Safety, Sustainability and Human Resources Panel

Date: 28 February 2018

Item: Update on TfL's Climate Change Adaptation Work

This paper will be considered public

1 Summary

1.1 Following the paper to the Safety, Sustainability and Human Resource Panel on the 21 March 2017, this paper updates on TfL's work to better understand climate change related risks to London's transport system and how these can be best managed at the strategic level.

1.2 When presenting a paper on TfL's consultation response to the London Environment Strategy (LES) at the meeting of the Panel on the 28 September 2017, Members asked for more information on what our current understanding of risks were and what data we use to inform this. This is also discussed in this paper.

1.3 This paper covers:

(a) **Climate Change Projections:** How UK Climate Change Projections are currently used to understand the impacts of climate change on London's transport system and the need for more detailed work to improve this understanding;

(b) **Policy Context:** The draft Mayor's Transport Strategy and London Environment Strategy policies and proposals relating to climate change adaptation;

(c) **Work since March 2017:** The work that City Planning has been leading since the paper to the Panel in March 2017, including the findings of extensive internal workshops with TfL asset managers. Informed by these workshops and discussions with other stakeholders (GLA, Network Rail, Boroughs etc), a list of proposed further research is set out in Appendix 3;

(d) **Transport Sector Steering Group**: Description of the Steering Group being set up to guide this work and the relationship with broader MTS governance; and

(e) **Next steps.**

2 Recommendation

2.1 **The panel is asked note the paper and comment on the proposed research programme (Appendix 3) and Transport Adaptation Steering Group (section 5).**

3 Climate Change Projections

3.1 The United Kingdom Climate Change Projections are the most comprehensive set of climate change projections for the UK. It is the product of a number of institutions coordinated by Defra, utilising methodologies designed by the Met Office.

3.2 As described in the paper to the Panel on the 21 March 2017, the 2008 Climate Change Act set out a requirement for key infrastructure owners to report on what actions they were taking to ensure resilience of their assets. TfL has published two reports (in 2011 and 2015) which include risk assessments for key asset types. TfL used the most recent 2009 climate change projections (UKCP09) medium emission scenario to quantify climate risks and inform this work. In this projection, risks in the 2050s are:

(a) Higher summer temperatures: 2.7°c to 6.5°c above baseline;

(b) Warmer winters: 2.2°c to 3.5°c above baseline;

(c) Wetter winters: 15 to 33 per cent wetter than baseline; and

(d) Higher sea levels: 12 to 76cm sea level rise by 2095

3.3 These projections were used to inform workshops with TfL business areas, which produced the risk maps included in the 2015 TfL adaptation report to Government[1]. Below is an example of one of these risks maps included in the 2015 report.

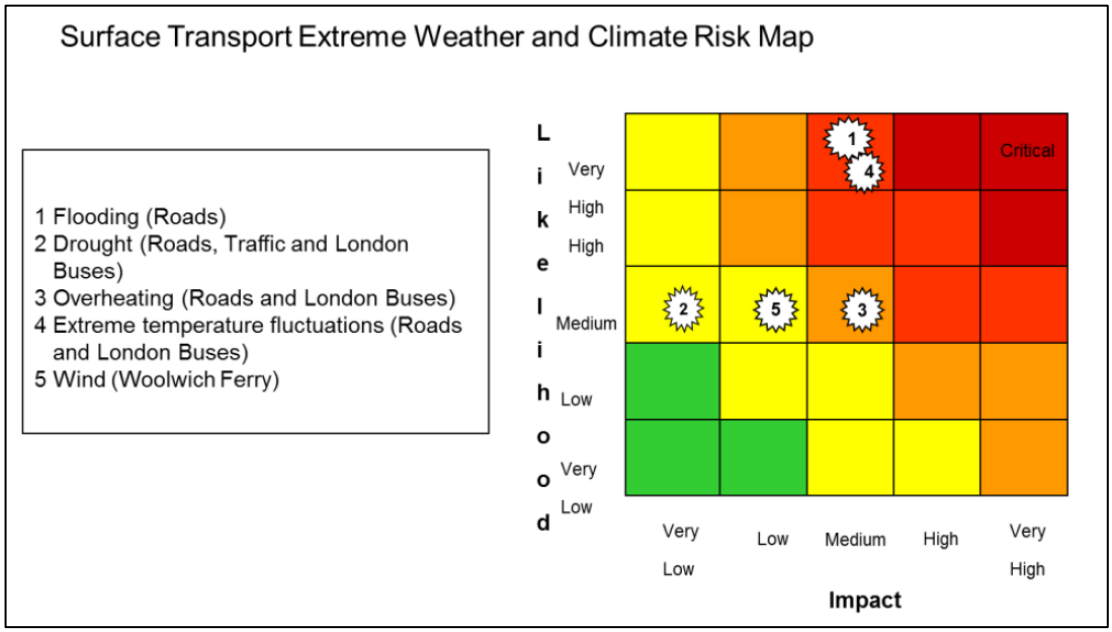

Figure 1: Example of a Risk Map from TfL's 2015 adaptation report to Government

[1] http://content.tfl.gov.uk/tfl-adaptation-report-may-2015.pdf

3.4 Our ambition is to build on the previous work so that where possible we are able to use existing or new data to quantify these risks, including in terms of monetised impact. This will better inform prioritisation and the business case for mitigation measures. Our proposed work to improve our approach to climate change adaptation is discussed further in sections 5 and 6 of this paper.

3.5 TfL's project management process, Pathway, requires that all new projects and programmes with an estimated final cost of £10m or more carry out a Sustainability Assessment at feasibility stage once a single preferred option has been identified, to set sustainable design principles for conceptual design. This process requires the Sponsor and Project Manager to consider the climate that the deliverable from the project will need to operate in during its whole design life. The Climate Change projections are used to inform this work.

3.6 TfL's Asset Management Policy requires asset managers to take account of climate change in managing assets. The climate change projections are intended to inform this, but in realty this process is limited by the quality of evidence and data available to asset managers regarding specific potential impacts, costs and effective mitigation measures.

3.7 There are examples of more detailed pro-active risk assessment of assets, such as the London Underground Comprehensive Flood Risk Review (see Appendix 1). In some limited cases there is also guidance which seeks to take account of climate change in relation to the design and renewal of assets. For example, design guidance recommends that drainage assets provide additional capacity to allow for climate change, although the final specification depends on a compromise over this guidance and other constraints (including funding).

3.8 Crossrail 2 is a good example of project that has built in adaptation right from the early stages of the scheme, before hybrid bill stage[2]. This builds on the work of Crossrail 1, which also had a strong approach to adaptation, although put in place after the hybrid bill.

3.9 However, these examples are few and for many asset types we do not currently sufficiently take account of climate change and in some cases, it is already challenging dealing with today's, let alone future, climate.

3.10 Since the publication of UKCP09, higher resolution models (1.5km) have shown future intensification of short-duration rainfall events in summer, especially when temperatures are warmer. Intense rainfall events can cause flash flooding, and an increase in their frequency would have a significant impact on the TfL network.

3.11 Updated UK climate change projections (UKCP18) are due to be published later this year. Raw data used by researchers will be released in May 2018, with the full UKCP18 products to follow in November 2018.

[2] http://crossrail2.co.uk/wp-content/uploads/2016/08/Crossrail-2-Sustainability-Policy-2016.pdf

3.12 UKCP18 will build on UKCP09 and will include projections in much finer detail; the finest resolution available will improve from 300km to 2.2km. This will enable policy-makers to formulate climate change adaptation strategies better tailored to their local area. The 2.2km model will be particularly useful for TfL as it will provide localised information on high impact events such as localised heavy rainfall in summer.

3.13 The UK Climate Change Risk Assessment (CCRA) 2017[3], produced by the Government's Climate Change Committee highlights a number of transport infrastructure related risks. These include flooding, high temperatures (overheating on public transport including buses and trains, increased urban heat island effect) and the interdependencies of critical infrastructure. The next CCRA will use data from the updated UKCP18.

3.14 Flooding and extreme heat are particularly critical issues in urban areas, such as London, because the high proportion of impermeable surface areas leads to rapid rainfall runoff and the thermal mass of buildings causes an urban heat island effect, making cities hotter than surrounding countryside.

3.15 As described in the paper to the Panel on the 21 March 2017, resilience to extreme weather and climate, particularly in the long term, has been identified as a strategic risk to TfL (risk reference SR17) with a risk rating of 20 (1 being lowest and 25 being highest). Monitoring of this risk is publicly reported to TfL's Executive Committee and included in risk review meetings with the Audit and Assurance Committee.

3.16 As UKCP18 data becomes available, TfL will assess the implications for London's transport system. It will be used to inform future reporting to Government (Defra are developing guidance for the next round of reporting, which is likely to take place in 2019 or 2020) as well as asset management and the assessment of mitigation requirements for new transport infrastructure. Consideration will be given to planning for a high emissions scenario (rather than medium as was the previously the case) given that global commitments on reducing CO_2 emissions are not currently enough to keep below a 2 degree increase in average global temperature.

4 Policy Context

Mayor's Transport Strategy

4.1 The draft Mayor's Transport Strategy (MTS), highlights the importance of ensuring London's transport is resilient to the impacts of severe weather and climate change and contains the following policy and proposals:

[3] Adaptation Sub-Committee (2016) UK Climate Change Risk Assessment 2017 Synthesis Report: priorities for the next five years. https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf

- Policy 8: ‘The Mayor, through TfL and the boroughs, and working with other transport and infrastructure providers, will seek to ensure that London’s transport is resilient to the impacts of severe weather and climate change, so that services can respond effectively to extreme weather events while continuing to operate safely, reliably and with a good level of passenger comfort.’

- Proposal 44: ‘The Mayor, through TfL, will work with transport and other infrastructure providers in London to undertake a dedicated programme of research to understand and prioritise the risk of severe weather and climate change adversely affecting the operation of London’s transport network and to minimise any such impacts on the most vulnerable user groups. [TfL will lead the work for the transport sector in London.[4]]’

- Proposal 45: ‘The Mayor, through TfL, will seek to undertake and implement an evidence-based programme of measures to adapt existing and to design and build new transport infrastructure to make it resilient to severe weather conditions and climate change.’

London Environment Strategy

4.2 Climate change adaptation is a prominent issue in the draft London Environment Strategy (LES). As well as several policies and proposals in relation to specific mitigation such as improving shade and shelter, reducing heat, Sustainable Urban Drainage etc, the LES includes the new sector-based approach to understanding and managing the risks of climate change:

- Policy 8.1.1 ‘Priority 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.’

5 Work since March 2017

5.1 As well as working with the GLA to developed the policies and proposals for the draft MTS and LES, since the paper to the Panel last March, TfL City Planning has continued to engage with the rest of the business and key stakeholders, including academia, boroughs and other transport operators to improve our understanding of climate change risks and shape our programme of work.

5.2 This has included an extensive series of workshops with TfL asset managers, which sought to identify for each asset type:

(a) How it is currently managed to be resilient to extreme weather?

[4] Proposed addition for the final MTS to align with the LES (which was published in draft after MTS) sector based approached.

(b) How it is managed to be resilient for future climate change?

(c) Potential areas for further study and research to improve our understanding?

5.3 Detailed notes were taken at each workshop and the key findings are presented in Appendix 2.

5.4 Informed by these workshops and ongoing discussions with stakeholders we have generated a long list of potential studies, which has been reduced to the short list of priorities to take forward. This is included in Appendix 3.

5.5 An overarching ambition of our research programme is to move from a position where our understanding of risk is based on expert opinion to a position where we are able test and support this with quantified evidence. We are inspired by the work of Network Rail, who has a dedicated team working on climate change adaptation. They are able to describe impacts of extreme weather in terms of a reduction in their "Public Performance Measure" as well as quantifying the risks for each asset type and monetising the impacts. Some examples of their outputs are included in Appendix 4.

5.6 Whilst Network Rail has a narrower scope in terms of assets compared to all of London's transport and a well-established reporting process already in place as a result of 'schedule 8' payments to Train Operating Companies, we believe TfL can achieve a similar or better level of quantified understanding of the risks and metrics for tracking performance. We already collect a large amount of data about the performance of London's transport systems as well as incidents that occur. This existing data could be used to improve quantification of climate change impacts and where there are gaps, we can seek to supplement with additional research or improve the way we currently report.

5.7 A piece of work which is already underway is looking at the effect of temperature on the performance of London Underground. The analysis considers how the frequency of delays varies with temperature. Figure 2 shows overall performance by line covering the period 2011 to 2016. The analysis also drills down to consider asset type and how performance changes through time (eg before and after a line upgrade).

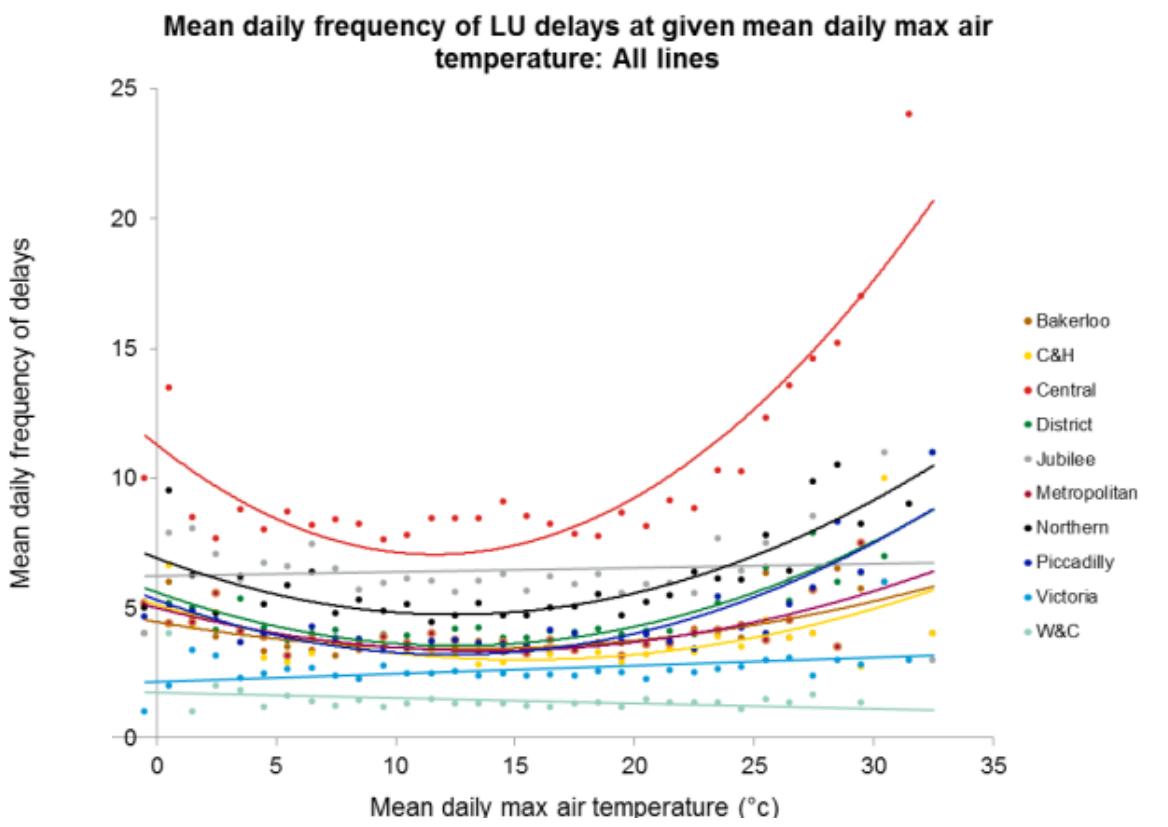

Figure 2: Example of preliminary findings looking at the effect of heat on LU network reliability (covering the period 2011 to 2016).

6 Transport Adaptation Steering Group

6.1 The draft MTS and LES proposes a sector-based approach for understanding and managing the risks of climate change in London, with TfL leading for the transport sector. In response to this, TfL is in the process of setting up a Transport Adaptation Steering Group (TASG).

6.2 TfL hosted a workshop on 12 January 2018, with representatives from across TfL, boroughs, GLA, London Climate Change Partnership, Network Rail, Crossrail 2, Environment Agency, Consultancies, train and bus operators and various sub-groups of the London Council's London Transport Advisory Group (LoTAG), such as the London Drainage Engineering Group (LoDEG), the London Highways Engineers Group (LoHEG) and the London Bridge Engineering Group (LoBEG).

6.3 This collaborative approach is important, because in order to be successful, the TASG will be completely dependent on input from business areas across TfL and external organisations, to develop the required evidence and implement its recommendations.

6.4 The objectives of the workshop were to:

(a) feedback on the work TfL has been doing and the findings of the workshops with asset managers, including a presentation by Network Rail on its work;

(b) seek ideas for further research and highlight potential issues in relation to climate change for agencies outside TfL; and

(c) discuss and shape proposed TASG.

6.5 The first formal meeting of the new TASG is planned for March 2018. The TASG will be chaired by TfL and includes representatives of the main organisations with responsibility for transport in London (membership TBC).

6.6 It is proposed that the TASG will have two main responsibilities:

(a) owning and managing a programme of work which aims to improve understanding of the risks and mitigating measures required to make London's transport more resilient to climate change as well as having sight of, and seeking to influence, the programmes of others where relevant; and

(b) reporting on progress in terms of London's resilience to climate change to TfL's internal MTS Delivery Group, this Panel, Defra, the London Climate Change Partnership (LCCP), the GLA, Environment Agency and the Mayor's Office.

6.7 The proposed objectives of the TASG will be:

(a) to capture and record a summary of the main vulnerabilities, thresholds and mitigating measures related to transport in London;

(b) to develop and manage a joint programme of work in order to fill gaps in knowledge;

(c) to proactively make the case for taking action to understand and plan for climate change;

(d) to provide advice and guidance in relation to the interpretation of the official climate change forecasts produced by the Met Office;

(e) to provide a forum for collaboration and coordination and the sharing and promotion of good practice across all members;

(f) to respond to requests and requirements from partners and other recognised bodies, for example, the Environment Agency, Defra; and

(g) To develop and agree and report on a metric or set of metrics which reflect the resilience of transport in London to climate change.

7 Next steps

(a) Finalise MTS and LES policies and proposals in relation to climate change adaptation.

(b) Hold first formal TASG meeting in March and agree membership and Terms of Reference (see 6.6 and 6.7 above).

(c) Take forward priorities for action listed in Appendix 3, working in collaboration with colleagues from across the business.

(d) Hold a series of workshops over the Summer with other transport operators, boroughs etc to supplement the findings of TfL internal workshops and add to the list of potential research projects and our understanding of vulnerabilities.

(e) Through the London Climate Change Partnership (LCCP), TfL will work with other sectors to consider interdependencies (e.g. energy, communications, buildings, water) and development of metrics to assess performance in the transport sector. It is proposed that by the end of 2018 options for performance metrics are brought back to the Panel for discussion before agreement with the GLA (as part of their work to develop performance metrics for all sectors).

(f) Ongoing work with colleagues to strengthen internal processes in relation to the consideration of climate change adaptation when defining, developing and implementing projects as well as through our asset management strategies (which are currently in the process of being updated and, where they don't exist, eg vegetation management, created).

(g) Longer term, work to develop an adaptive pathways framework informed by the work of the TASG (see Appendix 5).

List of appendices to this report:

Appendix 1: What is the LU Comprehensive Flood Risk Review?

Appendix 2: Results of workshops with TfL Asset Managers

Appendix 3: TfL adaptation proposed further research

Appendix 4: Example output of Network Rail's climate adaptation work

Appendix 5: Adaptive Pathways Framework

List of background papers:

Climate Change and Planning for Unpredictable Weather Events, SSHR Panel, 21 March 2017

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Appendix 1: What is the LU Comprehensive Flood Risk Review?

A1.1 The London Underground Comprehensive Review of Flood Risk (LUCRFR) was established to review all significant sources of flooding risk (both natural and non-natural) to all London Underground vulnerable assets. The scope required evaluation of risk in both safety and business terms.

A1.2 Phase 1 included a high-level assessment of risk at Approx. 800 sites (stations, vent shafts and tunnel portals) which were evaluated and ranked according to monetised value of risk exposure.

A1.3 The LUCRFR Phase 1 analysis identified and ranked the principal flood hazard sources in order of their significance. The results were as follows (figures rounded-up):

(a) Burst water mains flood hazard – 58% of total risk.

(b) Pluvial (and sewers) flood hazard – 27% of total risk.

(c) Tidal/fluvial out of bank flow/overtopping flood hazard – 13% of total risk.

(d) Direct connections flood hazard – 3% of total risk.

A1.4 The hydraulic modelling used to identify surface water flood risk explored a wide range of storm events including extreme events (1 in 100, 1 in 100+climate change & 1 in 200 years return period) over a 3hr duration event.

A1.5 As part of phase 2 the top 10 highest risk sites are now being reviewed in greater detail (representing 56% of the total estimated flood risk exposure), as a prelude to detailed site-specific flood risk assessment and quantitative cost benefit analysis which would then be required to identify and justify any required mitigation measures.

A1.6 Phases 1 and 2 didn’t include several other asset groups, for example, power, signals and communications. These all have the potential to cause significant business disruption if flooded and may also result in a degree of safety impact. It is proposed to assess flood risk to these and other assets within a Phase 3, subject to funding.

Appendix 2: Results of workshops with TfL Asset Managers

A2.1 This section summarises the findings of the workshops City Planning held with TfL Asset Managers. These findings have been reported to the internal TfL Asset Management Steering Group.

A2.2 **Carriageway and footway**

(a) Hotter summers mean that road surfaces will need to be made thicker and denser in order to reduce rutting (resulting in undulating road surface) and minimise maintenance requirements

(b) Road surfacing can be made permeable (which can help reduce flood risk), however permeable surfacing is softer and less resilient to high summer temperatures

(c) It is not clear whether boroughs are actively considering how to surface their roads in the context of climate change and TfL does not work closely with them on this issue

A2.3 **Drainage and pump stations**

(a) The poor condition of drainage assets on the surface network impacts vehicle journey times and recovery costs. Of the gullies inspected only 34 per cent are in a state of good repair and there is general uncertainty about the location and ownership of assets.

(b) Surface currently have a programme of works to improve the ability of drainage infrastructure to manage surface water (e.g. drain clearing and repairs) along known flood corridors.

(c) Both LU and Surface aim to provide new drainage assets which provide additional capacity to account for climate change, but the final specification depends on available budget etc. Different standards apply for Surface and LU.

(d) The LU Comprehensive Review of Flood Risk (LUCRFR)[1] included an assessment of flood risk at station entrances, shafts and portal entrances. It identified a priority list of locations most vulnerable to flooding on which a more detailed assessment is now taking place.

A2.4 **Station depots (LU and Buses)**

(a) Due to the risk of fuel spills there is already a lot of pressure to demonstrate that drainage in bus stations is adequate. Bus stations are generally very well ventilated.

(b) LU station temperature is affected by a number of factors including train ambient air temp. However, LU's thermal modelling software tells us that changes in future train frequency and performance will have a much bigger impact than gradual rises in temperature associated with climate change.

(c) Hydraulic lifts are unreliable in hot weather.

[1] Reference LU climate risk study

A2.5 **Signals and communications**

(a) Roadside equipment boxes are prone to failure on hot days (particularly on the first hot day of the year).

(b) Flooding/moisture in LU equipment rooms leads to a slow degradation of equipment over time.

(c) It is hard to justify spending much money analysing faults as a lot are very cheap to replace and have fail-safes.

A2.6 **Bridges and structures**

(a) Failures in cast iron structures tend to be significant when they occur, but they are hard to predict. Failure rates are exacerbated by fluctuations in temperature.

(b) Wind currently causes more Lost Customer Hours than any other type of extreme weather and is likely to be an increasingly important issue with a predicted increase in storms and tall buildings in London.

(c) TfL's current approach to maintaining structures focuses on regular inspections and maintenance.

(d) Much of the TfL network (road and rail) sits on London Clay which moves during periods of prolonged drought/heavy rain.

(e) Extreme droughts and heavy rain could lead to greater instability in embankments leading to reduced track stability and speed restrictions etc.

(f) LU have trigger points at which rainfall may impact on the stability of earth structures, and are currently improving their mitigation measures, including developing automated responses such as CCTV to identify land slips and stop trains.

(g) Ground water levels are rising, mainly due to Thames Water's changing approaches to abstraction. It is not yet clear how this might impact on LU tunnels.

(h) The standards for new infrastructure do not include a climate change factor.

A2.7 **Green estate**

(a) LU record green estate in terms of its level of encroachment on assets such as embankments, cuttings etc. (the general approach in LU is currently to remove trees and replant with grass / wildflowers).

(b) Surface has a comprehensive record of all green infrastructure on the TLRN; assets are managed in order to strike a balance between highway safety and ecosystem services.

(c) TfL have recently created a biodiversity baseline identifying all of the habitats across the TfL estate and developed a toolkit to measure biodiversity units based on the Defra's biodiversity offsetting metric[2].

A2.8 **LU Power**

(a) There are seven Bulk Supply Points where power comes from the National Grid. If one or two of these bulk supply points go down there could be delays and suspensions.

(b) The LUCRFR did not include power assets e.g. sub stations. This is a potential risk.

A2.9 **LU rolling stock**

(a) Central line trains suffer from corrosion of aluminium flooring, which must be regularly patched up. This is attributed to the operating environment.

(b) Electronic equipment boxes are now often sealed which helps safeguard against water ingress but does mean they get very hot.

(c) Ambient air temperature (i.e. air temperature in tunnel or outside) is the main factor influencing temperatures on trains. LU in general assume that inside the carriage is 2°C warmer than the tunnel (with no air conditioning). The Deep Tube Upgrade Programme assume temperatures of 26°C inside carriages and 30°C in the tunnel with the air conditioning running.

A2.10 **LU track**

(a) LU uses a continuously welded rail system on above ground lines which is engineered to be stress neutral at 27°C.

(b) Critical rail temperatures are identified and when they are experienced temporary speed restrictions are put in place.

(c) Increased summer temperatures won't have a big impact on track. Similar track management methods are used in much hotter countries.

(d) Less money is invested in track maintenance recently because the condition of assets has improved. LU is likely to move from an improving asset to a stable one.

(e) Track operability is dependent on other assets (e.g. embankments) which could be impacted by climate change.

A2.11 **Docklands Light Railway (DLR)**

(a) The DLR differs from LU in that much of its infrastructure is more modern, but also more lightweight. Many DLR structures are not particularly robust, are elevated, and are exposed to the elements.

(b) DLR stations only have one source of power (compared to LU stations which have three).

[2] https://www.gov.uk/government/collections/biodiversity-offsetting

(c) DLR operates an automatic ‘overlay’ system which reviews the weather forecast and automatically implements contingencies. For example during wet weather speeds are reduced in order to prevent rail damage and slipping.

(d) There are no specific standards relating to climate change. When replacing drainage assets, just replace like for like (unlike LU and Surface which have an additional factor for Climate Change).

A2.12 **London Overground and Trams**

(a) London Overground has just completed an assessment of the condition of their drainage assets. Most are ‘to standard’. The assets tend to be much more recent than those belonging to LU.

(b) Trams are generally quite resilient to extreme weather.

(c) Overhead tram lines are prone to sagging in hot weather, however this can be managed.

(d) Flooding is an issue on tram lines, leading to temporary speed restrictions being put in place.

Appendix 3: TfL adaptation proposed further research

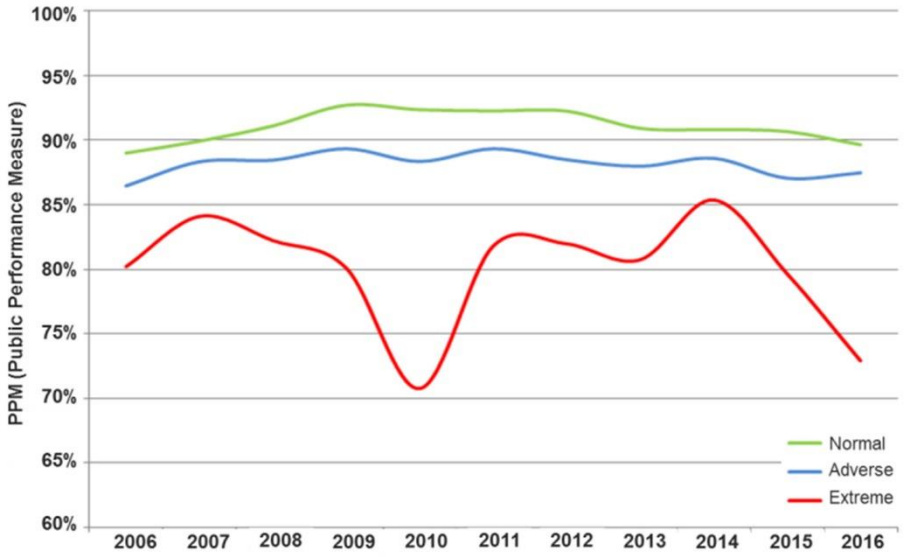
Ref	Project title	Climate risk addressed	Description	Progress	Potential project partners
1	Improved recording of asset failures related to extreme weather	general	Using consistent categories for Surface and LU. This could be done in as part of an existing asset management improvement programme (AMIS)	Proposed	
2	Building an evidence base to monetise the benefits of Green Infrastructure.	general	Develop a program of research to gather evidence to monetise the benefits of Green Infrastructure in order to build into business cases.	Proposed	CIRIA – GI on linear assets study LoDEG - Strategic SuDS pilot NERC
3	Review of new climate change projections (UKCP18) and highlight key impacts for transport	general	Review UKCP18 and highlight key impacts for transport and suggest mitigations, e.g. changing drainage standards	Proposed	LCCP NERC
4	Develop an Adaptive Pathways Framework (APF) for TfL	general	Develop an APF to help identify and plan mitigation measures. See Appendix C for further information.	Proposed	
5	Ensure resilience issues are highlighted through project assurance processes.	general	Surface Transport's Environmental Evaluation Report (EER) is being updated and will include resilience measures. The new EER will be used across TfL, not just Surface.	Underway	
6	Identifying trends between different forms of extreme weather and performance of different transport systems	general	Inspired by the analysis which is being completed into asset performance and temperature for LU (item 7) it might be possible to review similar trends between different forms of extreme weather and different parts of the transport network. E.g. precipitation and bus journey time, wind and LU delays	Scoping	NERC

7	Identifying trends between temperature and delay on LU	heat waves	An MSc student is identifying lines/asset types which suffer from delays most in hot/cold weather	Underway	Sarah Greenham (MSc student at Brunel)
8	Monetise the impact of disruption caused by a flood risk scenario	flooding	Use the new UKCP18 forecast to inform a flood risk scenario which can then be monetised to see the impact of disruption.	Scoping	NERC Ambiental (consultancy)
9	Proactive flood risk management on the TLRN	flooding	Looking to improve proactive investment through incorporating the same modelling approach that the LU drainage teams have been using	Initial discussions underway	
10	Understanding the vulnerability of LU sub-stations to flooding	flooding	The next phase of the LU Comprehensive Review of Flood Risk will include power, signals and communications assets which have the potential to cause significant disruption if flooded.	Planned (subject to funding)	
11	Trees in a changing climate	general warming plus summer droughts	The Arboriculture & Landscape Team will undertake a comprehensive literature review into trees for a changing climate.	Proposed	NERC

Appendix 4: Example output of Network Rail's climate adaptation work

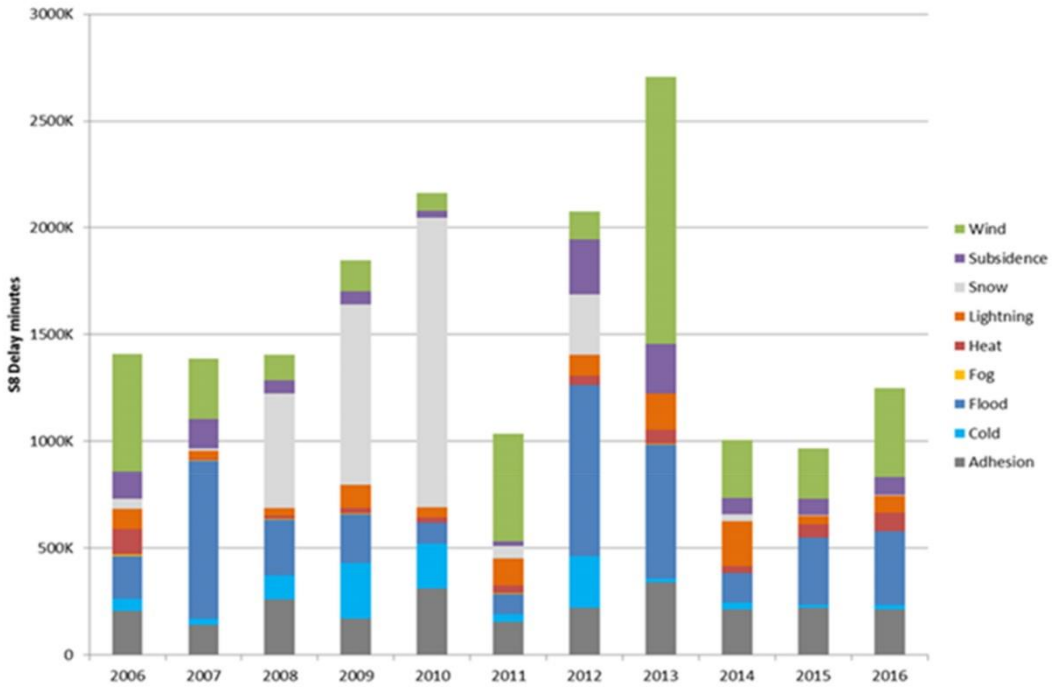
Current weather impact on performance

2-3% performance drop on adverse weather days



We plan to do further work to understand causal factors behind the change in performance including infrastructure reliability and the impact of changing timetables during adverse and extreme events

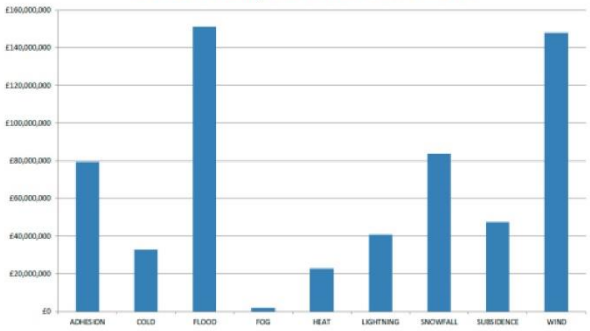
Schedule 8 Delay Minutes 2006 - 2016



Current weather impact and flood risk

- Wind and adhesion many small low cost incidents
- Flood and subsidence fewer incidents but highest cost
- In addition, 2014-16 ~£100m cancellation cost due to flood/rain (nationally)

Schedule 8 compensation costs 2006 - 2016



- 40% of track is at high (1:30 year) or medium (1:100 year) flood risk (excl climate change)
- 247km high risk criticality 1 track would cost £400–700m to protect against surface/ground water flooding alone

Length of track at risk

Flood Risk level	Coastal & River (% of total Track km)	GroundWater (% of total Track km)	SurfaceWater (% of total Track km)
Low	6.4%	8.0%	18.8%
Medium	4.2%	4.9%	9.6%
High	2.9%	14.3%	4.8%

Weather sensitivity

Analysis of the weather experienced at the time and location of incident and failure events has provided us with information on the sensitivity of assets to failure under different weather conditions.

- Green - no clear correlation between failure rates and weather could be derived
- Amber - incident rates double relative to the median
- Red - incident rates treble

	Buildings		E&P				Signalling																Telecoms												SE&PT		Track			Earthworks
Weather	Property	Structures	3rd Rail	OLE	Signalling Power	Traction Power	ATP	AWS	Axle Counter	HABD	Interlocking	Level Crossing	Miscellaneous	Monitor	POE	Remote Control	Signalling	Signalling Control	Staff Protection	TPWS	Track Circuit	Unknown	Cable	Concentrator	DOO	Miscellaneous	PABX	PETS	Power	Radio	SCADA	SISS	Telephone	Transmission	Voice Recorder	Cable Route	Lineside Equipment	S&C	Track	Sign	All
Daily Maximum (°C)	>22		>29	>24	>27	>21	>20	>25	>24	>25	>24	>31			>24	>22	>27	>27		>22	>21		>25	>21	>26		>25	>24	>27	>22		>29	>29	>29		>34		>25		
	>27			>30		>28	>31	>31	>30	>30	>30				>29	>27				>27	>26		>30	>25					>34	>27								>29		
Daily Minimum (°C)				<-10						<-12		<-15			<-5			<-7																		<-0			
				<-15											<-10																						<-3			
Diurnal Cycle (°C)	>13					>12	>10	>14		>13	>14				>13	>13		>14		>14	>13	>12			>13					>14									
						>16	>11	>18		>16					>16						>16																			
3 Hour Rainfall (mm)		>9	>11		>8																>7		>12														>7		>2
		>12			>13																>10																>12		>4
Daily Rainfall (mm)		>29			>46									>24							>38																>44		>11
		>37												>32							>60																>66		>16
15 day Rainfall (mm)														>112																									>68
														>137																									>102
Hourly Max Wind Gust (mph)				>49	>48	>59			>61			>54	>49								>49								>69								>50		>39
				>53	>57	>71			>67			>67	>57								>54																>57		>46
Daily Max Gust (mph)				>59	>70							>96	>55								>62								>76								>64		>42
				>66									>61								>72								>84								>76		>49
Daily Max Windspeed (mph)				>40	>41							>44									>37																>40		>25
																					>44																>51		>29

Appendix 5: Adaptive Pathways Framework

A5.1 Inspired by the approach taken by the Environment Agency in the Thames Estuary 2100 Plan, TfL is proposing to organise management of long term severe weather and climate change resilience around an 'Adaptive Pathways Framework' (APF).

A5.2 The APF approach, illustrated below, establishes thresholds at which different infrastructure would fail for increasing levels of weather impacts. Once thresholds for infrastructure failure have been identified, appropriate mitigation is identified, some to reinforce previous mitigation, others would be 'either / or' (i.e. could not be implemented together).

A5.3 When identifying mitigation, an understanding of the implementation lead in times would be required. In some cases, it may also be possible to identify opportunities to switch to a stronger mitigation measures (if necessary) during implementation, whilst minimising additional cost.

A5.4 The latest climate change forecasts are used to provide likely timings of when mitigation would be needed, informing investment decisions. As evidence and understanding improves and climate change forecasts are updated, the long-term mitigation plan is updated, either in terms of the mitigation required or timescales.

A5.5 The development of the first adaptive pathways for London's transport will be dependent to the progresses of the TASG research programme.

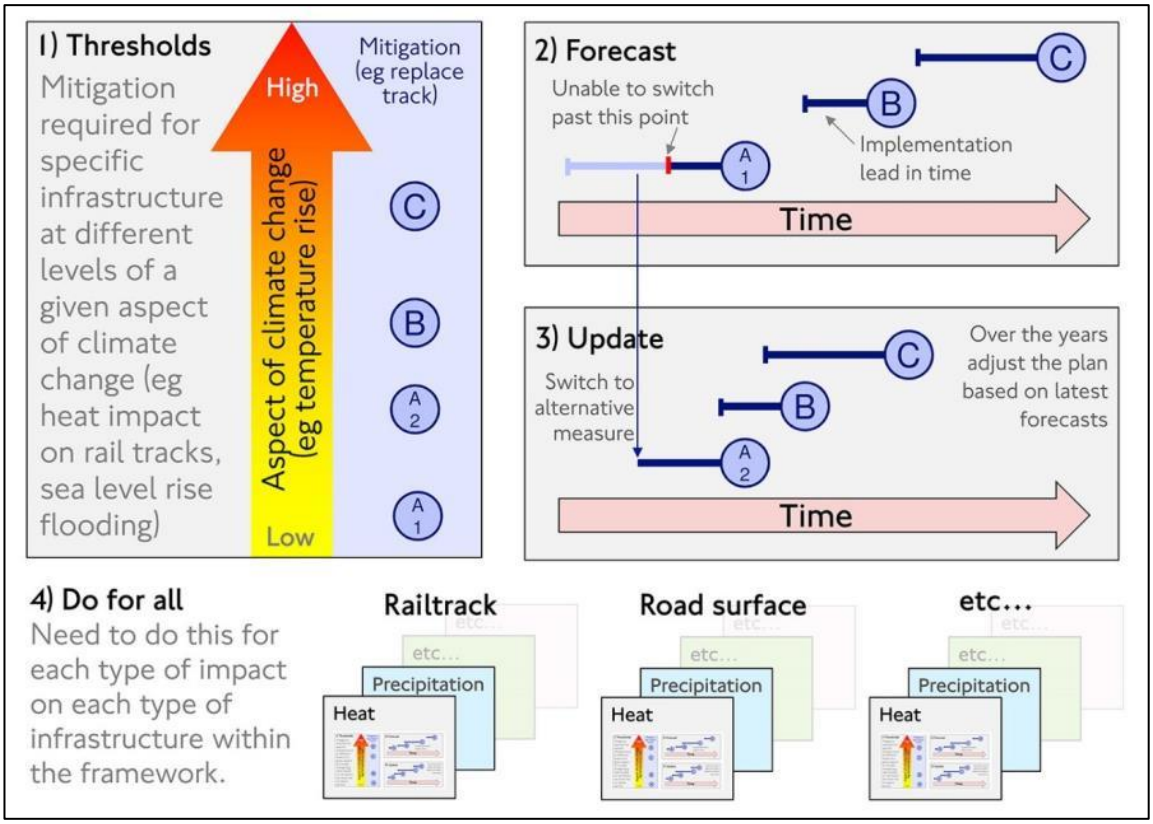


Figure 3: Illustration of the proposed Adaptive Pathways Framework