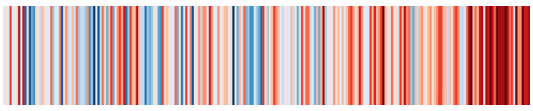
CLIMATE CHANGE RISKS FOR LONDON

A REVIEW OF EVIDENCE UNDER 1.5°C AND DIFFERENT WARMING SCENARIOS

A report on behalf of Caroline Russell AM, City Hall Greens

April 2019

Contents



This report was produced by JCSC on behalf of Caroline Russell AM, City Hall Greens with the help of George Raszka. The climate stripes above represent the increase in the Central England Temperature since the mid 1700's to 2017. JCSC is committed to providing expertise to help organisations adapt to climate change

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Key findings

London as a global city will experience the impact of climate change over the next century. This study aims to review and illustrate the main risks and impacts for London currently and under a 1.5°C scenario. The report found that:

Data is abundant, but disparate

The UK holds an abundance of data on climate risk and projections. However, data is often held in disparate places, by a range of agencies. In addition data is held in different formats with little standardisation.

London understands current risks…

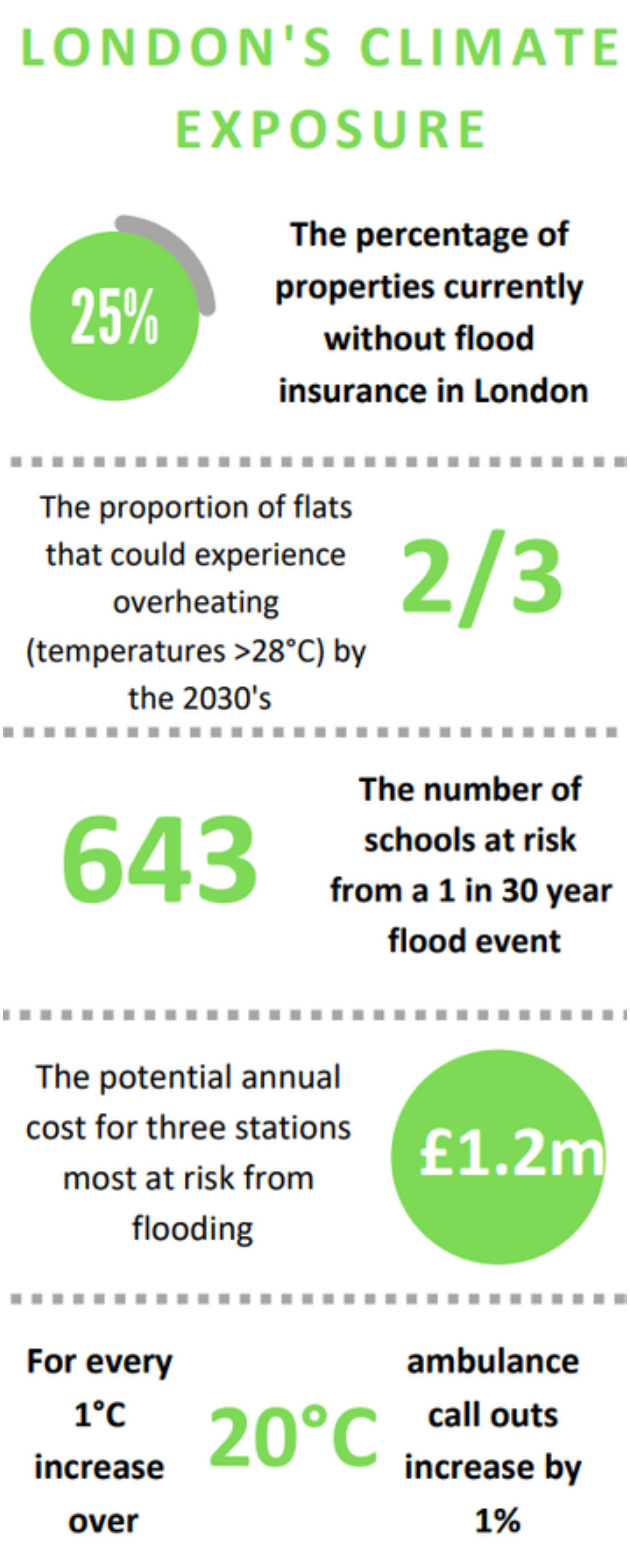
…But more work needs to be completed on the impact of 1.5°C and above impacts. Although UK Climate Projections 18 (UKCP18) is broadly in line with UKCP09, an updated London climate risk assessment is needed.

There are gaps in the data

In some areas, such as housing and health, there is a great deal of research on climate risks and their impacts, particularly around the impact of heat. This approach needs to be repeated, in areas such as schools and commercial organisations as well as on worker productivity and the London economy.

London is well placed to adapt

London has broad sectoral and stakeholder engagement, a track record of delivery and cross party political commitment. This can be complemented with deeper assessment of risk and more comprehensive data in a number of areas.



Introduction

The summer of 2018 was the joint hottest on record for UK alongside 2006, 2003 and 1976.[1] In April of 2018 the warmest April on record was recorded in London at 29.1°C. This was in sharp contrast to the beginning of 2018 when the 'Beast from the East' ushered in the New Year, seeing temperatures drop to as low as -5°C at Heathrow.[2] This year has seen the hottest February on record, when a temperature of 21.2°C was recorded at Kew Gardens in West London.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C, released in October 2018 was timely, clearly stating that there may be as little as 12 years remaining to keep global temperature rise below 1.5°C. Beyond this the Earth would begin to see dangerous climate change - increasing risk and severity of floods, droughts, extreme heat and other extreme weather conditions by the 2030's, putting mitigation efforts on the back foot and reducing the time to implement effective adaptation strategies. This has the potential to significantly impact on economies, human health, biodiversity and infrastructure. This stark headline message confirmed that global warming is accelerating with its effects being seen much sooner than originally anticipated. Despite an increasing awareness and commitments this message was reiterated when it was provisionally confirmed that global CO_2 emissions for 2018 could rise by 2.7% - the largest increase in seven years.[3]

Increasing weather extremes, the commitment to fossil fuels made by the American Government and a significant rise in global emissions in 2018 would indicate that the IPCC's warning is not being heeded - the world can expect to experience a 1.5°C increase in temperatures by the 2030's. While the weather events listed above give some indication of the climate we can expect over the next century, the compression of the timescale significantly raises the stakes for decision makers to act now and not wait until 2050 to realise their climate goals.

Report aims

The aim of this report is to review, summarise and illustrate the key projected climate risks and impacts for London under a 1.5°C scenario and compare that to the current risks and impacts under a 1°C scenario above pre-industrial levels.

Given the stark warnings from the IPCC, there is now a compelling argument that the existing strategy targets need to be revised in order to meet the new threshold year of 2030. In December 2018 The Mayor declared a climate emergency, following the precedent set by Bristol and Manchester City Councils, both committing to become zero carbon by the 2030's.

Method statement and scope

JCSC undertook a parallel review of both current and future risk under the 1°C and 1.5°C scenarios for London's Environmental strategy in relation to climate change. The following methodology for review was employed:

a) Identify exclusion/inclusion criteria – for additional sources to be included and or excluded from research
b) Identify, assess and collate sources – quality assessment of the sources was undertaken (e.g. identifying if peer reviewed, published by recognised sources)
c) Analysis of sources – Sources analysed using a comparative analysis method.
d) Where data is not available a gap analysis has been employed to identify areas where data could be improved.

Time and resource constraints mean that this report is tightly focused on the following risks:

- Flooding: sea level rise and incidence of tidal flooding; surface water and river flooding
- Heatwaves: incidence of heatwaves and overheating days
- Drought: incidence of dry winters
- Other: storminess and extreme events

Where possible the report has identified and quantified the impact on key sectors. These sectors have been identified and broken down in relation to those identified within the Mayor's Environment Strategy and the classifications used in various Committee on Climate Change reports. These are:

- Housing
- Workplaces including schools
- Critical infrastructure (water, waste and power)
- Transport and transport infrastructure
- Emergency services (fire, police, health)

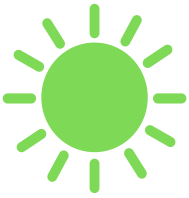
Economic impacts are out of scope, however, where possible this report will identify economic impacts within the context of a changing climate and extreme weather and provide some commentary.

UK projections and London specific impacts

At the time of writing the UKCP18 climate projections, produced by the Met Office had been available for several months. UKCP18 was an update of the previous UKCP09 projections. The updated projections integrate new observations of weather and climate as well as more recent inputs from climate models. In addition, the baseline period for UKCP18 is 1991-2000 as opposed to 1961-1990. This gives a baseline based on more recent climate. Most of the literature reviewed and analysed in this study uses UKCP09. This is because at the time of writing, sector and regional specific analysis of climate impacts had not been undertaken and was therefore unavailable for analysis. This has made analysis difficult, however, the Met Office has stated that UKCP18 is broadly in line with UKCP09.

A note on terms

This report analyses key sectors in the context of risks and impacts under four areas.



A heatwave refers to a prolonged period of hot weather, which may be accompanied by high humidity. This report also refers to overheating and overheating risk. Sustained external temperatures over 25°C may be considered as a heatwave, however, even at 21°C internal temperatures can exceed levels of comfort.

Drought is a situation which occurs within a defined geographical area when a prolonged period of below average rainfall leads to low groundwater, soil moisture levels and reduced river flow. A severe drought would typically occur after 24-36 months of below average rainfall.

Flooding in this report is referred to in terms of its risk in terms of the chance of it happening within a given year.

- High risk - there is a chance of flooding of greater than 1 in 30 (3.3%)
- Medium risk - there is a chance of flooding of between 1 in 100 (1%) and 1 in 30 (3.3%).
- Low risk - there is a chance of flooding of between 1 in 1000 (0.1%) and 1 in 100 (1%)

Cold weather in this report refers to mean temperatures of 2°C and/or widespread ice and heavy snow. The report may also refer to 'extreme cold'.

London and flooding

The 1928 and 1953 floods led to the creation of the Thames Flood Barrier. The barrier will need to be replaced in the next 60 years. But London's biggest flood risk is more likely to be in the form of surface water flooding.

1928

- **The Thames Flood**
- **Both storm surge and fluvial flooding**
- **14 fatalities**

1953

- **The North Sea Flood**
- **Both storm surge and fluvial flooding**
- **200 people left homeless**
- **Custom House, Silvertown and North Woolworth significantly affected**

2020?

- **Surface water now seen as the most critical flood risk to London**
- **c.164,000 properties are at risk from a 1:100 year surface water flood**
- **This compares to c.37,000 homes at risk from river or fluvial flooding**

Climate change risks and impacts for London

This report outlines the direct risks and indirect impacts within a 1.5°C warming scenario in comparison to a 1°C scenario. In analysis undertaken by Climate Tracker, the Paris Agreement, national policies and existing actions will still lead to an increase in global temperatures of between 3.1-3.5°C by 2100.

This would far exceed the Paris Agreement's aim of keeping global temperature rise well below 2°C. In order to meet the 1.5°C target at all, let alone by the 2030's, dramatic policies need to be put into place.

The Met Office has this year updated the UK's climate projections. UKCP09 modelling was used to develop many of the assumptions for the London Environment Strategy and for most of the evidence reviewed in this report.

Observed trends and future climate

The climate of the UK is changing. Overall the UK can expect to see the following climate change risks over the coming decades:

- Hotter, drier summers
- Changing rainfall patterns with more intense rainfall episodes and longer periods without rainfall
- Milder winters
- More frequent extremes in weather that are either prolonged or severe
- Sea level rise with potential for increased storm surges

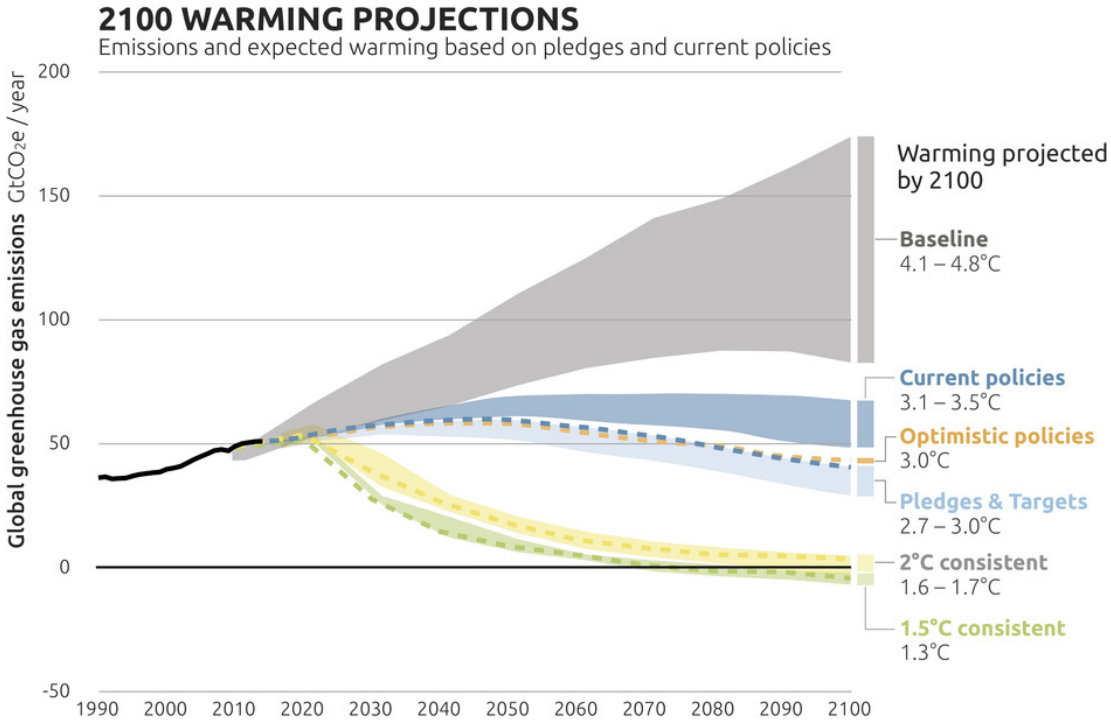


Figure 1 – The Climate Action Tracker's analysis of policy impact on warming projections. Current global climate policies will still lead to a 3.1-3.5°C increase in temperatures towards the end of the century[4]

Recent observed climate

Heat

- London has seen mean summer temperature increase by c.1.9°C between 1961 and the early 21st Century.
- The Central England Temperature dataset, shows that 2008-17 was around 1°C warmer than the pre-industrial period (1850-1900).
- The average hottest day of the year between 2008-17 was on average 0.8 °C warmer than the 1961-1990 average hottest day of 26°C.
- The London Urban Heat Island Effect is generally found to be greater than those of other UK cities. There has been no increase in UHI intensity with the observed increase in mean temperature over the past 30 years.[5]

Rainfall

- Summers in the UK between 2008-17 have been on average 17% wetter than 1981-2010 and 20% wetter than the 1961-1990 average.
- Total annual precipitation in London was observed to have fallen by 3.7% over the same period.
- Total rainfall from extremely wet days has increased by around 17% over 2008-2017), for the UK overall.

Sea level rise

- Mean sea level around the UK has risen by 16 cm since the start of the 20th century

Future Climate (UKCP09 1961-1990 unless stated)

Heat

- The heatwaves experienced in 2003 and 2018 will be normal summers by the 2040s.
- A summer such as that experienced in 2018 is estimated to be 30 times more likely to happen under current emissions.
- 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.
- The mean daily maximum temperature by the 2050's in London is expected to be 3.7°C under a medium emissions scenario under a 50% probability level.
- Relative humidity decreases by around –9% (–20 to 0%) in summer in parts of southern England.

Rainfall

- By the 2050's it is expected that under a 50% probability level and medium emissions scenario winter mean precipitation will increase by 15%. The equivalent figure for summer is projected to be -18% by the 2050s.

Sea level rise

- Sea level in London could rise by up to 1.15 metres by 2100 under a high emissions scenario.[6]

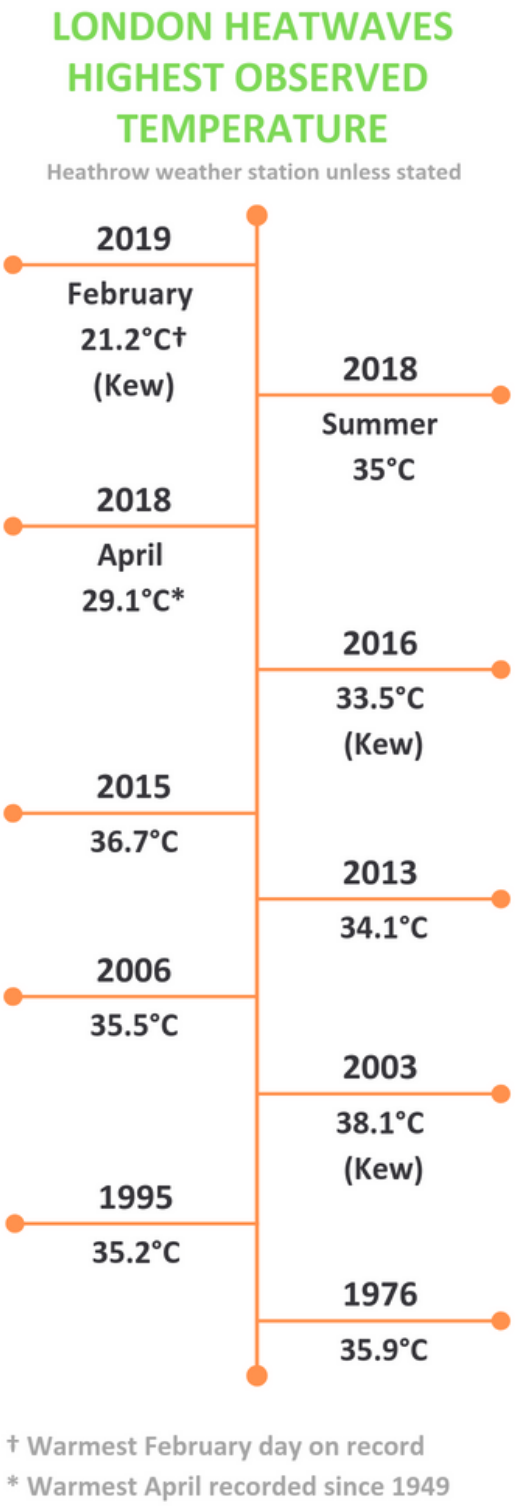
Current and future risks and impacts

In this section, the report will outline the current and future impacts from flooding, heatwaves, droughts, cold weather and where possible other extremes such as snow and storms. This is analysed in the context of five key sectors: housing, emergency services, workplaces and other buildings, transport and utilities. The current risks and impacts have been compiled using the London Environment Strategy, The London Risk Register, the Strategic Flood Risk Appraisal and other sources which contain London specific data and/or observed impacts. The size and scope of this report cannot capture all of the impacts observed in London, and under each sector, gaps in research and analysis have been identified.

At the time of writing, new climate projections (UKCP18) had been available for around six months. There has not been sufficient time for public and private actors to undertake sector or business specific analysis. In many cases the report has utilised data from sources including academic and non-academic research or reports.

Where possible the data is London specific, however, during the course of the research it became apparent that there is a need for London specific investigation and data. Where data is not London specific, but still relevant, this is clearly stated.

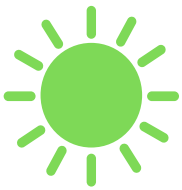
This section of the report focused on the current and potential impacts at different scenarios. Some modelling is not available at 1.5°C. For the purposes of this study medium to high emissions scenarios are used at 2°C or 4°C temperature increases.



Headline impacts by sector: Housing

Current risks and impacts

Currently there are 68,499 homes at risk from a 1 in 30 year surface water flood event with 164,546 homes at risk from 1 in 100 year flood.[7]



80% of Londoners experienced overheating in their homes in 2015.[8]

In 2009 there were about 30,000 domestic subsidence claims, with a total value of £175m.[9]

1.5°C and additional scenarios

There is a 40% increase in the number of properties exposed to flood risk greater than 1 in 75 years under all scenarios by the 2080s.[10]

By the 2050s, a maximum daily temperature of 26°C or above is projected to occur on approximately 50 days a year in London compared to 18 days on average at present.[11]

Gaps

More sector specific flooding studies are required. There is a need for more empirical and behavioural studies of London's residential behaviour during a drought and more quantification of future drought risk in general.

Impacts by sector: Housing in detail

Current risks and impacts

Flooding: all sources

37,359 existing homes are at high or medium risk of tidal or river flooding in London, and 1.25 million people are living and working in areas of tidal and fluvial flood risk.[12]

Almost 60% of the 750,000 people living within the Thames tidal floodplain are in the most deprived wards (figures from 2005).[13]

25% of homes in London are without contents or buildings insurance.[14]

Up to 250,000 homes and businesses are at risk of loss of gas, electricity and telecoms for up to 14 days as well as disruption to water supplies.[15]

Total damage to property is around £1.6 billion affecting a total 108,000 properties where flooding occurs from multiple sources.[16]

157,000 properties are at risk in a greater than 1 in 75 year surface water flood event for Kent, Hertfordshire and London with Estimated Annual Damages totalling £52 million.[17]

1400 properties flooded in London due to surface water flooding in July 2007.[18]

50 properties affected in February 2014 because of high groundwater levels in particular in Croydon and Bromley.[19]

Overheating

15 out of 36 monitored bedrooms in one London study experienced night-time indoor temperatures above 26°C for more than 1% of the time.[20]

Drought

30% of properties in London potentially affected by low water pressure in a drought.[21]

Homes in London built to 105 litres per person per day under the Code for Sustainable Homes actually perform within a range of 110 and 140 litres per person per day depending on occupancy.[22]

1.5°C and additional scenarios

Flooding: all sources

By the 2080s floods greater than a 1 in 75 year occurring for Kent, Hertfordshire and London under a medium emissions scenario would increase estimated damage by £106m annually leaving 360,000 properties at risk with an additional 58,000 in deprived areas.[23]

Overheating

59-76% of flats and 24-29% of detached properties in London are likely to experience overheating by the 2030s.[24]

80-92% of flats and 56-61% of detached homes would exceed overheating thresholds in a heatwave event by the 2050s.[25]

Energy demand for domestic cooling could triple between by 2050 in London, even if uptake of air conditioning systems is low (i.e. 1% by 2050). If 50% of households install air conditioning systems by 2050, energy demand for cooling in London could be 37 times greater in 2050 than today. If the occurrence of heatwaves is taken into account energy demand for cooling could be 100% higher than today.[26]

Headline impacts by sector: Transport

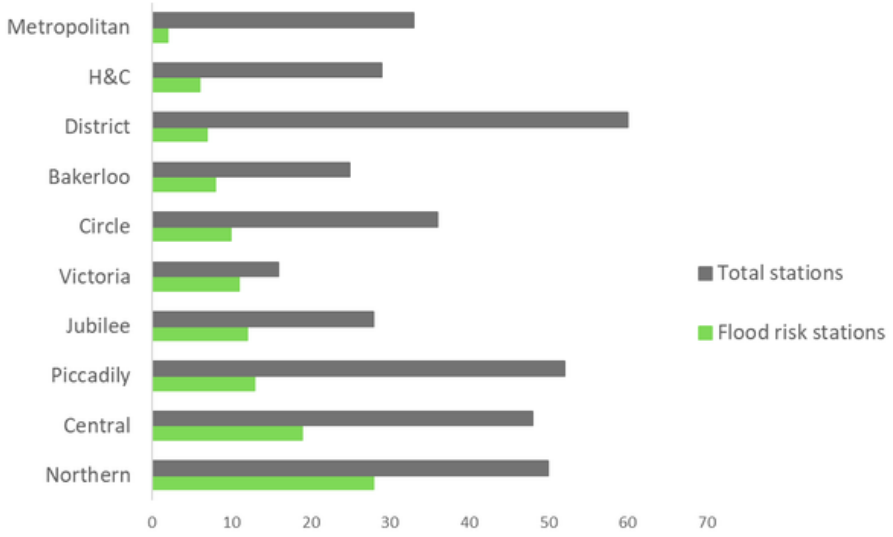
Current risks and impacts

With regards to the very disruptive one-off events, many of the extensive delays that originate from a single heat-related incident are located within Greater London.[27]

85 Overland rail stations (nearly a quarter) are at risk from a 1 in 30 year flood event. For a 1 in 100 year event, that number increases to 106.[28]

1.5°C and additional scenarios

Number of stations at risk of flooding and total number of stations on each line



Reproduced from the The Guardian. Source: LUCRFR

23 stations on the London Underground Network are at significant risk of flooding, with 57 at high risk. This represents nearly a third of all underground stations. The Northern and Central lines have the most stations at risk.[29]

Gaps

As heatwaves become more frequent there is a growing understanding of its direct impacts on transport networks. More investigation of employers' attitudes to heatwaves as extreme events would be useful. Are the expectations of employers on their employees the same in a heatwave as in snow or storm events? More analysis is needed of financial impacts of overheating on transport infrastructure in terms of productivity and cost to the London economy. Whilst research exists on the impact of high indoor temperatures on productivity, little has been researched in terms of excess heat and commuting.

Impact by sector: Transport in detail

Current risks and impacts

Flooding: all sources

London underground stations – 12 out of 24 central London stations would be at risk from a 1 in 30 year flood event. This doubles to 24 stations (7%) for a 1 in 100 year flood.[30]

125km (11%) of TfL owned roads are at risk from a 1 in 30 year flood increasing to 163km for a 1 in 100 year flood event.[31]

1.25 million people live in areas of fluvial and tidal flood risk.[32]

On the 20 July 2018 a one off rainfall event saw parts of south London experience, roads submerged under 2ft of water.[33]

Overheating

Rail buckling - The temperature of the steel rails in direct sunlight can be more than 20°C above ambient air temperature.[34] **This means that, during hot weather the rails can expand and the build-up of forces can cause the track to distort or buckle. Disruption to the railway network in London and the South East can occur when maximum temperature exceeds 27°C.**[35]

Tube train drivers on the London Underground, endured temperatures of up to 41.5°C during the summer 2003 heatwave.[36]

Deep tube lines such as the Central and Bakerloo lines can be 10°C hotter than surface temperatures, with in-car conditions of around 30°C in summer.[37]

Extreme Cold

Heavy snowfall particularly impacts on the overland rail network in the south of London. This is because of the 'third rail' network, whereby electric current used to power trains runs along a third rail that runs alongside the other rails. However, when this is covered by snow, electric current is disrupted thereby delaying trains.

All British Airways flights were cancelled on 18 December 2010 due to extremely heavy snowfall.[38]

1.5°C and additional scenarios

Flooding: all sources

There is some discrepancy between figures held in the London Risk Register, the Strategic Flood Risk Assessment and the London Underground Comprehensive Review of Flood Risk (LUCRFR). The LUCRFR identified which underground stations were at high and significant risk, as well as the potential cost.

The potential annual cost for London Bridge, King's Cross and Waterloo alone from flooding resulting in lost revenues and repairs totals £1.2m.[39]

According to the Met Office, the number of non-work days for maintenance (May-Sept) where track maintenance cannot be carried out due to adverse weather conditions will increase, from 30-40% in the London region in 1970-2000 to 50-60% in 2030-2089.[40]

Overheating

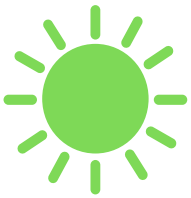
The annual cost of buckling and heat-related delays under a high climate change scenario could increase eight times by the 2080s.[41]

Under high climate change scenarios, all deep London Underground lines could experience near complete passenger discomfort, and while cooling on trains provides substantial benefits it may not be enough.[42]

Headline impacts by sector: Emergency services

Current risks and impacts

82 hospitals (42%) are at risk from a 1 in 30 year flood event with 92 (48%) at risk from a 1 in 100 year event.[43]



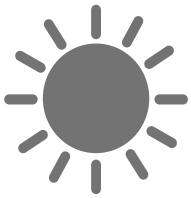
During a heatwave where daytime and night time temperatures exceed 32°C and 15°C respectively for 5 consecutive days. Up to 1,000 fatalities and 5,000 casualties would be expected, mainly amongst older people.[44]

1.5°C and additional scenarios

In the most vulnerable districts in London, the odds of dying from cardiorespiratory causes increased by more than 10% for every 1°C increase in temperature, compared with virtually no effect in the most resilient districts. In areas such as Hackney and Tower Hamlets, the likelihood of dying would more than double on hot days such as those seen in August 2003.[45]

Gaps

More research needs to be undertaken to understand increasing frequency and shorter return periods for flood and heatwave events.



Much more analysis is needed of the financial and resource impacts on all emergency services, which is not generally clear from the literature available. Understanding the secondary financial and resource impacts of increased ambulance call outs or hospital admissions for example, would make climate planning more meaningful for non-climate specialists and foster action in climate resilience planning.

Further understanding of the interrelationship of several factors is needed rather than a simple correlation between excess winter deaths and climate change being used.

Impacts by sector: Emergency services in detail

Current risks and impacts

Flooding: all sources[46]

12 ambulance stations (19%) are at risk from a 1 in 30 year event, increasing to 13 for a 1 in 100 year event.

28 fire stations (25%) are at risk from a 1 in 30 year flood event with 32 at risk from a 1 in 100 year flood event.

58 police stations (25%) at risk from a 1 in 30 year flood, rising to 68 for a 1 in 100 year event (29%).

3 prisons are at risk from a 1 in 30 year event and 7 from a 1 in 100 year event.

Overheating

At the national level, there is a 2.1% increase in mortality for every 1°C rise in temperature above the heat threshold.[47]

During sustained warm periods in London, for every 1°C above a mean temperature of 20°C, the total number of ambulance incidents increases by 1% on average. Incidents increase when the air temperature rises above 20°C or falls below 2°C.[48]

Violent crime was on average 14% higher when the temperature was above 20°C than when it was below 10°C, between 2010-2018.[49]

522 (59%) more people over the age of 75 died during the 2003 heatwave in London. Over the same period hospital admissions increased by 16% for the same age group.[50]

Extreme Cold

December 2010 was the coldest December for 100 years. The daily number of Category 1 (immediate life threatened) incidents for the London Ambulance Service was nearly 20% higher than November 2010.[51]

1.5°C and additional scenarios

Flooding: all sources

Sea level rise by the end of the century (when compared to 1981-2000), if carbon emissions are kept low is very likely to be in the range 0.29m to 0.70m. If emissions remain at current levels, the range is very likely to be 0.53m to 1.15m.[52]

Overheating

Heat-related deaths would be expected to rise by around 257% by the 2050s nationally. When the heat-wave effect is taken into account for London it represented a substantial additional burden of 58%, 64%, 70% and 78% on heat-related mortality in London during the 2000s, 2020s, 2050s and 2080s, respectively.[53]

By the 2050s under a high emissions scenario there could be an additional 842 heat related deaths in Greater London.[54]

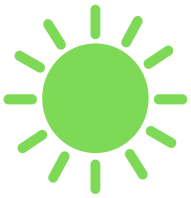
Extreme Cold

Higher temperatures from climate change will reduce the risk of cold-related deaths, but the ageing and growing population will result in only a small reduction in cold-related mortality by the 2050s.[55]

However, there is a mixed picture. The review found that climate change will not necessarily lead to decreased excess winter mortality; or that excess winter deaths was the correct indicator due to the fact that extremes in cold temperatures do not need to be reached before there is an increased incidence of mortality.[56]

Headline impacts by sector: Utilities

Current risks and impacts



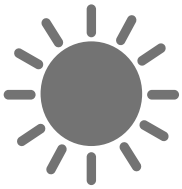
261 (44%) water pumping and power stations are at risk in a 1 in 30 year flood event, increasing to 286 assets (49%) for a 1 in 100 year flood.[57]

1.5°C and additional scenarios

An increase of between 5% - 40% in water supply is needed by 2040 in order to meet the water deficit in London and the South East.[58]

Thames Water estimate that by the end of the 2030's household demand for water will increase by 19% compared to a 2011 baseline.[59]

Gaps



The utilities sector in the UK and has been mapping supply and demand profiles in relation to climate change for some time. It also faces challenges in terms of changing demand profiles from electric based heating to electric vehicles. Mapping of some of the practical impacts of sustained de-rating on homes and businesses would be beneficial.

Several historic flood events nationally have demonstrated the potential low resilience of the assets within the sector. Suggested areas for further investigation:

- Potential costs to utilities in terms of compensation and return to normal service provision.
- Understanding the risks to physical infrastructure and the local/London impact of infrastructure failure is key.

Impacts by sector: Utilities in detail

Current risks and impacts

Flooding: all sources

250,000 homes and businesses would be affected by a loss of essential services (gas, electricity & telecoms) for up to 14 days.[60]

164 waste treatment plants (34%) at risk from a 1 in 30 year flood. 180 would be at risk from a 1 in 100 year flood.[61]

Overheating

During periods of hot weather (over 25°C) demand for water rises by about 20 mega litres per day per °C. Between May – Aug 2018 had more days above 25 °C than any year in Thames Water's historic record.[62]

Droughts

Rationing water availability for public use has been assessed to be in the range of £236m - £329m per day, for London in economic terms.[63]

For every degree above 20°C electricity demand rises by 350 Megawatts (MW). During June/July 2018, the wholesale price was 40% higher than the previous year.[64]

Extreme Cold

During colder weather the amount of gas used in the UK goes up – largely due to the rise in heating – which raises its price and this has a knock effect on electricity. For every 1p increase in the cost of gas, the cost of generating 1 MWh by a CCGT (combined cycle gas turbine) power station increases by around 70p. As CCGTs generate a large percentage of Britain's electricity, the overall price of electricity also goes up.[65]

1.5°C and additional scenarios

Flooding: all sources

The Drain London Project[66] is ongoing with expenditure approved for subsequent phases.

Overheating

De-rating, the process of reducing the amount of current pushed through the grid would lead to reduction in capacity of by 6-10% by 2070-99 on hottest days.

Under a high emissions scenario with an increased mean summer temp of 8°C transmission capacity falls by:

- Overhead lines – 3%
- Underground cables – 5%
- Transformers – 5%[67]

Droughts

The Thames River Basin region, which provides the current water supply to London of around 2,000 megalitres per day (Ml/d) is estimated to face the largest deficits of 478 Ml/d (0 to 1,040 Ml/d) in the 2020s.[68]

The costs for improving resilience in the Thames-London system are typically expected to be in the order of £4/customer/annum for a move to 'severe' resilience and £8/customer/annum for a move to 'extreme' resilience.[69]

The impact for business supplied by Thames Water under severe restrictions on water use (level 4) water restriction in a medium to high scenario is estimated to be £452-£773 per day in terms of gross added value (GVA).[70]

Headline impacts by sector: Workplaces and other buildings

Current risks and impacts

643 (22%) schools are at risk from a 1 in 30 year flood.
781 (27%) schools are at risk from a 1 in 100 year flood.[71]
158 schools were flooded in July 2007 due to heavy rainfall events leading to surface water flooding.[72]

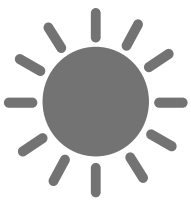
Gaps

During the course of the research the sector that had the least amount of evidence in terms of modelled impacts was that of workplaces and other buildings. Unlike housing there is less evidence on the number of workplaces that could potentially be affected in future. Beyond the current risks, evidence was much less specific and tended to focus on 'assets'.

Increased post occupancy evaluation is needed to give more insight into how new build schools cope under certain weather conditions.

Considerably more research is needed on the impact of heatwaves on productivity, given London's position within the global economy. This is supported by the 2017 Climate Change Risk Assessment. For schools similar research metrics are suggested for pupil attainment.

Surveying of London businesses and drought preparedness suggested.



The number of schools at risk of flooding within certain return periods is known, however, the impact climate change has on direct and indirect impacts needs more research. The following areas are suggested for further research and investigation:

- Potential secondary impacts of flood events at different return periods on teaching days and pupil attainment.
- Teaching days lost to extreme heat.
- Impact of extreme heat on pupil attainment.

Impacts by sector: Workplaces in detail

Current risks and impacts

Flooding: all sources

12,148 commercial buildings are at risk from a 1 in 30 year flood event with 25,623 at risk from a 1 in 100 year flood event.[73]

C. 200,000 people in the flooded area during the day due to the high working population: 184,000 weekday workers are located in 10,000 businesses modelled to flood in the London region.[74]

Overheating

The heating and cooling load of a typical air-conditioned office located within the London urban heat island, may be up to 22% lower and 25% higher, respectively, compared with a rural location.[75]

In 2010, approximately five million staff days were lost due to overheating above 26°C (UK wide).[76]

Droughts

Under severe drought conditions 385,000 businesses could be affected for up to 12 months.[77]

1.5°C and additional scenarios

Flooding: all sources

Climate impacts put assets worth £200 billion at risk in London alone due to the combined risk of tidal, fluvial and surface water flooding.[78]

Overheating

A working paper published by LSE estimated that in a warm year, such as those experienced in 2014 and 2018, the total losses to the urban economy could be around €1.9 billion for London.[79]

Losses vary greatly across sectors. For example, the manufacturing sector in London would account for 6% of total losses. Losses in the financial sector would amount to 24% of total losses in London.[80]

Analysis and findings

In order to complete a comparison, considerable work must be done to understand London's exposure to global temperatures reaching 1.5°C by the 2030's. Both Bristol and Manchester have already set a precedent by moving their climate targets to the 2030's. While much policy focus is on reducing emissions, additional benefits of adaptation, particularly in the case of Manchester, have been identified. There has since been the release of new climate projections in the form of UKCP18 and an ever growing understanding of the future trajectory of actual emissions. However, comparison in order to move targets forward remains difficult.

Data is abundant, but disparate

There is a wealth of data on previous events and projected future impacts held by a wide range of stakeholders, spanning a long time period. However, beyond UKCP climate projections (2002, 2009, 2018), data, modelling, sector or business analysis is held by a dizzying number of stakeholders, from academic institutions to sector organisations. This presents serious issues for policy and decision makers tasked with developing effective approaches. This is a significant barrier and sector level analysis of climate impacts (observed and projected) remains disparate.

London specific data needs updating

Data specific to London in all of the areas analysed exists in relation to current climate. However, in terms of climate at 1.5°C the amount and quality of that information greatly reduces. This is partly due to the relatively recent publication of the 2017 Climate Change Risk Assessment and the relatively recent release of new Met Office climate projections. While the latter is seen as being broadly in line with its predecessor, there are some gaps. In all areas, from housing to transport, there were gaps in London specific data, especially in terms of quantified secondary risks and impacts.

Analysis has only scratched the surface

It is clear that in some cases analysis of the impacts of climate change have been taken down to their secondary level beyond the direct impacts. The study outlines where these gaps appear to be, but much deeper understanding of indirect impacts is needed. For example, a heatwave similar to 2018 may impact on staff stress levels during their commute, leading to a drop in productivity, leading to estimated losses for the business of £X.

Shorter return periods pose a threat

An impact of the changing climate is the potential for shortening return periods for extreme weather events or those events that put pressure on infrastructure and resources. The heatwave of 2018 saw 40 consecutive days when the daily maximum temperature exceeded 20°C and the 14 consecutive days when it exceeded 25°C. As this study identifies, the impacts of heat are felt at lower thresholds than outlined in the London Risk Register.

Baselines are not synced

The Mayor's London Environment Strategy has used UKCP09 projections to provide the basis of its evidence base. UKCP09 projections use a baseline period of 1961-1990, but UKCP18 uses the period 1981-2000, due to higher resolution outputs and computational demands. However during the course of study a number of baselines were identified dependent on the holder of data.

London is well placed to take action….

But there is a distinct lack of action amongst individual stakeholders. Whilst some organisations in the public, private and third sectors are taking substantial actions on carbon emissions, the same cannot be said for climate adaptation. It was clear during the course of the study that the GLA has set a definitive framework for adapting to climate change. However, more granular analysis is required by all actors and in many cases it is apparent is that adaptation initiatives do not enjoy the same profile or financial weight that mitigation does.

London's GDP risk from climate change

A recent report by Lloyds of London, highlighted the major risks London faces from climate change. Lloyd's City Risk Index: Europe, measures the GDP at risk – i.e. how much economic output (GDP) a city would lose annually as a consequence of a climate event – and compares cities by region to establish which ones are most exposed.

Flood	Windstorm	Extreme Cold	Drought	Heatwave
London	London	London	London	Paris
£1.2bn	£143m	£70m	£362m	£69m
Paris	Paris	Paris	Madrid	London
£885m	£75m	£55m	£94m	£35m
Munich	N/A	Stockholm	Barcelona	Vienna
£285m		£33m	£58m	£13m

The table demonstrates London's relative exposure compared to other Western European cities. London is especially exposed in terms of flooding and drought risk when compared to other cities.[81]

Recommendations

Recommendation 1

The GLA should prioritise and commission further research and analysis of future climate risk, with a focus on quantification based on the UKCP18 projections.

The gap analysis identified the suggested areas for further investigation and research. There should be a clear focus on the sectors identified in this report (housing, transport, emergency services, utilities and workplaces), alongside social infrastructure such as schools. From the literature review, heatwave impact on schools was widely reported within the media, but rarely supported with quantifiable evidence.[82]

Recommendation 2

Additional research is needed in specific areas.

The IPCC special report clearly stated that there are less than 12 years left to avert dangerous climate change. The short timescale requires a focus on specific areas:

- Implications of 1.5°C global temperature increase by early 2030s.
- Assessing and updating the climate adaptation measures in the Mayor's London Environment Strategy to reflect the risks identified in a 1.5°C warming scenario.
- Assessment of Impact on carbon budgets of moving climate targets to early 2030s.
- Potential costs of moving targets to 2030s with reduced carbon budgets.

Recommendation 3

The role of the London Climate Change Partnership (LCCP) must be enhanced and its role in commissioning and advising the GLA must be strengthened.

Adapting to climate change is often seen as a secondary choice to mitigation. However, both should be done in parallel. Given the current global emissions trajectory and the momentum from previous emissions, London should expect to experience all of the impacts from climate change outlined in this report. Efforts to adapt must be stepped up. The LCCP must therefore be adequately resourced with a focus on the task of making London resilient to all climate risks through research and advice with the task of implementation down to the GLA. It is ideally placed to bridge the relationship between key sectors identified in this report, academia and decision makers.

Recommendation 4

It is recommended that a centralised climate data repository is created by the GLA to improve data access and ease of analysis, avoiding duplication or discrepancies.

The wide range of data held on current and future impacts makes analysis and policy development difficult. The Mayor's London Datastore would be an ideal repository for the diversity and range of data.

Recommendation 5

Rather than mapping climate impacts on their own, these should be analysed within the context of existing and new low carbon policies.

For example, an expansion of heat pumps with cooling capability may help with comfort in summer but put additional pressure on the grid during critical periods.

Glossary

Adaptation
Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Central England Temperature
Representative temperature of a roughly triangular area of the United Kingdom enclosed by Bristol, Lancashire and London.

CO_2
Carbon dioxide, a gas in Earth's atmosphere. It occurs naturally and is also a by-product of human activity such as burning fossil fuels and land-use change. It is the principal anthropogenic greenhouse gas.

Climate
Climate is typically defined as the average weather (or more rigorously a statistical description of the average in terms of the mean and variability) over a period of time, usually 30 years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change
A change in the climate's mean and variability for an extended period of decades, or more.

Drought
Drought is a situation which occurs within a defined geographical area when a prolonged period of below average rainfall leads to low groundwater and soil moisture levels, and reduced river flow. A severe drought would typically occur after 24-36 months of below average rainfall.

Emissions scenarios
A synthetic description of an event or series of actions and events.

Extreme weather events
Extreme weather describes weather phenomena that are at the extremes of the historical distribution, especially severe or unseasonal weather.

Fluvial flooding
Flooding from the overflowing of main rivers.

Global warming
A rise in the Earth's temperature, often used with respect to the observed increase since the early 20th century.

Glossary

Greenhouse gases
Gases in the atmosphere, which absorb thermal infra-red radiation emitted by the Earth's surface, the atmosphere and clouds e.g. water vapour, carbon dioxide, methane and nitrous oxide.

Groundwater flooding
Groundwater flooding happens when the earth is saturated and can hold no more water.

Heatwave
A heatwave refers to a prolonged period of hot weather, which may be accompanied by high humidity.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) is an international forum of experts brought together by the United Nations to undertake periodical assessments addressing how climate will change, what its impacts may be and how we can respond.

Mitigation
Reducing greenhouse gas emissions in order to slow or stop global climate change.

Pluvial flooding
This flooding occurs when surface water accumulating from the result of intense rainfall saturates the urban drainage system, and the excess water cannot be absorbed.

Projections
The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases, based on simulations by climate models.

Resilience
The ability of a social or natural system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organisation and the capacity to adapt to stress and change.

Return period
The average time between events of a given magnitude. A 100-year return period is the equivalent of the event that has a 1 per cent probability of occurring in any given year.

Surface water flooding
Surface water flooding occurs when intense rainfall overwhelms drainage systems.

Glossary

Vulnerability
Vulnerability is a function of exposure to risk, sensitivity to that risk, and the capacity to adapt to the risk for future situations.

Weather
Weather refers to the state of the atmosphere with regard to temperature, cloudiness, rainfall, wind, and other meteorological conditions.

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Picture references

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