Technical Assistance to Deliver London's Climate Action Plan

Climate Action Planning Technical Assistance Programme Work Package 4: Impacts Assessment

18 May 2018

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Executive summary

C40 is providing technical assistance to London to establish a climate action plan to make the city low-carbon and resilient, consistent with the 1.5˚C target and adaptation objectives of the Paris Agreement.

The aims of this report are:

- To provide an easy-to-read review of climate impacts for London, using up-to-date information in key sectors (including information about costs, where feasible);
- To identify gaps in London's understanding of climate impacts in its key sectors;
- To highlight where disruption might occur as a chain reaction due to dependencies between infrastructure systems, with suggestions for coordinated response efforts; and
- To inform sector-based approaches to resilience, including recommendations for stakeholder engagement.

This compilation of evidence will inform London's sector-based approach to adaptation, and will be used in ongoing discussions with sector representatives and key stakeholders about understanding and improving the climate resilience of each sector in London.

Key findings

1. A lot of effort has been made to research impacts of climate change in multiple sectors in London over the years;
2. This has been undertaken in a piecemeal and ad hoc way to date, with funding from many different stakeholders to meet their own individual needs;
3. This body of work has not yet been integrated into a consistent framework, or formally collated, and only some of it is available in digital or spatially disaggregated forms.
4. This report summarises information from reports focusing on London (see Figure 1, Figure 2 and Table 1). There is a much wider range of literature which is relevant to an understanding of the impacts of climate change on sectors in London, and some reports reviewed have been superseded by more recent targeted studies within sectors.

All sectors have recognised the importance of impacts from changes in floods, drought and heatwaves that may occur in London throughout this century. While no sector is immune, the nature of the impacts varies, and the vulnerability of different sectors to rapid onset climate shocks or slow onset climate stresses also varies. The different sectors in London are also vulnerable to greater or lesser extents to either place-based impacts (originating within London itself) or system-based impacts (affecting Londoners and London businesses by virtue of the networks and connections on which London depends). For example, heat in London has a direct impact on Londoners' health and comfort, while London businesses may be affected by risks that create disruption in their supply chains, often well outside London or even the UK.

Despite a general level of understanding, in almost all cases the available evidence base would benefit from refinement, particularly to give better quantification of the impacts, including in terms of costs. For example, it would be helpful to quantify the financial costs of extreme weather across a range of sectors. Also, further research to understand critical links and failure points between infrastructure would help to target adaptation efforts. However, it is possible for key stakeholders to do more to enhance their preparedness for the impacts of climate change given the currently available evidence.

There is now a wide understanding of the impacts of climate change on sectors in London, though the depth and level of detail in the evidence base still needs extending. Next steps should address developing a comprehensive London-wide knowledge base, filling knowledge gaps through new research, and communicating the available information to support adaptation planning and action in a sector-based approach. London is already working to fill these knowledge gaps and to encourage understanding of impacts among sector stakeholders

Figure 1: State of evidence reviewed on climate impacts in London across the 21st century (energy, built environment, IT and business and economy sectors)

Sector	Hazard	Nature of impact						State of evidence reviewed
ENERGY		Flood-related damage to infrastructure (site, site access, storage areas)	LOW	LOW	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
ENERGY		Subsidence-related damage to infrastructure; low water flows affecting cooling capacity and ability to discharge cooling water.	LOW	LOW	MED	MED	HIGH	Some knowledge at UK level; lack of London-specific information
ENERGY		Impacts of extreme high temperatures on the efficiency of processes, including electricy transmission and distribution	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
ENERGY		Impacts of extreme high temperatures on employee productivity	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
BUILT ENVIRONMENT		Impact of fluvial and surface water flooding on residential and non-domestic buildings in terms of property damage.	LOW	LOW	MED	MED	MED	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impact of flooding on building valuation and insurance premiums.	LOW	LOW	MED	MED	MED	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impacts of subsidence and heave movement due to drought on building foundations and facades.	MED	MED	HIGH	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUILT ENVIRONMENT		Impact of high temperatures on London's buildings making them more expensive to run through cooling energy costs.	MED	MED	MED	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impacts of high temperatures on London's buildings making them more uncomfortable, reducing employee productivity, affecting health and wellbeing.	MED	MED	MED	MED	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUILT ENVIRONMENT	MULTI	Damage to historic structures and sites from multiple climate-related hazards	LOW	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Flooding of infrastructure and problems with emergency access for engineers and staff.	LOW	LOW	LOW	MED	HIGH	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Subsidence, ground shrinkage leading to damage of structures supporting digital network.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Stress and shorter in-service life on components and hardware due to high temperatures/cable heave.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
BUSINESS AND ECONOMY		Impact of flooding leading to property losses, uninsurability and decreasing property values	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUSINESS AND ECONOMY		Impact of flooding leading to numerous indirect economic and social impacts	LOW	MED	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
BUSINESS AND ECONOMY		Impacts of extreme high temperatures on thermal comfort of the workforce, employee productivity and energy costs	LOW	MED	MED	MED	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUSINESS AND ECONOMY		Impacts of extreme high temperatures on goods/products and services and tourism.	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information

NOW → Scale of impact → FUTURE

Figure 2: State of evidence reviewed on climate impacts in London across the 21st century (health and social care, vulnerable populations and natural environment sectors)

Sector	Hazard	Nature of impact	NOW		Scale of impact		FUTURE	State of evidence reviewed
HEALTH AND SOCIAL CARE		Damage to health and care facilities, restricted access for staff and contractors, failure of key services such as heating, cooling or water supplies, water contamination and supply-chain interruption.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Increase the potential for transportation of disease organisms into the water supply due to a flood event.	LOW	LOW	LOW	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Immediate, short-term and long-term health impacts due to flooding.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Immediate, short-term impacts to health during to heatwaves.	MED	MED	HIGH	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
HEALTH AND SOCIAL CARE	MULTI	In-combination impacts due to water supplies being stretched during droughts and heatwaves.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Impact of flooding on the social and civil infrastructure that supports vulnerable populations.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Impact of drought on increasing levels of social inequality across London.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Extreme high temperatures pose risk to health and wellbeing, especially for vulnerable individuals (the elderly, young children, low-income and crowded households).	MED	MED	HIGH	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
VULNERABLE POPULATIONS	MULTI	Cumulative impact of several events taking place in a short timespan, affecting the ability of vulnerable populations to rebound from each event.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
NATURAL ENVIRONMENT		Impact of flooding on rivers, streams, standing water and wetlands habitats	LOW	LOW	MED	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
NATURAL ENVIRONMENT		Impact of changes in precipitation reducing river flows in summer and reducing groundwater recharge, increasing physiological stress on habitats.	LOW	MED	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
NATURAL ENVIRONMENT		Impacts of high temperatures on species composition favouring a transition to plant communities better adapted to drought conditions.	LOW	LOW	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
NATURAL ENVIRONMENT		Loss of urban vegetation through heat stress.	LOW	MED	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence

Source: Prepared for the current study

Table 1: Summary of findings on impacts

Sector	Findings on impacts and opportunities for further work in London
Energy	• Current short-term weather events present more of a risk than long-term trends in climate change. • These risks from short-term weather events are low compared to engineering-related faults leading to loss in generation. • Climate change is not expected to introduce any new types of risk to operations but rather change the likelihood or severity of risks which are currently managed.
Built Environment	• The changing nature of flood, drought and overheating events are making buildings unsuitable for our current and future climate. • Flooding and extreme hot weather pose the highest magnitude risks and represent the greatest need for action in the next five years • Further action is needed to adapt the existing building stock and design new buildings to counter the impacts of climate change.
Health and social care	• Relatively more is known about the impacts of climate change on physical health, than on impacts specific to service provision, social care, and management of mental health. • Health impacts of climate change in London include heat- and cold-related mortality and morbidity, morbidity and mortality resulting from extreme weather like flooding, vector-borne diseases, air quality impacts, etc. • More research is needed to understand the influence of climate change on air quality and consequent implications for health.
Vulnerable populations and migrations	• Increased temperatures and greater potential for heatwaves are likely to have the greatest impact on vulnerable populations (including migrant communities) in London. • Future projections of the impacts of flooding on vulnerable populations need to be better understood.
Natural environment	• Nature-based solutions offer the potential to improve London's resilience to extreme weather. • Most detailed work on impacts of climate change on the natural environment is at the national scale and there is relatively less at the city scale. • Little is known about climate change impacts on private gardens and brownfield sites, both of which are important components of London's natural environment. • More research is needed about the impacts of climate change on the provision of ecosystem services in London and knock-on effects to the goods and benefits dependent on London's natural capital.
Business and economy	• Main impacts of climate change on business activity within London arise from flooding and heat, but it is difficult to disentangle direct impacts on business from those on other contributing sectors. • Little evidence is available on the observed or experienced impacts of climate change on London's business and economy, beyond awareness at an anecdotal level. • The risks imported through dependencies on the financial service sector and international supply chains are acknowledged but poorly understood. • Measuring and demonstrating the economic activities that benefit from adaptation to climate change could help to grow the adaptation economy in London and the UK.
Information Technology	• Evidence and research on climate change impacts on IT structures and networks, and the IT sector more widely, is currently limited, and London-focused work is potentially non-existent. • IT infrastructure has some unique characteristics that may make it inherently resilient to climate change. • The sector is highly dependent on energy but not all interdependencies are known and rapid changes in technology may expose the sector to new and unexpected vulnerabilities.

Source: Evidence reviewed in this project

Despite the gaps in evidence highlighted by this study, it should not be assumed that London is under-preparing for climate change: there are current examples of detailed climate change impact and risk assessment work being undertaken in support of large investments in and around London. That this work is progressing on a project-by-project basis, rather than as a London-wide, or sector-wide assessment, may be entirely appropriate and the most cost-effective way for the needed level of detail to support adaptation planning. The GLA now should examine the role played by the city authority in facilitating, co-ordinating or even, to some extent, quality-controlling these research and assessment efforts. In this way, it can help ensure that planning across London is more coherent, and that interdependencies are not overlooked.

Based on this review of evidence, this study offers recommendations to improve the evidence base in four areas:

- Developing a comprehensive London-wide knowledge base
  - To support more consistency and comparability between sector assessments
  - To improve accessibility of information for policy and project work in London (e.g. facilitating resilient development in floodplain)

Where more detailed information is required by sector stakeholders to underpin adaptation decisions, then this may be most appropriately produced by individual stakeholders to suit their specific needs. However, there is an important coordination and facilitation role to enable cross-sector and inter-stakeholder collaborative working. One option may be for the GLA or London Climate Change Partnership (LCCP) to extend and maintain a repository of evidence, using that as a key part of the sector-based engagement on adaptation.

The evidence base relevant to an understanding of the impacts of climate change in London is extremely large, given the connections and dependencies that underpin this urban system. This evidence base is also being added to constantly, from academic research, policy analysis, strategic sector planning, and practical experience. Digital approaches may offer ways to facilitate the collation of this dynamic evidence base. In order to support adaptation in London, we suggest that a digital data repository should offer benefits to the widest possible range of London stakeholders, including vulnerable populations, from large infrastructure agencies and authorities, to London boroughs with responsibilities for small care home facilities. The GLA is developing data tools such as green infrastructure and infrastructure mapping to help improve London's adaptation interventions. We recommend that the GLA continue to explore the possibility and benefits of this kind of digital development, in the context of London's wider digital and data sharing aspirations and plans.

- Filling knowledge gaps through new research

Further research to fill gaps in the knowledge base for London is needed at both micro and macro levels, including case study type research to gather objective and quantitative information about the scale of impacts from recent weather events. Specific areas of work, or gaps for attention, are identified in the full report. These include:

- mapping of locations where multiple infrastructure points come together (e.g., water and electricity lines) to assess vulnerability
- the vulnerability of London's economy through supply chain risks
- the impacts of climate change on air quality in London
- London-specific studies of impacts on IT infrastructure
- Impacts on the provision of ecosystem services in London and potential knock-on effects on the benefits of London's natural capital.

- Communicating the available evidence base

Alongside a coordinating role around the development of new or updated information on the impacts of climate change, we recommend that the GLA builds on its convening and lobbying role, by enhancing the communication of the already available evidence base. Even where only qualitative information on impacts exists in some sectors, it is still possible for stakeholders to take further steps, while recognising where uncertainties lie, to improve their preparedness for climate change. The GLA may find that new efforts to communicate the available evidence also allow for stepping up the challenge to take action where appropriate. This has already been recognised in the new London Environment Strategy, which contains proposals to raise awareness of heat and flood risk through campaigns and communications protocols.

We recommend that the GLA share learning with other C40 cities about the most appropriate ways for data and information on climate exposure, vulnerability or impacts to be disseminated to London's stakeholders. Simple visual materials that communicate the impacts of climate change can support the GLA's sector-based approach, tailored to the needs of specific stakeholders.

- Engaging stakeholders in the sector-based approach

The London Climate Change Partnership (LCCP) can place a major focus on improving multi-sector engagement in understanding interdependent climate impacts, building on work from the Anytown project. A forum or workshop on interdependencies will also offer an opportunity to examine the co-benefits of climate change action, perhaps looking specifically to identify and quantify the multi-stakeholder benefits of adaptation action that addresses interdependent climate impacts.

Part A – Introduction

London has declared its aim of being a leader in the response to climate change.

1 Purpose and context

This report was commissioned by the C40 Cities Climate Leadership Group on behalf of the Greater London Authority (GLA) to help inform London's efforts to become more resilient to the effects of climate change. London is already tackling climate change by cutting greenhouse gas emissions to limit further climate change. Part A outlines the purpose and context of the report. Part B presents a sector-based impacts assessment, followed by a cross-cutting review in Part C of impacts and interdependencies, a consolidated gap analysis and finally conclusions and recommendations. This report will therefore inform discussions with sector representatives and stakeholders and to help identify ongoing research priorities for London that will enhance climate resilience.

1.1 Global and UK context

The impacts of climate change have been observed across the globe. The Paris Agreement builds upon the United Nations Framework Convention on Climate Change and for the first time brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort.

The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2^{o}C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5^{o}C. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. The Agreement also provides for enhanced transparency of action and support through a more robust transparency framework.

The IPCC Fifth assessment report (AR5) reported that urban climate change risks are increasing, and that many of the "key and emerging global climate risks are concentrated in urban centres". Cities, such as London, already experience weather-related hazards and disruption and report that some of hazards they face will become more serious and more frequent as the climate changes. This has the potential for profound impacts on people, infrastructure, environments, and local and national economies.

The Evidence Report for the second UK Climate Change Risk Assessment (CCRA2) was published in 2017 and assessed "the urgency of further action to tackle current and future risks, and realise opportunities, arising for the UK from climate change." It provides the most up to date scientific evidence on major climate risks in the UK and reinforces the need for London to work with a wide range of sectors to address these risks. However, while the national risks broadly align with London's priorities, there is local variation, and they need to be understood in the context of the characteristics and concerns across the city.

The CCRA2 highlighted six groups of risks affecting the UK as a whole, where there is a need for action within the next five years (Figure 3). All of these affect London to some extent, but perhaps groups 1, 2, 3, 4 and 5 may have the most direct impact on London or Londoners, or are those which can be most directly addressed by London's stakeholders. In this report, we have reviewed studies and reports from the last 15 years to collate the evidence for the nature and extent of climate impacts in London.

A major upgrade of the UK Climate Projections was announced by the Department of Environment, Food and Rural Affairs (DEFRA) on 15 January 2016, to ensure that decision-makers have the most up-to-date information. The UK Climate Projections 2018 project (UKCP18) will build upon the current set of projections available (UKCP09). Table 2 provides more information about these new projections.

Figure 3: Top six areas of inter-related climate change risks for the UK

Source: UK Climate Change Risk Assessment 2017

Table 2: UK Climate Projections 2018

Insights to the new climate change projections for the UK, currently under development.

Release date	The UKCP18 project is entering a phase of testing and evaluation ahead of launch. Currently, the delivery systems for the projections are being tested and improved, and will then be subject to extensive peer review of the climate science. The more extensively evaluated projections data will be made available in November 2018 along with interpretation and guidance products to support the needs of users. It will include up-to-date information on how the UK climate may change over the rest of the century.
Similarities and differences between UKCP18 and UKCP09 projections	In broad terms, the new projections will follow a similar scientific and methodological approach as that used in UKCP09 and many of the products that users are familiar with will continue to be available. Importantly UKCP18 will continue to present future climate variables as probability distributions (pdfs) to express the uncertainty that is inherent in modelling the climate system and ensure that users understand the range of futures that are possible. The pdfs will incorporate the latest climate science and the most recent observational data. UKCP18 will also include innovations to enhance the utility of the projections. To complement the pdfs - and in response to user feedback - 11 to 30 plausible pathways of future climate will be provided derived from an ensemble of runs from the Met Office climate model. These will give users a range of scenarios to undertake impact assessments and test their adaptation plans against. The UKCP18 project will also carry out some very high-resolution modelling (<5km) to provide new information on how certain types of weather event could change in future, such as localised heavy rainfall events in summer, often associated with flash flooding.
Representative Concentration Pathways	The next set of UK climate projections will use new scenarios called Representative Concentration Pathways (RCPs) which were used in the most recent IPCC report. These are

Insights to the new climate change projections for the UK, currently under development.

	an update to the existing emissions scenarios used in UKCP09, which did not consider specific climate change mitigation strategies to limit emissions.
From climate projections to impacts information	UKCP18 will provide the latest information on our future climate. We know that many users and decision makers want to know about the climate impacts related to these projections, such as future flood risk or heat stress. It is not within the scope of the UKCP18 project to provide impacts information, and it is currently unclear who this will be undertaken by. However, the UKCP18 project team has worked with potential users to understand what information and products are of most use, and provided an overview of these needs alongside summaries for a number of topic areas. This information can be used to develop research requirements or in discussion with wider networks.

Source: http://ukclimateprojections.metoffice.gov.uk/24125 and http://ukclimateprojections.metoffice.gov.uk/24126

1.2 Climate change policy in London

In August 2017, the Mayor of London, Sadiq Khan, published his consultation draft London Environment Strategy[1] (14). The strategy was finalised in June 2018. This is the first integrated environment strategy, bringing together eight previous statutory and non-statutory strategies into one document. The London Environment Strategy summarises the context for the current study: “As a growing city, London faces increasing pressure on housing, infrastructure, services, environment, and Londoners’ wellbeing and prosperity. Climate change will increase these existing pressures. It will make flooding more frequent and severe, threaten water resources, and increase the risk of overheating for buildings and infrastructure.”

London has been at the forefront of research and engagement on the impacts of climate change for almost two decades. The London Climate Change Partnership (LCCP) was established in 2002 and has been a centre for expertise on climate change adaptation and resilience to extreme weather in London since then, driving collaborative working among London stakeholders. London has a history of studies that consolidate the state of play of knowledge on impacts in London, for the benefit of the many stakeholders that depend on this growing evidence base to take appropriate and urgent steps to adapt.

With the London’s Warming Report of 2002, initial insights into potential climate hazards and impacts on different sectors were established. In 2005, London benefited from the UK-wide consolidation[2] of information produced in regional and sectoral impacts scoping studies undertaken by the UK Climate Impacts Programme (UKCIP). The 2009 Climate Impacts Profile[3] for London took a slightly different tack in gathering evidence about experiences of extreme weather events through a media trawl. The 2011 London Adaptation Strategy set out how London would build resilience to impacts arising from the three key hazards of flood, drought and heat, including the Urban Heat Island (UHI) effect (Table 3).

Table 3: The UHI Effect

Urban Heat Islands
UHIs are a factor in many urban settlements and refer to the difference in temperatures measured inside and outside the urbanised area. Several studies have quantified the role of the built environment in increasing outdoor temperatures. The UHI intensity is typically higher at night than during the day and shows seasonal variation for most cities in the UK. The temperature increment at the centre of a large city can be as large as 5 – 10°C compared with the surrounding countryside. The UHI effect may be considered as beneficial in winter, since it reduces somewhat the impacts on health from cold weather and heating demand. However, in summer, and especially during heatwaves, it may exacerbate building overheating since it prevents buildings from cooling down, particularly at night.

[1] https://www.london.gov.uk/sites/default/files/adapting_to_climate_change.pdf
[2] http://www.ukcip.org.uk/wp-content/PDFs/MeasuringProgress.pdf
[3] http://climatelondon.org/publications/wild-weather-warning/

Urban Heat Islands

In the UK, UHIs have been modelled in London, Birmingham, Manchester and Glasgow. The measurement of the heat island depends on the urban heat island metrics chosen (e.g. peak UHI intensity) and the urban–rural reference points. The London UHI is generally found to be greater than those of other UK cities.

Climate change projections often do not include the effects of the UHI, due to the difficulty in resolving city-scale detail in global models, which means that assessments of heat-related health effects which use these projections may underestimate the actual magnitude of future health impacts in areas with urbanisation.

Source: The UK CCRA2, 2017

The draft London Environment Strategy (14) highlighted that climate change will exacerbate the existing and growing pressures that London faces on housing, infrastructure, services, environment, wellbeing and prosperity. It identified London's main climate challenges as flood risk, drought, heat risk and "interconnected risks", acknowledging that cities are complex and interdependent systems and that adapting to climate change will depend on recognising the possible knock-on effects from disruption due to climate-related impacts. The aim of the adaptation section of the London Environment Strategy is that "*London and Londoners will be resilient to severe weather and longer-term climate change impacts. These will include flooding, heat risk and drought.*" There are four objectives for adaptation, and this report has particular relevance to the first of these. The full list of policies and proposals is provided in Appendix B.

- Understand and manage the risks and impacts of severe weather and future climate change in London on critical infrastructure, public services, buildings and people (Objective 8.1);
- Reduce risks and impacts of flooding in London on people and property and improve water quality in London's rivers and waterways (Objective 8.2);
- Ensuring efficient, secure, resilient and affordable water supplies for Londoners (Objective 8.3); and
- London's people, infrastructure and public services are better prepared for, and more resilient to, extreme heat events.

The London Environment Strategy (14) summarised the evidence underpinning the Mayor's ambitions for adaptation in London, but in doing so it also highlighted several areas where knowledge gaps exist and further work is required. This report sets out its own recommendations for knowledge gaps and further work.

1.3 Climate change in London

UKCP09 data can be interrogated to understand the nature of likely changes to London's climate over the next century. Table 4 presents the UKCP09 projections for London under the high emissions scenario for the 2020s, 2050s, and 2080s. Generally, a trend towards warmer, drier summers and wetter winters can be seen, with notable changes by the 2020s (baseline 1961–1990).

Table 4: High emissions scenario projections for London.

Climate Variable	Central estimate of change in 2020s (°C)	Central estimate of change in 2050s (°C)	Central estimate of change in 2080s (°C)
Summer mean temperature	• + 1.5ºC; • very unlikely to be less than 0.5ºC and is very unlikely to be more than 2.7ºC;	• + 3.1ºC; • very unlikely to be less than 1.4ºC and is very unlikely to be more than 5.2ºC;	• + 4.9ºC; • very unlikely to be less than 2.6ºC and is very unlikely to be more than 8.1ºC;
Summer mean daily maximum temperature	• + 2ºC;	• + 4.3ºC;	• + 6.7ºC;

Climate Variable	Central estimate of change in 2020s (ºC)	Central estimate of change in 2050s (ºC)	Central estimate of change in 2080s (ºC)
	• very unlikely to be less than 0.5ºC and is very unlikely to be more than 3.7ºC	• very unlikely to be less than 1.7ºC and is very unlikely to be more than 7.4ºC	• very unlikely to be less than 3ºC and is very unlikely to be more than 11.5ºC
Winter mean precipitation	• + 7% • very unlikely to be less than -3% and is very unlikely to be more than 18%	• + 16% • very unlikely to be less than 2% and is very unlikely to be more than 35%	• + 26% • very unlikely to be less than 6% and is very unlikely to be more than 58%
Summer mean precipitation	• - 4% • very unlikely to be less than -23% and is very unlikely to be more than 18%	• - 19% • very unlikely to be less than -43% and is very unlikely to be more than 9%	• - 29% • very unlikely to be less than -56% and is very unlikely to be more than 5%

Source: http://ukclimateprojections.metoffice.gov.uk/21708?projections=23860 Accessed April 2018

1.3.1 Projected impacts from flooding

UKCP09 projections suggest London will face increased summer and winter precipitation, with an increase in the frequency of intense precipitation events that lead to flash, surface and fluvial flooding (22). Under a medium emissions scenario, winter rainfall will increase 6% by 2020 and 15% by 2050, increasing the potential for flooding in the short-term (17).

London will also be affected by sea level rise, with projections of sea level rise in the Thames over the next century due to thermal expansion of the oceans, melting glaciers and polar ice estimating a likely increase between 20 cm and 90 cm. In the context of the Thames Estuary, this means a worst-case scenario for increases in water level of +2.7m before 2100 (38). Combined with a predicted increase in storm surges, this will lead to a significantly increased risk of flooding.

UKCP09 projections do not include changes to wind or snowfall. However, the Met Office Hadley Centre regional climate model projects a decrease in winter mean snowfall of typically 65% to 80% in high altitude areas across the UK and 80% to 95% elsewhere by the 2080s. Met Office projections for wind speed are for a change of less than +3% over the UK by the 2080s.

1.3.2 Projected impacts from drought

London has been in periods of drought on and off over the last 20 years (18). It is therefore familiar with the impacts of water stress, with careful management required to ensure that current resources are sufficient. Dry periods can be short, as experienced in the hot summer of 2003 or prolonged, such as the two dry winters experienced in 2004- 05 and 2005-06 (28). For an 18-month period leading up to March 2012, there was extremely low rainfall across most of England, and this was the driest period across the region since 1976 resulting in water companies implementing temporary use bans due to low groundwater and environmental stress (1).

A severe drought is a real and present threat to the capital, and would have extensive social and economic impacts. Most future projections point to increases in the number of periods of extreme high temperatures as well as drought (24). Climate change projections indicate that up to 2050 and beyond, London will experience drier summers. More specifically, the UKCP09 medium emission scenario has identified that by 2050s the average summer 19% drier and the driest summer 39% drier than the baseline average (12).

1.3.3 Projected impacts from heat

Over the last 30 years, London has seen an increase in average summer temperatures by 0.77°C per decade, with peak daytime temperatures increasing the fastest at 1.66°C per decade (28). Extreme high temperatures were experienced in the summers of 1976, 1989, 1990, 1995, 2003, 2006 and the unseasonal hot weather of April and October 2011 (15), although with differing occurrences, duration, and intensity.

Under the UKCP09 medium emission scenario, by the 2050s there will be higher summer temperatures in London, with the average summer days being 2.7°C warmer and very hot days 6.5°C warmer than the baseline average, and warmer winters - with the average winter day in London being 2.2°C warmer and a very warm winter day 3.5°C above the baseline. Furthermore, heatwaves, like that experienced in 2003, could reportedly become a normal event by 2040 (9), with the intensity and impact potential of heatwaves likely to increase (11, 28).

1.3.4 Other impacts

The potential for an increased number of storm events is likely to impact London greatly. Although it is most likely that storm events will be over in less than a day, disruption to infrastructure including power, communications, transport networks, homes and businesses could last for 1 to 4 days afterwards (4). There may be casualties and fatalities, mainly due to falling trees and structures or other debris. Some social disruption and economic impacts are likely, due to disruption to transport networks, power supplies, telecommunications links and water supplies, predominantly from fallen branches, trees and other debris.

1.4 Purpose of this report

This impacts assessment will provide a new sector-based consolidation of the evidence base on potential climate impacts in London. It will lay the foundation for appropriate response planning, assessment of interdependencies and ongoing sector and stakeholder engagement. It will also support the development of London's adaptation initiatives and highlight areas for further research.

The aims of this report are:

- To provide an easy-to-read review of climate impacts for London, using up-to-date information in key sectors (including information about costs, where feasible);
- To identify gaps in London's understanding of climate impacts in its key sectors;
- To highlight system interdependencies where cascading failures might occur, with suggestions for coordinated response efforts; and
- To inform sector-based approaches to resilience, including recommendations for stakeholder engagement.

2 Scope of the review

This section sets out the scope of the impacts assessment, including the documents that were reviewed. It acknowledges the limitations of the review and describes the structure of the rest of this report.

2.1 Sectoral scope

The selection of sectors for this report was proposed by the GLA in consultation with C40 and initially based on those used in the *London's Warming* report from 2002 and expanded according to need. The sector selection was informed by the perceived availability of information in London and the sector-based approach to adaptation applied in the London Environment Strategy. No priority has been given to any one sector and the level of content within each chapter is wholly dependent on the availability of information in the documents reviewed. The sector-based approach taken in this report is flexible and it would be possible to accommodate the addition of other sectors later, if necessary.

Sectors were chosen for inclusion based upon their ability to satisfy the following criteria:

- Sectors in need of capacity building;
- Sectors not yet covered by the kinds of London impacts reports we've seen in other sectors;
- Sectors where less is currently known about impacts; and
- Sectors where the GLA may need to take a stronger role in coordinating (e.g. there are multiple stakeholders).

A discussion of each sector against these criteria is given below.

1. Energy

The impacts of climate change on the energy sector (electricity and gas networks) are well-considered, with management of climate risk embedded within companies' overall risk management processes to ensure that appropriate actions are recorded and completed. Despite this, as the GLA do not currently have this information available, the sector has been included in this report.

2. Built environment

The impacts of climate change on the built environment sector are well-documented, and there is evidence to suggest that guidance is having an increasing influence on different actors in the sector, although this is fragmented. Nevertheless, further action is needed to adapt the existing building stock and design new buildings to counter the impacts of climate change. Therefore, this sector was deemed important to include in the final report.

Feedback from our sector experts has suggested additional sources that should be considered for a more complete and up-to-date summary of the evidence available on climate impacts to the built environment. These additional sources have been signposted.

3. Health and social care

The impacts of climate change on the health and social care sector are noteworthy, affecting multiple stakeholders and boroughs across London. Therefore, this sector was deemed important to include in the final report, with the potential to inform coordination of stakeholders and boroughs in their adaptation responses. Its inclusion complements the built environment sector.

4. Vulnerable populations

This sector has not been covered by high level impacts summaries, especially in comparison with main infrastructure sectors, though there has been some relevant recent work like ClimateJust[4]. There is a strong link between vulnerable populations and the health/social care and resilience sectors. Therefore, this sector was deemed important to include in the final report.

5. Natural environment

The impacts of climate change on the natural environment in an urban setting are less well understood; some of the evidence on particular species or habitats is old and framed in a policy context that no longer applies. Therefore, this sector was deemed important to include in the report, with the potential for improved coordination in the context of the London Environment Strategy. Its inclusion complements the built environment sector.

6. Business and economy

Past examples of the impacts of climate change on the business, economy, finance and insurance sectors of London are poorly documented in the reports reviewed for this study. Often there is awareness at an anecdotal level, but this has not been captured in a more comprehensive analysis. Therefore, this sector was deemed important to include in the report, particularly in the current context of the Taskforce on Climate-Related Financial Disclosures[5] (TCFD).

7. IT

Relatively little prior research on the impacts of climate change on IT in general, and even less that is specific to London currently exists, despite its increasing importance in the context of interdependencies. Therefore, this sector was deemed important to include in the final report, with the potential to inform future priorities regarding engagement and extension of the evidence base.

8. Water and sewerage

The impacts of climate change on the water and sewerage sector have been considered for many years. Impacts to the sector are mitigated and managed in water resources management plans, such as the Thames Water Resources Management Plan. Major stakeholders in the sector are well advanced and have a sophisticated understanding of the impacts. Therefore, this sector was omitted from this report, although has been provided in draft format to the GLA.

9. Transport

The impacts of climate change on London's transport sector (roads, railways, tunnels and bridges) are generally covered well, with the exception of aviation. A number of assessments have been undertaken by Transport for London (TfL) on the resilience of London's transport services, and many projects are underway currently. Coordination and knowledge sharing in the sector is improving with the new TfL Adaptation Steering Group. Therefore, this sector was omitted from the report, although was provided to the GLA in draft format. The work in the draft

[4] http://www.climatejust.org.uk/

[5] https://www.fsb-tcfd.org/

chapter could be deepened and carried forward within the TASG's work programme in due course.

10. Emergency planning and resilience

The impacts of climate change on the emergency planning and resilience sector are understudied in some respects. Although by its nature the sector is tuned to dealing with extreme weather emergencies, there is a need for capacity-building in consideration of long term climate change. This sector was omitted from the report due to budget constraints, although has been provided in draft to the GLA.

2.2 Typology of climate hazards

There are several different typologies for identifying and framing climate hazards that could be applied in this study. For example, the C40 CRAFT[6] framework has global applicability and identifies 5 hazard groups - meteorological, climatological, hydrological, geophysical and biological - with multiple hazard types (e.g. precipitation, extreme temperatures (hot and cold), water scarcity, flood, wave action, lightning, fog, wind and wildfire). However, not all of these are relevant for London. The European Climate-ADAPT platform[7] adopts a different selection of hazard categories (e.g. heatwaves, water scarcity and droughts, flooding and forest fires).

For this study, we have followed the precedent in London of grouping climate impacts simply under the three hazard themes of flooding, drought and heat, since this is likely to be most familiar to stakeholders with whom the GLA will be working to fill knowledge gaps and plan adaptation. For some sectors, we have also included other hazards if relevant (for example, if the documents reviewed contained information about impacts from snow or cold weather).

2.3 Document selection

In discussion with GLA the documents in Table 5 were agreed for review in this study. Following the initial focus on these documents, some further sources were identified in some sectors, within the limitations of the resource available to this project. The full set of references reviewed is in Section 13. During the review process, where other recent relevant sources came to light, these have been signposted at the end of the relevant sector chapter, even if it has not been possible to incorporate them in this report.

Table 5: List of documents reviewed in the current study

Title	Organisation/Author	Year	Relevant sector chapter(s)
Your Social Housing in a Changing Climate	Climate London	2018	Built Environment
Assessing overheating risk: evidence review	LCCP	2015	Built Environment
Your home in a changing climate	LCCP	2013	Built Environment
A Case Study Companion to the Checklist for Development	GLA	2007	Built Environment
Weathering the Storm: impacts on London's economy	London Assembly Economic Committee	2015	Business and economy Finance and Insurance
The impact of climate change on London's economy: A summary of views and information	GLA	2014	Business and economy Finance and Insurance

[6] http://www.c40.org/programmes/climate-risk-adaptation-framework-and-taxonomy

[7] http://climate-adapt.eea.europa.eu/

Title	Organisation/Author	Year	Relevant sector chapter(s)
London's Commercial Building Stock and adaptation	Climate London	2009	Business and economy Finance and Insurance
Business as usual	Climate London	2006	Business and economy Finance and Insurance
London Risk Register	London Resilience Partnership	2017	Emergency planning and resilience
Anytown	London Resilience Partnership	2016	Emergency planning and resilience
In sickness and in health	Carers UK	2012	Health and Social Care Vulnerable populations
Linking environment and health	LCCP	2012	Health and Social Care Vulnerable populations
Infrastructure interdependencies and climate risks report	C40	2017	Multi-sector
UK climate change risk assessment for London	LCCP	2012	Multi-sector
Managing risks and increasing resilience: The Mayor's climate change adaptation strategy	GLA	2011	Multi-sector
Wild weather warning: a London climate impacts profile	LCCP	2009	Multi-sector
Natural Capital Account for London	London Assembly	2017	Natural Environment
Nature based solutions for sustainable urban development	UNFCC	2017	Natural Environment
Green Infrastructure Task Force report	Green Infrastructure Task Force	2015	Natural Environment
Arup Cities Alive: Rethinking green infrastructure	Arup	2014	Natural Environment
Adapting to climate change - creating natural resilience	LCCP	2009	Natural Environment
The indirect and secondary impacts of changes to London's transport as a result of climate change	TfL	2016	Transport -
Direct impacts of climate change on London's transportation network	Atkins	2016	Transport -
Tomorrow's railway and climate change adaptation: final report	RSSB	2016	Transport -
Providing Transport Services Resilient to Extreme weather and climate change	TfL	2015	Transport Emergency planning and resilience
Weather and Climate Change	TfL	2015	Transport Emergency planning and resilience
London's response to climate change	GLA	2015	Transport Emergency planning and resilience
Managing extreme weather at Transport for London	TfL	2014	Transport Emergency planning and resilience
SHARPER project about vulnerability to heat in London, Shanghai, and New York.	Arup	N/A	Vulnerable populations Emergency planning and resilience
London's Regional Flood Risk Appraisal	London Plan	2017	Water and Sewerage Emergency planning and resilience
Thames Water Adaptation reporting power 2nd round Progress Report	Thames Water	2017	Water and Sewerage

Source: Mott MacDonald (2018)

We also reviewed the UK CCRA2 to consider the impacts that may be relevant to London, and with a focus on the risks that were placed in the top two urgency categories in that work.

2.4 Structure of this report

The rest of this report is organised as follows:

- **Part B – Sector-based review of impacts.** Includes a review chapter for each sector, presenting information about the impacts associated with floods, drought and heat.
- **Part C – Discussion.** Includes cross-cutting review of information about climate impacts and interdependencies, as well as a consolidated gap analysis, conclusions and recommendations.
- **Appendices**.

Part B – Sector-based review of impacts

3 Energy

On the basis of the material reviewed, the UK energy sector faces disruption from flooding, storm surges and extreme winds. There are uncertainties around future generation including the UK energy mix and changes in pattern of power station operation, coupled with regulatory uncertainty. Little has been reported on the costs that these impacts could impose, on any scale. Information specifically for London is scarce, with research largely focused on a national scale. Nevertheless, national research suggests that the sector overall demonstrates a high level of resilience to potential disruption from weather events. Looking towards the future, the grid will need very substantial upgrading if the UK is to make the changes necessary to deliver on its 2°C commitments and therefore the impacts of climate change are crucial when determining how this will be undertaken.

This chapter summarises the available evidence regarding the key impacts of climate change on London's energy sector. In this chapter, the sector is considered to be the generation, transmission and distribution of electricity and transmission and distribution of gas. National Grid owns and operates the high voltage electricity transmission system in England and Wales and operates the GB transmission network (43). National Grid Gas plc operates and owns the UK Gas transmission system and low-pressure Gas distribution in the heart of England, distributing to approximately 11 million homes, offices and schools (44).

Energy is vital for the economy, for critical services and for everyday necessities of life. The population depends on secure energy supplies that can provide homes and businesses with the power they need, when they need it (42). Therefore, a diverse range of stakeholders is involved in this sector. In 2014, 46% of primary energy supply was imported to the UK (mainly in the form of fossil fuels) following a record high of 47% in 2013 (2), which means that the impacts of climate change elsewhere in the world (e.g., affecting other oil-producing countries and import routes) may be important for the resilience of the sector in the UK. A consideration of the possible future climate impacts in the sector needs to allow for the fact that by the 2050s and 2080s the UK's energy system will likely have changed significantly from that of today.

3.1 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 addresses climate risks to the energy sector primarily in the chapter on infrastructure, but also implicitly in the chapters on people and the built environment, and business and industry, in connection with energy use in buildings, and in support of business functions everywhere. It highlights that climate risks should be considered in terms of assets, networks and services, and interdependencies.

Increasing frequency and severity of flooding represents the most significant climate change risk to UK infrastructure, including energy[8]. All infrastructure sectors are already exposed to multiple sources of flooding and the number of assets exposed to significant levels of flood risk could double by 2080s. Depending on their location, power generation facilities can be exposed to coastal flooding[9] and erosion, which will increase with sea level rise. Infrastructure networks near rivers[10] will be exposed to higher flows and erosion of bridge foundations.

[8] Risks to infrastructure services from river, surface water and groundwater flooding is Risk IN2

[9] Risks to infrastructure services from coastal flooding and erosion is Risk IN3

[10] Risks to bridges and pipelines from high river flows and bank erosion is Risk IN5

The CCRA2 highlights the need for more research to assess climate risks to existing and planned off-shore renewable energy infrastructure[11], such as from increased storminess, sea level rise and tidal surge impacts.

Risks from drought for the energy sector in England relate to the potential for subsidence-related damage[12] to physical structures, but the CCRA2 does not give this a high urgency score. Similarly, the CCRA2 assigns only the lowest urgency score to the risk of drought or low river flows affecting electricity generation[13], such as through availability of water for cooling processes.

Higher ambient temperatures across the UK would lead to line de-ratings (reduction in maximum capacity) of up to 10% for typical distribution lines and up to 4% for typical transmission lines under a high emissions scenario for the 2080s. Higher temperatures also reduce the efficiency of transformers, with estimates of up to 7% for 11kV transformers for the 2080s.

The CCRA2 identified some impacts from other weather hazards[14] as an area of research priority in England. Other extreme weather events that currently lead to faults on the electricity transmission and distribution network include high winds, solar heat, lightning, heavy rain, snow and sleet. High winds are a significant cause of disruption to electricity networks, causing 20% of all customer disruption between 1995 and 2011 (2, citing research from the ASC).

Finally, the CCRA2 emphasises the need for more action in connection with the potential for cascading failures[15] in interdependent infrastructure networks, which may affect the energy sector in London. Given that all infrastructure and business sectors require power for some (if not all) of their assets and functions, the importance of the energy sector in enhancing climate resilience of the services on which others depend is clear. This includes flood protection assets such as gates and pumping stations. Conversely, changes in temperature could affect energy demand, including altering the seasonal, daily and spatial variation of demand from buildings (domestic and service sector) and transport. The topic of climate risks in London's interdependent urban system is explored further in Section 10 of this report.

3.2 Review of climate impacts

In light of the importance of this sector, the UK Government has attempted to evaluate how well prepared the UK would be in the event of serious changes to our climate and weather patterns, including more severe rainfall, higher winds and/or colder weather. In 2010, electricity and gas companies received direction under the provisions of the Climate Change Act 2008 to report to Defra on how they were assessing and acting on the risks posed to their businesses by climate change, with a second reporting round issued on a voluntary basis in 2013. These were designed to help the Government understand the level of capacity to adapt in the sector, and to inform the UK Climate Change Risk Assessment published in 2017 and the subsequent update of the National Adaptation Plan.

In general, the energy sector recognises the benefits and uncertainties related to using UKCP09 projections to assess climate impacts in the UK, and companies use these projections in risk assessments to report. High emissions projections to 2050 and 2080 were used in the

[11] Risks to offshore infrastructure from storms and high waves is Risk IN12

[12] Risks to subterranean and surface infrastructure from subsidence is Risk IN8

[13] Risks to electricity generation from drought and low river flows is Risk IN10

[14] Risks to energy, transport and digital infrastructure from high winds and lightning is Risk IN11

[15] Risks of cascading failures from interdependent infrastructure networks is Risk IN1

Adaptation Reports to determine worst case scenarios and correlate against the lifetimes of existing assets.

Whilst electricity and gas network assets and processes may be vulnerable to certain aspects of climate change, it is recognised that the national and regional infrastructure has a significant degree of resilience to these impacts and risks are not considered ‘high’. Much work has gone into making Britain’s energy system more robust. The management of climate risks is embedded within companies’ overall risk management processes to ensure that appropriate actions are recorded and completed (34, 35). Nevertheless, whilst there is confidence in the ability of power stations to withstand climate challenges, the industry recognises that it cannot be complacent and interest groups such as Energy UK are working with other stakeholders to ensure resilience is continually improved (42).

Building on the above discussion, and using a common risk assessment procedure, 17 sources of hazards from climate change have been identified for the period 2017-39, a period reflecting the lifetime of existing power stations (see figure below and the AEP 2011 Climate Change Impacts Register). Hazards most relevant to the energy generation sector were identified as flooding extreme high temperature and drought, with ~95% of cases assessed as “low risk” or “very low risk”. Broadly, the flood risk and risk arising from high temperatures on turbine performance increase slightly, and the issues related to drought on abstraction and discharge to the aquatic environment increase more significantly. The remaining set of hazards are expected to be low risk under the climate change scenario studied (42).

Figure 4: Summary of individual company risk assessments against the common set of hazards

No	Climate Change Risk in the 2020s*	Scottish Power	Int. Power/ Gdf Suez	Centrica	EdF Energy ESCS	EdF Nuclear Gener-ation	InterGen	SSE	E.ON	Drax	RWE npower
1	Flooding of Site	27	27	24	28	20	24	20	27	16	16
2	Flooding of Access Routes to Site	21	14	21	20	28	11	16	19	16	16
3	Flood Events & Extreme High River Flow	28	26	20	9	n/a	11	15	23	16	9
4	Storm Surges	32	12	14	n/a	45	18	16	29	12	20
5	Extreme High Temperature on Steam Turbine	21	25	20	20	45**	27	28	28	15	15
6	Extreme High Temperature on Gas Turbine	20	16	16	n/a	n/a	27	28	29	n/a	15
7	Extreme High Temperature on Water Discharge	21	23	12	25	45	9	20	21	28	16
8	Drought on Water Availability	28	35	24	25	49	30	20	29	16	20
9	Drought on Water Discharge (Permitting)	19	20	9	9	n/a	9	12	35	16	9
10	Drought & Change in Water Abstraction Legislation	27	35	12	25	n/a	9	n/a	n/a	16	49
11	Extreme Snowfall	23	17	13	12	12	9	20	18	16	9
12	Extreme Low Temperature on Cooling Tower Fans	13	16	2	n/a	n/a	9	n/a	15	n/a	9
13	Extreme Low Temperature on External Systems	21	23	16	20	12	13	20	18	16	9
14	Extreme Low Temperature on Cooling Tower	13	11	2	9	n/a	11	16	19	16	9
15	Extreme Winds	29	30	9	16	15	27	35	25	20	9
16	Weather Conditions Causing Plume Grounding	11	11	9	n/a	n/a	15	9	21	n/a	9
17	Subsidence / Landslide	16	10	9	15	12	19	20	16	16	9

* Note: “The 2020s” refers to the period 2010 to 2039.
**Note: Steam turbine not affected, but other plant elements could be.

Legend
very high risk
high risk
medium risk
low risk
very low risk
risk “not applicable”

Source: (42)

3.2.1 Impacts from flood

Past experiences

Flooding and storm surges are well-recognised to impact the energy sector, with the flooding of site, flood events, extreme high river flow, storm surges and flooding of access routes to site. These impacts are described below, with case studies given where applicable.

National Grid recognises that flooding presents a serious risk to electricity networks, both today and in the future, as a result of increased rainfall and higher sea levels (43). The exceptional winter weather of 2013/14 (Dec-Feb) presented two main hazards to electricity generation: flooding and storm surges, accompanied by high winds. Electricity generation demonstrated a high level of resilience to potential disruption from weather events with only three reports of loss of production from the 55 power stations caused by incidents connected to severe weather. Over the three months, estimated lost production was 193 GWh. To put this in context, a GWh of electricity can power around one million homes for an hour.[16] In this event, there were no incidents associated with surface water or fluvial flooding or storm surges. This suggests reasonable levels of flood protection and coastal defences at present, agreed at the project design/planning stage (42).

Loss of power has been reported due to localised flooding in sub-stations. One example of this is the severe storm surge of 2013, which caused Immingham to lose power to large areas of the port, although the main coal and biomass terminal areas were not affected by the flooding. Mitigation measures have been implemented in response to this, for example the port operator ABP has installed new power mains to supply power to the main terminal operations area. The new biomass terminal at Immingham has therefore been designed to withstand a similar event with sub-station levels raised one metre above ground level. The underground conveyor tunnels below Phase I of the terminal development have storm surge barriers erected to stop flood waters getting into the below ground tunnels. On the Phase II development, the tunnels have been raised above ground level to achieve similar protection. Alongside a range of other measures implemented in the logistics chain, these have ensured greater robustness to storm surges and there was no disruption in supply of fuel to Drax Power Station during the storm surge of 2013 (42).

Contrastingly, whilst site operations can be lost due to surface water flooding, this does not necessarily affect electricity supplies to the local communities. On example of this is during the persistent storms in January 2014, when the local river (Kennet) and canal (Kennet and Avon) broke their banks and flooded the area and lakes around SSE's Burghfield Power Station (see figure below). Site operations were lost on 7 February 2014, but the loss had no direct impact on electricity supplies to the local communities. The main contributing factor to the flooding was that local ditches and waterways were not clear of debris and free-flowing. SSE evaluated shared learnings from similar situations elsewhere and identified flood mitigation measures that could improve resilience, such as installing permanent high-volume flood pumps and pipe system; improving flood defence barriers and improving communications with local sub-station and investigate issues with the Environment Agency's Floodline (42).

[16] https://www.ofgem.gov.uk/ofgem-publications/76160/13537-elecgenfactsfspdf

Figure 5: River Kennet flooding

Source: (42)

Figure 6: Kennet and Avon flooding

Source: (42)

Alongside the implementation of mitigation measures after an event, a trend can be observed of companies increasingly considering climate change resilience and adaptation at every stage of the process, notably in the logistics chain. Drax has implemented a multi-port strategy in order to maintain supplies of fuel to the power station. As part of this, the geographic split of the ports to ensure resilience to localised events such as storm surges and other potential climate change related impacts has been considered (42).

Access routes are also subject to flooding due to tidal surges. During the tidal surge experienced by the East Coast of the UK in December 2013, the River Trent was at risk of overtopping, and whilst this did not occur, there were several breaches to the flood defences. One of those breaches to the defences close to Keadby Power Station (SSE) site entrance prevented normal access to site. This led to amendment to the flood response plan, including the purchase and integration of additional emergency equipment, lightweight sand bags and flood door defences (42).

The extreme weather conditions occurring in winter 2013/14 provided the energy sector with the opportunity to evaluate its climate change adaptation assessment and resilience profile in the context of real extreme events. The table below summarises the conclusion of the evaluation of the impacts of these events, all of which are recognised in generating companies' risk registers:

Table 6: Summary of evaluation of Winter 2013/14 extreme weather events on electricity generating sector (42).

Hazard	Potential consequences for plant	Actual effect on plant	Evaluation
Flooding of site	Possible generation unit shutdown; water damage to infrastructure on a variety of scales; pipeline fracture due to erosion.	Only one reported incident of lost generation due to flooding (groundwater). River water levels of 1:100 years were experienced, but flood defences were not breached.	Current levels of flood protection, agreed at the project design/planning stage are adequate. Site with disruptive flooding is taking action.
Flooding of access routes to site	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown.	Some breaches in flood defences along the River Trent. The consequent fluvial flooding prevented normal access to a power station in the vicinity, but alternative access was gained via the rear of the site in accordance with the operator's flood management plan and no	Site plans to ensure access routes in case of flooding are adequate.

Hazard	Potential consequences for plant	Actual effect on plant	Evaluation
		production was lost. No other sites reported issues.	
Flood events and extreme high river flow	Higher maintenance	No issues reported.	Site flood management plans are adequate.
Storm surges	Commodity supply disruption; increased staff shifts; insufficient staff to maintain safe plant operation; partial or complete shutdown.	No reported incident of lost generation due to storm surges, but there was some disruption to fuel supply chains as a result of damage to East Coast ports.	Storm surge defences adequate at sites. Coal supply ports may suffer disruption during extreme events. Site coal stocks provide a buffer against fuel supply difficulties.
Extreme winds	Damage to installations; Health & Safety.	Two reported incidents of lost production due to extreme winds.	At these sites, operators have investigated the cause of the damage and effected repairs, incorporating design changes.

Source: (42)

Future projections

The key climate change related impacts from flooding are flooding of site, flood events, extreme high river flow, storm surges and flooding of access routes to site. These factors are described below, with case studies given where applicable.

In recent years cooling water pumps at a number of plants, such as the ENGIE (formerly known as GDF SUEZ) plant in Deeside have been operating close to their maximum ratings. At times of high turbidity water, stations experience tripping of the cooling water pumps on high current. Therefore, changing patterns in precipitation are likely to contribute to a reduction in water quality. Higher volumes of suspended solids in the abstracted water will only increase the risk of lost generation due to cooling water pump trips (42).

One of the primary concerns of a changing climate for the Electricity Supply Industry is the potential for increased risk of flooding because of rising water levels. A significant proportion of power stations are situated adjacent to estuaries, rivers, or coastal regions owing to the requirements for large volumes of water to be employed for cooling during the power generation process. As a consequence, there is a concern that these power stations are vulnerable to elevated water levels, and the first round of the Resilience and Adaptation reporting for Defra in 2011 identified flooding as a major threat. In response to this, relevant operators such as E.ON have undertaken Flood Risk Assessments for those stations which may be susceptible to flooding, modelling the consequences of flooding events on the power stations for a range of scenarios. Elevated water levels highlight areas where improvements could be implemented to ensure continued resilience against any future extreme tidal levels (42).

3.2.2 Impacts from drought

Past experiences

The issues for the energy sector related to drought are presented in Table 7.

Table 7: Climate hazards affecting water use (assessed by reporting companies)

Climate change hazard	Plant type	Potential consequences for plant
Extreme high temperature on water discharge	All	Load reduction to respect discharge limits
Drought on water availability	All	Load reduction, increased water treatment plant usage
Drought on water discharge (permitting)	All	Load reduction to respect discharge limits

Climate change hazard	Plant type	Potential consequences for plant
Drought and change in water abstraction legislation	CCGT, Coal	New permit conditions, additional operational constraints, load restrictions

Source: (42)

Future projections

The key climate change related impacts for electricity generation from drought is water availability and/or quality, classed as one of the main areas of risk in generating companies' reports (42).

Electricity generation companies including Centrica have already incorporated drought adaptation measures into their strategies. In order to reduce the demand for fresh water for steam generation, Centrica has initiated a rainwater recovery programme using storage facilities available on site. This has allowed the collection of approximately 12,000 m^3 per year which is then treated before being fed to the boilers. This has led to significant cost savings for the company as well as reducing fresh water demand.

Reliable access to sufficient quantities of water is a pre-requisite for the continuing operation of, and investment in, existing freshwater-dependent power stations. It is therefore vital for investment in new such power stations contributing to the diverse mix of technologies which together provide a thermal- efficient, resilient generation infrastructure. Operator responses to water abstraction licence reform may affect this generation mix (42).

3.2.3 Impacts from heat

Past experiences

High temperature has effects on abstraction and discharge of water to rivers. This includes the impact of extreme high temperature on steam turbines and on gas turbines.

Future projections

The key climate change related impact from heat for energy generation is the impact of extreme air temperature, classed as one of the main areas of risk (42). Table 8 and Table 9 present the risk assessment from the first round of adaptation reporting and detail projected impacts with an increase in temperature of up to 8°C.

Table 8: National Grid Electricity Solar heat – rise of up to 8°C

Key assets and processes	Solar heat – rise of up to 8oC
Substation Sites	Temperature increases may have a marginal impact on equipment ratings. More work is required to better understand any potential impact National Grid see this as a potential longer-term issue under current evidence there is very little firm evidence to justify changes to Design standards
Expansion of Existing Substation Sites (outside of Existing boundary)	Temperature increases may have a marginal impact on equipment ratings More work is required to better understand any potential impact
New Sites (Substations, Overhead lines, Tunnel Heads, Cable Sealing Ends)	Under current evidence there is very little firm evidence to justify changes to design standards Potential impacts of climate change would be evaluated on a case by case basis
Emergency	The process of responding to an emergency will be extremely unlikely to be impacted by working in high temperatures

Key assets and processes	Solar heat – rise of up to 8oC
Maintenance, Construction & Fault Repairs	Milder winters are expected to reduce peak demand and air conditioning load increase summer demand, resulting in a flatter demand curve resulting in difficulty in releasing circuits for maintenance
Control Centre Operations	Temperature increases may impact ratings and place greater restraints on the system. This could affect the split between winter/summer/autumn/spring ratings. Noting that current practice depends on maximum not average temperatures, no significant changes are anticipated in the short term. Future projections from UKCP18 and historic data need to be reviewed on a regular basis so that changes can be made as necessary if and when temperatures rise
Office Staff	Increased temperatures should not adversely impact National Grid's office based operations

Source: (43)

Table 9: National Grid Gas Solar heat – rise of up to 8ºC

	Solar heat – rise of up to 8ºC
Local Transmission Systems (above7bargsystem)	Assets are underground and so increases in above ground temperature rises likely to have a minimal impact
The distribution pipeline system (below7barg)	Assets are underground and so increases in above ground temperature rises likely to have a minimal impact
Pressure Reduction Installations (PRIs)	Max Design temperatures are +60ºC and these assets operate in far hotter temperatures than the UK therefore a 10ºC rise is unlikely to have a major impact
Control Systems and Telemetry	General instrumentation specification for design of systems. Majority of process instrumentation has a maximum operating temperature values of 60-80ºC.Telemetry outstation max operating temperature is 55ºC. Communications infrastructure to support telemetry components have maximum operating temperature of 40ºC.
Emergency	Increased temperatures should not adversely impact our ability to deliver an emergency service
Maintenance, Construction & Fault Repairs	Changes in weather may impact on working practices. Work should still be able to be completed but there may be increased costs
Control Centre Operations	Increased temperatures should not adversely impact our control centre operations
Office Staff	Increased temperatures should not adversely impact our control centre operations
National Transmission Pipework(~70barg)	Pipework is buried which therefore significantly reduces any increases in temperature.
River Crossings	Asset buried and under water, impact to increased temperature will be minimal
Compressor Stations	Compressors are being used in the summer-not what they were designed to do
LNG Storage Facilities	Increased temperature may reduce liquefaction efficiency but will not have a detrimental effect on security of supply or safety.
Above Ground Installations	The operation of AGIs will not be affected by increases in temperature
Gas Terminals	The operation of terminals will not be affected by increases in temperature.

Source: (44)

3.2.4 Other impacts

Previous incidents of lost production due to extreme winds have been reported. The most significant one was associated with damage to National Grid assets. Transmission system problems have also been experienced because of extreme winds, including the accumulation of wind-blown salt onto a transformer and damage to equipment at power stations.

A common list of hazards assessed by reporting companies is shown in Table 10. This excludes hazards related to flood and storm surge, extreme high temperature and climate hazards affecting water use as these are previously covered.

Table 10: Common list of hazards assessed by reporting companies.

Extreme Snowfall	All	Commodity disruption; increased staff shifts; insufficient staff to main safe plant operation; partial or complete shutdown
Extreme Low Temperature on Cooling Tower Fans	CCGT	Constraints in performance
Extreme Low Temperature on External Systems	All	Additional maintenance / repair; emergency water supply
Extreme Low Temperature on Cooling Tower	CCGT, Coal	Ice build-up on unloaded cooling tower and risk of packing collapse
Extreme Winds	All	Damage to installations; health and safety
Weather Conditions Causing Plume Grounding	CCGT, Coal	Hazards and complaints; additional restrictions
Subsidence / Landslide	All	Damage to infrastructure and pipelines on a variety of scales

Source: (42)

3.2.5 Interdependencies

Risks to generation from climate change cannot be viewed in isolation to risks from other parts of the national and local infrastructure (power distribution, water infrastructure, etc.) because many of the risks are regulatory and indirect. Power stations are dependent for their operation, inter alia, on delivery infrastructure for fuels and other essential chemicals and raw materials, water for steam raising and cooling, a functioning electricity transmission system, routes for waste disposal and access to a range of supporting services. The performance of a station is the result of the influence of ambient conditions on a combination of generation systems or components: gas turbine, boiler, steam turbine, auxiliary systems and cooling systems. The electricity generation sector is thus necessarily aware of the sensitivity of its operations to variations in weather and has long recognised the consequences of climate change for its business (43).

With regards to electricity transmission, key interdependencies in some sectors are highlighted. In particular, there are concerns regarding transport systems that enable access to key sites, and telecommunications for control room supervisory control and data acquisition and voice communications. Nevertheless, this are classed as ‘low risks’ to assets by the National Grid, although they continue to monitor and assess (43).

Misalignment between improving climate knowledge and the eight-year regulatory process could result in a delay between knowledge and investment. Despite the complex, unpredictable nature of climate change, this longer timescale of planning is not thought to be a problem (43).

Fundamental interdependencies with transport, telecommunications and the local authority sectors are recognised within the sector. The gas sector has high levels of cooperation between all the network operators to manage emergency situations including major incident simulations. This, alongside joint working via the Energy Networks Association, helps to create an environment of cooperation that is considered to address climate risk (44).

3.2.6 Costs

There was little reference to or analysis of cost related to impacts of climate change on the energy sector in the documents reviewed.

It appears that financial benefits have rarely been identified by electricity and gas-related companies to date, but there is an appreciation of the benefit of early adaptation response where necessary to help mitigate future costs (43, 44).

On sites where flooding risk to electricity transmission assets is very low, National Grid has taken a prudent incremental deferred investment approach to manage the flood risk until greater certainties of the risks and future of sites can be established (44).

3.2.7 Gaps in understanding

The documents reviewed were UK-wide studies from national organisations available in the public domain. London-only studies were not publicly available at the time of this review. Key uncertainties, assumptions and constraints in the analysis of impacts include (42):

- Uncertainties in the climate change projection data;
- Uncertainties in future generation including UK energy mix and changes in pattern of power station operation;
- Regulatory uncertainty, such as due to the Government review of the principles of water rights allocation, identified as a barrier to the implementation of appropriate adaptive measures and as creating risk.

3.2.8 Summary

Long term asset assurance is an essential component of the business strategies of the electricity and gas network and companies. The Adaptation Reporting and monitoring process has provided confidence in existing plans for the UK and has contributed to building adaptive capacity as part of a wider framework of business as usual processes.

Extreme weather conditions in winter 2013-14 provided the electricity sector with the opportunity to evaluate its climate change adaptation assessment and resilience in the profile of real extreme events. Electricity generation demonstrated a high level of resilience to potential disruption from weather events that occurred. All reporting companies have corporate risk management which are covered by company policies and have procedures subject to relevant review and audit. These reviews ensure the delivery of policies, capture change in risk appetite and altered thresholds that might change the nature of a risk. Deciding whether, and when, investments are made to mitigate climate risks is therefore integral to companies' risk management procedures ensuring that investments are timely and enabling close management of appraisals in areas of greater uncertainty (42).

Current short-term weather events are concluded to present more of a risk than long-term trends in climate change. These risks were low compared to engineering-related faults leading to loss in generation. Climate change is not thought to lead to introduce any new types of risk to operations but rather change the likelihood or severity of risks which are currently managed. For example, power stations are pro-actively managing potential specific vulnerabilities to events of extreme weather e.g. heavy snowfall, river flooding or high tides/tidal surges. These risks are currently picked up by Business Impact Assessments and Continuity Plans of companies (42).

Adaptive capacity across the sector as a whole is also ensured currently by the combination of a generating plant capacity margin, geographical diversity of generating plant (together with a national transmission network) and diversity in generation technology. Because of this, the electricity supply system is robust against individual plant failure and, in the last decades, electricity generation has demonstrated a consistently high level of resilience to potential disruptions from extreme events. Provided that these key factors are maintained over the next 20 years, this intrinsic 'robustness' is not expected to change (42). Nevertheless, it is important to bear in mind that energy systems are so interconnected with other systems, such as transport, water, communication, healthcare and banking, that the loss of power for any length of time would cause widespread damage.

The main impacts identified in this study are summarised in Figure 7. The majority of the literature refers to the UK energy sector as a whole, and is rarely London-specific.

Figure 7: Climate impacts on London's energy sector, across the 21st century

Hazard	Nature of impact					Nature of evidence reviewed
	Flood-related damage to infrastructure (site, site access, storage areas)					London impacts understood qualitatively
	LOW	LOW	MED	HIGH	HIGH	
	Subsidence-related damage to infrastructure; low water flows affecting cooling capacity and ability to discharge cooling water.					Known at UK level but not London-specific
	LOW	LOW	MED	MED	HIGH	
	Impacts of extreme high temperatures on the efficiency of processes, including electricy transmission and distribution					Known at UK level but not London-specific
	LOW	LOW	MED	HIGH	HIGH	
	Impacts of extreme high temperatures on employee productivity					Known at UK level but not London-specific
	LOW	LOW	MED	HIGH	HIGH	
	NOW → Scale of impact → FUTURE					

Source: Prepared for this study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

We are aware of other sources that would benefit this sector review but are limited by the scope of this project. These include:

- Committee on Climate Change 2017 Progress in preparing for climate change 2017 Report to Parliament. Available at: https://www.theccc.org.uk/wp-content/uploads/2017/06/2017-Report-to-Parliament-Progress-in-preparing-for-climate-change.pdf

4 Built Environment

On the basis of the material reviewed, the built environment faces an increased risk of overheating, subsidence due to drought and surface flooding. There are gaps in the evidence around empirical summertime indoor temperature data and the cost / benefits of good maintenance (e.g. to compare uptake of passive ventilation measures vs. air conditioning). Much can and should be learned from best practice in other EU countries. There remains a significant gap between most academic research and industry practice. Essential ongoing efforts to close this gap include facilitating engagement between communities, industry and researchers, through the independent communication of the value of research outputs to end users, and enhancing the understanding of what different communities need from each other.

4.1 Background

New buildings are designed to last for a significant period and although many will be substantially refurbished during their lifespans, their envelopes will remain significantly unchanged. This imposes severe limitations on how buildings can be modified to take account of a changing climate (55). As extreme summer and winter temperatures and snowfall cause disruption and discomfort, and increasing flooding and storminess expose our buildings to greater risk, the scale of new development in London means that it is vital for our future developments to be resilient to the impacts of climate change (1).

London's built environment sector has an international reputation for world-class design and architecture. It consists of three broad categories:

- Infrastructure – roads, rail, airports, power stations;
- Residential – public and private housing; and
- Non-domestic buildings – education, healthcare, commercial, retail, leisure, industrial.

In this chapter, we focus on the residential and non-domestic buildings categories. Energy infrastructure is covered in Chapter 3. With the region projected to see the largest impacts of climate change within the UK, it is therefore imperative that both domestic and commercial buildings can withstand the impact that climate change may have through flooding, water stress, overheating, and more acute storms. This is particularly important, with vulnerable populations in social housing likely to be affected the most (1).

4.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 addresses climate risks to the built environment primarily in the chapter on people and the built environment. It assigned the highest urgency category to risks to human health and wellbeing related to high temperatures[17] linked with the built environment. Around 20% of homes in England overheat even in the current climate. There is some evidence that the risks of overheating in hospitals, care homes, schools and offices will increase in the future. In London during a heatwave in the 2030s it estimated that around two-thirds of flats and up to half of detached properties would overheat.

Overheating was already identified as a key risk in the 2012 UK Climate Change Risk Assessment. The 2012 Department of Communities and Local Government evidence review on overheating in homes concluded there are substantial gaps in knowledge which would require

[17] Risks to health and wellbeing from high temperatures is Risk PB1

significant research activity to improve the fundamental understanding of health and behavioural issues related to heat, and the real performance of buildings. The CCRA2 cites a study suggesting that by the 2030s, 59 – 76% of flats and 24 – 29% of detached properties in London could experience overheating (defined as internal temperatures > 28°C) during a heatwave event (high emission scenario). For the 2050s, the values increase to 80 – 92% of flats and 56 – 61% of detached dwellings (high emission scenario, median result).

Urban heat islands may lead to assessments overestimating the space heating demand of core urban dwellings by up to 45%. Similarly, the CCRA2 reports that heating and cooling load of a typical air-conditioned office located within the London UHI may be up to 22% lower and 25% higher, respectively, compared with a rural location. Variations due to site microclimatic factors also need to be taken into account; for example, overshadowing by adjacent buildings has the potential to decrease the cooling load by up to 14% more than at a rural site.

The CCRA2 quotes a 2015 report for the UK Government by the Zero Carbon Hub which concluded: "*overheating cannot yet be considered to be a managed risk for much of the sector. There are gaps and uncertainties in current frameworks which mean inherently risky designs and buildings can be approved. Secondly, despite evidence gaps, there is enough information and evidence about the causes, extent of, and solutions to overheating in homes to warrant taking careful yet concerted action to tackle the issue*." Modelling studies suggest that as the climate becomes warmer and more extreme, it will be increasingly challenging for naturally ventilated buildings to maintain comfortable indoor thermal conditions using passive ventilation-based measures alone (34). The 2018 draft London Plan managing heat risk policy calls for dynamic thermal modelling to help ensure that heat risk is designed out of new developments.

The CCRA2 highlights the risks to people, communities and buildings from flooding[18], assigning the highest urgency category to this risk in England. It emphasises that increases in flood risk cannot be avoided under a 4°C climate scenario even if the most ambitious adaptation pathway the CCRA considered was followed.

The CCRA2 identified risks to building fabric[19] from moisture, wind and driving rain with high urgency. Moisture can damage building materials and components, leading to mould growth; chemical reactions with building materials and components; warping, swelling and rotting of wooden materials; and damage to brickwork from freeze-thaw cycles.

The CCRA2 also identified that climate-related hazards damage historic structures[20] and sites now, but there is lack of information on the scale of current and future risk, including for historic urban green spaces and gardens as well as structures.

4.3 Review of climate impacts

The London Plan (46) recognises the threat of climate change to London's homes and infrastructure, in particular from overheating and flood risk.

London's existing and planned building stock is at risk from the impacts of climate change, particularly from the increased risk of extreme events including flooding, heatwaves, and water scarcity (1, 28).

[18] Risks to people, communities and buildings from flooding is Risk PB5

[19] Risks to building fabric from moisture, wind and driving rain is Risk PB7

[20] Risks to culturally valued structures and the wider historic environment is Risk PB8

4.3.1 Impacts from flood

Past experiences

Almost a fifth of London is in the Thames floodplain. Currently 37,359 existing homes are at high or medium risk of tidal or fluvial flooding in London and 1.3 million people are living and working in areas of tidal and fluvial flood risk (14). Most of this area is very well defended by traditional hard-engineered flood defences, including the Thames Barrier. The Thames Barrier was closed 50 times over the winter of 2014-15 to protect 200,000 properties in and around London. This is far higher than any other previous winter and twelve times the annual average (46). However, the upstream part of the Thames and many of the tributaries to the Thames have lower standards of protection (17).

London is prone to flooding from five sources of floodwater: from the sea (tidal flooding), the Thames and tributaries to the Thames (fluvial flooding), heavy rainfall overcoming the drainage system (surface water flooding), the sewers (sewer flooding) and rising groundwater (groundwater flooding). Flooding can occur from a combination of these flood sources at the same time. Nevertheless, it is important to recognise that London currently has some of the highest standards of tidal flood defence in the world, designed to protect against a tidal surge that might statistically occur once every 2000 years (28).

Traditional flood defences can only protect London from more predictable fluvial and tidal flood risk. However, the city is also vulnerable to surface water and sewer flooding from storm and heavy rainfall events. This is due to increasing areas of impermeable surfacing (such as roads, roofs and pavements) and the legacy of a Victorian drainage system that was not designed to cope with demands of a city of more than 10 million people (17).

The city is highly vulnerable to surface water flooding (flash flooding) as a result of the drainage network being overwhelmed by heavy rainfall e.g. from storms, because of impermeable surfaces (28). The London Environment Strategy (14) indicates that, in terms of properties at risk, there are:

- Residential High: 68,499;
- Residential Medium: 164,546;
- Commercial high: 12,148;
- Commercial medium: 25,623

Flooding is recognised to have caused widespread damage and disruption to property in London in the past, including events in 2003 and 2006 (1). In summer 2007, average insurance claims for household properties affected by floods were £50,000 and the overall bill was in excess of £3 billion across London, the East and the South East of England (22).

Figure 8: Flooding in Richmond

Source: (1)

Future projections

The key climate change related impacts from flooding for residential and non-domestic buildings in London are property damage, valuation and insurance impact and lost business continuity.

Climate change is expected to increase the frequency, severity and extent of flooding. UKCP09 projections suggest London will face increased summer and winter precipitation, with an increase in the frequency of intense precipitation events that leads to flash, sewerage and fluvial flooding. When combined with increased urbanisation reducing capacity for the surfaces absorption, the risk of surface water run-off and related flood damage will increase (22). It is important to note that the future population exposed to flooding will depend on the rate of new development in the UK floodplain.

The majority of London’s commercial buildings currently use basement areas for services and plant operations which increases the vulnerability of basic business operations resulting from rain and flooding events and can have a negative effect on productivity and building valuation (28). For the domestic properties, this also causes financial and social ramifications, including property damages, displacement and increased insurance premiums for residents for residents and landlords.

London will also be affected by sea level rise, with projections of sea level rise in the Thames over the next century due to thermal expansion of the oceans, melting glaciers and polar ice estimating a likely increase between 20 cm and 90 cm. The Thames Estuary 2100 plan (TE2100) (see 38) considered future scenarios and options for protecting London and the surrounding area from tidal flood risk across this century. The strategy found that the current barrier with modification and upgrade should be able to protect London and the surrounding estuary to a reasonable standard at least until the 2070s, assuming sea levels rise as expected under a high emissions scenario. The Environment Agency estimates that a new Thames Barrier is likely to be required towards the end of the century (46). One illustrative indicator of financial impacts is the impact that climate change could have on revenue from tourism, which currently stands at around £15 billion per annum (38).

4.3.2 Impacts from drought

Past experiences

In most years, there is sufficient water in the Thames, the River Lee and the aquifer to meet London's current demands. Nevertheless, sustained periods of low rainfall results in water being drawn from the reservoirs and to manage the remaining reserves, water companies must apply to the government to initiate drought measures (28).

Future projections

The key climate change related impacts from water stress or drought for buildings in London are water shortage, subsidence and heave damage.

Climate change is not projected to significantly alter the amount of rain that falls in a year, but it will affect when rain falls, and how heavily it falls. Overall key projections from UKCP09 for London for the 2050s indicate that under a medium emissions scenario, summers will be drier, with the average summer 18% drier and the driest summer 39% drier than the 1961-1990 baseline, and winters will be wetter, with the average winter 15% wetter and the wettest winter 33% wetter than the baseline (28).

Climate change is expected to affect London's water availability by reducing river flows; reducing groundwater recharge, increasing evaporation, and increasing risk from broken water mains due to increasing subsidence (28). Much of London is built on clay which expands and shrinks according to its water content. Dry weather causes clay to shrink and land levels to fall, whereas wet clay expands and rises. More seasonal rainfall and hotter summers will cause soil moisture levels to fluctuate more dramatically, increasing the amount of subsidence and heave. For most of London this movement is minimal and unnoticed, but some buildings (e.g. those without foundations) and infrastructure (e.g. escalators and soil embankments) are more susceptible to this movement (28). Increasing subsidence and heave movement could increase the potential for damage to building foundations and facades, and structural or services damage could affect property or business evaluation and future insurance premiums. During the redevelopment of Kings Cross underground railway station, careful consideration of future ground water movement and additional robustness was built into the foundation design to meet 120-year design-life (29).

Combined with decreased rainfall and over-abstraction, increasing demand associated with projected population, agricultural, horticultural and commercial growth will increase the stress on London's water supply (22). Average water consumption in London is currently 149 litres per person per day, compared to a national average of 141 (14). UK Building Regulations now stipulate max 125/p/day internal (including 5l/p/day for outside use) and planners can stipulate down to 110l/p/day.

4.3.3 Impacts from heat

Past experiences

Extreme hot weather is considered a significant risk for London's built environment by experts and decision makers. In addition to climate change, the urban heat island effect has further increased the risk of internal overheating. The increasing density of development in London will amplify heat risk in the city's streets and public unless additional measures - such as green roofs, green walls and street trees - are incorporated into buildings and their surroundings to reduce the amount of hard surfaces that absorb and radiate heat.

All types of buildings are at risk of overheating including homes, hospitals, care homes, offices, schools and prisons and at present, no national policies are in place to adapt homes or other buildings to higher temperatures (2). The London Plan (current and draft new) contains requirements for developers to undertake overheating modelling to future weather scenarios (current London Plan is 2020s) to show compliance with certain targets. In London, the GLA requires that modelling is carried out using weather data and guidance from CIBSE 'Design Summer Years for London' (TM49: 2014). The guidance advises using weather files which account for both the UHI effect and for future climate change. For dwellings, the GLA requires further compliance with the guidance in the CIBSE TM59: 2017.

Overheating of commercial and other properties has arisen due to a number of factors, but has been especially acute in modern highly insulated lightweight buildings and highly glazed buildings.

Future projections

The key climate change related impacts from an increasing risk of overheating in buildings in London are reduced building and workforce performance, increased use of air conditioning and wider concerns for health and wellbeing.

The London Plan (46) indicates that new developments in London face two challenges in managing heat risk - the need to ensure London does not overheat (the urban heat island effect) and the need to ensure that individual buildings do not overheat. The urban heat island effect is caused by the extensive built up area absorbing and retaining heat during the day and night leading to parts of London being several degrees warmer than the surrounding area. This can become problematic on the hottest days of the year as daytime temperatures can reach well over 30˚C and not drop below 18˚C at night. These circumstances can lead many people to feel too hot or not be able to sleep, but for those with certain health conditions, and some young or elderly Londoners, the effects can be potentially lethal.

The risk of overheating in buildings is likely to increase as outdoor temperatures increase. In London, the number of days per year when overheating could occur is projected to rise from 18 days to between 22 and 51 days by the 2020s (central estimate is 33 days) (23). The projected increases in average and extreme temperatures will make London’s buildings more uncomfortable, more expensive to run through cooling energy costs and potentially dangerous to health as a result of high internal temperatures in poorly designed offices (28). This could result in productivity losses, the need for retrofitting mechanical ventilation and air conditioning systems, and reduced property valuations. Other consequences of prolonged high temperatures are an increase in use of air conditioning with significant energy requirements associated and under conventional operation, expelling hot air, thereby adding to the urban heat island effect (46); a rise in demand for water; damage to temperature sensitive infrastructure and an increase risk of blackouts due to increased demand for cooling (28).

The Chartered Institution of Building Services Engineers (CIBSE) has produced guidance on assessing and mitigating overheating risk in new developments, which can also be applied to refurbishment projects. As noted above, the London Plan ensures that going forwards, TM 59 should be used for domestic developments and TM 52 should be used for non-domestic developments. In addition, TM 49 guidance and datasets should also be used to ensure that all new development is designed for the climate it will experience over its design life. The GLA’s Energy Planning Guidance provides further information on how these guidance documents and datasets should be used.

4.4 Interdependencies

There are complex connections between buildings, communities, the health and social care system, and population health and health protection. For example, the built environment (urban planning, housing quality) is an important determinant of health and wellbeing (2).

4.5 Costs

Although the costs of climate impacts appear to be insufficiently quantified, discussion of adaptation options for buildings appears to be more widespread and is usually linked to a cost-benefit analysis. One example of the incorporation of climate change measures into social housing is the refurbishment of the Colne and Mersea tower blocks (1). The Your Home in a Changing Climate report (22) was used as a blueprint for adaptation here. The work sets out the costs of a range of measures for reduction of water usage, overheating, and flood risk, and presents a simple cost-benefit analysis. The benefits gained from the project include reduced water scarcity, reduced risk of flood damage and prevention of negative health impacts of overheating. Each of these have social benefits difficult to quantify in monetary terms including thermal comfort, reduced emissions, increased health, wealth, knowledge, fuel security, water security, security from flooding, and engagement between contractors and community. A simple payback of the costs and benefits of the total works is approximately 36 years (1).

Overheating in the built environment can be controlled effectively by a package of passive measures, including ceiling fans, lightly painted external walls, and night purging using natural ventilation. A 2008 report (22) by the LCCP indicated costs for a typical unadapted house in London, the south-east or east of England of approximately £16,000, or £8,000 if winter warmth measures have already been installed.

4.6 Gaps in understanding

Gaps in information on climate impacts on the built environment identified in the documents reviewed were:

- Further empirical summertime indoor temperature data, and an improved understanding of how energy-recovering ventilation systems such as mechanical ventilation and heat recovery systems may alter risks (2);
- Better quantification of the current and future risks to the historic built environment from climate change (2);
- Reduction in the level of uncertainty in increased cooling demand and the economic benefit is of uptake of passive ventilation measures vs. air conditioning (2)
- Impacts on and response to climate risks and historic environment and cultural heritage. Data from effective monitoring, surveys and imaging to identify current effects and early warning of damage. Increased take up of the research and translation of research to make it useful;
- Retrofitting low water use appliances and the benefits of joining up flood resilience across multiple sites, e.g. SuDs/green infrastructure at masterplanning scale; and
- Learning best practice from other EU countries.

4.7 Summary

Further action is needed to adapt the existing building stock and design new buildings to counter the impacts of climate change. The changing nature of flood, drought and overheating events are making buildings unsuitable for our current and future climate. In particular, flooding and extreme hot weather (46) pose the highest magnitude risks and represent the greatest need for action in the next five years.

Climate change projections and their expected impacts mean that decision makers across the built environment sector need to start thinking about evidence-based, risk management approaches to planning, designing, and managing for the impacts of climate change. The main impacts identified in this study are summarised in Figure 9.

Figure 9: Climate impacts on London's built environment sector, across the 21st century

Hazard	Nature of impact					Nature of evidence reviewed
	Impact of fluvial and surface water flooding on residential and non-domestic buildings in terms of property damage.					Impacts quantified, some costs for London
	LOW	LOW	MED	MED	MED	
	Impact of flooding on building valuation and insurance premiums.					Impacts quantified, some costs for London
	LOW	LOW	MED	MED	MED	
	Impacts of subsidence and heave movement due to drought on building foundations and facades.					London impacts understood qualitatively
	MED	MED	HIGH	HIGH	HIGH	
	Impact of high temperatures on London's buildings making them more expensive to run through cooling energy costs.					Impacts quantified, some costs for London
	MED	MED	MED	HIGH	HIGH	
	Impacts of high temperatures on London's buildings making them more uncomfortable, reducing employee productivity, affecting health and wellbeing.					London impacts understood qualitatively
	MED	MED	MED	MED	HIGH	
MULTI	Damage to historic structures and sites from multiple climate-related hazards					Known at UK level but not London-specific
	LOW	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
	NOW → Scale of impact → FUTURE					

Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

We are aware of other sources of information on the impacts of climate change on the built environment sector that were not within the scope of this project. These include:

- CIBSE Weather Data Sets. Available here: https://www.cibse.org/knowledge/cibse-weather-data-sets . More information here: https://www.cibsejournal.com/technical/using-weather-data-to-make-buildings-climate-proof/

- CIBSE TM59: Design methodology for the assessment of overheating risk in homes (TM59) The future of built environment research in the light of societal challenges 2016. Available at: https://www.arcc-network.org.uk/wp-content/pdfs/ARCC-BE-reportV2.pdf
- CIBSE TM52: the limits of thermal comfort: avoiding overheating in European buildings https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7f5AAC
- CIBSE TM49: Design Summer Years for London. Available here: https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I6yFAAS
- Urban Heat Island in London. Available here: https://www.cibse.org/getattachment/Networks/Groups/Resilient-Cities/Past-Events-and-Presentations/presentation3-Kolokotroni.pdf.aspx
- GLA London Datastore 2018. Available here: https://data.london.gov.uk/dataset/london-s-urban-heat-island
- Friends of the Earth 2013 Extreme weather events and climate change. Available here: https://friendsoftheearth.uk/sites/default/files/downloads/extreme_weather_cc.pdf Friends of the earth: https://friendsoftheearth.uk/sites/default/files/downloads/extreme_weather_cc.pdf
- Additional studies on impacts including:
  - CIBSE Climate Change and the Indoor Environment: impacts and adaption (CIBSE TM36 2005). Available at: https://www.bsria.co.uk/information-membership/bookshop/publication/cibse-climate-change-and-the-indoor-environment-impacts-and-adaption/

5 Health and Social Care

The Health and Social Care sector faces several challenges due to climate change, most notably the potential impact of prolonged periods of high heat on London's populace as well as the potential for large flood events to cause harm and a disrupted service. There are significant gaps in evidence regarding the impacts of drought on the sector as well as research into the exact nature of interdependencies - specifically for London. This chapter identifies the main climate related health impacts as well as how these may affect the continued running of the health and social care services that aid London's population and visitors.

5.1 Background

The health and social care sector serves London's residents and annual visitors, who rely on these services being available regardless of the weather (24). Impacts to the health of London's population and also to the ability of the National Health Service and Social Care services to operate in the long term are considered in this section.

Health and social care is influenced by many factors which may vary greatly between different areas of London, such as age, gender and ethnicity of the population, and the efficacy of local health services. Both patients and practitioners are considered prominent stakeholders in this sector.

The health and social care sector provides both an emergency service and longer-term care, which must be protected from disruption. Climate change also has the potential to exacerbate existing health inequalities, and measures to adapt amongst London's population need to maintain consistency between London's strategies to address health inequalities and the impacts of climate change (24).

5.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 addresses climate risks to health in the chapter on people and the built environment. It assigned the highest urgency category to four of the risks identified, all of which are highly relevant to London:

– Risks[21] to health and wellbeing from high temperatures
– Potential benefits[22] to health and wellbeing from reduced cold
– Risks[23] to people, communities and buildings from flooding
– Risks[24] to health and social care delivery from extreme weather

There are currently approximately 2,000 heat-related deaths per year across the UK[25], which equates to between 300-350 deaths in London. The risk to health is likely to increase in the future as temperatures rise. The number of heat-related deaths in the UK is projected to

[21] Risks to health and wellbeing from high temperatures is Risk PB1

[22] Potential benefits to health and wellbeing from reduced cold is Risk PB4

[23] Risks to people, communities and buildings from flooding is Risk PB5

[24] Risks to health and social care delivery from extreme weather is Risk PB9

[25] Based on the mortality rates in Hajat *et al* 2014, Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s, and depends on the exact population for the region.

increase by around 250% by the 2050s (median estimate) due to climate change and growing, ageing population[26].

The frequency and intensity of extreme heatwaves are expected to increase over this century. Modelling studies show that without effective adaptation, the number of heat-related deaths is likely to increase due to climate change. There is much uncertainty about how quickly populations can adapt to a warmer climate; the health burden of hot weather will also be amplified by the ageing population. Health impacts are likely to be greatest in London.

Modern built facilities are designed to support contemporary care models and to be thermally efficient in cold weather, but this has led to problems with thermal comfort during heatwaves, for patients and staff in hospitals and care homes.

Cold is currently a significant public health problem in the UK. Currently there are between 35,800 and 49,700 cold-related deaths per year across the UK. Climate change alone is projected to reduce the health risks from cold, but the number of cold-related deaths is projected to decline only slightly due to the effects of an ageing population increasing the number of vulnerable people at risk. Cold will remain an important climate risk, even with milder average winter temperatures, due to the poor thermal performance of the UK housing stock, and population ageing. The latest estimates at UK-level suggest a reduction in cold-related mortality of 2% by the 2050s (medium emissions and including population growth and ageing).

The CCRA2 emphasises that increases in flood risk cannot be avoided under a 4°C climate scenario even if the most ambitious adaptation pathway the CCRA considered was followed. As well as risks to life and property, flooding causes long-term damage to health, wellbeing, livelihoods and social cohesion. There is little data and considerable uncertainty regarding the total (i.e. direct and indirect) social and economic cost of flooding currently occurring in the UK.

The CCRA2 noted some evidence of inconsistent planning for extreme weather and health, and social care authorities may not have appropriate plans in place at local level. Floods and storms cause significant disruption to health and social care systems. Across England and Wales, the number of hospitals, GP surgeries, emergency service stations or care homes located in areas at or greater than a 1 in 75 annual chance of flooding (on average) are projected to increase by between 3 and 24% in the 2050s under a 2°C scenario, and between 27 and 110% under a 4°C scenario.

A further two risks assigned the second-highest urgency category in the CCRA2 have particular relevance for Londoners:

- Risks[27] to passengers from high temperatures on public transport
- Risks[28] to health from changes in air quality

The CCRA2 also confirmed potential health impacts from climate change linked to vector-borne pathogens[29]. Further research is needed to improve the monitoring and surveillance of vector species and related infectious disease, with a view to the greatest long-term risks. For example, higher temperatures in the future will increase the suitability of the UK's climate for invasive mosquito species, facilitating invasion by new species that can transmit diseases in the long term. While many vector species are more common in countryside areas, some are already

[26] Original study cited in CCRA2 is by Hajat *et al* 2014, Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. CCRA2 is unclear on the emissions scenario underpinning these numbers.

[27] Risks to passengers from high temperatures on public transport is Risk PB2

[28] Risks to health from changes in air quality is Risk PB10

[29] Risks to health from vector-borne pathogens is Risk PB11

known to breed well in urban environments, such as particular mosquitoes in urban gardens or even London Underground.

Other health-related risks were identified in the CCRA2 at lower urgency categories related to food-borne disease cases, risks to health from poor water quality, and risks of household water supply interruptions.

5.3 Review of climate impacts

The health and social care sector is particularly susceptible to the impacts of flooding and heatwaves (24). It is necessary when assessing the potential impacts of climate change on health, to evaluate a wide range of factors that are collectively referred to as the 'wider determinants of health[30]. The GLA suggests this should include the potential impact of climate change on: education, employment, income, housing, social networks, environmental factors such as air quality, access to affordable, nutritious food and quality green spaces, and access to public services, including health and social care.

According to the London Climate Change Partnership - "The balance of health impacts of climate change is anticipated to be substantially, and increasingly, negative"
(25)

5.3.1 Impacts from flood

Past experiences

At present, nearly 10% of London's hospitals are at significant risk from flooding (25). The majority of these are protected by the Thames Barrier and associated flood defences which protect London up to a 1 in 1000-year event - that is, an event with a 0.1% chance of occurring in any given year. London's flood defences (including the Thames Barrier) primarily defend London against tidal and fluvial flooding and as such there were no reports of any large-scale incidents within the last 25 years. Much less well understood is risk of surface and groundwater flooding, the potential for occurrence is far greater than other types of flooding and such events are also less predictable than tidal or fluvial (24). Historically, surface water flooding, has led to damage to health and care facilities, restricted access for staff and contractors, failure of key services such as heating, cooling or water supplies, water contamination and supply-chain interruption (25).

There have been no recorded deaths from flooding in the last 50 years, nevertheless long-lasting health impacts of surface water flooding, including psychological stress, are well-documented and can be very severe, especially when those affected are displaced from their homes for long periods of time. For people living in areas of high flood risk, there are also social and economic impacts (higher insurance premiums for instance), which can negatively affect the wider determinants of health outlined in the introduction.

[30] GLA (2007), Best Practice Guidance. Health issues in Planning

Future projections

The predicted increases in precipitation and flood risk in London can pose a risk to the health of Londoners, by increasing the potential for transmission of disease organisms into the water supply (24) - it is likely nonetheless that these organisms should be removed through adequate water treatment.

Generally, the increasing flood risk indicates that some fluvial or tidal flood events may now take place and that surface flooding will become more severe. Such flooding would be accompanied by a range of potential immediate, short-term and long term direct and indirect effects on health. Flooding can have an immediate impact from drowning, injury, damage to property, exposure to toxins and pathogens and infections from an inability to maintain good hygiene – especially for vulnerable groups (25). Long term impacts include the potential for disease and damage to health and care facilities, staff, and services as outlined in the 'Past experiences' section above. However, the increased amount of precipitation means that the effects are likely to be longer lasting. Table 11 shows some of the impacts on health and wellbeing arising from experience of flooding.

Table 11: Potential impacts on health and wellbeing from flooding

Immediate	Short-term	Long-term
• Drowning • Injuries from debris, and from damage to property • Heart Attack • Exposure to chemicals/ toxic gases • Exposure to pathogens • Impaired Capacity • Damage to property • Infections due to overcrowding/ Poor facilities/ reduced ability to maintain good hygiene • Lost school and work days • Displacement and anxiety	• Mental-Ill Health • Exposure to pathogens • Malnutrition • Dehydration	• Mental Ill-Health • Relationship breakdown • Long-term displacement from homes • Physical Ill-Health

Source: (25)

5.3.2 Impacts from drought

Past experiences

No historical drought related impacts to Health and Social Care were identified as historical droughts have not caused a significant shortfall in water supply to the capital, including its healthcare services and residents.

Future projections

Increases in the number of periods of extreme high temperatures and drought may, in-combination, present a greater impact to services, as the combination of high temperatures and low water availability reduce the coping capacity of the health and social care sector (24). The impacts of low water availability are mitigated and managed in Thames Water Resources Management Plan.

5.3.3 Impacts from heat

Past experiences

Past experiences of the impacts from heat are the most widely reported weather/climate related impact on the Health and Social Care sector. This is best explained as London's microclimate amplifies the impact of hot weather, meaning that London may be up to 10ºC warmer than its surrounding areas on summer nights and 5 ºC during the day (24). This paired with extremely high population density and old building stock mean that heat is also estimated to cause over 100,000 patient-days in hospital per year in London (23). However, these figures can increase noticeably for exceptionally hot years such as was experienced in 2003 and 2006, which may be the norm by the 2050s, for instance from 4-13 August 2003 there were 616 excess deaths in London (42%), of which the bulk were in the 75+ age group[31]. Additionally, it is estimated that heat related incidents cause 1,100 premature deaths (or deaths brought forward) per year in the UK, with London, followed by the South East, accounting for one-third of these (23).

Currently London's warmer climate is beneficial during winter months as it means that the city experiences warmer temperatures than the surrounding areas. This leads to less snowfall and ice, and a reduction in the number of cold related injuries (23). Nevertheless, on the coldest of nights, the age and poor standard of housing means that cold related deaths still do take place (24). In London, there were 13,390 excess winter deaths between 2011 and 2016 (14).

Future projections

Warmer winters may mean a reduction in accidents and injuries due to slips and falls on icy surfaces and the higher temperatures associated with a reduction in cold-related morbidity and mortality (24, 25). Additionally, milder winters may reduce cold weather-related deaths from Illness such as influenza or cardiovascular disease (25). There are therefore measured benefits for the Health and Social sector in this regard. On the other hand, the longer growing season brought about by milder winters will mean that the 'allergy season' may increase in length, and the timing that certain species of tree or plant flower or seed will also change. This may bring new allergens to prominence as well as altering the timing and relative abundance of existing allergens (26), therefore changing the nature of the allergen impact.

The predicted impacts of hotter drier summers and a greater number of heatwave events are numerous and principally negative. Direct impacts include a greater number of deaths from heart and lung-related diseases, as well as heat-related illnesses (heat cramps, heat exhaustion and heat stroke) increasing during heatwaves (24, 25). Additionally, higher temperatures increase perspiration and evaporation, so increasing the risk of dehydration. Older people and the young are particularly at risk, as the thirst response in older people decreases with age, and younger people require more water to maintain their growth and energy demands. (26). Higher concentrations of ground-level ozone are produced during summer photochemical smog episodes, which are caused by the interaction of oxides of nitrogen (NOx) and volatile organic compounds in the presence of sunlight. These can have detrimental effects on human health, leading to an increase in hospital admissions and premature deaths (23). Finally, there is evidence that an increase in UVB radiation flux associated with climate change, and potentially the incidence of skin cancers, may be largest in southern England, with an increase in melanoma of up to 20 per cent possible by the 2080s. However, the relationship between future incidence of skin cancer and environmental conditions is an extremely complex issue. Changes in social behaviour, and changes in the stratospheric ozone layer, are also determinants of the level of risk (23). Figure 10 shows the heat vulnerability of populations across London.

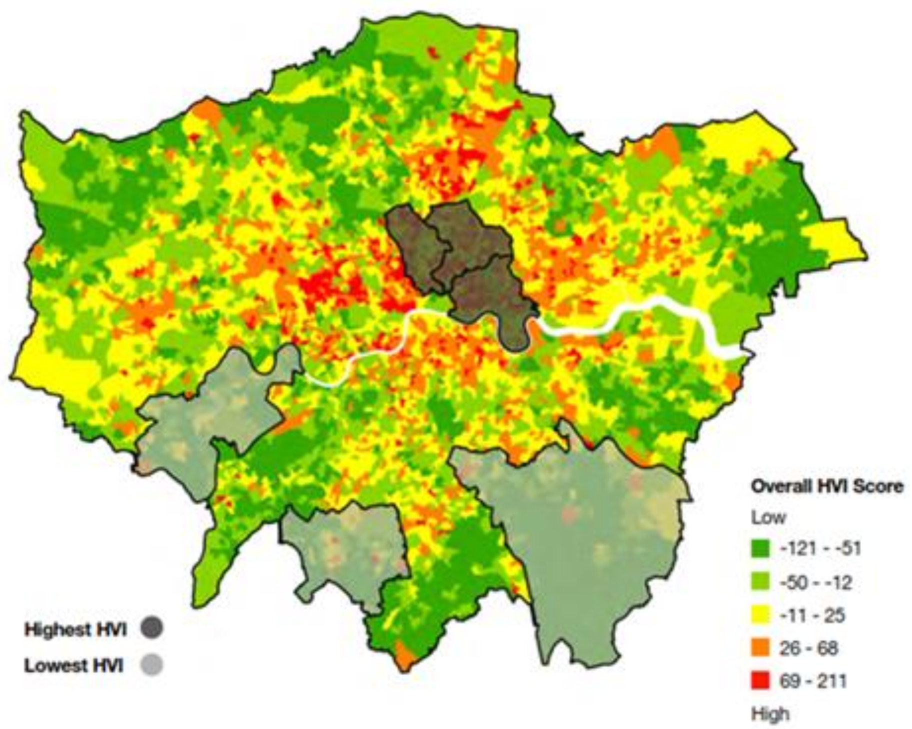
Indirect effects of heat events include greater incidences of food poisoning; research indicates that a 1°C increase in temperature might result in a 4.5 per cent increase in food poisoning.

[31] http://webarchive.nationalarchives.gov.uk/20151014023408/http://www.ons.gov.uk/ons/rel/hsq/health-statistics-quarterly/no--25--spring-2005/index.html

Studies have also shown that it is the temperature the week before illness (when food is prepared and stored) that most increases the risk of transmission. Food retailers and restaurants will need to be particularly aware of the increased risks, given that any food hygiene problems at this level can affect many people (26).

An increase in summer temperatures, combined with poor design, construction, and overcrowding will make internal temperatures uncomfortable and unhealthy, and could lead to summer 'cool poverty' due to use of energy-intensive air conditioning. (25). There is increased risk of power outages reducing the availability of power for demands currently seen as non-essential, such as air conditioning and IT facilities. Additionally, indoor mechanical ventilation has the potential to spread infectious diseases, this can contribute to the contamination of water and food leading to the potential loss of staff due to illness (25).

Figure 10: Heat vulnerability (HVI) across London



Source: Heat vulnerability (HVI) across London, based on the following metrics: population density, rented housing, no person speaking English, health, households with one single person being over 65, day to day activities limited significantly and central heating (32)

5.4 Interdependencies

Strong interdependencies can be identified between the following sectors: Health and Social Care, Emergency Planning and Resilience, Vulnerable Populations and Water. For instance, flooding because of heavy rain has led to significant peaks in demand for Fire Brigade/Ambulance services (11). Major flooding events would result in the closure of primary transport routes and other infrastructure issues. If major flooding took place, the loss of essential services (gas, electricity and telecoms) may affecting up to 250,000 homes across the UK including London, undoubtedly leading to the impacts outlined above (4). Those impacts in

Table 11 will be felt to a much greater extent by those individuals who are vulnerable and lack the resilience to respond to such events.

The Water sector has a direct influence over Health and Social Care by controlling the quality and supply of water to the sector (24). In periods of drought, this issue would be exacerbated as the sector would already be managing the ill-health effects of reduced water availability and diminishing water quality due to extreme low flows (24). Thames Water have water resource management plans in place, but there is a noted gap in understanding about the potential effect of extreme drought on Health and Social Care where research has not yet been carried out.

5.5 Gaps in understanding

Research on the impacts of climate change on health and social care in London has focused more heavily on physical health impacts, and less on those issues which may be specific to social care, including management of mental health.

The UK CCRA2 indicates that outdoor activities may become more attractive in higher temperatures, with perhaps an increase in active travel and other aspects of physical activity, which benefit health and wellbeing. Very little quantitative evidence exists that considers these benefits. *This could be an important research area for London with increasing emphasis on active travel modes around the city.*

CCRA2 highlights risks to health from changes in air quality as an area where more research is needed to understand the influence of climate change on air quality (e.g. ground level ozone), both with respect to outdoor air pollutants (particulates) and the links with indoor air quality.

5.6 Summary

The cost of not mitigating against and adapting to climate change, in terms of impacts to health and wellbeing, are too high to ignore (24). Table 11 outlines the identified potential health effects of weather and climate change on this sector.

Table 12: Potential health effects of weather and climate change

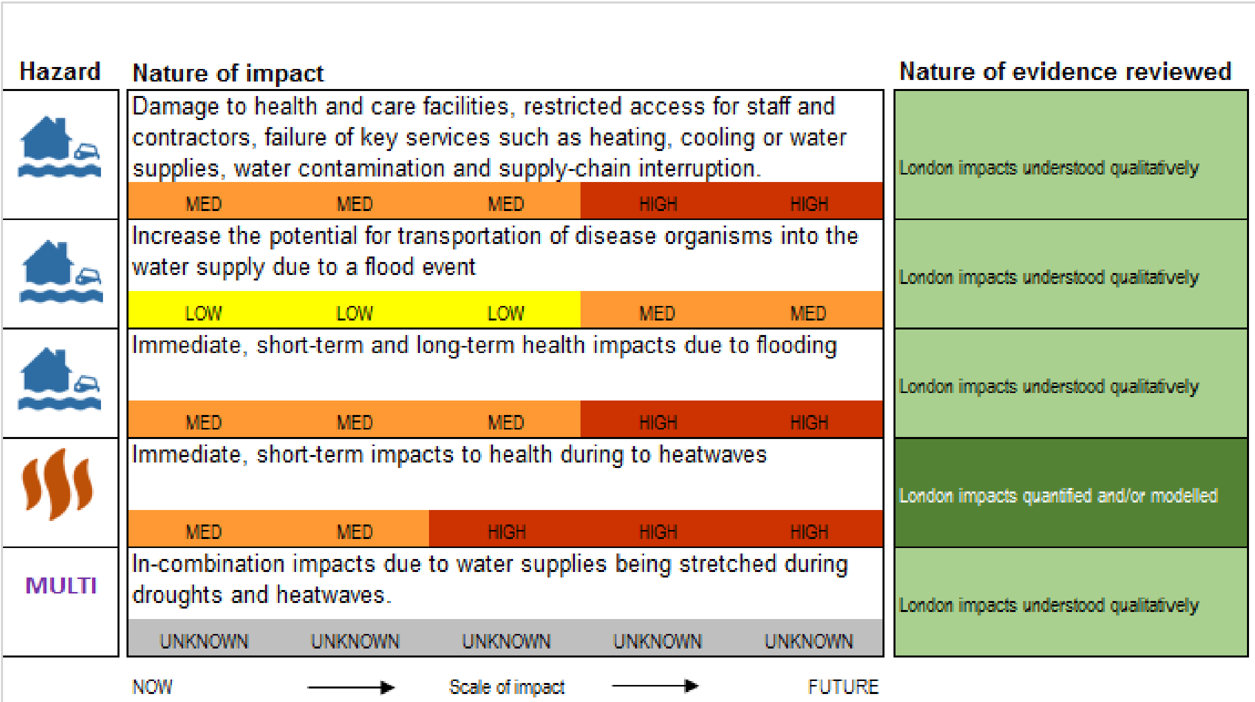
Health Outcome	Known Effect of Weather and Climate
Heat stress, cold stress	Deaths from heart- and lung-related diseases increase with hotter and colder temperatures. Heat-related illnesses (heat cramps, heat exhaustion and heat stroke) and death increase during heatwaves. Warmer winters may mean a reduction in cold-related morbidity and mortality.
Air pollution related morbidity and mortality	Weather affects air pollution concentrations. Weather affects the distribution, seasonality and production of air-transported allergens.
Morbidity and mortality resulting from weather disasters	Floods and windstorms cause direct effects (deaths and injuries), weather disasters infectious diseases, long-term mental health problems, and indirect effects (temporary limitations on access to health and social care services).
Vector-borne diseases	Higher temperatures shorten the development time of pathogens in vectors and increase the potential transmission to humans.
Water and food borne diseases	Risk of bacterial pathogens increases with rising temperature. Increases in drought conditions may affect water availability and water

Health Outcome	Known Effect of Weather and Climate
	quality due to extreme low flows. Extreme rainfall can affect transport of disease organisms into water supply.
Cataracts, skin cancers and sunburn	More cloud-free days and higher temperatures may encourage potential risk of over-exposure to UV radiation.
Accidents and injuries	Warmer winters may also mean a reduction in accidents and injuries due to slips and falls on icy surfaces.

Source: (24)

The main impacts identified in this study are summarised in Figure 11.

Figure 11: Climate impacts on London's health and social care sector, across the 21st century



Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

6 Vulnerable populations and migration

The exact number of vulnerable people in London is unknown, it is however evident that prolonged high temperatures and drought have the potential to increase the vulnerability of these individuals. There are gaps in evidence regarding the potential impacts of floods on vulnerable populations, even though a large amount of high density housing is located within the Thames floodplain. Further research is recommended to assess this, additionally, a detailed assessment of the interdependencies between this sector and others would be worthwhile in aiding the quantification of impact.

6.1 Background

This chapter summarises the available evidence on the impacts of climate change on vulnerable populations in London. There is some overlap with the impacts on the health and social care sector and so for the purposes of this chapter we consider only the additional issues for vulnerable populations, not the facilities and services that support them (i.e. NHS and Social Care). We have also considered migration within this chapter, as migration is strongly linked with particular determinants of vulnerability in this context.

The 'Seasonal health and resilience for ageing urban populations and environments (SHARPER)' report (32) considers vulnerable populations as individuals or households with elderly residents (one single person being over 65), young children, low income, no person speaking English, poor health, day to day activities limited significantly and no central heating.

6.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 highlights that impacts of future heatwaves on vulnerable people may be exacerbated by changes in social protection measures and the level of social care that elderly or vulnerable individuals receive at home. This population will likely increase due to population ageing and future changes in how health and social care is organised.

The CCRA2 assigns the highest urgency scoring to the impacts of climate change associated with or leading to international migration[32]. Displacement of vulnerable populations may arise both in connection with weather extremes (shocks), and longer-term climate stresses. When combined with other factors, weather-related events can cause people to migrate, mostly within or to neighbouring countries, but also further afield. Climate change over time may affect the economic attractiveness or viability of specific regions within countries (and across countries), improving prospects and jobs in some areas while others decline. Economic migration is expected in response.

The CCRA2 cited conclusions from the Foresight inquiry on Migration and Environmental Change from 2011, that the risks of large-scale climate-induced migration to the UK are low. However, there are significant transnational diasporic communities in the UK that have links to areas affected by changes in climate around the world, and this may be a particular concern for London, given the ethnic diversity of London's population. The relationship between climate change and migration is complex, and it is hard to disentangle climate from other drivers of

[32] Risks to the UK from climate-related international human displacements is Risk IT4.

displacement. Some of the links between climate and migration identified by the CCRA2 are provided in Table 13.

Table 13: Climate change and migration

Links between climate change and migration from UK CCRA2
Climate change is unlikely to be the sole direct cause of migration but it will interact with and change the effects of other potential drivers. Drivers of migration include changes in relative wealth and income inequalities, persecution of individuals and communities, and conflict either within or between states. Migration can be short term ('displacement'), and is often within states or to neighbouring countries ('next safe place'). Longer-term international migration arises from sustained internal or regional conflict as well as changes in the economic attractiveness of an area.
Migration has an impact on services, labour markets and long-term investments in both the origin and destination areas. The costs and benefits of migration are, in the main, directly incurred by those directly involved. Most voluntary migration brings long-term benefits for both sending and receiving areas. But there are significant social costs associated with both unplanned migration and exposure of people to weather hazards. The key social costs are due to (i) the local social and economic disruption caused by unplanned migration and (ii) the need to support displaced communities with humanitarian aid, or (iii) the investment in climate change adaptation that may be required to avoid exposed populations needing to move and be resettled.
Some people may lack the resources to move, and these resources, for example land productivity and incomes, can be affected by climate change. This creates an attendant risk of 'trapped' populations in areas exposed to significant climate-related risks. Climate change could also alter patterns of migration in complex ways, by changing the relative attractiveness of destination countries. As displacement following weather extremes is usually limited to the affected areas and adjacent countries, the UK will be less susceptible to inward migration flows arising from displacement from countries outside of the EU. However, this is strongly dependent on UK and EU migration policies that regulate migration flows.
Much of the scientific literature concludes that it is impractical to disentangle climate change from other drivers of migration. Climate change is therefore not a simple 'migration trigger'. Interactions of climate change with income and wealth inequalities, and with conflict within or between states, can lead people to move, but the majority of this movement is likely to be within states or to neighbouring states.

Source: edited from UK Climate Change Risk Assessment, 2017, Chapter 7 – International Dimensions

6.3 Review of climate impacts

Vulnerable populations are at significant risk of suffering from climate change impacts, particularly flooding, water stress and overheating (32).

6.3.1 Impacts from flood

The Regional Flood Risk Appraisal has revealed that as well as an estimated 1.25 million people and nearly half a million properties, there is extensive social and civil infrastructure (such as schools, hospitals and train stations) at high flood risk (18). Low-income households are more severely affected by the stress of the flood itself and future worry about flooding. This stress often results in long-term depression and anxiety, with increases in time off work, unemployment and family breakdown. The combination of the poorest Londoners living in areas of highest flood risk presents a double challenge.

6.3.2 Impacts from heat

Past experiences

The number of deaths in response to rising temperatures in London increases above 24.7°C which is a higher threshold than in other UK regions) and that above this threshold, there is a greater increase in the number of deaths per degree Celsius rise in temperatures than in other regions with lower thresholds. The reasons for this vulnerability are that London is in the warmest part of the UK and therefore our thermally poor homes are more likely to overheat (26).

It is estimated that over 2000 excess deaths in England and Wales, and 100% increase in mortality in 'retirement homes' were attributable to the 2003 August heatwave (11).

Prolonged high temperatures increase social inequality relating to those who live in poorly designed and/or overcrowded buildings and who have limited capacity to take measures to reduce or escape the heat (blinds, awnings, mechanical cooling, access to gardens and green spaces etc) (26). It should be noted that most Londoners are envisaged to acclimatise to warmer summer temperatures, although low-income households and the elderly are the least likely to adapt (26).

Future projections

Climate change will disproportionately affect those living in poor quality or overcrowded homes. London's existing housing stock is older than the national average, with 60 per cent of homes built before 1945. The capital also has a higher proportion of private rented homes where the owner will often have little interest in adapting the property for climate change. London also has more non-decent homes than other regions. In 2003, over one million homes failed to meet the government's Decent Homes standard, 71 per cent of which were in the private sector. Black, Asian and minority ethnic households were disproportionately likely to live in housing in a state of disrepair. (26)

People working outside, engaged in heavy manual labour, or working in buildings that are not well ventilated or thermally regulated, will experience increasing occupational health risks. Those Londoners who work in poor quality environments tend to be from the lower socio-economic groups who, on average, have worse health outcomes than other groups. Climate change may increase these inequalities. (26)

Educational attainment may be adversely affected in schools that are prone to overheating in hot weather, or schools that lie in the flood zone, or have been identified as rest centres for people displaced by flooding. Additionally, in London many schools do not have access to a quality outdoor space for children to play in during their breaks and after school. (26)

Extreme low temperatures can also cause health problems particularly in the elderly and vulnerable groups (11) at present. Warmer winters are likely to reduce the incidence of such events.

6.4 Gaps in understanding

Future projections of the impacts of flooding on vulnerable populations were made available recently via the ClimateJust website and map tool.[33] This has new flood risk and social vulnerability data within the map tool that is finer grained, includes future flood risk up to the 2050s (under 2 and 4^{o}C climate scenarios).

6.5 Summary

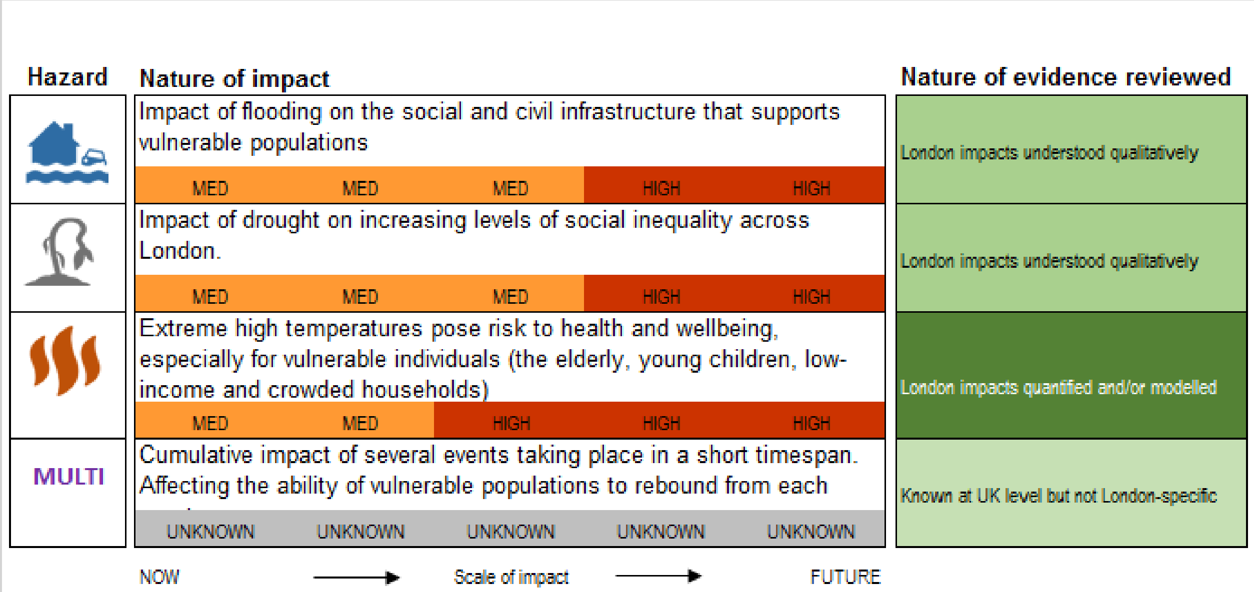
Increased temperatures and greater potential for heatwaves to occur are likely to have the greatest impact on vulnerable populations in London. Pre-existing poor conditions of habitation,

[33] http://www.climatejust.org.uk/welcome-climate-just-2

employment and support often experienced by the vulnerable individual(s) will be exacerbated during heatwaves, which will occur more frequently because of climate change.

The main impacts identified in this study are summarised in Figure 12.

Figure 12: Climate impacts on London's vulnerable populations, across the 21st century



Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

7 Natural Environment

Climate change is likely to have an impact on London's natural environment; although it is not easy to separate the impacts of climate change from other factors such as habitat fragmentation, recreational pressure, and the changes that result from the increased frequency of alien species in urban environments. Climate change could significantly alter the communities and ecosystems which make up London's natural environment; but further research is needed on habitat- and species- specific impacts to determine what measures might be needed to minimise loss of biodiversity, or to manage change so that the ecological value of areas of existing nature conservation sites is not diminished.

National UK environmental policy is placing a greater emphasis on using and managing land sustainably, including the use of natural adaptation solutions to climate change. This presents an opportunity for London to protect and enhance its natural environment while minimising climate change impacts and should therefore be further investigated in the context of the city.

7.1 Description of the sector

This chapter summarises the available evidence regarding the key impacts of climate change on London's Natural Environment, an extensive sector which encompasses all naturally occurring abiotic and biotic features. This report focuses on the ecosystems present in London which combine to form the city's natural capital, underpinning a range of ecosystem services that provide goods and benefits for people (48). This includes terrestrial and aquatic species and habitats, primarily supported by London's network of public parks, green spaces and green infrastructure.

London has an extensive network of public parks and green spaces (Figure 13), making it one of the greenest cities of its size in the world. Public parks are areas that are free to enter and use, including local and regional parks, woodlands, sports fields, and children's play areas (5). These tend to be owned or managed by the London boroughs, other public agencies (such as the Royal Parks), or environmental organisations, often supported by grants or contracts from local authorities. This sector is recognised for its great economic value with a gross asset value of London's public parks in excess of £91 billion, general amenity, benefit to health, and the value of recreation (5).

Figure 13: Areas defined as publicly accessible green space in Greater London

Source: (5)

Green infrastructure is defined as open spaces, natural areas, urban woodland and parks; green street, squares and public realm; sustainable urban drainage systems and healthy waterways, cycles ways and pedestrian routes within the city environment; and smaller scale green roofs, walls and facades (17). The importance of green infrastructure is supported by a growing body of research globally that presents its widespread social, environmental and economic benefits. It is part of a multifunctional design approach in contributing to climate change resilience in urban environments. Within London, the All London Green Grid (ALGG) policy framework has been established to promote the design and delivery of green infrastructure across the city (54).

"The potential benefits that green infrastructure can provide have been largely under-appreciated and unrealised. Green infrastructure is an urban infrastructure hidden in plain sight"
(17)

7.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 covers this sector primarily in its chapter on natural environment and natural assets.

Climate change presents a substantial risk to the UK's native wildlife and also to the vital goods and services provided by the natural environment to people. These goods and services include clean water, food and fibre, pollination, carbon storage, climate regulation, and natural protection from hazards such as flooding and erosion. Risks are typically exacerbated because the natural environment is already stressed by other non-climate pressures including pollution, habitat loss and fragmentation, unsustainable use of soil, water and marine resources, and introduction/spread of non-native and invasive species. These other pressures act to constrain the natural resilience of species and ecosystems to adjust and adapt to change, meaning that future climate change is likely to accelerate current rates of decline and loss of biodiversity and ecosystem function.

For London, five risks identified in the CCRA2 and assigned either the top or second highest urgency category are directly relevant:

- Risks[34] to species and habitats due to inability to respond to changing climatic conditions
- Opportunities[35] from new species colonisations
- Risks[36] to soils from increased seasonal aridity and wetness
- Risks[37] to agriculture and wildlife from water scarcity and flooding
- Risks[38] of land management practices exacerbating flood risk (which includes upstream land management practices impacting flood risk in London)

One risk assigned the second highest urgency category is relevant to London's natural environment sector:

- Risks[39] to freshwater species from higher water temperatures

Other risks to the natural environment that the CCRA2 assigns to the highest urgency category may occur elsewhere in the country, yet may have an indirect impact on London or Londoners (such as the risks[40] and opportunities that may arise from climate-related changes in agricultural and forestry productivity, or the loss[41] of natural flood protection at the coast due to sea-level rise).

In the context of the built environment, the CCRA2 also recognises that climate-related hazards damage historic structures and sites now, but there is lack of information on the scale of current and future risk, including for historic urban green spaces and gardens as well as structures.

Any increase in the frequency and duration of prolonged drought periods will reduce tree growth. Woodlands in the south and east of the UK and those on lighter and shallower soils will be at highest risk. Severe drought stress may lead to mortality and forest dieback, as was evidenced in several parts of Europe during the 2003. In addition, there are likely to be effects on street trees due to higher urban temperatures and reduced effective water availability in many urban soil substrates. Any increases in incidences of drought are likely to affect landscapes dominated by semi-natural habitats as well as urban settings due to the impacts on greenspace and street trees.

[34] This is Risk NE1
[35] This is Risk NE2
[36] This is Risk NE4
[37] This is Risk NE6
[38] This is Risk NE8
[39] This is Risk NE7
[40] Risks and opportunities from changes in agricultural and forestry productivity and land suitability is Risk NE3
[41] Risks to habitats and heritage in the coastal zone from sea-level rise; and loss of natural flood protection is Risk NE12

7.3 Review of climate impacts

Climate change has been shown to affect biodiversity in a range of ways, with further impacts anticipated from projected trends (49, 50, 51). The primary effects of climate change on species include changes to: habitat preferences, distributions, timing of life history events (phenology) and resulting alterations in the composition of communities and ecosystems.

It is anticipated that London's natural environment will be affected by these impacts, threatening the ecosystem services it provides. The significance of this will vary depending on the sensitivity, adaptive capacity and vulnerability of the species and habitats in question. However, studies have demonstrated that cities with extensive, well designed and planned green infrastructure, including policies to green the exterior of buildings, are more likely to adapt and become resilient to the impacts of climate change (17). Nature-based solutions are thought to provide cost-effective approaches to urban sustainability challenges, with additional direct and indirect benefits generated that are likely to exceed the costs of implementation and maintenance (6).

In addition to direct climate change impacts on biodiversity, adaptation responses to flooding, drought and overheating are also likely to result in threats to biodiversity, as well as create opportunities for enhancement (27).

In reviewing potential climate impacts of flooding, drought and temperature increases on London's natural environment, this chapter focuses on the seven key semi-natural habitat types identified in the LCCP report (27): acid grassland, heathland, chalk grassland, rivers and streams and associated habitats, standing water and associated habitats, and woodland.

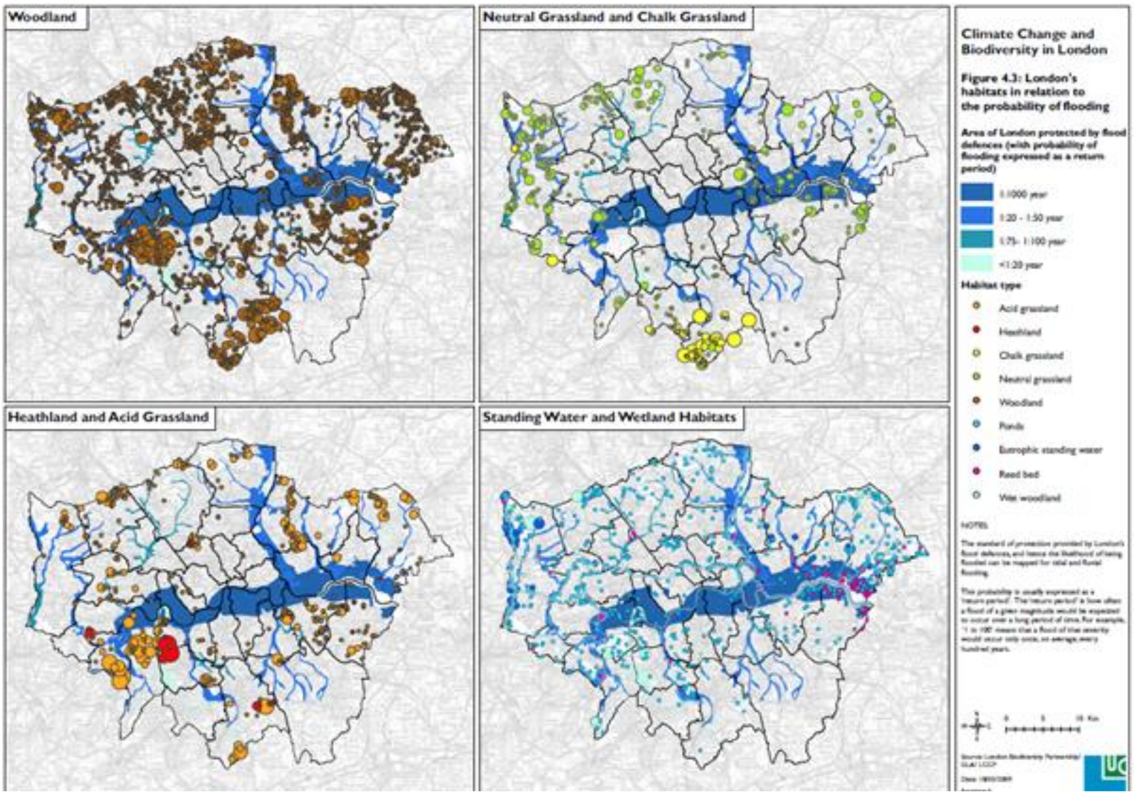
7.3.1 Impacts from flood

Future projections

The key climate change related impacts from flooding for the natural environment in London will be felt by rivers, streams, standing water, other wetland habitats, and the species they support.

As shown in the figure below, increased risk of fluvial flooding could affect a wide area of London and potentially all of the seven semi-natural habitat types known to occur. Extensive flood management is in place, much of which will be enhanced in the face of future flood risk (e.g. Thames Estuary 100 project advising on tidal management requirements). However, flood management itself, from restoration of floodplains to engineered solutions, could also greatly affect habitats (17).

Figure 14: Climate change and biodiversity - London's habitats in relation to the probability of flooding



Source: (17)

Increased occurrence of flash flooding could lead to extreme flows scoring stream beds and banks and enhancing erosion (17, 51). Additionally, heavy rainfall events will result in higher run-off into receiving water courses, estuaries and standing water. This may increase turbidity, nutrient loads and input of contaminants into water bodies, with knock-on impacts for the species they support (50). Dependent upon flood management objectives, green spaces located on floodplains across London could be managed to incorporate a range of additional plant and animal communities suited to wetter conditions.

Coastal and estuarine habitats in the Thames Estuary, including mudflats, salt marshes and grazing marshes, may be affected by flood risk in various ways, with changes depending on the flood responses in place. The intensification of flooding events can have effects on the structure and function of estuarine communities (50). Additionally, a serious issue facing coastal habitats in the future is a reduction in sediment availability. This can be caused by hard flood defences which, combined with rising sea levels, contributes coastal squeeze and a reduction in coastal habitat. Managed retreat, where farmland is allowed to flood, will result in a change in habitat type (17).

Surface water flooding affected by drainage capacity, topography, soil type and permeability, could impact habitats adversely, for example on street trees and gardens (17). Additionally, fluctuations in the water tables caused by flooding and altered rainfall patterns may increase infection by soil-borne pathogens and reduce the rooting depth for certain tree species, thereby causing negative impacts on woodland habitats (51). However, flooding is unlikely to have a significant effect across the broader spectrum of habitats in London.

“Existing urban tree cover can reduce storm water by 4 to 8% and modest increases in tree cover can further reduce runoff”
(17)

Green infrastructure interventions are widely recognised as playing an important role in reducing the risk of flooding by absorbing, storing or dispersing floodwater, and filtering the pollutants. River restoration in various London parks, initiated following the publication of the London Rivers Action Plan (2009) have created opportunities for upstream flood storage; whilst sustainable urban drainage projects such as retention ponds, rain gardens and green/brown roofs can slow the discharge of rainwater run-off into the drain and sewer network, lowering the risk of inner-city flooding and waterlogging. These approaches and others are detailed in the draft London Sustainable Drainage Action Plan (17).

The role of natural flood management, where natural processes are used to reduce the risk of flooding and coastal erosion, is increasingly being investigated and used across the UK (52). This may present opportunities to utilise and enhance London’s natural environment to mitigate the risks of flooding from climate change.

7.3.2 Impacts from drought

Future projections

The key climate change related impacts from drought or water stress for the natural environment in London will include reduced river flows, groundwater recharge and increased leakage, resulting in changes in the habitat extent and species composition.

Changes in precipitation are likely to have multiple impacts on the natural environment, characterised by spatial and temporal variation. These will include reduced river flows in summer; reduced groundwater recharge due to more intense rainfall saturating soils and increasing surface runoff; increased evaporation and transpiration during hotter summers with more cloud- free days; and increased leakage due to increased seasonal changes in soil moisture damaging infrastructure (27). These impacts will put additional pressure on London’s already limited water resources.

Aquatic habitats will be impacted in various ways. Reduced water levels will cause the exposure of littoral zones, leading to the drying of marginal vegetation and increased erosion (51). A loss of physical connection between habitats may be caused by the drying out of ditch and river systems, contrary to the recommendations of the ‘Making space for nature’ report, which highlights the importance of a connected natural environment (53).

Acid grassland, heathland, chalk grassland and neutral grassland habitats are thought to be generally resilient to climate change impacts up to the 2050s. However, transitions to plant communities better adapted to drought conditions may occur and certain common plant species may disappear as a result of increased incidence of drought (17). In particular, lowland heathland of south-eastern England is extremely threatened by predicted climatic conditions, with drought shown to be an important factor in determining the competitive success of bracken and heather (50). A shift in habitat types present in Greater London may occur through changes in species distributions due to drought conditions. For example, drier summers are predicted to favour the spread of dry heath into acid grassland (51).

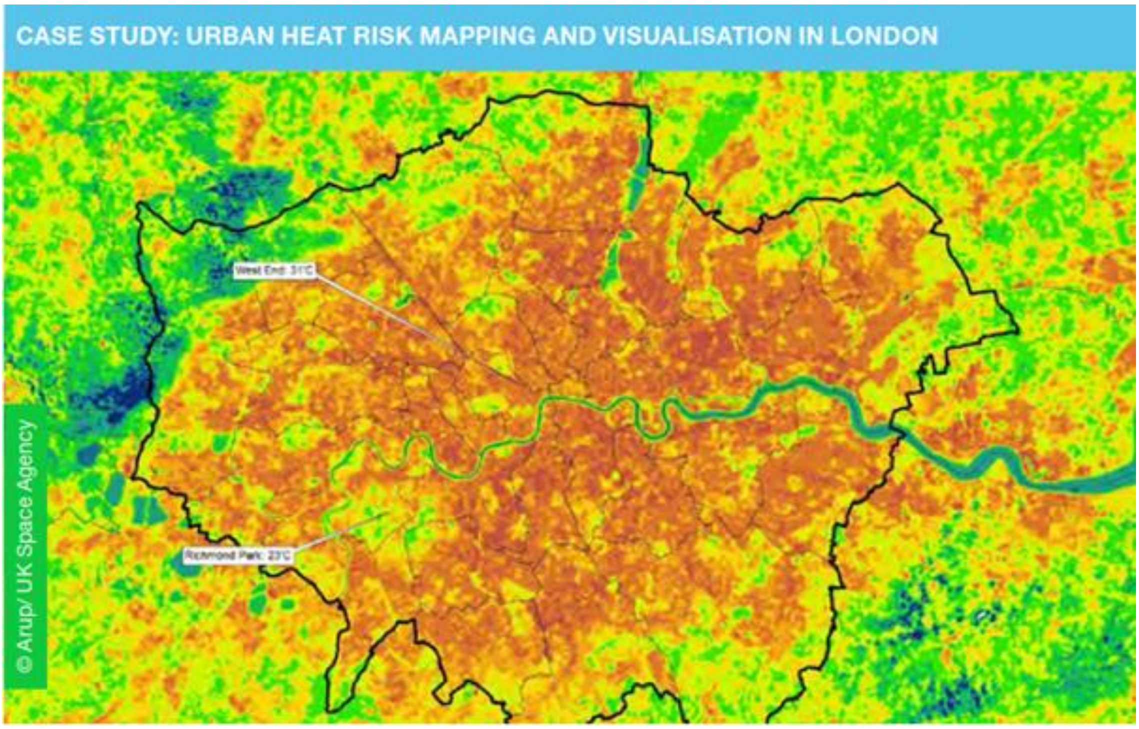
Woodlands are considered to be more resilient habitat types, up to trends predicted for the middle of the century. Nevertheless, summer drought will increase physiological stress on trees and may make woodlands more susceptible to pests and pathogens as well as reduce their productivity (17, 50). This could therefore impact the ability of the tree stock to cool the environment (23). Species adapted to summer droughts in the canopy and field layer may fare better, with changes in species composition likely to reflect this. This may increase competition from invasive species (51), particularly in southern areas of the UK, such as London.

7.3.3 Impacts from heat

Past experiences

Figure 15 shows the cooling effect of London's green space within its urban heat island. Green infrastructure can mitigate heatwaves which are more pronounced in built up areas due to the high heat absorption rate of grey infrastructure. Urban trees decrease ambient air temperatures, green corridors offer better ventilation and green roofs and walls enhance residents' thermal comfort (6).

Figure 15: Visualisation of land surface temperature across Greater London on a summer's day based on satellite data. Note that the West End with very little green space is 8^{O}C hotter than Richmond Park.



Source: (21)

During the summer heatwave of 2003, the impacts included drought, loss of urban vegetation through heat stress and an increase in animal pests. This heatwave, followed by a series of others, encouraged the Greater London Authority to adopt the All London Green Grid framework (54). This focuses on forming natural urban systems that support and permit growth by creating links between places where people live and work, public transport hubs, the green belt and the River Thames (21). Even small park spaces have been found to be two degrees cooler than surrounding areas (17). This signifies a move towards managing London's urban ecosystem to ensure long-term resilience, appeal and health with a major function of the ALGG to enable adaptation to climate change.

Future projections

The key climate change related impact from heat for the natural environment in London is a change in species composition, with resultant shifts in habitat types. Additionally, phenological changes are already being recorded, whereby the timing of life history stages of plants and animals alter in response to climate warming (e.g. earlier budburst).

As a result of the UHI, habitats in London will experience hotter conditions than those outside the city. This may exacerbate climate impacts on those habitats which are most vulnerable to higher temperatures (e.g. rivers, standing waters and other wetlands such as swamps and marshes). Generally, it is anticipated that most species will experience a northward shift in their range; however, less mobile species will be less able to adapt and are therefore more susceptible to climate change impacts. In certain circumstances, the UHI effect may benefit the emergence of new drought adapted communities, particularly those with non-native species of European origin which are currently present but with restricted distribution (17). However, a small proportion of the non-native species are likely to be or become invasive and may include pathogenic species, which will put further pressures on the native species. The increased risk of impact from non-native invasive species is likely to affect all of the habitats which make up London's natural environment.

Increased temperatures are likely to cause significant changes in the phenology of species present in all of London's key habitat types. For example, grasslands and heathlands may experience flowering and seed setting earlier in the season (51). This may have negative repercussions if there is a mis-match in timings between species, thereby disrupting ecological food webs with knock-on effects for higher trophic levels (e.g. shift in tree bud burst mis-matched with invertebrate phenology, impacting food source for bird species).

7.4 Impacts on specific habitats and species in London

The primary climate change impacts of flooding, drought and increased temperatures are anticipated to affect London's natural environment in a variety of ways. This includes: shifts in species distributions and habitat composition; an increased risk of non-native species establishing and spreading; phenological changes with potential alterations in species interactions; changes in ecosystem processes.

These impacts are inter-connected with each other and with wider anthropogenic pressures. Exact climate change impacts effects are dependent on the species and habitats in question. Table 14 shows how seven key semi-natural habitats, selected for their importance to London's biodiversity, could be affected positively or negatively by climate change (27).

Table 14: Impacts of climate change on habitats in London and the ecosystem services they underpin

Potential response to climate change (based on literature review) [a, b]	Ecosystem services provided [b]	Strength of evidence	Sensitivity to climate change [c]
Acid grassland Lowland acid grassland is a threatened habitat in the UK due to land-use impacts such as land conversion, however it is expected to be relatively robust to the direct threats of climate change. Species are already	Wild species diversity / environmental settings (cultural) Wild species diversity (cultural)	Poor	Low

Potential response to climate change (based on literature review) [a, b]	Ecosystem services provided [b]	Strength of evidence	Sensitivity to climate change [c]
adapted to conditions of drought stress. Suitable climatic conditions are likely to be available for this habitat type in south east England up to at least the middle of this century. This may allow for maintenance of this habitat at its current distribution in London. There is evidence that certain common plant species may disappear as a result of increased incidence of drought (e.g. common stork's-bill *Erodium cicutarium*). These may be replaced by European species which are better adapted to drought conditions (e.g. Spanish catchfly *Silene otites*). Little is known about possible climate change effects on a range of acid grassland fauna including invertebrate communities of conservation importance.	Climate (regulating) Pollination (regulating) Water quality (regulating) Soil quality (regulating) Air quality (regulating) Hazard (eg regulation of soil erosion, flood risk) (regulating)		
Heathland Suitable climate space may be available in the short to medium term for maintenance of lowland heathland habitat in London. However, conditions may become unsuitable towards the end of this century as lowland heathland is already a threatened habitat in the UK and is sensitive to changes in hydrological conditions and competition from more tolerant grassland species. Predictions based on the highest rate of climate change indicate climate space for *Ericoid* species (which are a core constituent of heathland habitats, for example, heather) will diminish significantly towards the end of this century. The competitive balance between heath and acid grassland communities may shift in favour of grassland if warmer conditions result in higher soil nitrogen through increased decomposition. Anecdotal evidence and informal plant recording indicate that certain species which are currently restricted to southern English heathlands may not possess the dispersal powers to exploit new climate space in London.	Trees, standing vegetation, peat (provisioning) Wild species diversity / environmental settings (cultural) Climate (regulating) Hazard (eg regulation of soil erosion, flood risk) (regulating) Water quality (regulating) Soil quality (regulating)	Good	Medium
Chalk grassland In general, this habitat may be resilient to direct impacts from climate change towards the middle of this century. For example, many plants of chalk grassland are typically hardy and include species tolerant of dry, exposed conditions. It is possible that chalk grassland species currently restricted to southern England may find suitable climate space in London. There may be a shift in community composition to greater abundance of deep rooted herbs if droughts are more prevalent. Predictions based on the highest rate of climate change indicate that suitable climate space may not exist for certain species, for example, chalk grassland species in Hampshire such as the silver-spotted skipper butterfly *Hesparia comma* and crested hair-grass *Koeleria macrantha* by 2080 and 2020 respectively. The effect of climate change on chalk grassland would also be compounded if vulnerable species perform a 'keystone' ecological function (for example certain grass species).	Wild species diversity / environmental settings (cultural) Climate (regulating) Hazard (eg regulation of soil erosion, flood risk) (regulating) Water quality (regulating) Soil quality (regulating)	Moderate	Low
Neutral grassland In general, maintenance of this habitat may be resilient to a climate change impacts up to the middle of this century.	Hazard (eg regulation of soil erosion, flood risk) (regulating) Water quality (regulating)	Poor	Low

Potential response to climate change (based on literature review) [a, b]	Ecosystem services provided [b]	Strength of evidence	Sensitivity to climate change [c]
There may be a transition to plant communities better adapted to drought conditions such as deeper-rooted plants. The productivity of grasses may be reduced with knock-on impacts higher up the food chain for species which shelter/nest in grasslands Little evidence was found relating to species specific effects of climate change.			
Rivers streams and associated habitats Extensive changes to in-stream habitats due to altered magnitude and frequency of flooding. Increased urban run-off may increase instances of flash flooding, scouring of river channels and increased mobilisation of pollutants and organic matter. Low river flows may lead to concentration of pollutants and reduced oxygen. Increased water temperatures would lead to reduced oxygen levels. Characteristic riverine species such as Atlantic salmon may become extinct if excessive low flows lead to a reduction in the availability and/or degradation of upstream spawning gravels. River systems are under threat from a range of non-native species, and some of these will have a larger range as a result of climatic warming. If soft-engineering solutions are adopted to address the increased risk of flooding (i.e. natural flood management), species and habitats associated with riparian habitats (woodlands, reedbeds, flood-meadows) could benefit.	Wild species diversity / environmental settings (cultural) Water supply (provisioning) Hazard (eg regulation of soil erosion, flood risk) (regulating) Disease and pests (regulating) Water quality (regulating) Soil quality (regulating)	Moderate	High
Standing water and associated habitats Extensive changes to hydrology of many wetlands due to the reduced availability of water, both in terms of precipitation and human resource requirements. Elevated temperatures in combination with the high nutrient loads found in urban areas may lead to proliferation of certain invasive aquatic species and/or increased abundance of cyanobacteria within lake and pond phytoplankton communities. Elevated temperatures may also lead to reduced oxygen levels in standing water bodies. Some aquatic and riparian non-native plant species may become invasive due to improved winter survival rates. If soft-engineering solutions (for example, SUDS) are adopted to address the increased risk of flooding and drought, species and habitats associated with standing water habitats (ponds, reedbeds, lakes) could benefit.	Wild species diversity / environmental settings (cultural) Water supply (provisioning) Hazard (eg regulation of soil erosion, flood risk) (regulating) Disease and pests (regulating) Water quality (regulating) Soil quality (regulating)	Moderate	High
Woodlands Lowland mixed deciduous woodland is considered to be one of the more resilient habitat types based on predicted climate change to the middle of this century. In general, species adapted to summer droughts in both the canopy and field layer may fare better. Changes in woodland species composition may reflect this. If trees are placed under increased physiological stress through summer drought or increased exposure to storms they may experience greater susceptibility to pests and pathogens. This risk may be intensified by	Trees, standing vegetation, peat (provisioning) Wild species diversity / environmental settings (cultural) Climate (regulating) Hazard (eg regulation of soil erosion, flood risk) (regulating) Noise (regulating) Water quality (regulating) Air quality (regulating)	Good	Low

Potential response to climate change (based on literature review) [a, b]	Ecosystem services provided [b]	Strength of evidence	Sensitivity to climate change [c]
an increase in invasive pathogens able to survive in London due to altered climatic conditions. It is likely that certain canopy species such as beech *Fagus sylvatica*, which is relatively shallow rooted, may undergo a decline in response to relatively poor adaptation to drought and/or lower tolerance of increased climatic storminess. It is noted that the susceptibility of beech to climate change may be more prevalent where this species has been planted on unsuitable soils. New scrub communities may emerge based on drought adapted garden escapes and colonists from southern Europe in the long-term future.	Soil quality (regulating)		

Source: [a] Habitats assessed include acid grassland, heathland, chalk grassland, neutral grassland, rivers and streams and associated habitats, standing water and associated habitats, and woodland (27, 51); [b] (51); [c] Sensitivity from Mitchell et al (2007) England Biodiversity Strategy – Towards adaptation to climate change

A sample of key species and species groups, selected for particular public resonance, conservation importance or wide range, was investigated to look at potential effects of climate change on biodiversity in London (27). Table 15 summarises potential positive or negative impacts of climate change, based on detailed literature review. As is the case for habitats, there is a high level of uncertainty. The assessment of risk represents professional judgement of the authors of the source and should be regarded as tentative until further detailed research is published.

Table 15: Examples of key London species and potential effects of climate change

Species	Habitat affinities	Trend/predicted impact of climate change	Risk of direct impacts of climate change
Sand martin	Rivers and streams and associated habitats Standing water and associated habitats	Sand martin has undergone a decline in recent years. This is associated with loss of summer breeding grounds in London as well as droughts in sub-Saharan Africa, where they spend their winters. Milder winters and warmer summers could promote an increase in insect populations. However, increased summer drought conditions could degrade wetland habitats favoured by sand martins. The availability/condition of sand martin nest sites may diminish if increased incidence of flooding damages nesting sites.	Medium
Grey heron	Coastal and floodplain grazing marsh Ponds Reedbeds Rivers and streams Standing open water and canals	Previous studies suggest that grey heron is experiencing an increase in numbers linked to the absence of severe winters and greater numbers of freshwater fish resulting from improving water quality. This species might be expected to continue to increase with milder winters. However, this will depend on the availability of suitable prey species (for example, freshwater fish and amphibians).	Low
House sparrow	Built environment Parks and gardens Brownfield sites	Urban populations of house sparrow have undergone a 60% decline between 1979 and 1995. Reasons for decline are not fully understood but may include: a reduction in the availability of favoured food (including	Medium

Species	Habitat affinities	Trend/predicted impact of climate change	Risk of direct impacts of climate change
		insects when young are being reared), increased levels of pollution in urban and suburban habitats, loss of suitable nesting sites, increased prevalence of disease, changes in the use and type of loft insulation and increased levels of predation. No research has been identified on potential direct effects of climate change on house sparrow. Certainly, the global distribution of this species includes a broad range of climatic zones both to the north and south of the UK. It would seem that the species is tolerant of a range of climatic conditions and would probably be adaptable to any variation brought about through climate change. However, given that populations are currently declining and fragmented across London, if climatic change acts to exacerbate any of the existing threats (noted above) there may be potential for further local extinction of this species in areas of London.	
Peregrine falcon	Roosts in built structures, trees, hedgerows Feeds over all habitats	Currently considered to be increasing numbers in London. The effect of climate change on this species may be mediated though its effect on the availability of prey items and breeding success. The global distribution of peregrine falcon includes a broad range of climatic zones occurring both to the north and south of the UK. Therefore, it would seem the species is tolerant of a range of climatic conditions and suitable climate space is likely to continue to exist in London.	Low

Source: (27)

7.5 Interdependencies

The natural environment is an important sector for interdependencies, both in problems and solutions. There is the potential both for adaptation measures to benefit biodiversity (27) and for the natural environment to contribute to wider adaptation. This will require coordinated environmental policy, cross-sectoral collaboration and a 'landscape scale' approach which encompasses all of London's natural environment (53). Policy in the London Plan ensures the protection of the core network of nature conservation sites in London - known as Sites of Importance for Nature Conservation (SINCs). The new draft London Plan also encourages new development to incorporate green infrastructure to help achieve the Mayor's ambition to make London greener in the future than it is today. This can contribute to restoring London's wildlife by helping to strengthen green corridors or stepping stones across the city. The recently published London Environment Strategy also sets targets for habitat restoration and will initiate projects and programmes that will enhance London's parks and green spaces for wildlife.

The London Environment Strategy also contains policies designed to recognise and take advantage of opportunities to achieve wider benefits from green space, including alleviating flood risk and creating space for wildlife.

7.6 Costs

In the reports reviewed, there is little information available regarding the costs of impacts on the natural environment or the cost of adapting green infrastructure. There is, however, increasing recognition of the need to consider urban landscape elements in cost-benefit analysis of development given their longevity and design life compared to contemporary development (17).

Ongoing efforts to value the ‘natural capital’ of green infrastructure are also making progress, with the intention of quantifying the benefits and informing cost-benefit analysis.

7.7 Gaps in understanding

The following gaps in understanding of climate impacts on London’s natural environment have been identified by the documents reviewed and through the literature review conducted for this chapter:

- **Data collection and management**: London would benefit from better data collection and management across disciplines to ensure that the benefits of nature-based solutions can be more effectively monitored and measured (17). An improved evidence-base that quantifies ecosystem services, assesses added value and/or co-benefits, and engages with stakeholders for policy development and planning would benefit decision-making (6);
- **Spatial variation:** In seeking to address the differing spatial effects of climate change at the city scale, it should be noted that the majority of in-depth studies exploring possible impacts of climate change focus on the regional or national scale and do not consider detailed spatial considerations. There is little evidence on which to base conclusions at the city scale (17).
- **Further habitat-specific and species-specific research**: Further research is needed on habitat- and species-specific impacts to determine what measures might be needed to minimise loss of biodiversity. For example, there is little information on the impacts on invertebrates and fungi, despite the fact that many of London’s rare species are invertebrates and fungi play a critical role in nutrient recycling (17);
- **Fragmentation**: Future research should incorporate the fragmentation of London’s existing habitats and the quality and quantity of habitat resources in London and the surrounding landscape. Investigating shifts in theoretical distribution overlooks the propensity of species to colonise newly available habitat and to escape unfavourable conditions (17).
- **Impacts on ecosystem services**: the impacts that climate change will have on the provision of ecosystem services in London is not well researched. Further knowledge is required to identify how climate change impacts on London’s natural environment and natural capital will have a knock-on effect on the goods and benefits it provides.
- **Opportunities for natural adaptation to climate change**: there is currently a move in national policy towards using and managing land sustainably, including in adaptation solutions to climate change (56). Further research is needed to determine how approaches such as natural flood management can be used in London’s natural environment.

7.8 Summary

The main impacts identified in this study are summarised in Figure 16.

Figure 16: Climate impacts on London's natural environment sector, across the 21st century

Hazard	Nature of impact					Nature of evidence reviewed
	Impact of flooding on rivers, streams, standing water and wetlands habitats					London impacts quantified and/or modelled
	LOW	LOW	MED	HIGH	HIGH	
	Impact of changes in precipitation reducing river flows in summer and reducing groundwater recharge, increasing physiological stress on habitats					London impacts understood qualitatively
	LOW	MED	MED	MED	MED	
	Impacts of high temperatures on species composition favouring a transition to plant communities better adapted to drought conditions					London impacts understood qualitatively
	LOW	LOW	MED	MED	MED	
	Loss of urban vegetation through heat stress					London impacts understood qualitatively
	LOW	MED	MED	MED	MED	

NOW → Scale of impact → FUTURE

Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available.

Nature-based solutions offer the potential to improve London's resilience to extreme weather events, both alone and in conjunction with conventional grey infrastructure solutions. They provide the crucial regulating and supporting ecosystem services that enhance resilience, and cost-effective approaches to urban sustainability challenges.

We are aware of other sources that would benefit this sector review but are limited by the scope of this project. These include:

- The All London Green Grid. Available at: https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/supplementary-planning-guidance/all-london-green-grid
- All London Green Grid Supplementary Planning Guidance 2012 https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/all-london-green-grid
- Airports Policy Statement - Revised Draft Airports National Policy Statement: new runway capacity and infrastructure at airports in the South East of England 2017. Available at: https://www.gov.uk/government/publications/revised-draft-airports-national-policy-statement
- Biodiversity 2020: A strategy for England's wildlife and ecosystem services 2011. Available at: https://www.gov.uk/government/publications/biodiversity-2020-a-strategy-for-england-s-wildlife-and-ecosystem-services
- Natural England reports on climate change and biodiversity.

8 Business and economy

On the basis of the material reviewed, the business and economy sector primarily faces the impacts of flooding and extreme weather events, which damage assets and disrupt business operations. There are large gaps in the evidence around past examples of the impacts of climate change on London's business and economy, which are poorly documented in the reports reviewed for this study. The effect of such extreme weather conditions is likely to fall most heavily on small and medium-sized businesses, outside the FTSE 100, which are least equipped to cope.

8.1 Background

This chapter provides a summary of the climate impacts on London's business sector and economy, based on the documents reviewed. Given the importance of the finance sector to London, there is also a focus on finance and insurance within this chapter.

There are many ways to sub-divide the business sector in order to examine external impacts, such as those from weather and climate change. The UK CCRA2 took a "business function" approach to assessing the impacts of climate change on business and industry, categorising risks to five business function areas: site location, capital, labour supply chains and distribution networks and products/services. These map to some extent into the sectors considered elsewhere in this London assessment:

- Site location – built environment, natural environment, emergency and resilience;
- Capital – finance and insurance (this chapter only);
- Labour – health and social care, vulnerable populations and migration;
- Supply chains and distribution networks – energy, water, transport; and
- Products and services – (this chapter only).

Thus, many of the impacts of climate change on business functions are transferred from these other sectors. The focus in this chapter is on the evidence base that is not covered elsewhere in the review.

The UK's financial services sector is primarily headquartered in London. It accounts for about 7% of total national output, and about a quarter of total corporation tax receipts (33).

8.2 Insights from the UK Climate Change Risk Assessment

The CCRA2 recognised that only a very limited amount of peer-reviewed analysis covered this sector, and had to include information from opinion pieces and documents from business actors in order to build up a more comprehensive picture of the potential risks. This sector is therefore likely to be an important research priority for London also.

The CCRA2 found that flooding and extreme weather events that damage assets and disrupt business operations pose the greatest risk[42] now and in the future. The level of disruption to

[42] Risks to business sites from flooding is Risk BU1.

business and the economy depends in part on the resilience of local infrastructure including transport, IT and energy.

Risks to business from reduced employee productivity, due to infrastructure disruption and higher temperatures in working environments[43] were assigned the second highest urgency category. Workers engaged in particular sectors or occupations, for example heavy outdoor manual labour, are likely to be at the greatest risk of heat stress. The limited evidence available suggests sustained periods of higher temperatures, for example the 2003 heatwave, resulted in large losses for the UK manufacturing sector. Very few studies have considered the impacts of higher temperatures on productivity in the UK and so there is considerable uncertainty about the magnitude of impacts.

Through their international supply chains, distribution networks and global markets, UK businesses are exposed to the risks[44] of extreme weather around the world. Climate change is expected to increase the risk of weather-related disruptions, with trade networks in south and south-east Asia and sub-Saharan Africa indicated as more vulnerable. However, despite only limited available evidence, the CCRA2 assigned a relatively low urgency category to this risk in the business and industry chapter. The CCRA2 chapter on international dimensions reinforces that impacts[45] will also be imported to the UK through the price and safety of food and other commodities, changes in the patterns of trade, disruption to global supply chains, and risks to overseas investments.

International elements of UK businesses' distribution and supply chains are already impacted, and expected to be more at risk as they may involve countries deemed highly vulnerable to climate change and less able to adapt. The reliance of UK businesses on overseas markets as part of their supply chain or for distribution of goods and services can make companies more resilient to domestic (and international) risks but creates exposure to climate change impacts abroad. The manufacture and supply of food, clothes and electronic equipment are understood to be particularly exposed to international climate change impacts.

The CCRA2 identified both risks[46] and opportunities for business from changes in demand for goods and services. CCRA2 assigned lowest urgency category to this risk, emphasising a need for ongoing monitoring of sales of adaptation goods and services in the UK. CCRA2 concluded that the risks and opportunities in relation to the design and type of new products and services are particularly relevant for the following sectors: engineering and consulting, tourism, insurance and other finance products, and agriculture and food, all of which are integral to London's economy.

The CCRA2 identified a potential risk of reduced access to capital (BU4), but assigned lowest urgency category to this. Climate change could have an impact on access to capital through primary channels (exposure of assets to climate hazards and increasing exposure of the insurance industry) or through secondary channels (regulatory change in response to future climate, development of new tools to manage risks, changes in credit ratings and changes in market expectations and investor behaviour).

The response of the financial sector to the recent recommendations from the Taskforce on Climate-Related Financial Disclosures (TCFD) (see Table 16) may become a key factor in business access to investment and project finance, and is an indirect impact of climate change ("secondary channel"). The CCRA2 noted this connection "Access to capital may become

[43] This is Risk BU5.

[44] Risks to business from disruption to supply chains and distribution networks is Risk BU6

[45] Risks from weather-related shocks to international food production and trade is Risk IT1

[46] This is Risk BU7

material if credit becomes more expensive or limited for companies that are considered to be taking insufficient adaptation action. In this way, the cost of capital could begin to reflect risks from climate change, raising capital costs for vulnerable companies." Risks and opportunities for businesses' access to capital can be understood as the 'flip side' of the risk and opportunities faced by the financial institutions, which provide much of the lending and investments, and their response to changing risks.

Table 16: Description of the TCFD

In June 2017, the Taskforce of Climate Related Financial Disclosures (TCFD) issued its final recommendations requiring financial institutions to assess and disclose the financial risks to their investments from physical damage to assets and the transition risk risks related to the move away from fossil fuels in compliance with the 2°C Paris Pathway. The recommendations are voluntary, but are unlikely to remain so and global standards such as the equator principles are having their first update since 2013 specifically to integrate the TCFD recommendations. Major fund managers have made it clear that they will vote against investments where climate risks are not adequately disclosed and managed or that do not support progression towards a 2°C future. The commitment from the investment community is now spreading directly into our industry and is anticipated to have major implications on the management of both existing and planned infrastructure, in both the public and private sectors, as blended finance becomes increasingly the norm.

Source: Mott MacDonald 2018

The insurance industry plays an important role in the UK economy. Services and products of UK insurers are directly and indirectly exposed to climate risks both in the UK as well as abroad. This applies to those insurance arrangements that provide compensation for climate-related losses, such as flood insurance, business continuity or liability insurance, but it could also have broader implications for other lines of business. With London being one of the world's most important insurance markets, many global risk transfer products are underwritten by companies operating in the UK. The impact of climate change on insurers' risk profile, for both assets and liabilities, remains uncertain and hard to quantify.

8.3 Review of climate impacts

While past examples of the impacts of climate change on the business and economy of London are not well documented in the reports reviewed for this study, studies have shown that London's economy and business sector is set to suffer ongoing direct and indirect impacts from climate change in future and acknowledges the increasing risks it faces (11,20,23,30).

8.3.1 Impacts from flood

Future projections

With climate change, the tracks of winter storms, which typically flow north of Scotland, may move further south causing more frequent storms like those in 1987 which materially affected the south coast of England, leading to large aggregations of property losses and a marked decline in their value (30). This may mean an increase in the incidence of people in negative equity in areas that have been badly flooded (23).

Some properties may become uninsurable due to heightened risk of flood and a subsequent potential buyer may therefore be unable to raise a mortgage. A report from the Met Office and the Association of British Insurers found that a 4°C rise in global average temperatures would lead to a 14 % increase in annual insured losses caused by floods in the UK. These issues may cause demand for some properties of certain designs or in certain geographies to decline significantly in market value.

The Association of British Insurers estimates a significant tidal flood in London could have an economic impact on London 'equivalent to the scale of the recent recession'. However, despite this headline, little is still known about the likely economic impacts of the full global complexity of climate change at the city level (20).

In terms of flooding, SMEs are noted to be more vulnerable than larger organisations because of difficulty affording flood insurance in future (20), less continuity planning, less of other types of insurance, often fewer resources available, and reduced capacity.

8.3.2 Impacts from drought

Future projections

A severe drought scoping study for London (40) identifies the following impacts of drought on business and finance:

- Most large businesses have business continuity plans that plan for and manage extreme events. Most small / medium sized enterprises do not have, or only have limited business continuity plans and would struggle to maintain operations during a severe drought. The impact on SMEs may therefore affect larger businesses through the supply chain;
- Many businesses operate from rented workspaces managed by third-party facility management organisations. The impact of low water pressure on welfare facilities and fire suppression systems in these circumstances is poorly understood and may be difficult to resolve due to differing interests of those involved;
- Loss of productivity as staff focus on securing water for personal/domestic needs;
- Loss of income as visitor and tourist numbers decline;
- Sensitive equipment (e.g. IT systems, cooling systems and manufacturing processes) may be irrevocably damaged by non-potable water,

Water shortage may affect the running of businesses reliant on making industrial water abstractions or discharges. Extreme weather is likely to cause disruption to supply chains, staff availability, increased damage to commercial property and business continuity (23).

8.3.3 Impacts from heat

Past experiences

Across Europe, the heatwave in the summer of 2003 when temperatures were on average about 3°C warmer than the historical average, brought US$15bn economic losses due to heat-related impacts (30).

Future projections

Increased temperatures reduce the comfort of occupants in domestic, commercial and public buildings and the productivity of business can be significantly affected as a result (11). London's businesses are also expected to face the greatest increase in energy costs for cooling as they try to counteract this trend.

The CCRA projects that increasing temperatures may cause a shift in the regional distribution of tourists (from both the UK and internationally) under future climate change projections. By 2080, it is anticipated that the general pattern for both domestic and international tourists is that the south of England will have a reduced market share, whilst Scotland, the north of England and

Wales will have an increased market share. In a high emissions scenario, the drop in market share is considered disproportionately high for London, compared to other UK regions. In absolute terms, however, it is worth noting that all regions are expected to have increasing numbers of tourists during the 21st century (23).

8.3.4 Adaptation goods and services

According to (45), the UK's adaptation economy[47] is the sixth largest in the world. Based upon an estimated *global* GDP of £54,044,564bn then A&R equates to 2.6% of global GDP and adaptation and resilience directly related to climate change (A&RCC) equates to 0.38%. Geographically, the UK accounts for 3.1% of global market share for adaptation and resilience (A&R) and A&RCC. This ranking is consistent with the UK's market share in its other priority sectors.

Specifically, UK A&R sales was estimated at £43.8bn in 2012/13 (around 3% of GDP). In comparison A&RCC sales was estimated at £6.3bn (around 0.44% of GDP). A&RCC employment was estimated at 76,347 people in 2012/13 and the company count (where A&RCC activities comprise a significant percentage of sales) was estimated at 4,080.

The adaptation economy has been strong even throughout the recession period - and is forecast to remain strong to 2020/21 and beyond, with growth forecasts between 4.1 and 4.8% (45).

London's Adaptation Economy

London's adaptation economy is different to the national picture, with a greater focus on the built environment and professional services sectors. Its adaptation economy has been estimated to comprise 0.2% of the capital's GDP, with London A&RCC employment estimated at 9,707 people in 2012/13 with the company count estimated at 508.

This represents a large value of sales and importantly the sectors are growing (45):

- London is ranked first in the UK and second against its international competitors (in terms of sales).
- London A&RCC sales were worth an estimated £897m in 2012/13, with year-on-year growth in sales of 3.1%, 3.4%, 3.5% and 3.7% since 2008/09.
- The rate of growth for A&RCC sales is forecast at 4.1% for 2013/14 (compared with historical growth of 3.7% in 2012/13), increasing to 7.4% by 2020/21
- Forecast growth in London A&RCC sales shows an increase of £244m or 27% by 2017/18 and an overall cumulative addition to the economy of £664m.

London also exhibits different historical patterns to the global and UK adaptation economies at the sub sector level (45):

- Built Environment includes 31% of sales, 29% of employment and 35% of companies, reflecting the higher number of smaller companies engaged in sub sector activities.
- Professional Services (including finance) includes 16% sales, 16% employment and 16% of companies.
- Both Built Environment and Professional Services represent a larger percentage of the totals for London than for the UK.

[47] The adaptation economy means measurable economic activities that can be attributed with some confidence as a reaction or planned response to extreme weather. These economic activities are performed within the private sector, funded either by the private sector or by government or its publicly funded agencies.

8.4 Interdependencies

Interdependence with economies elsewhere in the world means that London 'imports' risk through the financial services sector and its international supply chains of large and small businesses. Because London is a global centre, impacts from global extreme weather events, as well as local events, will affect its businesses directly and indirectly. This provides opportunities as well as challenges for businesses (23).

Climate change has the potential to affect virtually all segments of the insurance industry — including those covering damages to property, crops, and livestock; pollution-related liabilities; business interruptions, supply-chain disruptions, or loss of utility service; equipment breakdown arising from extreme temperature events; data loss from power surges or outages; and a spectrum of life and health consequences. (30).

Specifically, in terms of supply chains, the largest climate risks appear to be in the earlier stages of product manufacture. These tiers of the supply chain are less likely to be understood and managed by UK businesses (20). The clothing, agriculture and electronics sectors are thought to be particularly vulnerable. For instance, the 2011 floods in Thailand affected computer supplies worldwide as the affected area was the centre of global hard drive manufacturing (20).

8.5 Costs

A study presented to the government in 2012 estimated that the impact of a severe drought on London's economy would be in excess of £250 million a day. Such a drought could last for months and even after the drought broke, it may take many more months before the impacts subsided (40). The London Environment Strategy (14) estimates the cost of a severe drought to London's economy estimated at £330m/day.

8.6 Gaps in understanding

From the documents reviewed, there is little evidence available on the observed or experienced impacts of climate change on London's business and economy. Often there is awareness at an anecdotal level, but this has not been captured in a more comprehensive analysis of the sector.

The risks imported through dependencies on the financial service sector and international supply chains are acknowledged but poorly understood.

Furthermore, measuring and demonstrating the economic activities that benefit from adaptation to climate change would contribute to the growth of the adaptation economy, as organisations seek to protect and enhance their production systems, supply lines and markets and other assets by pursuing adaptation related opportunities.

8.7 Summary

The main threats caused by climate change to business activity within London are likely to be impacts from flooding and heat which appear to be more significant to business and the economy in London than impacts from drought, though this may also be a reflection of the scanty evidence base.

The main impacts identified in this study are summarised in Figure 17.

Figure 17: Climate impacts on London's business and economy sector, across the 21st century

Hazard	Nature of impact					Nature of evidence reviewed
	Impact of flooding leading to property losses, uninsurability and decreasing property values					London impacts understood qualitatively
	MED	MED	MED	HIGH	HIGH	
	Impact of flooding leading to numerous indirect economic and social impacts					Known at UK level but not London-specific
	LOW	MED	MED	HIGH	HIGH	
	Impacts of water scarcity on a lack of water availability for business					London impacts understood qualitatively
	LOW	LOW	MED	MED	HIGH	
	Impacts of extreme high temperatures on thermal comfort of the workforce, employee productivity and energy costs					London impacts understood qualitatively
	LOW	MED	MED	MED	HIGH	
	Impacts of extreme high temperatures on goods/products and services and tourism.					Known at UK level but not London-specific
	LOW	LOW	MED	HIGH	HIGH	

NOW → Scale of impact → FUTURE

Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

Specifically, surface and tidal flooding will lead to property losses, un-insurability and decreasing property values, coupled with numerous indirect economic and social impacts, while heat will impact on the thermal comfort of the workforce, their productivity and energy costs, while it could also impact goods/products and services and tourism. Global and local supply chains are noted to be increasingly at risk by flooding and heat - further impacting London's economy in future.

There are several areas for London to focus on in this sector:

- Consolidation of those impacts into experience from perspective of business located or trading in London, especially in terms of costs felt by business and the potential for individual businesses to adapt (and perhaps assessing relative to specific locations or sectors of London's economy)
- Specific issue of changing markets – demands – note especially finance and insurance
- Knock on from international impacts – relating to either of the above
- Measuring and demonstrating the economic activities in London that benefit from adaptation to climate change which will hopefully boost adaptation and resilience (and associated business opportunities for London).

9 Information Technology

The IT sector is a network of interconnected and inter-reliant physical and cloud based infrastructure, the former of which is at risk of a greater potential of flooding impacts due to climate change. The sector is ever evolving and with this comes a difficulty in carrying out assessments, as conclusions made are often out of date by the time they are published. A forward thinking and London-specific assessment would provide a more detailed appraisal of the potential impacts and interdependencies present in this sector.

9.1 Background

The Information Technology (IT) sector is vulnerable to current and future climate risks; rather than changes in average climate it is extreme weather that poses the highest risk in this sector (31). One could argue that IT is more resilient to climate change as the network can adapt in real time to climate stresses. Nevertheless, such '*digital infrastructure'* underpins the economy on which London operates and however 'virtual' an application or activity may appear, it will invariably rely on some form of hard infrastructure to function. IT is not a single system but multiple systems and networks that operate in interdependent ways, therefore climate change has the potential to present a great risk to this sector as an impact on one network may disrupt the operation of the remaining.

The three main constituents of IT are as follows:

1. Fixed line telecommunications (made up of the high capacity and highly resilient core network plus the access network which runs from the exchanges to tens of millions of individual customer premises);
2. Mobile telecommunications (that interacts with the core network but provides customer coverage through a cellular network); and
3. Data centres (that manage, transmit, process and store data for government, businesses, individuals and academia). Satellite and broadcast communications also play important roles in digital infrastructure (41).

Relative to the timescales of climate change, IT infrastructure consists of elements with a wide range of expected lifetimes. End-user equipment, such as mobile phones and computers, have life expectations as short as a year. Over five to ten years, expectations of quality and level of service can increase dramatically, leading to infrastructure renewal. Masts and antennae have lifetimes of approximately 30 years, while buildings that house equipment may be in use for 50 years or more. Furthermore, infrastructure such as bridges and railways routes that often carry cables will change and require maintenance.

9.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 addresses climate risks to the IT sector primarily in the chapter on infrastructure, but also implicitly in the chapter on business and industry, with the dependence of business functions on data and communications. It highlights that climate risks should be considered in terms of assets, networks and services, and interdependencies. However, the CCRA2 also acknowledges that IT networks typically exhibit considerable inherent resilience due to diversity of systems and their network topology and redundancy, and this is especially likely to be the case in major centres like London.

Increasing frequency and severity of flooding represents the most significant climate change risk to UK infrastructure, including IT[48]. All infrastructure sectors are already exposed to multiple sources of flooding and the number of assets exposed to significant levels of flood risk could double by 2080s. Increased frequency of coastal, fluvial or pluvial flooding could damage assets such as cables, masts, pylons, data centres, telephone exchanges, base stations or switching centres. The CCRA2 cited an example in the north-east of England where the winter 2015/16 floods inundated key IT assets in Leeds and York. This led to loss of communications for thousands of local homes, businesses (who were unable to process card payments), bank machines and even police hospital services as far away as Tyneside.

Risks from high winds or storms[49] are considered particularly important for the IT sector, relating to the potential for damage to tall structures (e.g. communications masts) and overhead lines, and the CCRA2 gives this the second highest urgency score.

Risks from drought[50] for the IT sector in England may arise as a result of ground shrinkage leading to failure of electrical, gas and water pipes, which then damage co-sited IT infrastructure, but overall the CCRA2 does not give this a high urgency score.

Higher temperatures[51] have been cited as a potential risk to the infrastructure supporting IT and communications networks. Extreme high summer temperatures, as well as rapid fluctuations in temperature and humidity, could pose challenges to data centres, which need to be kept cool to operate.

Finally, the CCRA2 emphasises the need for more action in connection with the potential for cascading failures[52] in interdependent infrastructure networks, which may start with or affect the IT sector in London. Perhaps the most significant issue for IT highlighted by the CCRA2 is the increased pervasiveness of IT, such as increased uptake of 'smart' systems, which is "altering the interdependent risk profile of many infrastructure sectors and little is understood about the longer-term implications of this for climate change risks".

9.3 Review of climate impacts

Climate change risks relevant to IT are primarily flooding from increased winter rainfall, changes to humidity and temperature and high winds (31). As with other sectors, IT has adopted the 50-year UKCP09 projections, medium emissions scenario and central probability in their framework for assessing impacts.

9.3.1 Impacts from flood

Table 17 outlines the predicted impact of flooding and increased precipitation (that would lead to flooding) on the three main IT constituents.

Table 17: Predicted impacts of flooding on the IT sector

	Data Centres	Fixed Line Telecoms	Mobile Telecoms
Coastal flooding *Erosion, inundation by salt water, increase in salt spray.*	Flooding of exposed infrastructure, damage to cabling, scour damage to	Flooding of exposed infrastructure, damage to cabling, scour damage to	Flooding and salt water damage to expose infrastructure – cabling and

[48] Risks to infrastructure services from river, surface water and groundwater flooding is Risk IN2

[49] Risks to energy, transport and digital infrastructure from high winds and lightning is Risk IN11

[50] Risks to subterranean and surface infrastructure from subsidence is Risk IN8

[51] Risks to transport, digital and energy infrastructure from extreme heat is Risk IN13

[52] Risks of cascading failures from interdependent infrastructure networks is Risk IN1

	Data Centres	Fixed Line Telecoms	Mobile Telecoms
	foundations, subsidence, cabling exposed or damaged, salt damage to materials. Problems with emergency access for engineers.	foundations, subsidence, cabling exposed or damaged, salt damage to materials and equipment. Problems with staff access and safety.	underground ducting and cabling. Masts and base stations usually positioned on high ground but base stations may occasionally be flooded. Problems with staff access and safety.
Fluvial flooding *Erosion, inundation by fresh water, silt and sewage deposit*	Flooding, silt and sewage, water ingress and/or damage to heavy plant and switchgear, erosion and scour of cabling and buildings. Problems with emergency access for engineers.	Scour of cabling, flooding of ducting, underground cables, cabinets and access points. Water damage to assets, silt damage, disruption to fleet operations. Problems with fleet operation and emergency access.	Flooding of ducting, water damage to cabling and hardware, scour damage to buildings, exposed cabling. Occasional flooding to base stations, silt and sewage deposit. Problems with fleet operation and emergency access.
Pluvial flooding *Flash floods, inundation of localised area.*	Flooding of facilities. Heavy plant and switchgear disabled, damage to cabling, water damage to other hardware. Problems with emergency access for engineers.	Water damage and flooding to exchanges, cabinets, ducts, exposed infrastructure below and above ground. Disruption to fleet operation and emergency crew access.	Flooding and water damage in exchanges, ducts, exposed infrastructure below and above ground. Disruption to fleet operation and emergency crew access.
More/heavier rain, larger droplets	Not significant, no known incidences	Greater penetration into cabinets, damage to connection points such as tops of poles. Higher groundwater may change shear strength of substrate and reduce pole stability.	Mobile signal can be affected by rain (rain shading). Mainly a problem above 10GHz. Connectivity may be reduced. Possible penetration into exposed base stations. Higher groundwater may change shear strength of substrate and reduce mast stability.

Source: Format (41) with additional text added from (31)

9.3.2 Impacts from drought

The potential impacts of drought include damage arising from subsidence around fixed assets and ducts, and restricted access to water for water-cooled facilities, thereby reducing their effectiveness.

9.3.3 Impacts from heat

Table 18 outlines the predicted impact of higher temperatures on the three main IT constituents.

Table 18: Predicted impacts from higher temperatures on the IT sector

	Data Centres	Fixed Line Telecoms	Mobile Telecoms
Sustained high summer temperatures	Poor working conditions for staff. Some legacy sites may struggle to maintain required temperature or avoid hot spots. May compromise some activity if cooling cannot be maintained. Cooling costs may increase for other facilities.	Maintaining safe working conditions in exchanges etc. Component failure, IT equipment failure, especially legacy kit (NB: Newer equipment has higher temperature and humidity tolerances).	Maintaining safe working conditions in exchanges, component and equipment failure in base stations.
Increased rapidity of temp change	Higher HVAC (Heating, Ventilation, Air conditioning) costs. Stress on components and hardware	Stress on components and hardware. Shorter in-service life.	Stress on components and hardware. Shorter in-service life.

	Data Centres	Fixed Line Telecoms	Mobile Telecoms
Increased humidity	More active humidity management required. higher risk of damage to hardware, may affect reliability and life expectancy.	Damage to exposed assets. Shorter in-service life.	Damage to components and IT hardware and supporting equipment. Can speed up degradation and affect reliability

Source: Format (41) with additional text added from (31)

9.4 Interdependencies

The sector relies heavily on electricity and to a lesser extent on transport – for regular operations, emergency access and generator replenishment in times of power outage, and on water (31). It is also vulnerable to failures in physical “pinch points” like bridges that carry multiple utilities – communications, electricity and water. Within IT there are critical sub-sector dependencies: data centres cannot function without communications and vice versa (41).

The complexity of our digital infrastructure can sometimes make it difficult to understand and identify these interdependencies (41). Even the UK CCRA2 noted that insufficient information about the location of IT and the criticality of its function in managing other infrastructure sectors has hindered comprehensive analysis. The potential magnitude of cascading impacts, were IT systems to fail, indicated there is a need for better understanding of the interdependencies between the IT sector and critical infrastructure to help in planning for the risk of failures (31).

The effects of climate change around the world provide a further source of indirect impacts on IT. This international interdependence extends not only to the global supply chains supporting provision of materials and devices, but also to the hosting, storage and transmission of data (31).

Many online and telephone services critical to business and leisure in the UK are hosted at data or call centres physically located overseas. Rising sea levels and extreme weather events may affect the operation of data centres and service centres in low-lying areas such as the Netherlands and vulnerable areas of the sub-continent of India. Raw materials (such as pine for telegraph poles, and rare or precious metals) and components are sourced from or manufactured in different countries, and may face increasing climate impacts on their production and transport. Supporting architectures and infrastructure, such as fibre-optic networks, are routed across the world, and potentially vulnerable to a wider range of climate impacts (31).

As noted in Section 10, the level of dependence of other sectors and systems on IT cannot be overestimated: the increased pervasiveness of IT, particularly as a result of increased uptake of ‘smart’ systems, is altering the interdependent risk profile of many infrastructure sectors and little is understood about the longer-term implications of this for climate change risks

9.5 Gaps in understanding

Both (31) and (41) state that the evidence and research base on climate change impacts on IT structures and networks, and the IT sector more widely, is currently limited. Specifically, the potential impacts for London are poorly understood as both documents cover the sector UK-wide. There are therefore many opportunities for location specific assessments and policy-oriented studies to substantiate the largely qualitative findings established in (31) and (41).

Even at national level, there is limited information on the location and connectivity of IT infrastructure, making it difficult to make a rigorous and quantitative assessment of risks to networks and services or to assess vulnerability to extreme weather events (2).

It is noted that the rapidity of change that the IT sector experiences presents its own issue regarding closing these knowledge gaps (31). By the time funding has been obtained, research conducted and the report finalised, the issue would likely have resolved or the sector grown to cope (31). Many of the components that make up IT infrastructure have short lifetimes relative to climate change. Unlike other national infrastructure, some components may be renewed and replaced many times before the major effects of climate change are felt (31). Research opportunities outlined in the paragraph above therefore need strong consideration of these.

9.6 Summary

The climate changes of concern for IT infrastructures are increased winter precipitation with associated risk of flooding (fixed line access networks and data centres) changes in mean summer temperatures with associated impacts on sustained high temperatures, temperature and humidity variations (exchanges and data centres). IT infrastructure has some unique characteristics that make it relatively resilient to climate change: equipment life is relatively short so more resilient assets can be deployed as part of the natural replacement cycle, there is more built-in redundancy in IT infrastructures, and technology development is fast and often able to innovate around threats. On the other hand, the sector is highly dependent on energy and we are increasingly dependent on IT for our economic and social wellbeing. The multiple interoperable systems that make up IT infrastructures confer advantages in terms of redundancy and overlap but they are also complex. Not all interdependencies are known and rapid changes in technology may expose the sector to new and unexpected vulnerabilities. Further assessment is deemed necessary to determine the precise impacts in London.

Figure 18: Climate impacts on London's IT sector, across the 21st century

Hazard	Nature of impact					Nature of evidence reviewed
	Flooding of infrastructure and problems with emergency access for engineers and staff.					Known at UK level but not London-specific
	LOW	LOW	LOW	MED	HIGH	
	Subsidence, ground shrinkage leading to damage of structures supporting digital network.					Known at UK level but not London-specific
	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
	Stress and shorter in-service life on components and hardware due to high temperatures/cable heave.					Known at UK level but not London-specific
	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
	NOW →		Scale of impact →		FUTURE	

Source: Prepared for the current study. For nature of evidence reviewed, darker green indicates more comprehensive London-scale evidence available

Part C – Discussion

10 Interdependencies

Modern urban systems incorporating the sectors reviewed in this report are widely recognised to be interdependent. Climate change is expected to increase risks to interdependent urban systems mainly as a result of an increase in the magnitude and frequency of extreme weather events including inland flooding, droughts and heatwaves. This chapter summarises the available evidence regarding inter-sector interdependencies and climate impacts in London, and sets this in wider global context.

Only limited assessment of sector interdependencies has been undertaken at the level of London specifically. There is more discussion of interdependencies in relation to the UK as a whole, and of approaches used by other city governments to understand, communicate and respond to interdependencies. When combined, this can be used to inform London's future approach, not least because the interdependencies affecting London are not confined to the geographical area of the city.

Stakeholders in all sectors examined in this report have responsibility to understand and manage their interdependencies.

10.1 Defining interdependencies

Figure 19 below represents the key interdependent systems that enable a city to function. It should be acknowledged that these are largely physical and organisational categories, and complex social and cultural systems within and across each category affect perceptions of risk and approaches to decision making. With increasing urbanisation, it's likely that cities will continue to extend beyond their "ecological hinterland" through dependence on infrastructure (7).

Figure 19: London as a system of fifteen urban systems

Source: (15)

Infrastructure interdependencies in the UK

A 2013 report by Engineering the Future, a broad alliance of engineering institutions and bodies, has analysed planning timelines for five infrastructure sectors in the UK (39). It highlighted discrepancies between sectors in the level of planning, and the time horizons planned for, with sectors such as IT characterised by much shorter time horizons than the transport sector, explained by the speed of technological development and replacement in the sector. Planning horizons are significant in the context of timescales for climate change impacts.

The same report highlighted the importance of dependencies of all other sectors on the energy sector (39). Inadequate resilience of the energy sector, such as a reduction in spare electricity generation capacity, could have a significant impact on the UK's energy security and also the resilience of other infrastructure.

The energy sector provides necessary power to aspects of the IT sector, such as cooling equipment, and relies on IT for control systems. Collaboration between the two sectors leads to development of energy efficient equipment, for example. However, organisational and ownership issues may inhibit this approach, if there are restrictions in data sharing. Energy distribution and transport assets can share the same physical space (route corridors) and the energy sector provides the transport sector with fuel (petrol and electricity for Electric Vehicles (EVs) and rail) and lubricants (39).

Energy is also important to the water sector as electricity is required for pumping and many waste water processes. Indeed, some UK water companies successfully generate their own electricity from renewable sources or from waste by-products (39). Water is required for cooling in some electricity generating processes, which could become increasingly difficult, particularly in situations where inland water sources are required for cooling purposes (39). Defra's 2012 Climate Change Risk Assessment indicated that lower river flows in summer caused by climate change may impact on the amount of freshwater inland energy stations can abstract for use in cooling.

Infrastructure interdependencies can be grouped into four categories (Table 19):

Table 19: Description of four types of interdependencies.

Type	Description
Physical interdependency	• A transfer of resources, the output of one element becomes the input to another. This could be further refined to capture the nature of the transfer (e.g. Transfer of people). • A shared physical dependency between the two elements on a third resource (i.e. both elements consume the same fuel or use the same trained staff).
Digital interdependency	• A cyber transfer of information. Again, this could be refined to capture additional detail of the transfer. • A shared dependency between the two elements on the transfer of information from a third-party source.
Geographic interdependency	• The elements are located in the same place, or within close proximity. • Bridges, for example, typically convey multiple infrastructures.
Organisational interdependency	• The elements are linked through a financial or logical mechanism. • The elements are organisationally linked by shared ownership, shared governance, or shared oversight. • The elements are mutually dependent on the services provided by a third-party organisation

Source: (39)

Physical and organisational interdependencies appear to be the most well-identified categories of interdependencies in the documents reviewed.

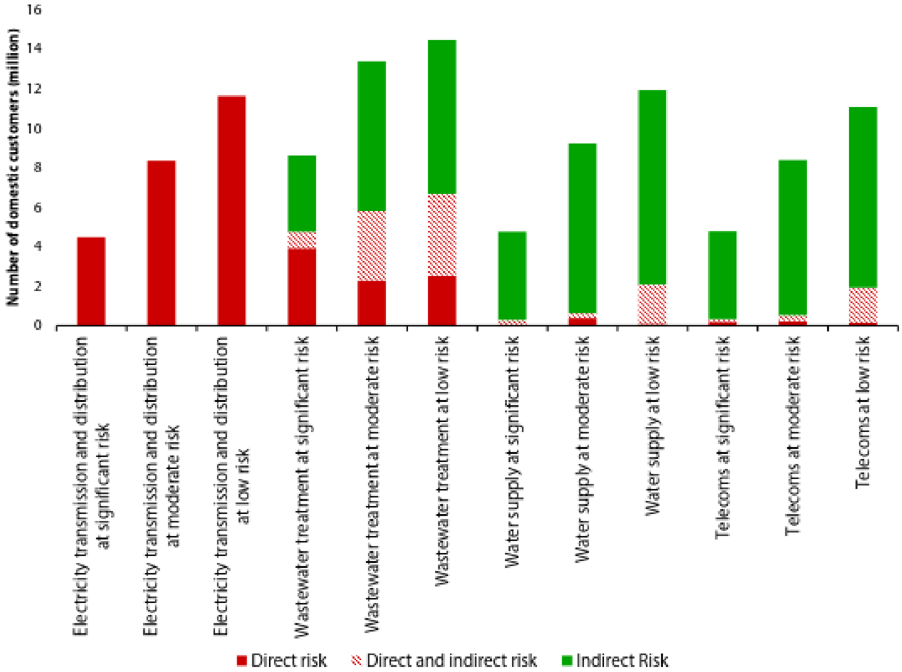
10.2 Insights from the UK Climate Change Risk Assessment

The UK CCRA2 assigns the highest urgency category to risks of cascading failures from interdependent infrastructure networks in its chapter on infrastructure. While information about risks to individual infrastructure sectors has improved over recent years, the impacts of climate change could be amplified by interdependencies between sectors. The CCRA2 discusses key climate risks arising from interdependencies in UK infrastructure, including reliance on power, IT, transport and water.

Figure 20, taken from the CCRA2, is an assessment of the exposure of infrastructure to flooding and disruption in the Thames catchment, a region that was inundated during the winter 2013/14 storms. It shows the potential number of infrastructure customers who could be disrupted as a result of flooding affecting other sectors.

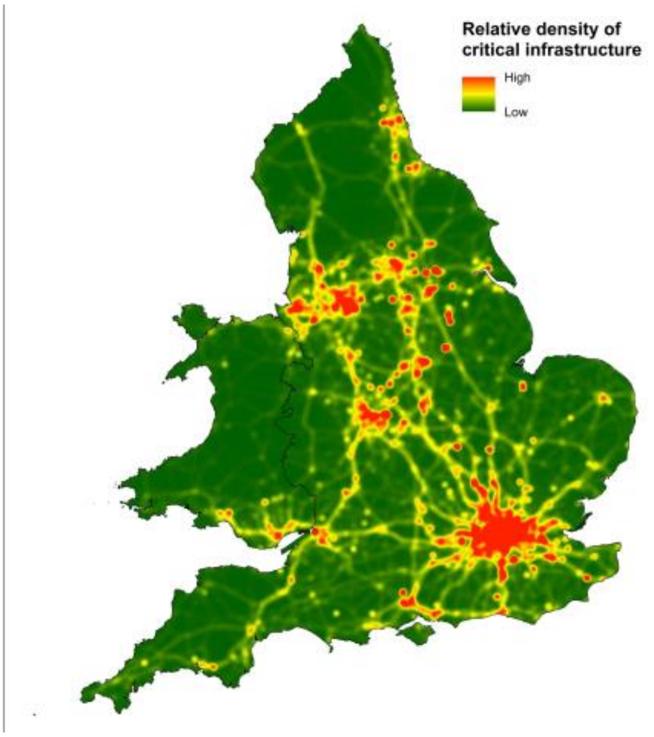
With respect to geographical co-location, the CCRA2 states that inadequate data exists, or is not readily available, on the location of multi-infrastructure conduits in order to be able to assess vulnerability. However, using best available data on the location of national infrastructure, a composite criticality hotspots analysis, measured according to the number of users directly or indirectly dependent on all infrastructure in that location, shows that London is a major focus of criticality for the UK (Figure 21).

Figure 20: Estimated number of customers within the Thames catchment exposed to risk of losing infrastructure services from a 1 in 1000 year flood event



Source: UK Climate Change Risk Assessment, 2017, Chapter 4 - Infrastructure.

Figure 21: Composite assessment of the concentration of critical infrastructure from all sectors



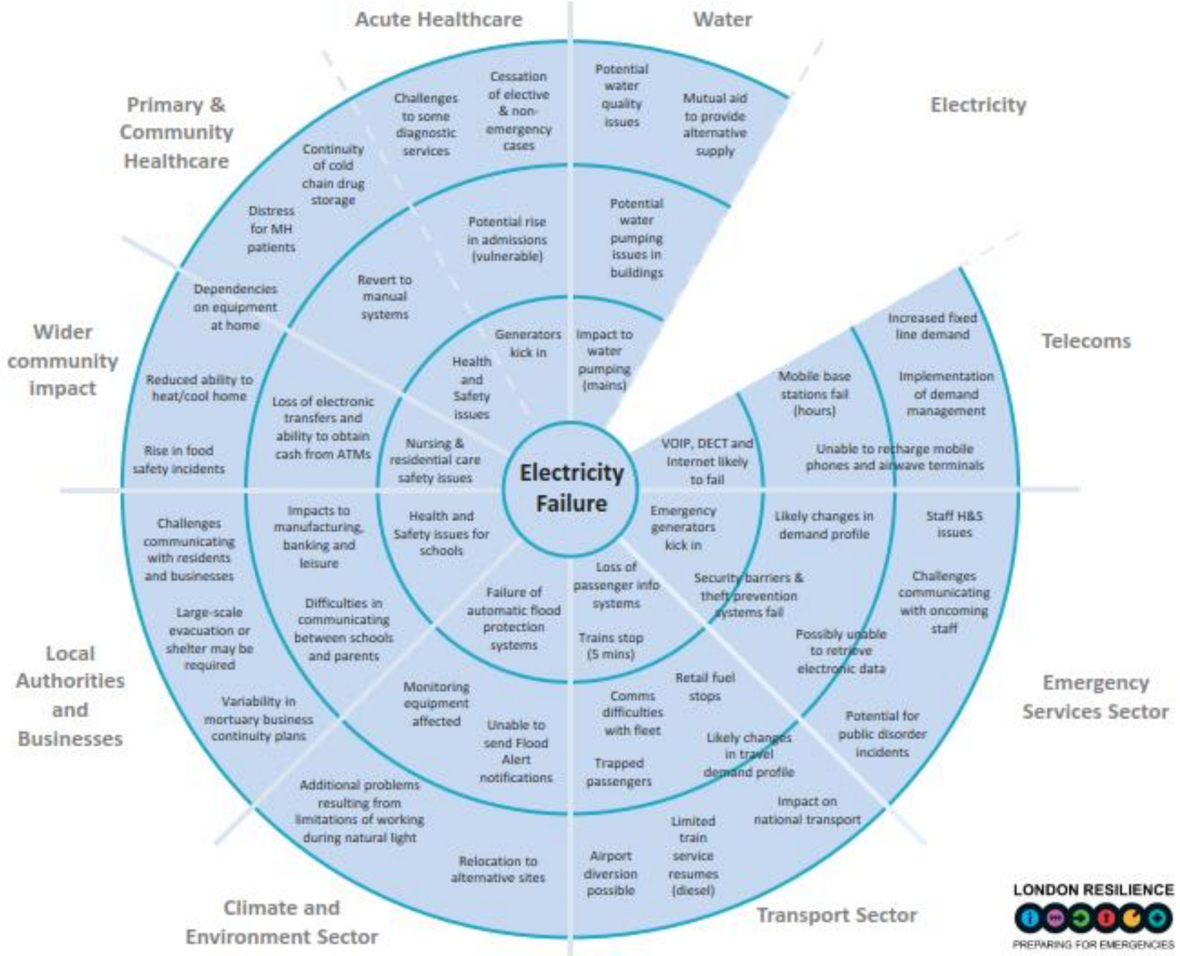
Source: UK Climate Change Risk Assessment, 2017, Chapter 4 – Infrastructure.

The CCRA2 also noted that increased pervasiveness of IT, particularly as a result of increased uptake of 'smart' systems, is altering the interdependent risk profile of many infrastructure sectors and little is understood about the longer-term implications of this for climate change risks.

10.3 City-level approaches to understanding climate impacts on interdependent systems

In London, the Anytown project (7) was undertaken by the London Resilience Team to raise awareness of cascading impacts in urban systems resulting from disruption to infrastructure, and to help in business continuity planning. Through workshops held in 2013, a generic model of infrastructure interdependency was produced, and Figure 22 shows a visualisation of the ripple effect of impacts in connected sectors initiated by an electricity failure.

Figure 22: Ripple effect of impacts initiated by an electricity supply failure, from Anytown workshop discussions



Source: (7)

Other local agencies globally have initiated the process of climate adaptation planning by conducting vulnerability and risk assessment of community-wide assets, including interdependent infrastructure systems, using a range of different approaches. In each case, these assessments have enabled better understanding of the nature of climate impacts in the complex urban systems (3).

Both traditional mapping and more innovative visualisation tools aids have been used to communicate vulnerability or infrastructure exposure to climate hazards. While Anytown used a conceptual mapping of cascading impacts, as part of the Silicon Valley 2.0 project, the County of Santa Clara, and the City and County of San Francisco conducted a comprehensive climate vulnerability and risk analysis to identify high risk assets and services. The outcome of this was an interactive online climate exposure, risk and vulnerability visualisation tool to allow users to see the impact of climate hazards on assets. Maps show various infrastructure assets in the building, energy, transport, water, wastewater and telecommunications sectors, and the extent to which they are projected to be exposed to hazards such as sea level rise, precipitation and extreme heat (see Figure 23) (3).

Figure 23: Silicon Valley decision support tool exposure analysis

Source: (3)

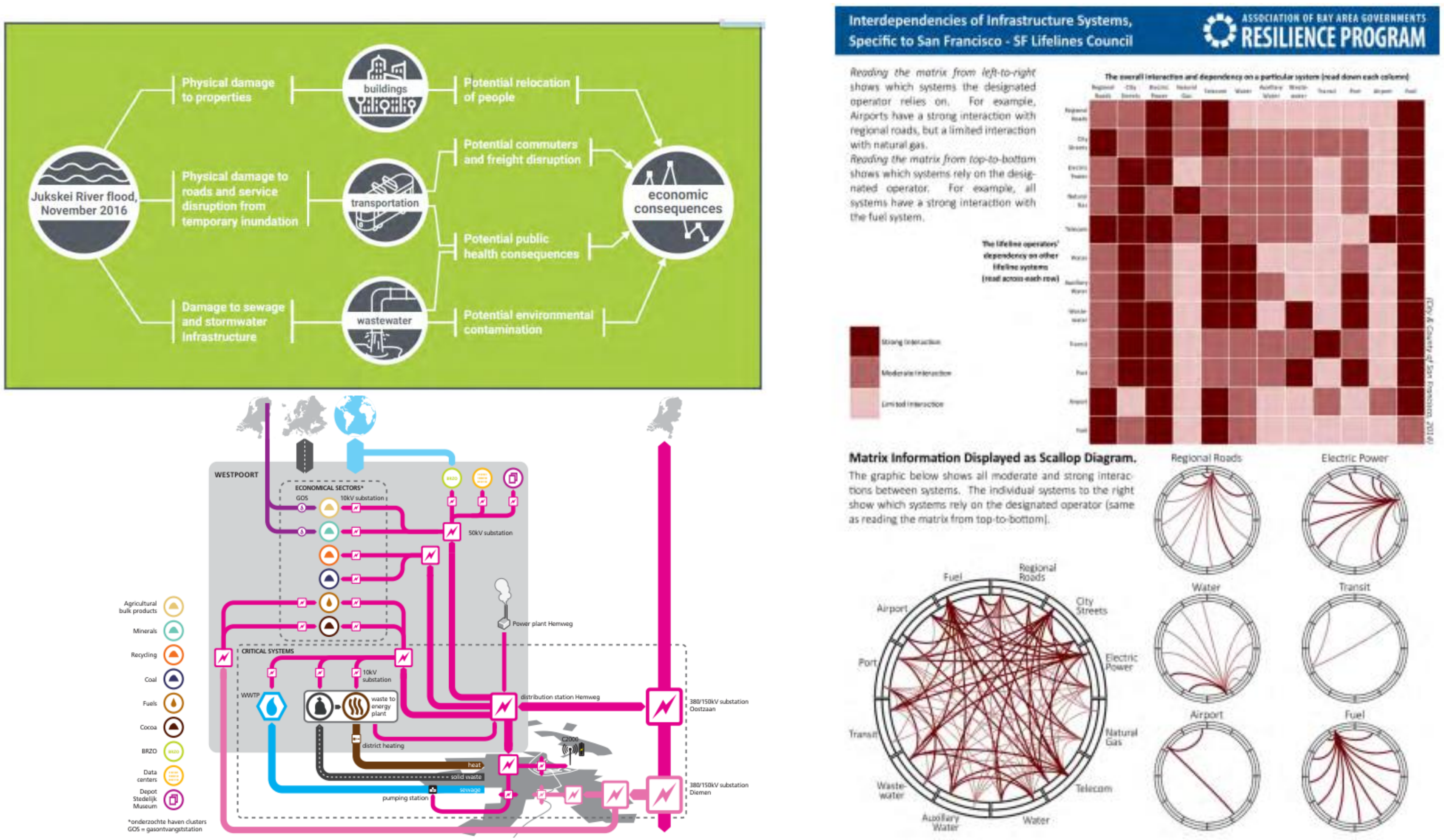
Quantitative and qualitative risk assessments with inputs from infrastructure sector representatives have been used to investigate functional interdependencies between sectors in cities (3). The cities of Eugene and Springfield in Oregon conducted a high-level climate vulnerability assessment with inputs from infrastructure sector representatives. This found a high level of functional interdependence among all sectors. Table 20, below, displays the result of discussions for the food sector, with a high functional dependency on energy, transport and natural systems.

Table 20: Eugene and Springfield food sector vulnerability assessment summary (3).

Food Sector Summary Table	
Critical Interdependencies: Systems of all types are dependent on other systems in order to function. In order to operate, this sector is particularly dependent on:	**Crucial Vulnerabilities:** Each sector has a number of vulnerabilities. For this sector, the following are particularly notable:
▪ Electricity ▪ Transportation ▪ Fossil Fuels ▪ Natural Systems	▪ The majority of food consumed in Eugene-Springfield is stored in Portland and travels down I-5 by truck and trailer. ▪ Grocery stores stock only a three day supply of food. ▪ External influences on agriculture and transportation sector have an undue influence on the price and availability of food in Eugene-Springfield.
▪ Local growers are impacted by flooding but flood is not a significant concern to the local food sector as a whole. ▪ With the potential impact on electricity supply and the critical dependence on tractor trailers to distribute food from Portland to Eugene, winter storms can have a significant impact on the local food system. ▪ An earthquake will have catastrophic impacts to the system. Other hazards are of much lower concern.	

Understanding sectoral interdependencies and first-order vulnerabilities enables better anticipation of second and third order failures in dependent systems from climate hazards. Johannesburg, Amsterdam, and San Francisco investigated the cascading impacts of potential hazards using co-learning exercises, workshops and working sessions to inform their adaptation actions. Johannesburg undertook a co-learning exercise exploring topics related to climate adaptation, including the context in which adaptation occurs e.g. in response to cascading impacts of weather-related disasters. The City of Amsterdam used workshops, working sessions, and round tables to investigate critical infrastructure networks and evaluated flood risks for components in the networks, covering electricity, wastewater, district heating, telecommunications, pipelines and roads and railways. The cascading economic impacts of disruption on sectors were also discussed. The City of San Francisco's Lifeline Council, with representatives from key organisations managing infrastructure systems, produced an interdependence study covering twelve sectors. The outputs of these collaboration exercises were all communicated graphically (Figure 24).

Figure 24: Top left: Schematic of potential cascading impacts from flooding along the Juksei River; Bottom left: Dependencies of critical infrastructure networks and economic sector clusters on electricity. Right: Interdependencies of infrastructure systems in San Francisco (3).



10.4 Gaps in understanding

A wider discussion of sector interdependencies exists in the literature, including how some city authorities worldwide have started to include infrastructure interdependencies in climate risk and vulnerability assessments and to examine the cascading impacts of climate change on interconnected systems.

It is broadly accepted that that networks of infrastructure sectors with critical interdependencies are at a higher risk of failure from external shocks and stresses, including climate hazards such as inland flooding, extreme heat or drought. However, the documents reviewed contain little reference to climate impacts and interdependencies for London specifically.

Reference (3) concludes that work on interdependencies often needs refining, and rarely identifies the failure points in complex systems.

Reference (7) considered the benefits and challenges of developing a combined topographical map of critical infrastructure assets. While this information may help multiple actors appreciate wider impacts of individual incidents, a map would not adequately represent network complexity and redundancy. Instead, with respect to emergency response and hazard management, specific detailed knowledge of asset networks is provided at the time of an incident by the most relevant organisation. However, this does not offer a comprehensive evidence base for longer-term planning in the context of climate change.

Very limited evidence exists regarding whether and how interdependencies analyses have led to the development and implementation of risk mitigation strategies and adaptation plans in cities (3).

According to (3), the following areas of further research would help London to incorporate results into its climate adaptation planning efforts:

- **Research on potential for computer models to refine vulnerability and risk assessments**: Current climate exposure assessments use static, two-dimensional mapping techniques to show exposure of infrastructure systems to climate stressors. A more advanced analysis could use computer models to show interdependencies among infrastructure systems, simulating normal operations and then introducing external shocks and stresses to visualise their impacts on systems on a time-lapse basis;
- **Research on identification of critical links and failure points**: Current level of analysis is rarely detailed enough to isolate critical links in networks or likely failure points. Future research must identify examples of city agencies which have carried out granular analyses of failure points to facilitate the development of targeted adaptation solutions e.g. minimum functionality;
- **Research on how infrastructure interdependency and climate risk analyses are directly informing adaptation strategy development and implementation**: A library of best practices on emerging adaptation strategies from infrastructure sectors and mechanisms in place to implement them; and
- **Research on investment models for adaptation strategy implementation**: Shared risks between interdependent infrastructure mean that there is potential to benefit from pooling technical and financial investment resources among various infrastructure sectors to implement multi-benefit adaptation solutions. Future research should examine financing models for such solutions.

- **We also note that** we have found little evidence in any of the documents reviewed in this study of any attempts to quantify the costs associated with the interdependencies aspects of climate impacts on infrastructure sectors.

Interdependencies and climate risk for London's social infrastructure, such as recreation, day care and immigrant services, is poorly covered. This is likely to be because social infrastructure relies heavily on physical infrastructure, and the first-order impacts of climate change tend to occur on physical infrastructure (3). Nevertheless, second- and third-order impacts such as this need to be better understood, perhaps within the context of cascading impacts of disruption to physical systems.

In conclusion, for the GLA, while gaps for further research on interdependencies exist, there is nevertheless a considerable amount known about the problem. As a strategic authority, the GLA could now look to facilitate sectors in moving the information they do have into practical actions to manage interdependent climate risks. This may involve at least two aspects – facilitating the communication of existing knowledge on impacts between sectors in London, and challenging stakeholders to identify known climate-related risks that require input from multiple actors to resolve.

11 Gap Analysis

There has been a significant volume of research on the impacts of climate change in London leading to a growing awareness of the nature of the impacts in all of London's key sectors and by most key stakeholders. However, the evidence base has been developed in a piecemeal fashion, driven by the interests (and budgets) of different stakeholders. Gaps remain in terms of depth of analysis, including level of detail and quantification, and consistency of coverage, both geographically and by sector.

This section draws together the gaps identified in the sector-based reviews to highlight common themes. Figure 25 and Figure 26 bring together the summary of information on climate impacts by sector and hazard available in the documents reviewed for this study. Despite the variability in depth of evidence across and between sectors, these gaps should not necessarily be perceived as a barrier to action: it may still be possible for stakeholders in each sector to advance their preparedness for the impacts of climate change given the current level of evidence.

11.1.1 By sector

Information about possible impacts is readily available in almost all sectors at a qualitative level. The water and transport sectors have more detailed, quantitative information available than some of the other sectors. The emergency planning and resilience, health and social care, and business and economy sectors have some gaps in relation to the potential impacts from drought (though this may be partly because those sectors are less vulnerable to slow onset risks like drought than they are to the climate shocks of flood and heat). The vulnerable populations (and migration) "sector" appears to have a gap in understanding around quantifying the impacts from heat, which may be an artefact of the selection of documents reviewed, but if not this may be a high priority to address.

11.1.2 By hazard

Turning to the coverage of impacts by hazard, we note some patchiness and variability in level of detail. In general, flood hazards appear the most well-covered, whilst drought impacts appear to be the least well-covered. However, often heat and drought impacts are combined, perhaps exposing a lack of clarity about the primary drivers of climate impacts affecting some sectors.

11.1.3 Timescales

In relation to timeframes, the sector reviews show that there is, unsurprisingly, more knowledge of current impacts, particularly flooding, than projected impacts. The UKCP09 projections are referred to by most of the sectors and there appears to be good understanding of the projected changes in London's climate in general terms, although this is not often carried through into quantified or modelled assessment of future impacts. Those studies which have made use of the projections have not necessarily adopted a consistent approach in the choice of scenarios and probabilities. Much of the description of potential impacts of climate change is provided in the context of current extremes. This may indicate a significant gap in the evidence base that can support robust preparation for potential long-term trends and changes (a point highlighted in the people and built environment chapter of the UK CCRA2).

Figure 25: State of evidence reviewed on climate impacts in London across the 21st century (energy, built environment, IT and business and economy sectors)

Sector	Hazard	Nature of impact	NOW		Scale of impact		FUTURE	State of evidence reviewed
ENERGY		Flood-related damage to infrastructure (site, site access, storage areas)	LOW	LOW	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
ENERGY		Subsidence-related damage to infrastructure; low water flows affecting cooling capacity and ability to discharge cooling water.	LOW	LOW	MED	MED	HIGH	Some knowledge at UK level; lack of London-specific information
ENERGY		Impacts of extreme high temperatures on the efficiency of processes, including electricy transmission and distribution	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
ENERGY		Impacts of extreme high temperatures on employee productivity	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
BUILT ENVIRONMENT		Impact of fluvial and surface water flooding on residential and non-domestic buildings in terms of property damage.	LOW	LOW	MED	MED	MED	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impact of flooding on building valuation and insurance premiums.	LOW	LOW	MED	MED	MED	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impacts of subsidence and heave movement due to drought on building foundations and facades.	MED	MED	HIGH	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUILT ENVIRONMENT		Impact of high temperatures on London's buildings making them more expensive to run through cooling energy costs.	MED	MED	MED	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
BUILT ENVIRONMENT		Impacts of high temperatures on London's buildings making them more uncomfortable, reducing employee productivity, affecting health and wellbeing.	MED	MED	MED	MED	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUILT ENVIRONMENT	MULTI	Damage to historic structures and sites from multiple climate-related hazards	LOW	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Flooding of infrastructure and problems with emergency access for engineers and staff.	LOW	LOW	LOW	MED	HIGH	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Subsidence, ground shrinkage leading to damage of structures supporting digital network.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
INFORMATION TECHNOLOGY		Stress and shorter in-service life on components and hardware due to high temperatures/cable heave.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
BUSINESS AND ECONOMY		Impact of flooding leading to property losses, uninsurability and decreasing property values	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUSINESS AND ECONOMY		Impact of flooding leading to numerous indirect economic and social impacts	LOW	MED	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information
BUSINESS AND ECONOMY		Impacts of extreme high temperatures on thermal comfort of the workforce, employee productivity and energy costs	LOW	MED	MED	MED	HIGH	London impacts understood qualitatively; but lack of quantified evidence
BUSINESS AND ECONOMY		Impacts of extreme high temperatures on goods/products and services and tourism.	LOW	LOW	MED	HIGH	HIGH	Some knowledge at UK level; lack of London-specific information

NOW → Scale of impact → FUTURE

Source: Prepared for the current study.

Figure 26: State of evidence reviewed on climate impacts in London across the 21st century (health and social care, vulnerable populations and natural environment sectors)

Sector	Hazard	Nature of impact	NOW		Scale of impact		FUTURE	State of evidence reviewed
HEALTH AND SOCIAL CARE		Damage to health and care facilities, restricted access for staff and contractors, failure of key services such as heating, cooling or water supplies, water contamination and supply-chain interruption.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Increase the potential for transportation of disease organisms into the water supply due to a flood event.	LOW	LOW	LOW	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Immediate, short-term and long-term health impacts due to flooding.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
HEALTH AND SOCIAL CARE		Immediate, short-term impacts to health during to heatwaves.	MED	MED	HIGH	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
HEALTH AND SOCIAL CARE	MULTI	In-combination impacts due to water supplies being stretched during droughts and heatwaves.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Impact of flooding on the social and civil infrastructure that supports vulnerable populations.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Impact of drought on increasing levels of social inequality across London.	MED	MED	MED	HIGH	HIGH	London impacts understood qualitatively; but lack of quantified evidence
VULNERABLE POPULATIONS		Extreme high temperatures pose risk to health and wellbeing, especially for vulnerable individuals (the elderly, young children, low-income and crowded households).	MED	MED	HIGH	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
VULNERABLE POPULATIONS	MULTI	Cumulative impact of several events taking place in a short timespan, affecting the ability of vulnerable populations to rebound from each event.	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Some knowledge at UK level; lack of London-specific information
NATURAL ENVIRONMENT		Impact of flooding on rivers, streams, standing water and wetlands habitats	LOW	LOW	MED	HIGH	HIGH	Some quantitative information on the impacts in London; but gaps in coverage or depth
NATURAL ENVIRONMENT		Impact of changes in precipitation reducing river flows in summer and reducing groundwater recharge, increasing physiological stress on habitats.	LOW	MED	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
NATURAL ENVIRONMENT		Impacts of high temperatures on species composition favouring a transition to plant communities better adapted to drought conditions.	LOW	LOW	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence
NATURAL ENVIRONMENT		Loss of urban vegetation through heat stress.	LOW	MED	MED	MED	MED	London impacts understood qualitatively; but lack of quantified evidence

Source: Prepared for the current study

11.1.4 Spatial coverage

This study has not examined the spatial coverage of knowledge on climate impacts across London. The existence of the right information about climate impacts at the appropriate geographic scale is important as it determines the extent to which London boroughs or major projects can integrate measures to enhance resilience to the impacts of climate change. The documents reviewed have not provided specific data on climate impacts at the necessary level of granularity to support adaptation action at a project level, but this is because the document set is primarily aimed at high-level policy.

11.1.5 Costs

There is poor coverage of the costs of climate impacts in the documents reviewed. This is disappointing, since information relating to costs of impacts and adaptation is needed to justify stakeholder decision-making around adaptation planning in London's sectors.

11.1.6 Interdependencies

There is scarce information on climate impacts on interdependencies specific to London. This could be partly because the interdependencies affecting London are not geographically constrained, except insofar as failures in one place can impact on multiple sectors due to co-location of services. In the work that does exist at UK level or further afield, there is a perceived need for more clarity around the interplay between climate impacts and interdependent systems, over and above an examination of the interdependent system relationships themselves. Much of the published work in this area is still at the level of qualitative judgment or opinion, and greater efforts to quantify the climate impacts cascading through interdependent systems in needed.

A few city agencies globally have recognised the importance of factoring infrastructure interdependencies into climate vulnerability and risk assessment. C40's study on this topic emphasises that further research and implementation of interdependency analysis is required building on that currently undertaken by universities and commissioned by governments around the world. This research agenda would benefit from better coordination and communication between and among regulators and asset owners. London may be able to learn from the experiences of other cities that have developed sophisticated interdependency modelling, or even to work with other global megacities to develop this information base.

12 Conclusions and recommendations

All sectors included in this review have identified impacts from changes in floods, drought and heatwaves that may occur throughout this century. There is now a very wide literature which is relevant to an understanding of the impacts of climate change on sectors in London, though the depth and level of detail in the evidence base still needs extending. Next steps should address developing a comprehensive London-wide knowledge base, filling knowledge gaps through new research, and communicating the available information to support adaptation planning and action in a sector-based approach. London is already working to fill these knowledge gaps and to encourage understanding of impacts among sector stakeholders.

12.1 Conclusions

The summaries provided in each sector chapter highlight the main impacts of climate change in London, based on the documents reviewed. Each chapter has also noted the gaps in knowledge that have been identified in the literature, and these have been synthesised in an overarching gap analysis.

12.1.1 Key findings

1. A lot of effort has been made to research impacts of climate change in multiple sectors in London over the years.
2. This has been undertaken in a piecemeal and ad hoc way to date, with funding from many different stakeholders to meet their own individual needs.
3. This body of work has not yet been integrated into a consistent framework, or formally collated, and only some of it is available in digital or spatially disaggregated forms
4. This report summarises information from reports focusing on London. The study has identified there is a much wider literature which is relevant to an understanding of the impacts of climate change on sectors in London, and some reports reviewed have been superseded by more recent targeted studies within sectors.

12.1.2 Understanding climate change impacts in London

This study has shown that all sectors have recognised the importance of impacts from changes in floods, drought and heatwaves that may occur in London throughout this century. While no sector is immune, the nature of the impacts varies, and the vulnerability of different sectors to rapid onset climate shocks or slow onset climate stresses also varies. The different sectors in London are also vulnerable to greater or lesser extents to either place-based impacts (originating within London itself) or system-based impacts (affecting Londoners and London businesses by virtue of the networks and connections on which London depends). Despite a general level of understanding, in almost all cases the available evidence needs refinement, particularly to give better quantification of the impacts, including in terms of costs.

London still lacks an understanding of the full range of social and environmental impacts under different scenarios, distribution and equity considerations (especially in the context of a rapidly changing demographic), and the way in which climate impacts can be transferred or multiplied through interconnected and interdependent infrastructure sectors.

Table 21: Summary of findings on impacts

Sector	Findings on impacts and opportunities for further work in London
Energy	• Current short-term weather events present more of a risk than long-term trends in climate change. • These risks are low compared to engineering-related faults leading to loss in generation. • Climate change is not expected to introduce any new types of risk to operations but rather change the likelihood or severity of risks which are currently managed.
Built Environment	• The changing nature of flood, drought and overheating events are making buildings unsuitable for our current and future climate. • Flooding and extreme hot weather pose the highest magnitude risks and represent the greatest need for action in the next five years • Further action is needed to adapt the existing building stock and design new buildings to counter the impacts of climate change.
Health and social care	• Relatively more is known about the impacts of climate change on physical health, than on impacts specific to service provision, social care, and management of mental health. • Health impacts of climate change in London include heat- and cold-related mortality and morbidity, morbidity and mortality resulting from extreme weather, vector-borne diseases, air quality impacts, etc • Very little quantitative evidence exists on potential benefits from an increase in outdoor active travel with climate change, which could be relevant research for London. • More research is needed to understand the influence of climate change on air quality and consequent implications for health.
Vulnerable populations and migrations	• Increased temperatures and greater potential for heatwaves are likely to have the greatest impact on vulnerable populations (including migrant communities) in London • Future projections of the impacts of flooding on vulnerable populations are not currently available.
Natural environment	• Nature-based solutions offer the potential to improve London's resilience to extreme weather • Most detailed work on impacts of climate change on the natural environment is at the national scale and there is relatively less at the city scale. • Little is known about climate change impacts on private gardens, or on invertebrates and fungi, important components of London's natural environment • Little information about the impacts of climate change on the provision of ecosystem services in London and knock-on effects to the goods and benefits dependent on London's natural capital.
Business and economy	• Main impacts of climate change on business activity within London arise from flooding and heat, but it is difficult to disentangle direct impacts on business from those on other contributing sectors • Little evidence was available on the observed or experienced impacts of climate change on London's business and economy, beyond awareness at an anecdotal level. • The risks imported through dependencies on the financial service sector and international supply chains are acknowledged but poorly understood. • Measuring and demonstrating the economic activities that benefit from adaptation to climate change could help to grow the adaptation economy in London and the UK
Information Technology	• Evidence and research on climate change impacts on IT structures and networks, and the IT sector more widely, is currently limited, and London-focused work is potentially non-existent • IT infrastructure has some unique characteristics that may make it inherently resilient to climate change • The sector is highly dependent on energy but not all interdependencies are known and rapid changes in technology may expose the sector to new and unexpected vulnerabilities

Source: Evidence reviewed in this project

On the basis of the documents reviewed, this project has confirmed that a broad understanding and awareness of climate impacts exists in these sectors in London, but this is still often only at a qualitative level. There is still a need to extend the depth and detail of the evidence base, to support adaptation planning and action, although it is possible for key stakeholders to do more to enhance their preparedness for the impacts of climate change to the extent to which the currently available evidence allows.

This raises questions about who should be developing the evidence base, and for whom, and the role of both the GLA and the LCCP in supporting this. As more detailed information is required by sector stakeholders to underpin adaptation decisions, then this may be most appropriately produced by individual stakeholders to suit their specific needs. However, there may be an important coordination and facilitation role to enable cross-sector and inter-stakeholder collaborative working. One option may be for the GLA or LCCP to extend and maintain a repository of needed further evidence, using that as a key part of the sector-based engagement on adaptation.

12.1.3 Informing sector-based stakeholder engagement

No single organisation has direct control over all the actions necessary to prepare London for the projected impacts of climate change. Adapting London to the changing climate will require national, regional and local government, the private sector and London's communities to work together. Every sector has a role to play in improving adaptation to climate impacts.

The Anytown project (7) recommended that greater sharing of information between sectors would derive benefits including reduced duplication of work, greater transparency between sectors, improved basis for training, capability validation and a reduced demand on exercise scenario generation through a pre-existing list of typical consequences.

Despite the gaps identified in this study, it should not be assumed that London is under-preparing for climate change: there are current examples of detailed climate change impact and risk assessment work being undertaken in support of large investments in and around London, in transport and water sectors and broader flood management along the Thames. The recommendations of the Taskforce on Climate Related Financial Disclosures (TCFD) may become the driver for a similar level of detailed assessment at organisational or investment level in large organisations in many different sectors. That this work is progressing on a project-by-project basis, rather than as a London-wide, or sector-wide assessment, may be entirely appropriate and the most cost-effective way for the needed level of detail to support adaptation planning.

It may therefore be appropriate as a next step for the GLA to examine the role played by the city authority in facilitating, co-ordinating or even, to some extent, quality-controlling these research and assessment efforts to ensure that planning across London is coherent, and that interdependencies are not overlooked. Similarly (and particularly as new UK climate projections are published), guidance to improve the consistency in the way climate change projections are selected and handled in London could be a valuable role for the GLA.

12.1.4 Limitations of this study

This assessment is based on the analysis of a selection of publicly-available reports agreed with the GLA, reviewed by the project team and wider Mott MacDonald community. It is not a fully comprehensive assessment of sector impacts and research gaps, but is the starting point for further sector-based work. Readers should note the following limitations of the study:

- **Sample size.** This study draws on evidence presented in an initial agreed set of 56 reports, published over a period of 15 years, to provide insights to around 10 sectors. This sample was subsequently augmented with a further 15 documents that addressed particular queries raised in the review process. Within the scope and budget of the project, reports within the public domain deemed to be most relevant and important were prioritised and chosen. The selection was agreed by the GLA and the C40 and determined to provide a comprehensive assessment for the intended purpose.
- **Limited prior research on impacts.** For some sectors, we found only little prior research specifically on the impacts of climate change, and/or explicitly focused on London, in the documents reviewed. Even where there was plenty of information about climate impacts, the availability of quantitative research was extremely limited. In some cases, reports showed that a general understanding of the impacts of climate change was assumed and the focus

of effort had moved on to approaching adaptation. To some extent, this was balanced where possible with UK-level insights from the UK CCRA2, but it also showed the need for further research to fill gaps at the London level.

- **Subjectivity.** This affected the study in at least two ways. First, the nature of some of the information contained in many of the source documents was often subjective, combining anecdotal evidence with material based on stakeholder workshops or individual opinion. Second, the compilation of material within the review was to some extent subjective on the part of the project team, with the selection of material based on the team's perceptions of what would be most relevant and important. The availability of objective assessment of the scale of climate impacts in sectors was low in the documents reviewed.
- **Lack of common metrics.** This links with the issue of subjectivity. We found little quantified information about the impacts of climate change in the documents reviewed, and even less information in monetised or other economic terms. A lack of common metrics is often an obstacle to making comparative assessments of the scale of impacts across sectors, and such an assessment is not possible within this study. With further work, likely requiring some level of stakeholder engagement, it *would* be possible to develop metrics or categories that can be used to provide a more consistent indication of the scale of impacts[53] in different sectors, and this could be considered for the future.
- **Temporal constraints.** The evidence base on the impacts of climate change in London is constantly being added to, for example through environmental impact assessment associated with new developments, through academic studies, or through the practical experience of stakeholders dealing with extreme weather events. Any study like this one can only represent a snapshot in time, and will need updating as new information becomes available.

12.2 Recommendations and next steps

We offer the following recommendations for further work on the impacts of climate change in London. These are made in the context of the policies and proposals for adaptation set out in the London Environment Strategy.

12.2.1 Developing a comprehensive London-wide knowledge base

- To support more consistency and comparability between sector assessments
- To improve accessibility for policy and project work in London

The evidence base relevant to an understanding of the impacts of climate change in London is extremely large, given the connections and dependencies that underpin this urban system. This evidence base is also being added to constantly, from academic research, policy analysis, strategic sector planning, and practical experience. It is difficult to collate in any more than a narrative without undertaking a more comprehensive assessment that will try to establish some consistency in scenarios and scale. Digital approaches may offer some solutions.

Table 22: Approaches to developing a comprehensive knowledge base

Options for collating the expanding evidence base on impacts of climate change in London
There are several approaches that could be considered for creating a dynamic and updateable digital repository of knowledge on the impacts of climate change in London. Two options which GLA might consider for the future are:

[53] The report authors have experience of developing this kind of common approach to assessing the scale of impacts at an international level for the DECC-funded Country level impacts of climate change (CLICC) project.

Options for collating the expanding evidence base on impacts of climate change in London

1. Digital approaches to capture largely textual or qualitative information so that it can be interrogated or analysed in different ways in future include using a structured set of spreadsheets, a searchable database, or a web-based (e.g. wiki) system. These all offer benefits of filtering or search functionalities, and the ability for new sources to be added at later stages.
2. Where more quantitative and spatially disaggregated information is available, then compilation in a GIS-based system can be useful, particularly to support identification of hotspots of vulnerability, and to facilitate visualisation of different impacts across the city region.

The information collated in sector templates during the current study could be a starting point from which to develop these (or other) formats.

As a first step, digital tools can be used to enhance the ways in which relevant content can be brought together, from a library of documents. "Concept Search" is a tool recently developed to support knowledge management within Mott MacDonald, drawing together relevant information from a vast repository of documents in internal systems. With some initial work to establish structures and taxonomies[54], a similar tool may provide a new way for the GLA to expand and update the information drawn together in this project, making it accessible to members of the LCCP and interrogable by other parties. It may be possible to link this kind of effort with proposals in the Smart London Plan.

Going further, and linking with the work of the Smart London Board[55], a more ambitious vision could look to integrate available climate impacts information fully into a spatial repository of data on London, a so-called “Digital Twin” that can be used to explore the impacts of weather events on London’s urban system today and in the future. For example, a London-wide database and tool could make it easier for multiple parties to be aware of all development occurring within the city, which would support coordinated flood management strategies and help identify opportunities to enhance planned developments to reduce flood risk. Figure 27 offers one concept of the layers that could be developed to provide this kind of digital support tool.

In order to support adaptation in London, we suggest that a digital data repository should offer benefits to the widest possible range of London stakeholders, including vulnerable populations, from large infrastructure agencies and authorities, to London boroughs with responsibilities for small care home facilities. Potential overlapping needs and benefits might include:

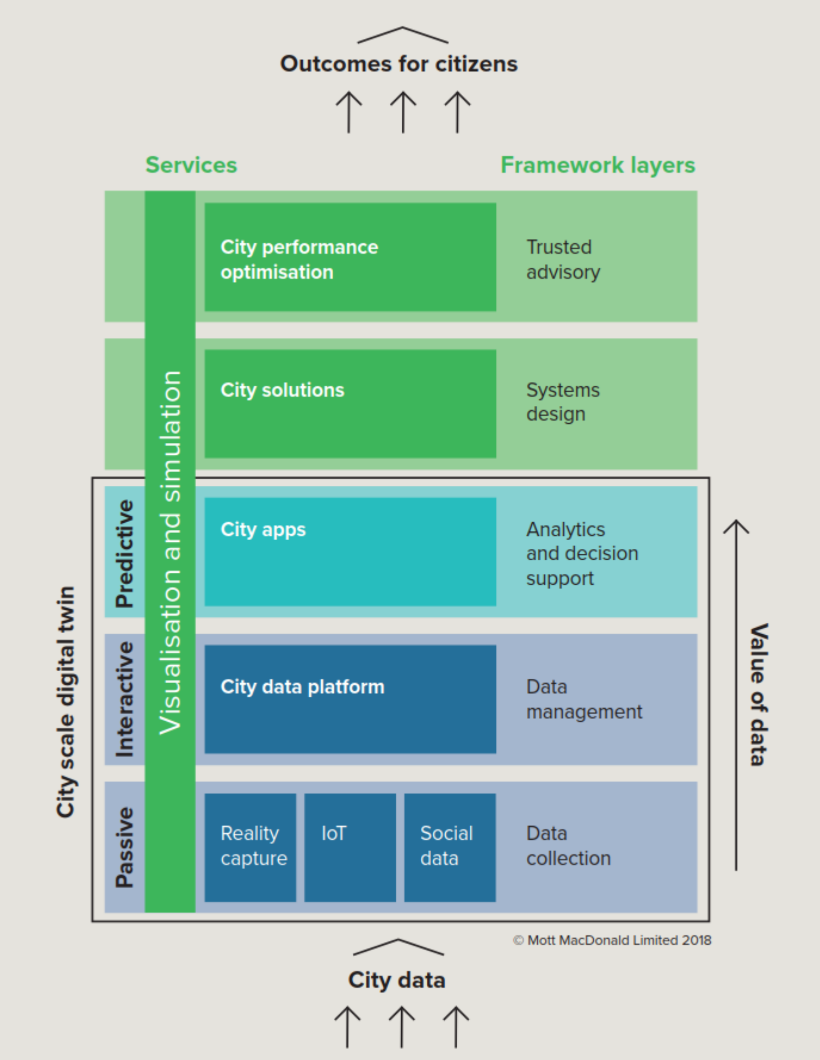
- For major infrastructure projects, more efficient access to data, saving money and ensuring consistency, plus improve systems approaches;
- Supporting resilience of London’s business and economy sector; and
- Informing local level geographic concerns e.g. vulnerability of individual assets, borough.

The GLA is developing data tools such as green infrastructure and infrastructure mapping to help improve London’s adaptation interventions. We recommend that the GLA continue to explore the possibility and benefits of this kind of digital development, in the context of London’s wider digital and data sharing aspirations and plans.

[54] Taxonomies help organise information into hierarchical relationships. Classifying content and knowledge assets using a controlled taxonomy makes searching much easier

[55] https://www.london.gov.uk/what-we-do/business-and-economy/supporting-londons-sectors/culture-consultation/smarter-london-together

Figure 27: Components of a London-wide digital data repository



Source: Mott MacDonald 2018

12.2.2 Filling knowledge gaps through new research

Further research to fill gaps in the knowledge base for London is needed at both micro and macro levels. While it may be important for the GLA to undertake specific pieces of research, in some cases it may be more appropriate for other organisations or projects to procure or undertake research. The GLA, together with the LCCP, may have more of a facilitating or coordinating role.

Some further case study type research is needed to gather objective and quantitative information about the scale of impacts from recent weather events, e.g. damage to London businesses from flooding.

Further sector-wide studies targeting research gaps in the evidence base on climate impacts are also needed. Many specific areas of work, or gaps for attention, are identified in each of the sector chapters, but out of those we highlight the following topics:

- The UK CCRA2 stated that inadequate data exists, or is not readily available, about locations where multiple infrastructure points come together (e.g., water and electricity lines) to assess vulnerability. Further work on this to support understanding of geographical interdependencies, including IT, in London may be valuable;
- Research to examine the proportions of different segments of London's economy traded from countries most vulnerable to climate change, and/or work to map the major supply chain vulnerabilities of London's economy, considering cascading impacts;
- Further research on the impacts of climate change on air quality in London, and consequent implications for health; and
- Impacts of climate change on the provision of ecosystem services in London and knock-on effects to the goods and benefits dependent on London's natural capital.
- London-specific studies of impacts on IT are potentially non-existent, but any further work should be tightly scoped to be of direct relevance to adaptation planning by dependent sectors and businesses in London.

In support of the London Environment Strategy, more detailed work is needed to develop metrics and commence systematic collection of data to monitor London's progress in adaptation. One element of this could address common ways to categorise the scale of impacts in different sectors in London, even where comprehensive information on costs is not yet available. The Country-Level Impacts of Climate Change (CLICC) project[56] developed new approaches for communicating the impacts of climate change at national level, in different sectors in a consistent way. While this was not applied at the city level, it did tackle the challenge of very different countries with different levels of data availability and capacity to find common ways to present and communicate the magnitude of current and future climate impacts.

12.2.3 Communicating the available evidence base

Alongside a coordinating role around the development of new or updated information on the impacts of climate change, we recommend that the GLA builds on its convening and lobbying role, by enhancing the communication of the already available evidence base. Even where only qualitative information on impacts exists in some sectors, it is still possible for stakeholders to take further steps, while recognising where uncertainties lie, to improve their preparedness for climate change. The GLA may find that new efforts to communicate the available evidence also allow for stepping up the challenge to take action where appropriate.

Several cities around the world have used mapping and other forms of data visualisation to present climate exposure, vulnerability or impacts in accessible ways for stakeholders to engage with. The GLA attends webinars and participates in networks like the C40 Cities to learn about other cities' and countries' approaches to communicating risk and impacts information. Given the volume of material available in London, tools and approaches like London's Green Infrastructure Focus Map will also be of interest to those seeking to present evidence in ways useful to decision-makers across sectors. The GLA should continue to share learning with other cities about communicating risks, impacts, and the need for adaptation with stakeholders.

Table 23 gives an example of a tool that accesses complex datasets, including weather and climate information, for the city of Auckland in an accessible way.

[56] This was a Department of Energy and Climate Change funded project in collaboration with the UN Environment Programme from 2014-2016, now hosted by UN Environment. More information

Table 23: SafeSwim app case study

Moata Safeswim was launched in November 2017 to provide real-time information about beach safety and water quality at 84 of Auckland's beaches. The site allows locals and visitors to pick the safest beach before they set out and also gives real-time warnings about unexpected beach safety risks as they occur, and provides information about wind direction and tides.
Accessed online or via an app, Safeswim is supported by a data management platform called Moata, created by Mott MacDonald, which aims to help identify problems and risks associated with watercourses within the local area by providing water quality forecasts and up-to-date health and safety risks. Moata has been developed as a city data platform with the potential to accommodate many applications of city data analytics to improve the outcomes for a city and its citizens - SafeSwim is just one example.
Beach users can make decisions about where to swim based on predicted and current levels of risk enabling them to check before they swim on a beach, lagoon, or waterway, anytime, anywhere. By accessing a map at www.safeswim.org.nz they can immediately identify the beaches with the best water quality and receive live alerts on wind and wave conditions, tides and currents, and the presence of marine life such as stinging jellyfish, sea slugs and sharks.

Source: Auckland Council's Safeswim website: https://www.safeswim.org.nz/

Further work to improve access to or awareness of higher resolution data on climate impacts could also be considered, perhaps in connection with the publication of new UK Climate Projections.

We also recommend that the GLA considers developing simple visual materials that communicate impacts of climate change to support the sector-based approach. These could be developed in an ad hoc manner based on existing information appropriate to the nature of each stakeholder engagement.

12.2.4 Engaging stakeholders in the sector-based approach

Building on the heritage of its work in convening a wide range of stakeholders in London to understand and act on climate change, the LCCP can place a major focus on improving multi-sector engagement in understanding interdependent climate impacts. The Anytown project recommended convening further multi-sector workshops to continue building understanding of interdependencies in London.

The LCCP is facilitating such engagement, drawing in stakeholders in the context of London’s sector-based approach to adaptation. While most of the work in Anytown focused on business continuity in the case of disruptions, the model outputs from that project offer a starting point for development of understanding and awareness of changing frequency or severity of cascading impacts due to climate change. A forum or workshop on interdependencies could follow different formats, depending on whether the priority is to draw information out of sectoral stakeholders for wider dissemination or to co-create new knowledge. This forum also offers an opportunity to examine co-benefits of climate change action, perhaps looking specifically to identify and quantify the multi-stakeholder benefits of adaptation action that addresses interdependent climate impacts.

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Appendices

A. List of acronyms used in the report

Table 14: Acronyms used

CAMS	Catchment Abstraction Management Strategy
CCRA2	Second UK Climate Change Risk Assessment
CREW	Community Resilience to Extreme Weather
Defra	Department for Environment, Food and Rural Affairs
GIS	Geographic Information System-based
GLA	Greater London Authority
ICT	Information and communications technology
IPCC	Intergovernmental Panel on Climate Change
LCCP	London Climate Change Partnership
LES	London Environment Strategy
LU	London Underground
NHS	National Health Service
RCPs	Representative Concentration Pathways
TCFD	Task Force on Climate-Related Financial Disclosures
TfL	Transport for London
UHI	Urban Heat Island
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018
UNFCCC	United Nations Framework Convention on Climate Change
WwTW	Wastewater treatment works

B. London Environment Strategy policies and proposals on adaptation

The London Environment Strategy contains 13 policies and related proposals to achieve its objectives for climate change adaptation, summarised in Table 24. The current study can support work with priority sectors to understand the impacts of severe weather and climate change (Policy 8.1.1).

Table 24: London Environment Strategy policies and proposals on climate change adaptation

	Policy statement
Policy 8.1.1	Sectors understand the impacts of severe weather and climate change, prioritise the key risks and identify mitigation measures where appropriate.
Proposal 8.1.1a	The Mayor will work with the main infrastructure providers in transport, energy, water and buildings to identify thresholds for disruption and produce integrated plans for addressing long-term climate risks.
Proposal 8.1.1b	The Mayor will promote ways to continually improve resilience in infrastructure among priority sectors to ensure that London remains a leading global city.
Policy 8.1.2	Develop, refine and monitor plans and indicators of London’s resilience to severe weather and longer term climate change impacts on flooding, heat risk and water pollution.
Proposal 8.1.2a	Through the London Climate Change Partnership, the Mayor will agree indicators with priority sector representatives and establish a baseline for regular monitoring.
Policy 8.2.1	Reduce the risk and manage the impacts of surface water, sewer, fluvial, reservoir and groundwater flooding in London.
Proposal 8.2.1a	The Mayor will work with partners to increase awareness of all forms of flood risk across London and develop options for targeting areas at particular risk from surface water flooding.
Proposal 8.2.1b	The Mayor will support flood risk management authorities in London to manage fluvial flood risk and promote best practice approaches in hard and soft-engineered flood management
Proposal 8.2.1c	The London Plan includes policies that manage flood risk for new developments.

Policy 8.2.2	Ensure London maintains its standard of protection from increasing risk of tidal flooding
Proposal 8.2.2a	The Mayor will support delivery of the measures in the Thames Estuary 2100 Plan
Proposal 8.2.2b	The Mayor will support the safeguarding of sites for a new Thames Barrier east of London
Policy 8.2.3	Increase the amount of sustainable drainage prioritising greener systems across London in new development, and also retrofit solutions
Proposal 8.2.3a	The London Plan includes more ambitious requirements for sustainable drainage in relation to new development
Proposal 8.2.3b	Implement the actions in the London Sustainable Drainage Action Plan to retrofit more sustainable drainage for London
Proposal 8.2.3c	The Mayor will consider a range of mechanisms to encourage sustainable drainage retrofit on non-residential properties
Policy 8.2.4	Work with stakeholders to improve London's sewerage system so it is sustainable, resilient and cost effective and makes best use of innovation
Proposal 8.2.4a	The new London Plan includes policies to support appropriate and sustainable new sewerage infrastructure.
Proposal 8.2.4b	The Mayor will work in partnership with Thames Water, London Boroughs, and other relevant stakeholders to raise awareness of the problem of misconnected drains and dual manholes from household and business premises.

Policy 8.3.1	Reduce London's water consumption and leakage rate
Proposal 8.3.1a	Holding to account London's water companies on the need to further reduce leakage rates and reduce the likelihood of major water mains bursts
Proposal 8.3.1b	Work with London's water companies to promote water metering, encouraging wise water usage and a reduction in leaks
Proposal 8.3.1c	Support delivery of water saving measures through Energy for Londoners
Proposal 8.3.1d	The London Plan includes policies which require new housing development to be more water efficient

Policy 8.3.2	Support the planning for a new strategic water resource appropriate for London
Proposal 8.3.2a	The Mayor will support plans for new strategic water resources to serve London and will assess whether the preferred options are appropriate for London and Londoners
Policy 8.4.1	Ensure Londoners can prepare, respond to and recover from the impacts of extreme heat and cold events in London
Proposal 8.4.1a	Develop a communications protocol for Londoners in times of extreme heat and cold events
Policy 8.4.2	Ensure critical infrastructure providers of homes, schools, hospitals and care homes are aware of impacts of increased temperatures and the Urban Heat Island to protect health and reduce health inequalities
Proposal 8.4.2a	Provide locally specific data and modelling to demonstrate and evidence the impacts and the effects of the Urban Heat Island
Policy 8.4.3	Minimise the risk of new development overheating
Proposal 8.4.3a	The London Plan includes policies to minimise the risk of new developments overheating, and reduce their impact on the Urban Heat Island
Policy 8.4.4	Minimise the risk of existing homes and non-domestic buildings overheating
Proposal 8.4.4a	The Mayor will work to miminise overheating in existing buildings through Energy for Londoners energy efficiency programmes
Policy 8.4.5	Reduce the impacts of heat on streets
Proposal 8.4.5a	Proposal 8.4.4a The Mayor will work with TfL and the boroughs to provide shaded areas for Londoners to enjoy
Proposal 8.4.5b	The Mayor will work with TfL to put in place initiatives that will minimise heat on the underground and bus networks

Source: London Environment Strategy 2018 mottmac.com