rise across all UK capital cities in the UKCP18 projection and the rise increases with higher emissions scenarios.

Under the medium emissions scenario, for 2020-2050, the sea level is projected to increase up to 0.26m. Under the high emissions scenario, for 2020-2050, the sea level is projected to increase up to 0.3m and the projections at 2100 for sea level show an increase up to 1.15m in London (Figure A3). The UKCP18 shows a slightly larger sea level rise compared to UKCP09, e.g. UKCP18 RCP4.5 is equivalent to UKCP09 SRES A1B.

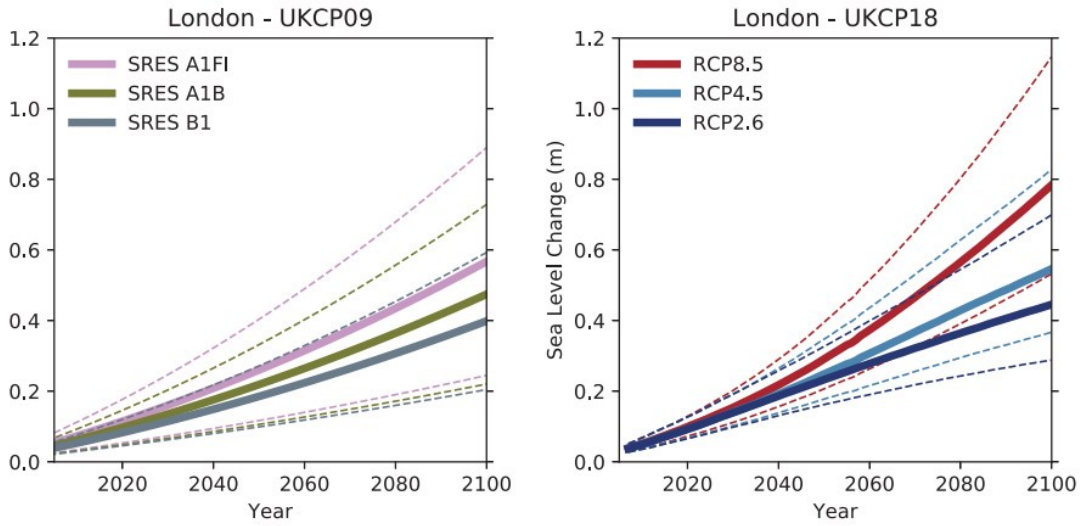

Figure A3 Sea Level Rise projections for London from UKCP09 (1980-1999 baseline) and UCK18 (1981-2000 baseline). The different in baseline period equates to 1-2 mm differences [41].

A4. RAINFALL

The historical observations show a high level of variability in precipitation from year to year with a slight overall increase in winter precipitation in recent decades. Under both medium and high emissions scenarios, the precipitation rate is predicted to increase in the winter but decrease in the summer in the Thames region (Figure A4). For 2020-2039, the winter precipitation is most likely to increase by 7% while the summer precipitation is most likely to decrease by 5 – 16% relative to the 1981-2000 baseline.

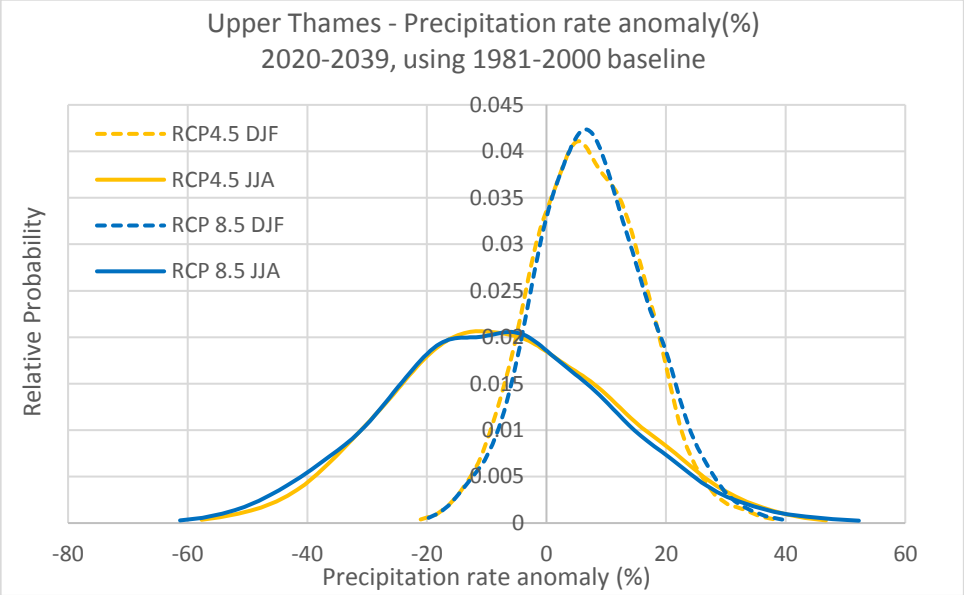

Figure A4 The relative probability of precipitation rate anomaly in winter and summer in the upper Thames for 2020-2039 relative to the 1981-2000 baseline under the medium and high emissions scenario.

As a warm atmosphere can hold more moisture, the frequency of intense rainfall events is likely to increase. The 5-days total precipitation with a 20-year return period in the upper Thames is projected to be 68.7 mm by 2050 at 50th percentile under the medium emissions scenario, which is 2.5 mm more than in 2015 (Figure A5). This can have a large impact for the tidal Thames due to its large catchment area.

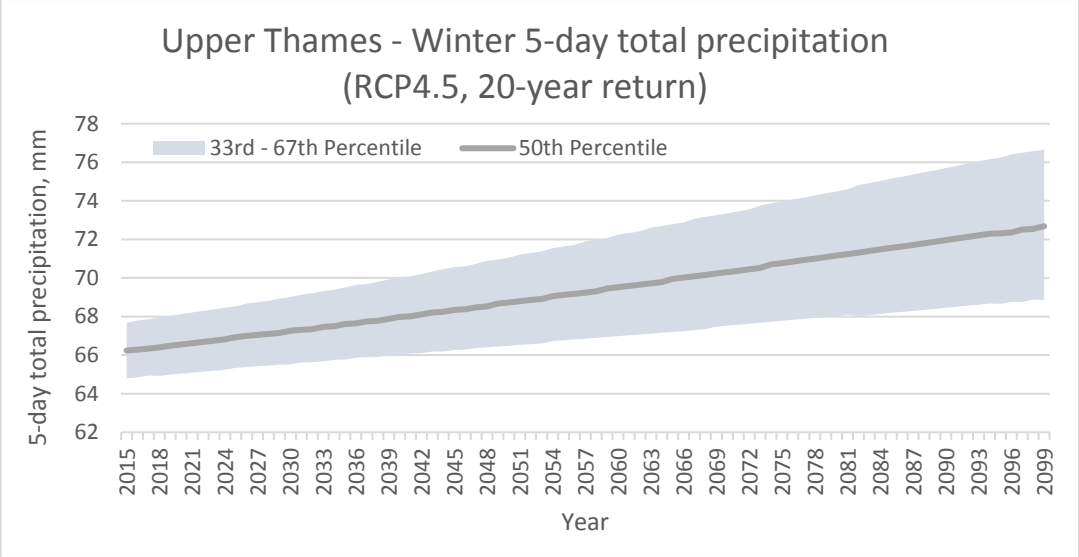

Figure A5 The 5-days total precipitation with a 20-year return period in the upper Thames under the medium emissions scenario.

A5. RIVER FLOW

In general, the annual rainfall in the Thames basin is relatively evenly distributed through the year and around 65% lost to evaporation predominantly during summer, which creates a pronounced seasonal pattern on the flow regime. The river flow at the catchment outlet is the sum of water flows from the fast pathway ("surface storage") and the slow pathway ("groundwater storage"), which depends on the rainfall, water storage capacity, potential evaporation, and soil moisture deficit.

As shown in Section A4 that the winter rainfall is likely to increase while the summer rainfall is likely to decrease. The potential evaporation is projected to increase in all season due to the warmer air temperature.

Table A1 The median change in the average river flow (Q_{mean}), high flow (Q_5), median flow (Q_{50}) and low flow (Q_{95}) in Kingston, Thames catchment for the 2050s (2040-2069), using the medium emissions scenario in UKCK18 and UKCP09 [24]

	UKCP18	UKCP09	Differences
Q_{mean}	-7.1	-6.3	-0.8
Q_5	0.0	0.7	-0.7
Q_{50}	-14.4	-13.5	-0.9
Q_{90}	-13.1	-12.5	-0.6

Based on the UKCP09 medium emissions scenario, the estimated flow peaks by 2080 with a 20-year return period at the downstream end of the fluvial Thames is 36% with a range of -11% to +68% [25].

Table 3A change in the 50-year return period flood peak in the Thames Basin under the UKCP09 medium emissions scenario in 2020s, 2050s and 2080s [42].

	2020s	2050s	2080s
H++	25	40	80
Upper (90th)	25	35	70
Higher Central (70th)	15	25	35
Central (50th)	10	15	25
Lower	-5	0	5

A6. WIND

The UKCP18 projections indicate no compelling trends in storminess, determined by maximum gust speeds from the UK wind network over the last four decades. The projections under the high emissions scenario over the Thames Basin show an increase in near surface wind speed during the winter season from 2050, when more significant changes in wind speed occur (Figure A6). The projections for Northernly wind indicate an increase in wind speed in the winter (Figure A7). However, the increase in wind speed is small compared to the inter-annual variability. The UKCP18 projections for wind speed anomaly in summer indicate an overall periodic decrease in wind speed within the Thames under a high emissions scenario (Figure A8).

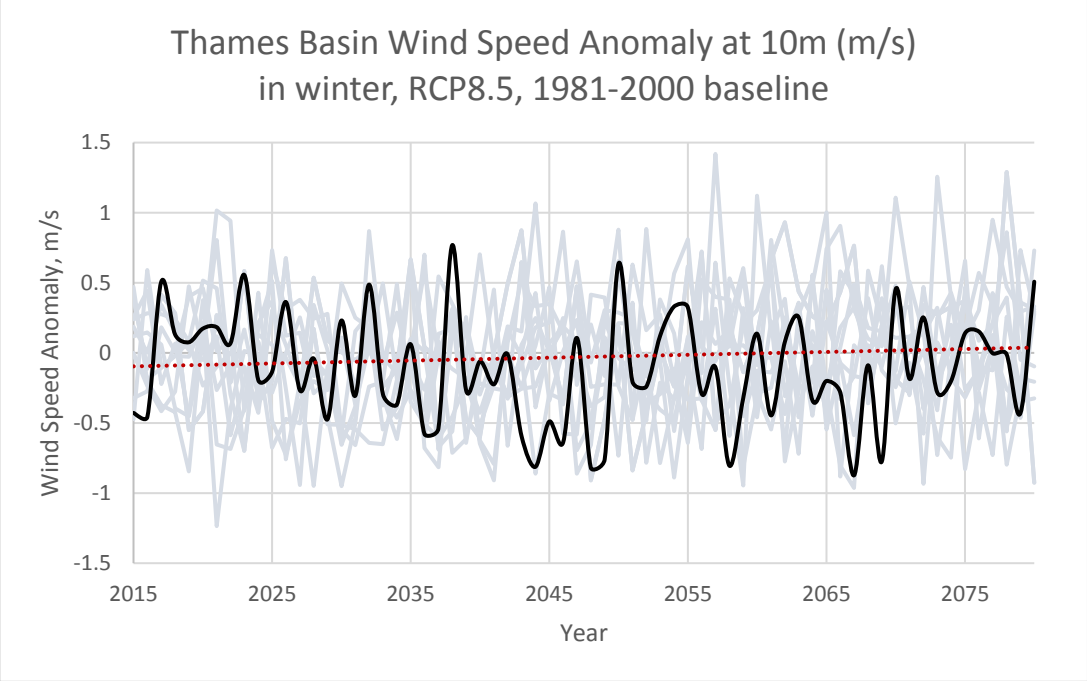

Figure A6 Winter Wind Speed Anomaly at 10 m relative to 1981-2000 baseline in the Thames Basin under emissions scenario RCP 8.5, with red dotted line as the trend of the mean of the 11 members.

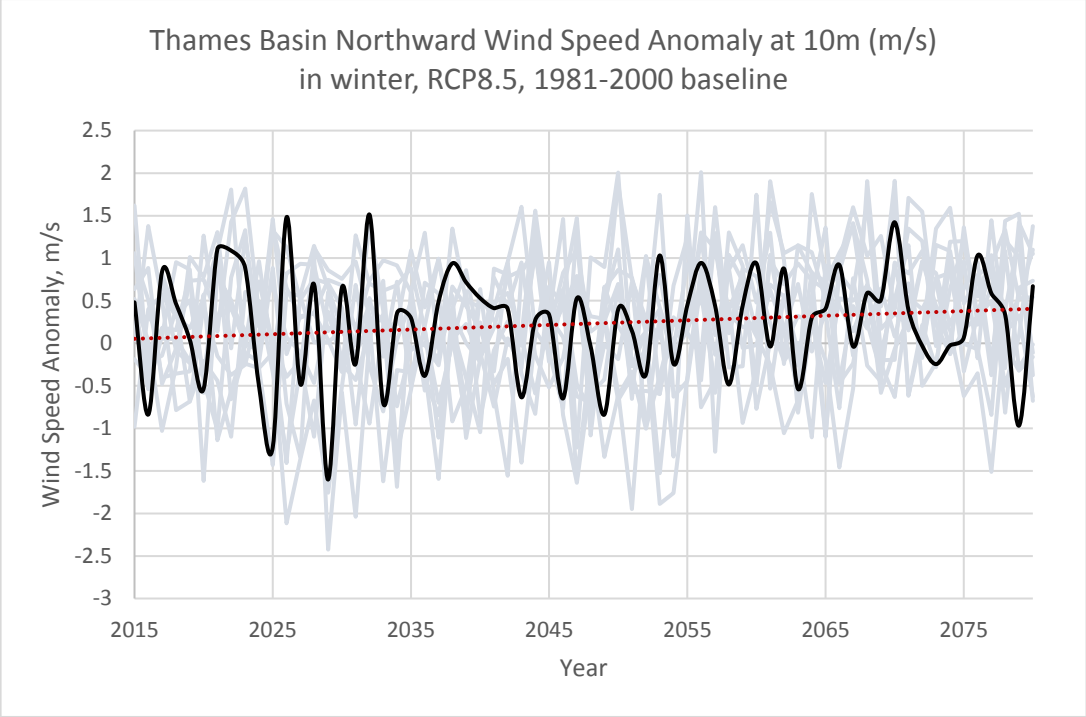

Figure A7 Winter Northward Wind Speed Anomaly at 10 m relative to 1981-2000 baseline in the Thames Basin under emissions scenario RCP 8.5, with red dotted line as the trend of the mean of the 11 members.

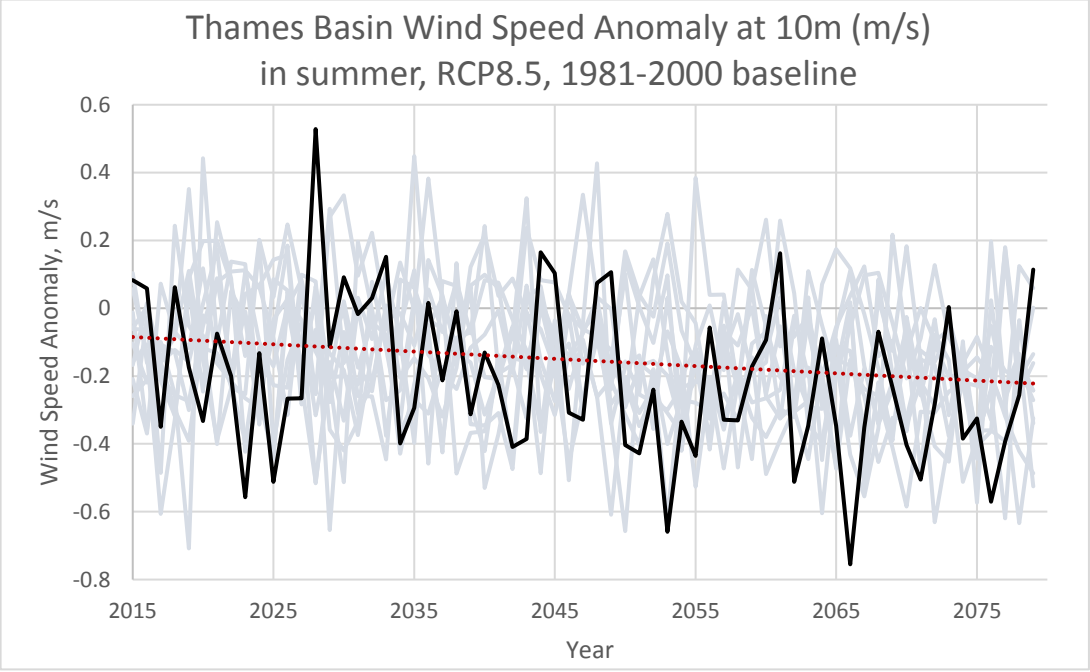

Figure A8 Summer Wind Speed Anomaly at 10 m relative to 1981-2000 baseline in the Thames Basin under emissions scenario RCP 8.5, with red dotted line as the trend of the mean of the 11 members.

A7. WAVES

Wind can generate and influence wave heights and also affect tidal flow. The wave climate, including significant wave heights, direction and period, in the Thames is

dominated by the speed and the rate of change of speed of the predominant wind, wind direction, and its variation in the North Sea [26]. The significant waveheight in the estuary is of the order of 1.5 m [19]. Studies have shown an increase in annual median extremes, or winter mean and extreme significant wave heights within the southern and eastern North Sea. The future changes vary between 5 – 8%, or up to 18% for seasonal and annual extremes, or between 0.25 and 0.35 m for the annual 99th percentile for 30-year period 2071–2100 based on analysis on the two global climate models for two emissions scenarios SRES A2 (most similar to RCP8.5 in terms of temperature rise) and B2 (most similar to RCP 6.0 in terms of temperature rise) [26]. Furthermore, waves can influence the erosion, transportation and deposition of sediments.

A8. EXTREME STILL WATER LEVEL

Still water level (SWL) is the level that the water surface at a given point and time would be in the absence of wind waves. It is influenced by the combination of the astronomical tide and the storm surge. The tidal range of the Thames increase upstream as a result of the funnelling effect of the estuary, with a mean spring tide range of 5.2 m at Sheerness gradually increasing upstream to 5.9 m at Tilbury and 6.6 m at London Bridge [19]. The SWL can be affected substantially with the increase in sea level and the tidal characteristic, including tidal range [43].

The water level in the tidal Thames can also be increased by the North Sea surge. The storm surge occurs when a low-pressure system moves across the Atlantic towards the British Isles then passes Northern Scotland and moves south into the North Sea. The depression carries a mass of water from the deep ocean with it and bring it to the relative shallow part of the North Sea just outside the Thames Estuary and causes a surge tide [16]. In the present of strong northerly wind, the surge tide can be heightened by over a meter.

The UKCP18 suggested no additional change in the extreme SWL due to storm surge but will increase due to the rise in mean sea level. The estimated extreme SWL at Sheerness to be 6.76, 7.44, and 8.08 m relative to the local chart datum with a 1/1, 1/50, and 1/1,000 year return by 2050 under the medium emission RCP4.5 scenario at 50th percentile (Figure A9), which is 0.15 m higher than the 2020 projections. The 1/1,000 return values are often used for mapping of flood risk areas in the UK.

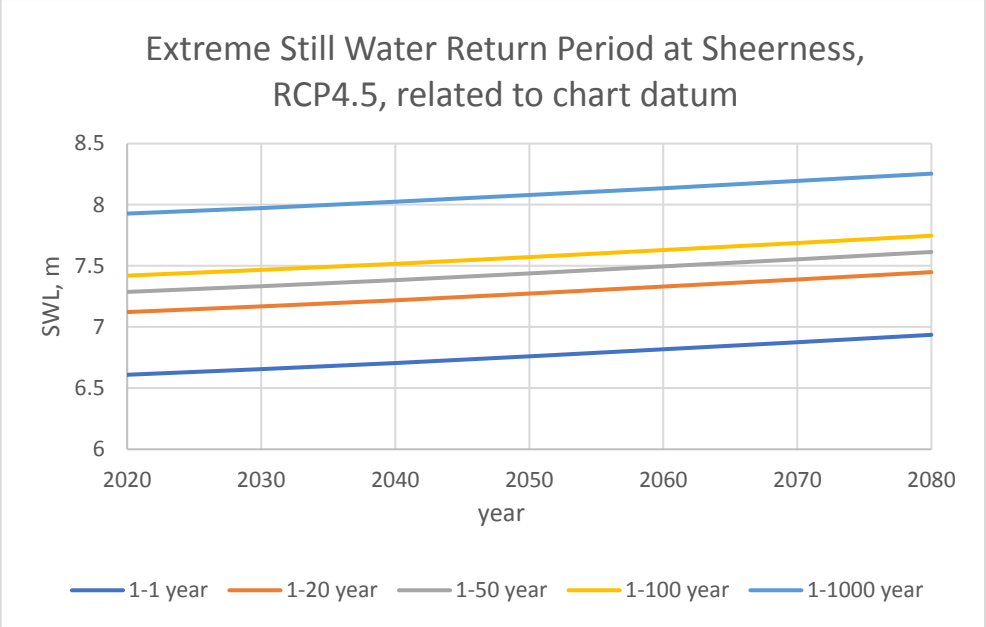

Figure A9 UKCP18 Extreme Still Water Level (SWL) Return at Sheerness under emissions scenario RCP 4.5 at 50th percentiles with 1,20,50,100, and 1000-year return. The SWL return are relative to the local Chart Datum (CD) and correct to base year 2017. [7]

[7] The UKCP18 SWL return level are given in meters ODN and being converted to CD by adding 2.9 m, the different between ODN and CD at Sheerness [50].

A9. FLOODING

The tidal Thames has an extensive floodplain of about 350 km^2. The main source of flooding on the tidal Thames is tidal flooding, then wave action and fluvial (freshwater) flooding, especially between Teddington and Richmond half tide lock, downstream of Richmond.

As mentioned in Section A8, the extreme SWL is estimated to be 0.15 m higher by 2050 relative to the 2020 due to the rises in sea level, which increases the chance of tidal flood. With increased wave height, the flood water volume will increase in the flood zones and the energy of the waves will increases by the square as wave that is twice as high will have four times the energy [26]. Higher sea levels also allow a bigger wave to reach the flood defences. Therefore, it is expected the rises in sea level is possessing a greater threat to coastal defences than changes in offshore wave [26].

In a natural environment, the flow of rainwater to the watercourse is slowed down by the percolation of soil or the interception by vegetation, which reduce the volume and speed of run-off. Downstream from Teddington, the Thames has twelve tributaries, which have a combined catchment area of about 3,000 km^2 [16]. As most of these catchments are situated in the London clay basin and drain heavily urbanised areas within the M25 that makes them very responsive to rainfall run-off. The increase in winter rainfall intensity can increase the chance of local fluvial and surface water flooding where the drainage network is overwhelmed.

The flood risk in the Thames Estuary is monitored and managed by EA under the TE2100 plan. Currently, there are various flood defences (or structure) in the region to reduces the risk of flooding (Figure A10), such as the Thames Barrier and 8 other flood barriers, over 350 km of walls and embankments, and over 400 other structures such as flood gates, outfalls and pumps. The raising sea level will have an impact on the Standard of Protection (SoP), the return period of a flood event against which the defence should be effective. The recent future flood risk study by the CCC indicated the in the River Medway and Swale Estuary Shoreline Management Plan region, the flood defence that could have a SoP of 100 years is reduce to 37 years with a relative Sea Level Rise (rSLR)[8] of 0.35 m [40]. The EA is currently undertaking a 10-year review to update the recommendation in the TE2100 plan using the latest evidence and data, expertise and knowledge.

[8] Relative Sea Level Rise (rSLR) have accounted for local vertical and land movement where the mean Sea Level Rise is relative to the centre of the earth

Figure A11 Flood map that indicate the flood zones and areas that are benefiting from flood defences within PLA's jurisdiction [44]

Table A 2 Future Standard of Protection (SoP) assuming relative Sea Level Rise (rSLR) of 0.35 m in the River Medway and Swale Estuary Shoreline Management Plan [40].

Present day SoP return period	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**
A 0.35 m rSLR	0	2	4	7	18	37	73	229	622

A10. DROUGHT

Hydrological droughts in river arise due to change in the rainfall, evaporation pattern, and additional impact of anthropogenic water use. The local drought impacts will depend on the management of water resources on national and regional scales. The characteristics of a drought are intensity (the deficit), duration (length of time in deficit), and severity (duration multiplied by mean standardise drought intensity) [45].

Under the high emissions scenario in UKCP18, the duration, intensity and the severity of droughts in the Thames region is projected to increase in the future. The median severity is projected to increase by 14% in the 2030s (2020-2049) and 24% in the 2080s (2070-2099) related to recent historical average (1970-1999). The median intensity is projected to increase 4% in the 2030s (2020-2049) and by 6% in 2080s (2070-2099) relative to the recent historical [46].

The severity of soil moisture drought is also projected to be 4% higher in the 2030s and 12% higher in the 2080s relative to the recent historical.

A11. FOG

The UKCP18 projections did not include fog projection. The risk assessment is based on the UKCP09 fog projection. In the winter the London area shows a 20% increase of fog days while the number of fog days in spring, summer and autumn reduces. A large percentage reduction is predicted in the summer months [28].

Table A 3 The change in the number of fog days, from 1961-199 to the 2080s in the London and South East England under the UKCP09 medium emissions scenario.

	Ann	DJF	MAM	JJA	SON
London	-19 %	+20 %	-38 %	-67 %	-28 %
SE England	-24 %	+7 %	-42 %	-70 %	-31 %

A12. CAVEATS AND LIMITATIONS OF UKCP18 PROJECTION

Table A 4 The caveats and limitations of UKCP18 Projection [47]

Caveats and Limitations	Potential impact on interpretation
Climate projections are dependent on future greenhouse gases assumptions.	Cannot reliably choose one scenario which is 'most likely'. Potential impacts of climate change could be different to those interpreted in the report.
Estimated ranges for future climate are conditional.	As science evolves the conditional choices for methodology and data may change, leading to new estimates of uncertainty. The projections reported may not be the most up to date at that point.
UKCP18 does not capture all possible future outcomes.	The probabilistic projections may not capture all possible future outcomes, therefore may not be completely accurate.
Climate model data contain biases.	Some climate model projections may exhibit systemic differences between model results and observations.
Finer model resolution does not necessarily provide greater confidence.	Some smaller resolution models used may only provide the same confidence as some of the larger resolution models.
Cannot rule out substantial additional sea level rise	Projected sea level rise and impact on flooding may be much larger than forecast due to accelerated loss of ice from West Antarctic Ice Sheet.
There are different levels of confidence for different products	Not all projections carry the same confidence, therefore derived projections and surge simulations used in section 3 are not as robust compared to the other projections used.
Take care when combining/ comparing variables	If variables aren't compared using the same parameters, they are likely to be inconsistent.
Climate projections are likely to evolve	Future projections are likely to change as technology and knowledge advances; therefore, these may impact on the actions taken in a risk assessment to build resilience against climate change.

APPENDIX B – THAMES BRIDGE CLEARANCES

*Table B 1 Individual arch clearance heights in meters above Mean High Water Spring (MHWS); Arches that are highlighted in blue refer to the main navigational arch; Arches that are or will have a clearance height less than 4m now or with a 0.31 m increase in mean sea level are displaced as red text; Arches that will have a clearance height less than 4m with a 1.15 m increase in mean sea level are displaced as blue text; * refers to headway above maintained water level; ** refers to minimum clearance to bottom of cable car gondolas, when loaded and at the bottom of the catenary.*

		Individual Arch Clearance Heights in metres above MHWS						
BRIDGE	Built in	1	2	3	4	5	6	7
Snapper		2.9*						
Richmond	1777	3.6*	4.5*	5.5*	4.4*	3.1*		
Richmond Rail	1908	5.4*	5.5*	5.5*				
Twickenham	1933	5.8*	6.1*	5.8*				
Richmond Footbridge, Lock & Weir			5.7	5.6	5.6	5.2		
Lots Ait Footbridge		3.9						
Kew	1903	4.4	5.2	4.3				
Kew Rail	1869	5.4	5.4	5.4	5.5	5.5		
Chiswick	1933	6.4	6.6	6.4				
Barnes Rail	1849	5.4	5.4	5.3				
Hammersmith	1887	2.4	3.5	2.4				
Putney	1886	3.3	4.3	5.2	4.3	3.4		
Fulham Railway	1889	6.1	6.4	6.6	7	7.2		
Wandsworth	1940	3	5.7	3				
Battersea Rail	1863	5.9	5.9	5.9	5.9	5.9		
Battersea	1890	2.4	3.8	5.4	3.8	2.4		
Albert	1873	4.2	5.2	5.2	4.1			
Chelsea	1935	6.1	6.4	6.1				
Victoria Rail	1963-1967	5.9	5.9	5.9	5.9			
Vauxhall	1906	3.8	5	5.6	5	3.8		
Lambeth	1932	3.1	5	6.3	5	3.2		
Westminster	1862	4.1	4.7	5.1	5.3	5.1	4.7	4.1
Charing Cross Rail	1882	6.8	6.9	6.9	6.9	6.8		
Waterloo	1937	6.1	8.4	8.5	8.5	6		
Blackfriars	1869		5.9	6.9	5.8	4.4		
Blackfriars Rail			6.9	6.9	7	7.2		
Millennium Foot	2002	8.5	8.8	6.3				
Southwark	1819	5.6	6.5	7.2	6.5	5.5		
Cannon Street Rail	rebuilt in 1981	6.7	7	7.1	7	6.8		
London Bridge	1973	6.6	8.6	6.6				
Tower	1894	6.8	8.5	6.8				
QE2	1991		53.9					
London Cable Car	2012	60.4**						

APPENDIX C – RISK ASSESSMENT METHODOLOGY

The PLA has reviewed the existing Evaluation matrix that was last updated in 2019 (based on the matrix presented within ARP 2015). Following the previous approach and in order to fully harness the expertise within the PLA, a session was held where staff could consider, discuss and review;

- update of the UK climate projections, the difference between UKCP09 and UKCP18
- the extent and timing of climate change on the tidal River Thames;
- the PLA's operations and duties likely to be affected by climate change;
- the likely timing and severity of these climate change risks taking account of the existing actions already delivery adaptation; and
- how the PLA should plan in any additional short and long-term.

Senior Managers representing the following functions of the Port of London Authority were invited to the session facilitated by the Environment team:

- Harbour Master
- Navigation Systems Engineering;
- Vessel Traffic Services;
- Marine Engineering;
- Hydrographic Surveying;
- Pilotage;
- Finance;
- Planning & Environment;
- Civil Engineering;
- Human Resources.

Risk assessment for each of the climate change impact had been undertaken using the 5 by 5 matrix, same as the one used in ARP 2015 (Section 5.1). The significant interest has also been assigned to each impact, which categorised into most relevant departments and three categories; 1. Corporate Operation, the impact on the organisation's ability to carry out its function; 2. Corporate Financial, the impact on the organisation's finances either in lack of income or cost; 3. Corporate Reputational, the impact on the organisation's reputation.

The PLA has been making good progress in developing and implementing climate adaptation and mitigation actions. Therefore, new evaluation matrices (Section 5) are now presented in a different way to the ARP 2015, to demonstrate better the impacts, ongoing actions, new or

planned actions to minimise or mitigate the risks in various area. It also listed some potential future actions if the future data show the existing actions are not effective enough.

In order to keep track on the progress of the adaptation and mitigation actions, the most relevant impacts and the associated risk level listed in the ARP 2015 have been matched to the new evaluation matrix.

Major changes between current and previous evaluation

- Assessment mainly based on UKCP18 medium emissions scenario (RCP4.5) at 50% probability whenever possible (See Section 3 for further information)
- "Ongoing actions" are the actions that have been taking place before 2020 to adapt and mitigate the relevant climate impact and will be continuing in the future.
- "New actions" are actions that have started in 2020 and "Planned actions" are actions that have already planned and will be implemented in the near future.
- "Potential future actions" are suggested actions in the long-term future if future data suggest the existing actions are not enough to minimising or mitigate the impacts. Further data collection and analysis are required to reduce the uncertainties in the associated long-term impact.

The following statements from the previous evaluation still apply in the revision

- The evaluation undertaken by the PLA provides details of the various impacts of climate change that have been identified. These impacts have been assessed on a geographical basis, including where necessary a consideration of the approaches to the Port of London. The responsibility within the PLA for those impacts has also been assessed including, where appropriate, third parties.