

# **IMPACTS OF CLIMATE CHANGE ON LONDON'S TRANSPORT SYSTEMS**

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## **ABSTRACT**

There is much discussion about the contribution of transport to global warming, but what about the impact of our changing climate on transport mode, infrastructure and passengers? This paper examines the potential impacts of climate change on London's transport systems, based on the findings of a research study undertaken for the London Climate Change Partnership between 2004 and 2005.

The current climate already presents significant problems. Recent extreme weather events have had significant impact on London's transport systems; for example, the effect of high temperatures on the Underground and major flooding of roads and railway stations.

Scenarios of climate change show that London will experience hotter summers, wetter winters, more intense rainfall and a rise in sea level over the coming century. This poses a number of risks to the operation and use of transport systems in a city where 26 million trips are made everyday.

The study focuses on four case studies

1. Flooding affecting new infrastructure in the Thames Gateway;
2. Flooding of road and rail infrastructure;
3. Hot weather damage to road and railway infrastructure; and,
4. Passenger comfort on the Underground in a warmer climate.

Each case study assesses:

- The issue now, drawing on current weather-related effects.
- How climate change will affect the future, including the changing likelihood of extreme events and the implications for management;
- The action already underway in London to address climate impacts; and
- Options and timescales for adaptation, including research, monitoring and changes in design.

It is apparent that most risks already exist – climate change will simply make them worse. However, with forward planning, successful and cost-effective adaptation can be achieved.

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## **1. INTRODUCTION**

London's position as a dynamic world city clearly depends significantly upon its transport system with 26 million trips made each day for work, education or leisure. Extreme weather in recent years has brought challenges to keeping London moving – flooding, heat waves and storms have all brought about delays and increased costs that have affected London's economy and the well being of Londoners. Predicted climate change will increase the frequency and intensity of extreme weather on top of a general trend towards hotter, drier summers and warmer, wetter winters.

In its strategic assessment of the impacts of climate change, the London Climate Change Partnership (LCCP) (2002) concluded that the city's transport systems are particularly vulnerable to climate change. As a result, the LCCP commissioned Atkins to undertake a more detailed evaluation of the potential risks of climate change to London's transport systems, the consequent impacts and costs (e.g. of disruption) and how the management of the risks identified should be incorporated into transport management strategies.

One of the primary objectives of this work was to provide an initial step towards ensuring that London has a transport network that is fit for the 21st century, supporting its world city function in the face of a changing climate through raising awareness of the impacts of climate change and enabling partners to realise their responsibilities in adapting to those changes.

This paper describes some of the challenges faced by London's transport systems that will be exacerbated by climate change, what is already being done to address them, and what still remains to do. Actions which could reduce or eliminate the adverse effects of climate change are described. In particular, actions undertaken at the design stage can require little or no extra cost while ensuring that transport infrastructure remains useable throughout its design life. Given that significant elements of transport infrastructure have asset lives of 50-100 years (for example, tunnels, bridges and earthworks), the risks of climate change impacts can be significant.

## **2. CLIMATE CHANGE AND TRANSPORT**

### **2.1 Climate change scenarios**

Climate change is now firmly established as an issue of concern for us all. Scenarios of climate change (Hulme, M., Jenkins, G.J., et al., 2002) show that London can expect:

- Warmer, wetter winters
- More intense downpours of rain
- Hotter, drier summers, with more frequent and extreme high temperatures
- Sea level to rise further, with an increased risk of tidal surges

The main characteristics of a changing climate for London are described in Text Box 1.

## **Text Box 1. The Main Characteristics of a Changing Climate<sup>A</sup>.**

### **Temperature**

Observations of temperature show:

- A rise in global average air temperature of 0.6°C over the twentieth century (LCCP, 2002)
- The warmest 10 years on record include 1990, 1991, 2002, 1997, 1995 and 2003 (Palutikof, 2004)

By the 2050s, London is expected to experience:

- Increase in winter ambient air temperatures of 1.0 to 2.0 °C
- Increase in summer ambient air temperatures of 2.0 to 3.5 °C

Analysis of daily climate change data<sup>B</sup> for Heathrow in west London suggests that the number of days with a maximum temperature of at least 25°C is likely to double by the 2020s and increase by 3 to 5 times by the 2050s. Days with temperatures exceeding 30°C will also become more common, as will extreme temperatures such as those experienced during the heat wave of August 2003.

### **Heat island**

The centre of London can currently be up to 6°C hotter than the surrounding countryside; the greatest difference tending to occur on summer evenings. Under climate change, it is anticipated that the effects of the urban heat island effect will be exacerbated.

### **Precipitation**

Over the last century, there has been an 11% increase in winter and 10% decrease in summer precipitation (LCCP, 2002).

By the 2050s, London is expected to experience:

- Increase in winter precipitation by up to 20%
- Decrease in summer precipitation by 20 to 40%
- Intense rainfall events (summer and winter) are likely to become more common and more severe

### **Sea level**

- Relative mean sea level rise is expected to rise by between 26 and 86cm by the 2080s
- The 50 year return period storm surge height could increase by between 0.8m and at least 1.4m by the 2080s (including mean sea level rise), although this is highly uncertain

<sup>A</sup>Constructed from data in Hulme, M., Jenkins, G.J., et al., 2002 unless otherwise stated.

<sup>B</sup>Produced using data from the Built EnvironmentT: Weather scenarios for investigation of Impacts and eXTremes project. See <http://www.cru.uea.ac.uk/cru/projects/betwixt/>.

## **2.2 Impacts on transport**

Transport is often viewed simply as a source of greenhouse gas emissions and a wide range of measures have been established to encourage a more sustainable balance of transport in London, including encouraging the use of public transport and restricting the use of cars. Technical measures have included the pioneering trial of hydrogen fuel cell buses.

However, it is also essential to consider the impacts of climate change on transport infrastructure and users and how we can plan ahead to adapt in the context of these impacts. For example, we need to assess the requirement and feasibility of cooling and ventilation in the various modes of transport used by Londoners as hotter summers become more frequent.

## **2.3 This study**

The study has focused on case studies of four potential future impacts on London's transport systems:

- Tidal and river flooding affecting new infrastructure in the Thames Gateway.
- Local flooding of Underground, rail and road infrastructure, including station closures.
- Damage to national rail and road infrastructure from hot weather.
- Passenger comfort on the Underground in hot weather.

## **3. CASE STUDY 1: TIDAL AND RIVER FLOOD RISK AND LONDON THAMES GATEWAY**

### **3.1 The issue now**

The Thames Tidal Defences, which includes the Thames Barrier, 185 miles of floodwalls, 35 major gates and over 400 minor gates, provide some of the highest standards of flood defence in the world and currently protects London and most of the Thames Estuary against storm events that might happen on average only once every 2,000 years.

Whilst the likelihood of a tidal flood is therefore extremely low, were such an event to occur then a significant proportion of the proposed Thames Gateway development (north and south of the River Thames) would be in the floodplain. Key components of the Thames Gateway transport network infrastructure have been designed to be above potential flood levels but rely on current standards of protection being maintained.

### **3.2 The risk of climate change**

Sea levels are rising and the risk of tidal surges is increasing. As a result, the risk of tidal flooding is increasing, and the area at risk is growing. Heavier and more frequent intense downpours will also increase the risk of river flooding.

Developers have assumed that flood defences will continue to provide a high level of protection to infrastructure for the next 100 years. However, due to sea level rise, the level of protection provided by the Thames barrier will drop to its design specification by 2030 and unless further investment takes place, the standard of flood defence will continue to decline thereafter.

The additional annual cost of flood damage arising from the Gateway development has been estimated at €68.8 million (ABI, 2005). An extreme event could incur damages of €23.4-29.3 billion of which €5.9 to £7.3 billion could be in relation to new development in the Gateway.

There is a risk that individual transport components of the Gateway are being developed in isolation from the rest of the transport network and general development. As a result, whilst key elements of transport infrastructure may be resilient to climate change, flooding will remain an issue for the wider Gateway development and at key locations on the transport network e.g. affecting access and egress from stations.

As many of the projects are still at an early stage, design adaptations to address climate risks can still be incorporated and the additional costs are low in comparison to the total costs.

### **3.3 Action already undertaken or underway**

Some aspects of the Thames Gateway developments include climate adaptation e.g. the height of discharge points for runoff from Thames Gateway Bridge and the elevation of DLR extensions compared to flood levels.

A number of studies of flood risk in the Growth Areas are being undertaken; work by The Association of British Insurers has been recently reported (ABI, 2005) and a Strategic Flood Risk Assessment has been undertaken by Thames Gateway London Partnership to evaluate the potential flood risk and can be used to guide the appropriate location and type of development. A Checklist for Development has been prepared by the Three Regions Climate Change Group (Three Regions Climate Change Group, 2005).

### **3.4 Recommendations**

The pace of development of the Thames Gateway dictates a number of actions and priorities:

- Re-evaluation of design and design adaptation in view of impacts identified through the East London Strategic Flood Risk Assessment (SFRA).

- Adoption of the Checklist for Development to ensure climate proofing at design stage.
- Ensuring developments minimise flood risk e.g. by building the most vulnerable infrastructure away from the river edge or above extreme flood levels.
- Incorporating flood proofing in high risk areas e.g. planning for flooding at stations (e.g. use of flood boards) and ensuring critical components (e.g. switch gear, substations) are above flood levels or can be isolated.

## **4. CASE STUDY 2: INFRASTRUCTURE DAMAGE AND STATION CLOSURE CAUSED BY LOCAL FLOODING**

### **4.1 The issue now**

In the period from 1992 to 2003, over 1200 flooding incidents and 200 station closures were recorded by London Underground Limited (LUL); approximately half were related to flash flooding.

Flooding of the London Underground between September 1999 and March 2004 has cost approximately €21.4 million in passenger delays alone, with the flooding of 7 August 2002 costing approximately €1.1 million.

The costs of flooding in the London Borough of Camden on 7 August 2002 were well in excess of €1.5 million (LBC, 2003). Flood related traffic disruption during peak periods are estimated to cost at least €146,000 per hour delay on each main road affected, excluding infrastructure damage costs.

Current flooding problems are mainly associated with intense summer downpours and restricted capacity of storm drainage systems. However, the modification of drainage systems required to maintain current service levels, even for small increases in storm rainfall, are significant and costly (UKWIR, 2004).

### **4.2 How climate change will affect the future**

Under climate change, intense rainfall incidents are expected to be more frequent and more intense, leading to an increasing risk of both summer flash flooding and winter flooding.

This will alter the distribution and increase the risk of flooding and the disruption it causes to surface rail, the Underground and highways, requiring significant modification of drainage systems.

### **4.3 Action already undertaken or underway**

A number of areas subject to recurrent risk have been mapped (Arkell and Darch, 2005). LUL have mitigation measures in place to help manage flood risk at key stations. This includes the use of physical barriers. Further work is currently being scoped by LUL to assess the future risks of flooding from

climate change. In addition Network Rail is undertaking research into the effect of climate change on earthworks, scour and flood risk.

London Underground's Quantified Risk Assessment (QRA) includes modelling of flooding-related hazards. The model allows identification of reasonably practicable engineering and operational means of reducing risks, and these risks have recently been reviewed.

Options being considered by the Thames Tideway Strategic Study (Thames Tideway, 2005), including Sustainable Urban Drainage Systems (SUDS) and source control, may provide some benefits in reducing flood risk. The recent study undertaken by UK Water Industry Research (UKWIR) will need to be fully assessed in the context of this work and broader London drainage network issues.

#### **4.4 Recommendations**

Flooding is an existing problem that is likely to worsen and providing adaptation to climate change in the short to medium term will reduce long-term costs as well as providing more immediate benefits of improved resilience to weather. Recommendations include:

- Action now to fully assess the risks of flooding, understanding of flood sources, pathways and receptors (including Underground and railway stations) and how climate change may affect those risks.
- Identifying those areas (e.g. stations) which have the highest flood risk to provide a focus for adaptation.
- Implementation of measures to reduce flood risk, including source control (e.g. green roofs, pervious pavements), flood storage, construction of higher capacity drains, better drain maintenance, flood warning, construction and operation of barriers to prevent water ingress to stations, and better information on flooding to transport users.
- Ensuring risk assessments and adaptation planning involves all relevant agencies.
- Collation of data on the full costs and impacts incurred as a result of flooding – including infrastructure rehabilitation as well as passenger delays.
- Assessment of the impact on transport caused by potential changes in groundwater levels under climate change.

### **5. CASE STUDY 3: INFRASTRUCTURE DAMAGE IN HOT WEATHER**

#### **5.1 The issue now**

Recent hot weather has caused significant problems for rail infrastructure. Progressive speed restrictions, applied by Network Rail at air temperatures of 36 and 41°C, and at lower temperatures where the rail and track is at anything less than ideal condition, have been imposed.



In 2003 there were 165,000 delay minutes nationally (compared with just 30,000 in the cooler summer of 2004)<sup>3</sup>. The number of buckled rails (approximately 130) was also high and consistent with other hot years (1976 and 1995). The economic cost of the delays in 2003 in four of the railway sectors around London was at least €1.1 million.

No evidence of problems with the road network was found in London in summer 2003; most of the problems recorded occurred in surrounding counties.

## **5.2 How climate change will affect the future**

Temperatures exceeding 30°C will become more common and temperatures as high as 36°C are expected to occur for up to 3 days in the average 2080s summer. The temperatures of summer 2003 are expected to become the norm by the 2040s.

In the absence of adaptation measures (engineering improvements or shading of rails) speed restrictions are likely to become far more common in future as average, and in particular extreme temperatures, rise.

Although London's road network appears resilient, hot weather impacts that are only experienced mildly at present, or not at all, may become more serious. Examples include carriageway rutting, embankment subsidence, deterioration of concrete, problems with expansion joints, an increase in dust levels and reduction in skid resistance.

Indirect impacts on roads are also likely, arising for example through the need to respond to increased repairs as a result of shrinkage and expansion effects of the London clays on underground services such as water mains (as was the case during 2003).

## **5.3 Action already undertaken or underway**

Measures being implemented by Network Rail to improve safety will also increase resilience to higher temperatures, helping to avoid heat wave related problems such as those experienced during 2003.

Network Rail and RSSB<sup>1</sup> are involved in further research in the EPSRC/UKCIP BKCC portfolio<sup>2</sup>, including the BIONICS project, which will investigate the impact of climate change on embankments, and will have practical implications for both rail and road.

Thames Water is currently embarking on a major programme of mains replacement in London to reduce leakage and manage growth in demand. Drier summers linked to climate change increase the urgency of this work. The company believes this work will lead to a reduction in the potential for future bursts and leaks, minimising the disruption caused by street works.

## **5.4 Recommendations**

- Further work is needed to cost the potential future impact of delays on the railways as well as the infrastructure costs (such as repairs and renewals). This is important for evaluating the costs and benefits of adaptation measures.
- Further research is required to quantify the effect of better maintenance and improved standards currently being undertaken by Network Rail, to understand the residual implications of hot weather and to assess what further actions are needed in the face of climate change.
- Review of Network Rail's duty to maintain the network at 1994 'asset condition' and whether this may impose constraints on adapting to climate change.
- Some of the climate impacts on the road network are related to long-term infrastructure assets e.g. bridges and should therefore be investigated now, with finance and construction plans established, so that major reactive adaptation measures are not required in a few decades.
- Indirect impacts associated with roads should be explored in more detail, with the aim of understanding the future risk of disruption to traffic through street works.

## **6. CASE STUDY 4: PASSENGER COMFORT ON THE UNDERGROUND**

### **6.1 The issue now**

The London Underground is the oldest underground railway in the world, a vital part of London's public transport infrastructure, and passenger demand is growing.

High temperatures are regularly experienced by passengers in hot weather on the Underground, particularly during summer evening peak time. On stations such as King's Cross, Waterloo, Victoria and Oxford Circus, the temperature can be 11°C higher than ambient temperature above ground (LUL, 2002). In some instances recorded temperatures have reached 40°C.

Temperature is the main factor affecting passenger thermal comfort, although air movement is also significant. Survey work in summer 2003 commissioned by LUL (BRE, 2004a) identified the average temperature range for thermal comfort as between 21 and 26°C in trains and between 17 and 25°C in stations. This compares with average observed temperatures over the same period of 28°C in trains and 26°C in stations. Maximum temperatures of 41.5°C and 36.2°C were recorded on a train and station respectively.

The current ventilation system, based on fans and draft relief shafts is already inadequate for cooling the Underground. Compliance with LUL standards for ventilation (including maximum temperatures) is not achieved in all situations.

## **6.2 How climate change will affect the future**

As outside temperatures increase under climate change, so will those in the Underground, although not in direct relation, as the exchange of heat between the atmosphere and the Underground tunnels is limited. Very high open air temperatures are likely to become far more common. By the 2050s London will experience between 28 and 45 days per summer on average in excess of 25°C. This will mean that many Underground lines will experience temperatures approaching 30°C, with certain hotspots reaching 35°C in peak periods. On the hottest days Underground temperatures may exceed 40°C in the hotspots.

This anticipated increase in temperatures has implications for Underground users. Overcrowding, and failed or delayed services further compound the problem of over-heating, particularly for passengers within the trains.

Passenger dissatisfaction is likely to increase in future unless adaptation measures are implemented. Comparison of climate change scenarios with research commissioned by LUL (BRE, 2004b) suggests that the Underground thermal environment will be considered uncomfortable by the majority of passengers for several weeks to months each year by the 2050s, even allowing for some acclimatisation.

The increase in temperatures, particularly extremes, and the numbers of people this is likely to affect (over 3 million journeys are currently made every weekday) poses the greatest challenge of climate change to keeping London moving.

Plans to enhance capacity (more frequent trains and the related impacts of acceleration and braking) are anticipated to generate significantly higher temperatures than would be the case under climate change alone. Furthermore, as the population of the UK ages, the vulnerability of passengers to hot weather is likely to increase.

Existing models of passenger demand indicate that weather has little effect on switching between transport modes. However, in future hotter weather may alter passenger preferences, particularly if the Underground thermal environment cannot be improved. This may put additional pressure on an already busy road transport system through increased use of buses, or worse (in terms of carbon dioxide emissions, air pollution and congestion) the increased use of air conditioned cars.

Perception and reputation of comfort on the Underground will be important and could influence tourism as well as regular users. Changes in use may occur in the short-term i.e. users may travel off-peak when conditions are cooler, or avoid the Underground on particularly hot days. Alternatively people may make a long-term switch to other forms of transport.

### **6.3 Action already undertaken or underway**

Current projects to help cool the Underground include:

- An audit of fan and ventilation capacity.
- Identification of where new ventilation capacity could be added to existing lines.
- Design of control systems to manage fans and local cooling installations.
- Work with South Bank University on trialling local cooling measures.
- Ordering of air-cooled trains on the sub-surface lines – Circle, District, Hammersmith & City and Metropolitan lines – due to be delivered from 2009.

LUL has allocated €261M to address the challenges posed by heat and climate change to the Underground.

A €146,000 prize which the Mayor offered as an incentive to find a workable solution for cooling the Tube has yet to be awarded, as none of the 3,500 entries were deemed workable.

LUL ventilation standards are being reviewed to help prioritise investment decisions.

### **6.4 Recommendations**

Key recommendations include:

- A detailed, strategic monitoring programme of temperature and humidity in the Underground, both in stations and inside trains.
- A review of passenger comfort in a warmer world following LUL research on the physiological aspects of heat.
- Further research by Transport for London to examine the behavioural response of passengers to higher temperatures, including identification of the costs and benefits of adaptation measures (e.g. air conditioning) and practicalities to address both temperature and air movement.
- Identification of the potential risks and thresholds where a change in transport mode (e.g. a switch from the Underground to buses) may be triggered.

## **7. MANAGING THE RISKS – TAKING ACTION**

### **7.1 Basic principles**

There are a number of basic principles that should be incorporated into transport planning strategies to manage the risks of climate change (Willows and Connell, 2003). These include:

- Incorporating climate risks into routine risk management procedures to help prepare for future adverse events.
- Minimising the costs of adapting to climate change by building it in:

- At the planning stage for new developments.
- When infrastructure is upgraded.
- When plans come up naturally for review.
- Before organisations are forced to act by a sudden extreme climatic event or mounting maintenance costs.
- Decision-makers should ensure, where practicable to do so, that climate risk management measures are sufficiently flexible, that schemes can be adapted if necessary, to manage uncertainty in future impacts.
- Where possible, decision-makers should avoid actions that will make it more difficult and costly to cope with future climate impacts. For example, new infrastructure projects (such as storm drainage) should include a reasonable allowance for climate change risks where the costs of subsequent upgrading would be prohibitive or very difficult to engineer.

## 7.2 Key actions

There will always be extreme weather events such as heat waves and floods. This research is about the long-term trend of climate change, which is already underway, and will make some of these events more likely and more extreme.

Key actions identified are to:

- Monitor temperatures and humidity in the Underground, both in trains and at stations.
- Design new infrastructure, rolling stock and vehicles for the climate throughout its design life.
- Instigate a review of existing infrastructure to determine the risks posed by climate change, including consideration of the appropriate Strategic Flood Risk Assessment, and set out actions to address them.
- Consider how the use of transport may change in the future as a result of climate change.

In addition, the research has identified many areas where better information is needed to enable the risks arising from climate change to be properly assessed and addressed.

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**Notes:**

1. RSSB: Rail Safety Standards Board.
2. EPSRC: Engineering and Physical Sciences Research Council; UKCIP: United Kingdom Climate Impacts Programme; BKCC: Building Knowledge for a Changing Climate.
3. Source: Network Rail