Providing Transport Services Resilient to Extreme Weather and Climate Change

2015 Update Report following last report to Government in 2011

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Contents

Executive Summary

This report is published by Transport for London (TfL) to give an overview of the risks it has identified to its activities and services from extreme weather and climate change. The government set the Adaptation Reporting Power in the Climate Change Act 2008 and required operators of national infrastructure to report on these issues publicly. TfL published its first report in 2011.

Government has invited TfL and other operators to submit an update report during 2015. Those submitted before the end of May will help to inform the national climate change risk assessment.

This report outlines significant pieces of work that TfL has delivered since our last report, for example London Underground's delivery of air cooled trains on the sub surface lines, the Earthworks Review and Comprehensive Flood Risk Review as well as the Streets pumping station and underpass reviews. It summarises a small number of weather related incidents that have occurred since 2011 and how our operational businesses have made improvements to their infrastructure and services.

Finally, the report summarises our plans for managing extreme weather, in our business as usual approach, our medium term asset management and our longer term planning.

1. About TfL

TfL was one of the UK infrastructure operators who submitted a report under the Adaptation Reporting Power in 2011. This report provides an update on the key issues since then, changes to our business, changes to the risks, mitigation activities and ongoing plans.

TfL's purpose is to keep London working and growing, and to make life in the Capital better. We are therefore delivering our Business Plan to modernise the transport system, investing in improved capacity, frequency and facilities to help meet increased demand for our services driven by London's population growth. TfL businesses have a range of different service and commercial models e.g. relationships with franchisees, infrastructure maintainers. Therefore there are different approaches such as business areas that do maintenance in house and those who contract it out.

Transport for London (TfL) is the integrated transport authority for the Capital, providing:

London Underground - London's metro system, delivering more than 3.5 million passenger journeys a day. It has 11 lines covering 402km and serving 270 stations. During peak hours, more than 500 trains are in operation.

Surface Transport - London Buses, the TfL Road Network (TLRN), maintenance of London's traffic operations, including 6,000 traffic signals, licensing of taxis and private hire vehicles, London river services, Victoria Coach Station, Congestion Charge, Low Emission Zone, Dial a Ride and cycle schemes such as Super Highways and Hire bikes).

London Rail – London Overground, Tramlink, the Docklands Light Railway and Emirates Air Line as well as the operation of Crossrail.

TfL is part of the Greater London Authority and delivers the Mayor's Transport Strategy in partnership with the London Boroughs and other transport providers such as Network Rail and the train operating companies.

Changes in TfL Structure and Responsibility Since 2011

In 2011, the Mayor published his Climate Change Adaptation Strategy. This includes an analysis of the impacts of climate change on London and proposals for the GLA Functional Bodies and other organisations to help become adapted to the changing climate.

Emirates Air Line

Since 2011, TfL has designed, built and operated the cable car across the River Thames – The Emirates Air Line.

London Underground and London Rail

Since the last report, the London Overground has become a fully orbital railway around the Capital. TfL is the infrastructure operator for the East London Line section. The rest of that network operates on Network Rail infrastructure and we are the train operating company, via our franchisee, LOROL.

Surface Transport

Extensions to Cycle Hire services and Cycle Super Highways.

2. Risks to TfL's Services from Extreme Weather and Climate Change

TfL has assessed and evaluated the risks from extreme weather today and from future climate impacts on its assets and services. Current weather related risks are more likely to include winter ice, rainfall and shorter periods of summer heat. These can occur throughout our London-wide networks and we have assessed known 'hotspot' locations for the different risks in all our businesses.

We assessed the risks from climate change in collaboration with the GLA during development of the Mayor's Climate Change Adaptation Strategy (2011). We used the 2009 United Kingdom Climate Projections (UKCP 09), focusing on the predictions for Greater London rainfall and temperature in the 2020's, 2050's and 2080's. The medium emission scenario has been used and it has identified that the risks in the 2050's are likely to be:

> **Higher summer temperatures**, with the average summer days being 2.7°C warmer and very hot days 6.5°C warmer than the baseline average
> **Warmer Winters** - Winters will be warmer with the average winter day being 2.2°C warmer and a very warm winter day 3.5°C above the baseline.
> More seasonal rainfall - Summers will be drier, with the average summer 19 per cent drier and the driest summer 39 per cent drier than the baseline average
> **Wetter Winters** - with the average winter 15 per cent wetter and the wettest winter 33 per cent wetter than the baseline average
> **Sea level rise** - Sea levels are projected to rise by up to 96cms by the end of the century.

In the short to medium term for flooding and high temperatures there is likely to be increased frequency and consequence e.g. flooding from increased frequency and intensity of winter storms. High temperatures are more likely to become common in the summer months from the mid 21st century.

In most cases, the longer term risks will be similar. For flooding and high temperatures there is likely to be increased frequency and consequence e.g. flooding from increased frequency and intensity of winter storms. High temperatures are more likely to become common in the summer months from the mid 21st century. The temperatures reached in the hot summer of 2003 are likely to feel average by the 2040's and cool by the 2080's. For low temperature snow and ice events, there is likely to be increased severity when such events occur, although they may not be as frequent.

The TfL functions which are most likely to be affected by climate change include:

- Those relating to the provision of public passenger transport including tube, rail, bus and river services
- Functions as Highway Authority and Traffic Authority for GLA roads
- Facilitation of the discharge of the Mayor's general transport duty (which is a duty to develop policies and proposals for the implementation of safe, integrated, efficient and economic transport services to, from and within Greater London);
- Implementation of the policies and proposals contained in the Mayor's Transport Strategy, in particular proposals which relate to adaptation to climate change

3. Review of Weather Incidents since 2011

We have reviewed any weather incidents that occurred since our last report that affected our services, with a view to learning any relevant lessons that will inform activities and forward planning.

- **2012 –** Lightning Strike at DLR Crossharbour equipment room. As a result, DLR has changed its design standards to ensure that earthing and bonding is more rigorous and introduced measures to break the charge.
- **2013** – the Fore Street tunnel was affected by a hail storm which temporarily blocked the drain gullies with ice. Learning – whilst we have an emergency response function in our maintenance contractors, we had to request help from the police on this occasion to unblock the gullies as our contractors couldn't access the site through the traffic jam.
- **February 2014** storms and subsequent groundwater flooding – TfL coped well, with its usual pumping processes. We worked with the local authority and emergency services to supply assistance to communities near Croydon evacuated due to groundwater flooding.
- **July 2014 heat** – no reported issues
- **August 2014** localised rainfall – eg A41 in the summer. We have reviewed all the locations on the TLRN where topology and drainage could make them susceptible to a similar impact.
- **2014** - Cloudburst flooding affecting Island Gardens DLR station which was addressed through improved preventative maintenance (improved proactive gully sucking)

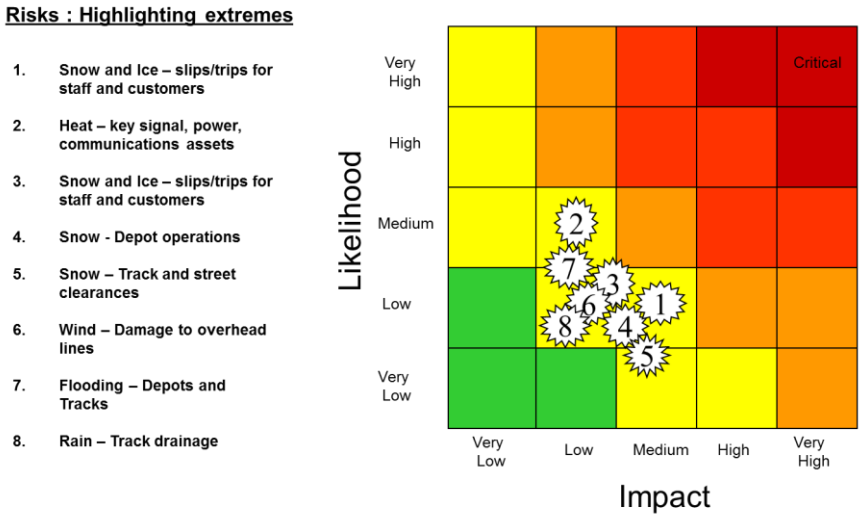
4. Review of TfL's business areas and their Key Extreme Weather and Climate Risks

TfL Business Extreme Weather and Climate Risk Maps

TfL analyses extreme weather and other risks to its assets and services as part of its corporate approach to risk assessment, which is detailed in Appendix 1. Each business area uses a scoring methodology which is based on this approach. They adapt this to suit any local circumstances, for example there will be a difference in what impacts warrant a 'high' score in different types of operational service. Examples of key scoring mechanisms have been supplied to Defra.

During 2015, TfL has reviewed all the extreme weather and climate risks compared with those done in 2011 using UKCP 09. The exercise has not resulted in major changes from the 2011 review. However, any changes have been added to update TfL's risk management system. This process has generated snapshots of the key current, mitigated risks. These are outlined in the risks maps produced by each TfL business area (Figures 1-4). Managers use these risk maps to provide a current view of the key mitigated risks and as part of their annual risk reviews.

London Rail : Extreme Weather and Climate Risks



London Underground Combined Extreme Weather and Climate Risk Map

1- Extreme Hot Weather - Key track, signals, & communications assets and staff & passengers.

2- Rain & Flooding - Track & signal failure

3- Cold & Freeze - Impact on track integrity

4- Rain & Flooding – Key infrastructure drainage

5- Drought - Vegetation impact

6- Snow – track, signalling and depot operations

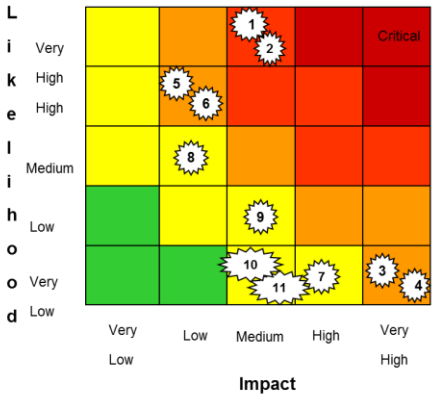
7- Cold & Freeze - Train system components

8- Cold & Freeze – Slips/trips for staff and customers.

9- Rain, Flooding and snow - Damage to inside of carriages

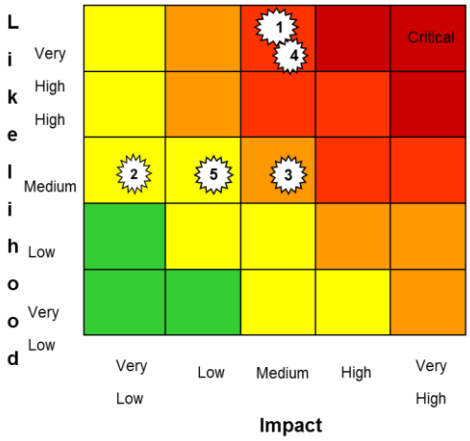
10- Wind- Damage to infrastructure, track and vegetation.

11- Drought - Ground stability impacts



Surface Transport Extreme Weather and Climate Risk Map

1 Flooding (Roads)
2 Drought (Roads, Traffic and London Buses)
3 Overheating (Roads and London Buses)
4 Extreme temperature fluctuations (Roads and London Buses)
5 Wind (Woolwich Ferry)



5. How Risks from Extreme Weather and Climate Change are Managed in TfL

This report provides an overview of the risks TfL has identified arising from extreme weather and climate change. It then outlines the approach to managing these risks relating to:

- Our business as usual approach to managing day to day operations
- Our asset management plans
- Longer term – Our design of infrastructure and planning of schemes

5.1 Business as Usual Approach to Managing Extreme Weather Risks

There is political and senior leadership commitment and support to keep TfL's services running and safe if at all possible when extreme weather events are forecast. This is an important element of keeping London moving and operating smoothly.

5.1.2 We achieve such resilience by having a range of approaches in our business as usual systems. This starts with advance seasonal weather planning. Well before the start of each season, TfL uses Met Office seasonal forecasts to plan for the likely weather patterns, e.g. predominantly wet and windy, cold and icy, hot.

5.1.3 On a day to day basis, all TfL businesses use regular weather forecast bulletins from the Meteo Group supplemented by business specific, local real time monitoring e.g. of track or road surface temperature. These inform us whether critical thresholds such as temperature, humidity or rainfall are imminent and if so, this triggers well rehearsed plans to carry out activities that help minimise the impact of such events.

5.1.4 For example, Surface Transport responds to forecasts of heavy rainfall with well practised plans for maintenance contractors to clean out key gullies. For cold weather and ice forecasts, there are processes for applying salt and grit to road surfaces, bus station approaches, platforms etc.

5.1.5 London Underground has a set of '54321' plans where all key roles know their responsibilities for managing the activities from five days before a particular weather event is forecast to arrive. The London Underground operational daily morning phone conference in which the most senior leaders review service issues includes a weather report and a reminder of whether we are in a particular day of a '54321' status. It includes a reminder that all relevant plans for managing such an event should be ready.

5.1.6 For management of current heat issues, London Underground has doubled the capacity of ventilation shafts on the Victoria line, which provide more air flow. We have installed air cooling units and mechanical chillers at two key busy stations, Oxford Circus and Green Park. In addition LU has upgraded existing ventilation fans and installed new fans at a number of stations across the network. We are looking at technologies and opportunities to reduce traction energy consumption and to recover braking energy before it is converted to heat. We are looking at opportunities to extract waste heat from the system and find beneficial uses and markets for it.

5.1.7 In Rail and Underground we also respond to include stressing the tracks when alerted to nearing critical rail temperatures, to prevent rail buckling.

5.1.8 This is achieved using agreed plans to use speed restrictions, driver observation, track walking and detailed real time information to communicate to customers the nature of the impact on services, e.g. a storm where a tree may have come down across the tracks.

5.1.9 Another important element of business as usual preparedness is our vegetation management work. We review vulnerable trees, branches and other vegetation that could become dislodged during high winds or rainfall. Where possible we will remove the vulnerable parts of such vegetation and where not possible, we will plan for the likelihood of twigs and leaves falling on to track points.

5.1.10 Where there is an impact from a weather event, the operational staff and franchisees have planned activities to ensure that the service is able to resume within the shortest time frame possible. This planning, proactive plans and resilience means that TfL has been recognised for keeping services running during weather events of the last few years.

5.2 Asset management in TfL

5.2.1 TfL's services require different types of asset, such as rail, signals, trains, roads, subways, tunnels and bridges. These are managed by Underground and London Rail or Surface Transport according to the particular needs and contractual arrangements in place.

5.2.2 Through effective and efficient asset management and every department working collaboratively, TfL can make best use of available funds and ensure that our assets are fit for purpose – including the need to perform during a range of weather and future climate scenarios.

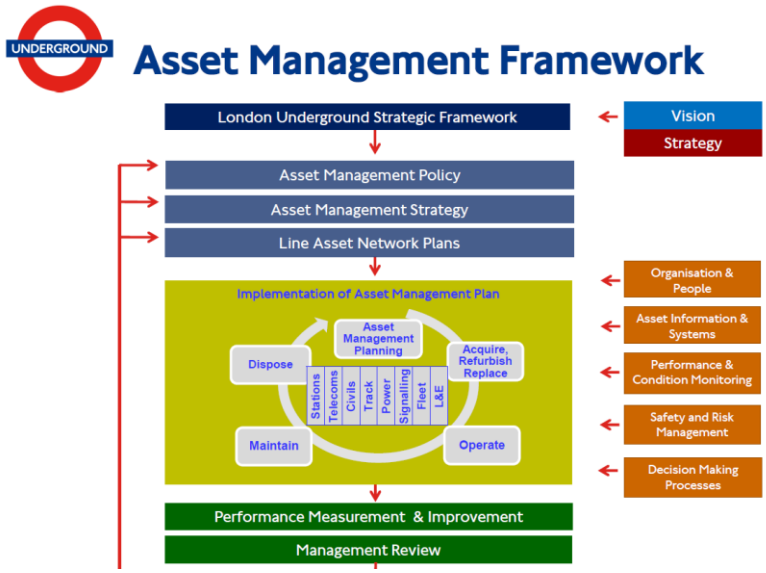
5.2.3 There is a structured asset management process that has been developed in line with PAS 55 and is now being certified to ISO 55000 – the standard for physical asset management. Asset management is the way assets (such as trains, signals, stations and tunnels) are managed throughout their life to achieve the right balance of cost, performance and risk for the organisation and follows a 'plan, do, check, act' process.

5.2.4 The Asset Management Policy sets out the high level principles for asset management for staff to manage our assets. It provides the links and line of sight from our vision, down to the asset strategies in the different business units, through to planning, delivery and monitoring of our work banks and processes.

5.2.5 The Asset Management Strategy sets out the detailed strategies for each asset group to the end of the current business plan. These determine the performance and condition required in each asset group, the maintenance strategy (preventative and reactive), and the major capital interventions.

5.2.6 The London Underground Line Asset Network Plan is produced annually as part of the business planning cycle and sets out the project and maintenance activity that is funded in the business plan. The Asset Control Report is an

annual summary of the condition of our assets. The report uses data that is collected throughout the year from condition assessments and summaries from daily operational issues. It classifies the condition of assets by residual life and condition related risks.



5.2.7 The Asset Managers work in partnership with Sponsors (clients) and Managers (delivery) of Programmes and Projects to achieve the asset related goals of the full service planning and delivery.

5.3 Specific Examples of Addressing Weather and Climate Risks through Asset Management

5.3.1 London Overground

Since 2011, London Overground (LO) has operated an orbital service around London. It has also increased train length, platforms and depots to be five cars rather than four. As part of this capacity improved, the Silwood Stabling Facility has been equipped with heated conductor rails and points. London Overground is aware (from its risk assessment) of the potential for extreme weather to impact on its services. It has used this information to help inform improvement activities such as:

- Knowing the flood risk and low points in its infrastructure so has mitigation measures in place eg underground rainwater storage tanks and balancing pond at Silwood depot
- For cold weather and ice risk, point and track heaters have been installed its depots as part of its process to extend the service from four to five car trains
- Use rainwater harvesting at its depots for train washes
- Signal relay failures can occur in high temperatures. There have been trials of 'top hats' to cool signalling cabinets and LO is looking at Network Rail's use of adaptation units, which are heat absorbent, louvered covers for the units

5.3.2 **Docklands Light Railway (DLR)**

DLR's weather and climate change risk assessment has meant that it has been able to deliver the following improvements:

- Specify air cooling in its new trains
- Have detailed plans for operating or restricting the cable car due to heat, wind and lightning
- Revise standards and improve design for control rooms in case of lighting strike
- Ensure that its new franchisee has detailed plans in place to prevent the impact of extreme weather eg proactive gully sucking
- Consider flood risk as part of planning service capacity improvements
- Use rainwater harvesting at its depots for train washes
- Designed extra capacity and resilience into fibre option replacement for copper signal circuitry. Since the last report, DLR has invested several £million in changing the copper communications and signalling circuits to fibre optic ones. These are designed to have 200 per cent extra capacity than needed to provide resilience in case of part failure. They are armoured and situated either side of the guideway rail as a parallel system. The design is more resilient to humidity and flood

5.3.3 **Tramlink**

Tramlink infrastructure is being developed to meet the predicted growing demand for the service eg for the arrival of new retail developments in Croydon, for new residential developments and to link with services such as Crossrail 2 at Wimbledon. They have assessed weather and climate risks and are prepared for events by having processes in place eg submersible pumps on standby, a proactive drain cleaning programme, gritting or fast response to issues such as trees falling across the tracks.

5.3.4 **London Underground**

5.3.4.1 LU has a series of programmes to ensure Stations are able to support the needs of London now and in the future. For all line upgrades, during feasibility stage of each programme, LU considers climate change impact on the thermal environment tunnelled sections of the line. UKCP 09 projections for 2030's and 2050's are included in the evaluation of cooling asset requirements. At mid life replacement of these assets, LU re-evaluates the impact of climate change.

5.3.4..2 **Station Capacity Programme** – major works to deliver larger and modern stations at Victoria, Bank, Bond Street, Tottenham Court Road. All of these programmes had a detailed climate change assessment carried out as part of the design and consents process.

5.3.4.3 **Integrated Stations Programme** – Construction work to ensure that stations are fit for a range of needs, including step free access, larger capacity, smarter technology and working methods, improved lifts and escalators, better retail opportunities. Each programme has identified risks and used its risk register to inform its plans and design. For example: Fit for the Future stations has planned for energy efficient lighting and machines, one of the benefits of these is to ensure that extra heat is not generated. Examples include Holborn,

Camden Town, Elephant and Castle, South Kensington. These have all assessed and planned for flood risk and cooling as part of their design process.

5.3.4.4 The priority assets for stations are the signalling equipment rooms as failure there could shut down operation of a whole line. They all have Comfort Cooling Units and these are being replaced by more energy efficient Variable Refrigerant Flow units.

5.3.4.5 LU has been working to understand and manage heat risk for many years. Recently, we have seen the comprehensive roll out of new trains on our sub surface lines (Hammersmith and City, Metropolitan, Circle and District) which have air cooling. We are also looking at how salon air cooling can be introduced on the deep tube lines as part of the specification and procurement of the New Train for London that will run on the Piccadilly, Bakerloo, Central and Waterloo and City lines.

5.3.4.6 LU has assessed the risk to its embankments and cuttings stability from extreme rainfall, over current and future return periods. As part of its asset management system London Underground has a strategy for its earthworks, which has delivered an approach to identifying the condition, risk of failure and targeting delivery of earthworks renewal.

1. Understanding Asset Condition
   A full assessment of all earthworks assets that was carried out in 2011, so there is now an excellent understanding of the full earthworks asset catalogue and the condition of all existing slopes on the London Underground network.

2. Risk Assessment and Remediation
   A detailed risk assessment has been carried out mapping the likelihood of different failure modes (flow failure, frost shattering, scour erosion and prolonged rainfall saturation) with their potential impact on all earthworks assets. This follows the As Low as Reasonably Practicable principle and the knowledge and risk assessment has provided an excellent foundation from which to prioritise maintenance, repair, refurbishment, renewal, replacement and upgrade activities.

3. Good Practice
   LU engineers have considered not just the technical aspects of the work, but how it can be undertaken in a way that will enhance the environment and maximise sustainability, e.g. by ensuring the use of existing fill materials in earthwork remedial works' design and construction, and with sensitivity to the surrounding environment.
   London Underground has commissioned Mott McDonald to produce a design guide containing the latest understanding of clay cuttings and embankments. This will help to deliver a new understanding of analysis and failure methods to inform future upgrade works.

5.3.4.7 LU Comprehensive Flood Risk Review

London Underground has reviewed the risks to its services from flooding for decades and put in place a series of mitigation measures which have been kept under review.

More recently, London Underground has been carrying out a Comprehensive Flood Risk Review, which covers all assets and all causes of flooding, natural and non-natural, focusing on the impacts related to loss of service. This summer, the project will make recommendations to the Underground and London Rail Board that prioritises key assets and the current tolerability of safety risk as well as the costs of current business risk exposure should flooding occur. It will make recommendations for the optimisation of risk exposure in the future, by providing advice on steps necessary to manage and mitigate future flood events. The recommendations will be addressed via the appropriate process, such as the asset management plans or the business as usual operational response.

The flood risk review will also provide a dedicated Flood Risk Management *Geographical Information System* (GIS) to facilitate the management of this important hazard category in the future. More details about the review and a case study showing how it has been used to inform design of mitigation options as part of the Victoria Station works is provided in Appendix 4.

5.3.4.8 **London Underground – Heat Risk Mitigation Activities**

Since the last report, we have seen the comprehensive roll out of S stock trains on our sub surface lines (Hammersmith and City, Metropolitan, Circle and District) which have air cooling.

We are looking at how salon air cooling can be introduced on the deep tube lines as part of its specification and procurement of the New Train for London that will run on the Piccadilly, Bakerloo, Central and Waterloo and City lines. . The priority asset for stations would be the signalling equipment rooms as failure there could shut down operation of a whole line. They all have Comfort Cooling Units and these are being replaced by the updated, more energy efficient Variable Refrigerant Flow systems.

For management of current heat issues, we have doubled the capacity of ventilation shafts on the Victoria line, which provide more air flow. We have also installed air cooling units and mechanical chillers at two key busy stations, Oxford Circus and Green Park. In addition we have upgraded existing ventilation fans and installed new fans at a number of stations across the network.

We are looking at technologies and opportunities to reduce traction energy consumption and to recover braking energy before it is converted to heat. We are looking at opportunities to extract waste heat from the system and find beneficial uses and markets for it. We continue to monitor the deep tube line platform temperatures and humidity levels in order to evaluate both the heat input to the tunnels, and the impact of seasonal weather variations/climate change.

We continue to monitor external weather conditions and review these against the UKCP 09 projections.

5.3.5 Surface Transport

5.3.5.1 TfL's highway drainage asset is a complex arrangement of local private drains, drainage channels, balancing ponds, pump stations, attenuation tanks, all initially fed from road gullies. This is not one interconnected network, but

rather a large number of local systems. These typically connect to sewers under the control of Thames Water (particularly in Central part of the TLRN), or in some cases waterways under the control of the Environment Agency. Some TfL highway drains are interconnected with local authority highway drainage systems, receiving or discharging surface water before it flows into sewers or watercourses.

5.3.5.2 While it is not possible to mitigate against storms which exceed design capacity without significant investment, it is practicable to maintain highway drains in such a condition that they perform optimally when such events do occur.

5.3.5.3 Surface Transport Asset Managers assess weather and climate risks and develop plans to mitigate the highest risks identified as part of their asset management programme. These are further informed by analysing the issues and lessons learned involved in any extreme weather events, such as the highway drainage strategy review that was carried out following the August 2014 flooding issues on the A40. They considered all aspects of what caused the flooding, what happened re response and lessons learned to apply elsewhere on the network. This review identified critical locations where flooding would have the greatest impact on the road network. It identified a number of improvement actions, looking at CCTV monitoring, maintenance and supplementary cleansing, roles, training and relationships with other key organisations. Interdependencies with Thames Water is a key issue and there is close liaison to work through these.

5.3.5.4 The Surface Highways Asset team are also about to carry out a trial of material viability for different porous asphalts under London's road use conditions. This will look at how much the material ages, how it degrades - whether it blocks up with detritus and seizes to operate, whether it needs additional salting in winter, how best to remove water from the material, can it be rejuvenated.

5.3.5.6 The trial will look into five materials for a length of 100m each. There will be a conventional HRA 35/14, a Stone Mastic Asphalt surfacing, a Close Graded Asphalt Concrete Surfacing, A 14mm Open Graded (porous) and an 8mm Open Graded (porous) – and all we be compared to the same criteria. The asphalts are being designed and tested as they are not readily available, aggregate source is an issue.

5.3.5.7 Various testing will be carried out on each for a length of 36 months (or more) but we will have initial readings around March 2016. We are testing for:

- Water conductivity
- Noise
- Skid Resistance
- Ageing
- Defect Propagation

5.3.5.8 The highway drainage system already includes sustainable drainage measures in the form of vegetative systems, i.e. ditches, filter drains and balancing ponds which slow and store run-off, and which have a secondary biodiversity benefit.

5.3.5.9 The Surface Asset Management team have a dedicated extreme weather and climate change plan. This covers effective response process and equipment, partnership working, communications and testing. We are looking to increase and improve these in the coming years.

5.3.5.10 Bus infrastructure includes the buses themselves and bus stations. Most bus garages are the property of the contracted service operators. Bus stations have plans in place to manage the effects of any extreme weather. Where new infrastructure is built, eg West Ham Bus Garage or Richmond bus crew accommodation, the opportunity to include trees or green roofs is taken where feasible. For the buses, TfL's specification requires them all to have white roofs, tinted glass and openable windows or air conditioning in the case of the New Bus for London.

6 Long Term Planning for Climate Change in Proposed Transport Services

6.1 TfL is responsible for sponsoring, designing and building new transport infrastructure in the Capital, to meet the population growth demand forecasts and to deliver modern services that contribute to London as a liveable city. We are designing new infrastructure, eg stations, Northern Line Extension. Also into rolling stock eg New Tube for London, included in specification to ensure they are air cooled.

6.2 TfL's project management process, Pathway requires that all new projects and programmes with an estimated final cost of £1m or more carry out a Sustainability Assessment at feasibility stage, 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.

6.3 We have factored in climate change adaptation into early stages of putting a proposal together for planning permission eg The Garden Bridge, Crossrail 2. This includes a detailed consideration of future flood risk which is included in choosing location options and factored into design, engineering and construction choices.

7 The Role of Green Infrastructure and Sustainable Drainage

7.1 TfL has experience of installing and operating (maintaining) vegetated tracksides and road verges as well as green infrastructure such as green walls and roofs and sustainable drainage such as swales.

7.2 We have trialled these because they bring a range of benefits, together known as ecosystem services and to ensure that they fit in well with our primary purpose of operating transport services.

TfL Summary of Green Infrastructure and Sustainable Drainage Activities – March 2015

	Corporate	Rail and Underground	Surface Transport
Delivered	Environment Agency Partnership project looking at trialling SUDS for water quality and diffuse pollution improvement - which has funded the LU Upminster swale	Pathway project management process – review of drainage impacts of new projects	Has 26,000 street trees and green estate (woodland, ditches, verges, balancing ponds). Green walls at Edgware Road and the Mermaid Theatre. Use the CAVAT and iTree, surveying TLRN
	Head office green roofs	Sustainable drainage requirement in standard	Green Estate Management Plan
	Valuing urban realm toolkit	Comprehensive Flood Risk Review analysis and mapping	Streetscape Guidance
		Green roofs eg Ruislip depot, Stratford Train Crew Accommodation, Rotherhithe station	Review of drainage in all streets schemes
Current Work	Valuing green infrastructure – monetising benefits for business case (and link with CIRIA)	Comprehensive Flood Risk Review - Pathway requirement to assess flood risk	Will start a permeable asphalt trial in April on A127
	Nine Elms Planning Design Guidance	Pathway benefits of ecology	Starting discussions on a Greening the A12 EU funding bid with Newham.
		Building swale at Upminster	Greening Nine Elms Lane (Opportunity Area Planning Framework) – challenge with underground utilities, river light tree planting
		Building swale at Upminster Putting funding case together for green roofs at Embankment station and Upminster depot.	Designing green wall on the A406, funded by the Tunnels Investment Plan
		Writing a business case for project managers to justify new green roofs based on improved maintenance for roof leaks and seepage	

Planned	Green infrastructure monetised in business case methodology	Writing a green roof standard, to codify how a retrofit installation should be done	Business Plan has funding for green infrastructure from 2018

8 TfL's Interdependencies with Other Organisations

8.1. We have reviewed risks from extreme weather and climate change to those organisations providing our power and information communication technology (ICT) systems.

- The majority of ICT problems are caused by something happening further up the chain, i.e. loss of power supply
- We have a growing dependence on wifi networks, they don't perform well in extreme temperatures
- We are therefore undertaking work to look at the operational dependency on ICT

8.2.1 We have reviewed risks from water management companies being impacted by extreme weather and climate change. We work closely with them on operational issues such as failure of water mains that cause leaks into our systems. We have regular engagement with water suppliers and sewerage companies such as Thames Water and Sutton and East Surrey Water. London Underground has a specialist third party risk engineering team. Surface Transport has worked closely with Thames Water on streets drainage issues.

8.2.2 Since 2011, there has been a Partnership Programme established between TfL and the Environment Agency to identify and implement Sustainable drainage opportunities on the transport network that would help to improve water quality from our drainage to improve diffuse pollution to water courses under stress. This has culminated in the Agency funding TfL's installation of a track drainage swale near Upminster on the District Line.

8.2.3 We are now embarking on a new piece of joint working to identify areas in LU and Streets where the Agency's flood defence investment programmes could be aligned to our work.

Appendix 1 – TfL's Risk Management Policy and Process

TfL has a well established approach to risk management which has recently been enhanced with the development of a Pan-TfL Risk Management Policy and Procedure (fully aligned with the British Standard 31100:2009 Risk Management). This helps to ensure:

- clear links between risk management and strategic objectives
- risks are regularly reviewed
- adequate resources are allocated to support development of a risk management culture
- roles and responsibilities are clearly defined
- visibility of strategic and key business risks

The approach has a 'top down' set of strategic risks coupled with a 'bottom up' approach of risks generated by each operational business area. Figures 1 and 2 show an overview of the risk management process.

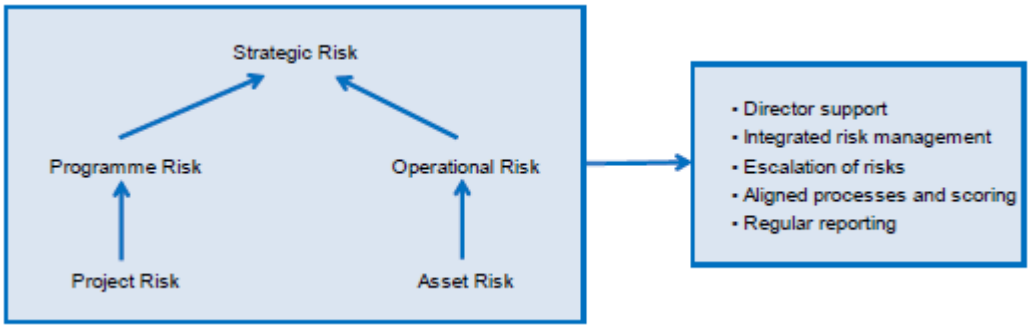


Figure 1 Overview of effective risk management

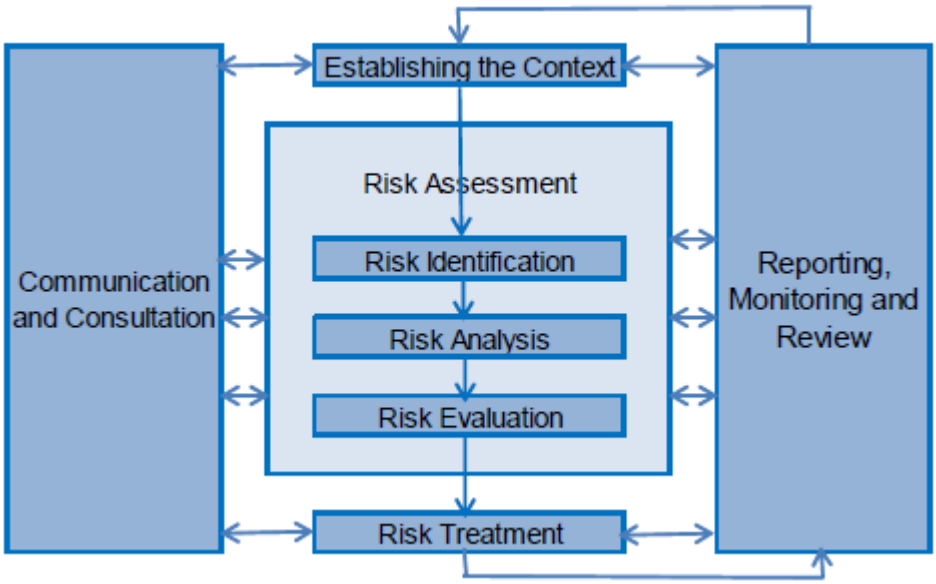


Figure 2 A summary of the process to manage risks in TfL

Risks are managed in the operating business by senior managers with support from embedded risk teams with formal reviews conducted on a periodic or quarterly basis depending on the impact of the risk as measured against the TfL risk appetite. Risks are identified, assessed, and recorded on to TfL's risk management system ARM (Active Risk Manager).

Weather and climate related risks are considered amongst a wide range of potential risks to the TfL business areas.

Regular updates regarding strategic risk are provided to the various business units via forums such as the Value Programme Board (VPB) and the London Rail Programme Board (LRPB). The consolidated position in the form of the TfL strategic risk register is captured and reported at the Pan TfL level by the Chief Finance Officer at the TfL Audit and Assurance Committee on a quarterly basis.

Strategic risks are owned by members of the Leadership Team and Senior Directors within the operating businesses.

The Assurance Delivery Group (ADG) chaired by the General Counsel continues to oversee risk and assurance arrangements within TfL on behalf of the Leadership Team

Improvements to the Risk Management Framework

Since the previous adaptation reporting power TfL has created the Strategic Risk Management Panel (SRMP), chaired by the Chief Finance Officer and includes the Finance Directors and Senior Risks Managers of the operating business. The purpose of this Panel is to develop a change programme to enhance the TfL Strategic Risk Management framework with the objective of fully integrating and evidencing risk in the decision making processes.

This Panel meets on a periodic basis to review progress and ensure consistent application of the risk management process. Progress includes:

- The risk management framework has been reviewed and updated. A new risk policy has been issued which commits the business to proactively manage all risks in order to enhance the business' ability to deliver its objectives;
- An updated risk procedure clearly laying out roles and responsibilities has been implemented to support the embedment of risk management across TfL;
- As part of the procedural update the Leadership Team has reviewed and updated the strategic risk appetite so that operating businesses clearly understand which risks must be escalated;
- The strategic risk process has been enhanced with an improved reporting format clearly evidencing the key controls and risk management plans. Each risk management plan has an identified owner and an action date with progress monitored periodically;
- Increased emphasis has been placed on quantifying the level of risk with each strategic risk being assessed against performance, cost, time and reputation impacts as well as the likelihood of occurrence;
- In order to support a risk management culture, a pan TfL risk awareness training programme has been developed and is being rolled out across the business during 2015;
- The risk management system has also been strengthened. Previously each part of TfL had individual management systems. All risks management processes and guidance have now been consolidated within the TfL Management System ensuring a consistent and standardised process;

- A programme is underway to achieve ISO 55001 asset management accreditation for each of the operating businesses. A key feature is the embedment of risk management throughout the asset life cycle.

Integrated Assurance Planning:
Assurance planning workshops are run annually to inform the planned assurance activity for the upcoming year based upon the agreed strategic risks and risk management plans.
The workshops are attended by the Directors from the operating businesses who are given the opportunity to identify areas of concern and key risks against which assurance activity is required to provide confidence in how these risks are being managed.
Workshops were held in December 2014 across TfL and will inform the 2015/16 assurance activity across TfL. Quarterly progress updates against the assurance plan is coordinated by Internal Audit and is reported to the relevant Boards in the operating businesses.

Risk Appetite
The TfL risk appetite is the level of risk TfL is prepared to tolerate in pursuing its strategic objectives. The risk appetite is based on an assessment of the current level of risk taking into account the potential impact should the risk materialise and the likelihood of the risk occurring using the criteria outlined in Appendix 1. The current level is assessed considering the existing controls embedded in the process. This helps the business to focus on those risks which are still assessed to be high and require further mitigation using the risk escalation routes outlined in Table 1. TfL currently recognises cost, time, reputation and customer service as the key impacts.

Likelihood						
	Very High	11	16	20	23	25
	High	7	12	18	21	24
	Medium	4	8	13	19	22
	Low	2	5	9	14	17
	Very Low	1	3	6	10	15
		Very Low	Low	Medium	High	Very High
		Impact				

Figure 3 The TfL Probability Impact Diagram

ARM Score	1-20	21-22	23-25
Rail & Underground	• Risk is managed within routine management meetings • Monitoring kept for deterioration and effectiveness of mitigations • Evaluation undertaken to see if there are any common themes or interdependencies that mean the risk needs to be escalated	• Escalate immediately to relevant Director for review of mitigation effectiveness and residual level of risk	• Escalate immediately to relevant Director for review of mitigation effectiveness and residual level of risk • Director to escalate to next London Underground and London Rail Board meeting
Surface Transport	• Risk is managed within the Directorate by the action owner. • Mitigations are monitored to ensure effectiveness; this is part of the Quarterly Risk Review process.	• Escalate to appropriate Director for evaluation of current mitigation in place to review effectiveness	• Escalate to appropriate Director for evaluation of current mitigation in place to review effectiveness • Director to escalate at Surface Board
Corporate Directorates	• Risk is managed by the risk owner and mitigation action owner. • Risk is reviewed and monitored by the Senior Management Team (SMT). • SMT, Director and Corporate Risk Manager to review risk and impact on services delivered by the Corporate Directorates to decide if further escalation is necessary	• Escalate to the Director for discussion at SMT meeting to ensure effective mitigating and review of scoring. • SMT, Director and Corporate Risk Manager to review risk and impact on services delivered by the Corporate Directorates to decide if further escalation is necessary • Review risk to determine if any	• Escalate to the Director discussion at SMT meeting to ensure effective mitigating and accuracy of scoring. • Director and Corporate Risk Manager to consider escalation to MD for discussion and further action. • Review risk to determine if any financial impact should be included in the quarterly

ARM Score	1-20	21-22	23-25
	• Review risk to determine if any financial impact should be included in the quarterly forecast process.	financial impact should be included in the quarterly forecast process.	forecast process.

Table 1 Risk escalation routes

The impact of catastrophic events, including weather-related is one of the 7 TfL strategic risks in the top level Risk Register for the organisation. This risk is owned by the HSE Director with appropriate mitigation plans and action owners detailed, as with all risks, on the system.

Risks are communicated across the business in a transparent and consistent manner. These risks include those from daily operations as well as capital projects and procurement processes. Mitigation actions and owners are identified.

Appendix 2 - Detailed Responsibilities of Transport for London

About Transport for London

Transport for London (TfL) provides most of the Capital's transport system. TfL organises the delivery of its responsibilities into grouped business areas:
London Underground providing London's metro system, responsible for more than 3.5 million passenger journeys a day. It has 11 lines covering 402km and serving 270 stations. During peak hours, more than 500 trains are in operation.
Surface Transport (London Buses, the TfL Road Network (TLRN), maintenance of London's traffic operations infrastructure, including 6,000 traffic signals , licensing of taxis and private hire vehicles, London river services, Victoria Coach Station, Congestion Charge, Dial a Ride and Barclays Cycle Hire).
London Rail (Tramlink, the Docklands Light Railway, Emirates Air Line and London Overground). In this report, Crossrail is also considered. Whilst it is a project under delivery, there are opportunities for adaptation and related long term operational aspects are being mitigated through design. Construction-related issues are also considered.
Corporate (including information management, planning, insurance, risk management and health, safety and environment).

In addition, TfL is the licensing authority for hackney carriages (taxis) and for private hire vehicles (PHVs), the highway authority for GLA roads and is the traffic authority for GLA roads and GLA side roads. As a traffic authority TfL regulates the way in which the public uses highways and is responsible for traffic signs, traffic control systems, road safety and traffic reduction.

The primary role of TfL, which is a functional body of the Greater London Authority, is to implement the Mayor of London's Transport Strategy and manage transport services across the Capital both directly and through its subsidiary companies such as London Underground Limited. TfL is a statutory corporation established under section 154 of the Greater London Authority Act 1999 ("the GLA Act").
The GLA Act requires that, when preparing his Transport Strategy, the Mayor must have regard to the effect the proposed strategy would have on climate change and the consequences of climate change.

The 2010 Mayor's Transport Strategy (MTS) therefore includes proposals 110 to 114 specifically relating to adapting to climate change which can be summarised as follows:

- Proposal 110: Determine the vulnerability of transport assets to the impacts of climate change and maintain existing infrastructure to improve resilience to climate change.
- Proposal 111: Prepare adaptation strategies to improve network safety and resilience to threats posed by climate change, which include – impacts risk assessments of infrastructure and operations; prioritisation of identified risks for appropriate management and mitigation including emergency planning and investment plans; and guidelines for major procurement projects.
- Proposal 112: Develop the transport system with climate change in mind by designing, locating and constructing new infrastructure to withstand climatic conditions anticipated over its design life; introduce energy efficient air conditioned rolling stock where feasible; continue to investigate cooling methods for the Tube network; and ensure all new buses entering the fleet feature specific climate change adaptation measures.

- Proposal 113: plant additional street trees.
- Proposal 114: develop and test plans and procedures to minimise risk to people and property, manage disruption and ensure rapid transport system recovery from the impacts of climate change events.

These proposals are to be achieved by working with Boroughs, Network Rail and other relevant stakeholders including transport infrastructure owners, the Highways Agency and airport operators.

In 2011, the Mayor published his Climate Change Adaptation Strategy. This includes an analysis of the impacts of climate change on London and proposals for the GLA Functional Bodies and other organisations to help become adapted to the changing climate.

TfL's Stakeholders

TfL has an extensive range of stakeholders, reflecting the wide scope of services it is responsible for delivering and the policy influence that it has. At the broadest level, most Londoners and visitors to the Capital have the potential to be TfL's customers, using its public transport services or TfL road network to access work, health, education and leisure destinations. People visiting London or commuting into the Capital are also important.

Other key stakeholders for TfL include the Mayor of London and national Government as well as the London Boroughs, London's businesses, TfL's suppliers, contractors such as train and bus operators and its employees.

TfL has identified climate change adaptation risk interdependencies with other organisations that are also stakeholders. These are described in more detail in section 7 of this report.

The broad scope of stakeholders for TfL means that there are a number of issues relating to the impact of climate change that are important to them. These can be summarised into how they affect service availability, reliability, safety and comfort. TfL has found through experience of managing weather-related incidents that communication with stakeholders is of prime importance as well as highlighting the value of focused planning, collaboration between different organisations and public agencies, and clear communication with business partners and customers. TfL's stakeholders value receiving clear and consistent messaging about the impacts of weather on its services. Providing information and advice that helps stakeholders to plan their route and timing of their journey is an essential part of TfL's activities.
The legal functions of TfL are set out in Part IV of the GLA Act. These include the power to:

- provide and secure the provision of public passenger services to, from and within Greater London;
- regulate the London bus network;
- operate London Underground;
- exercise control over London River Services and the promotion of the safe use of the Thames for passenger and freight movement;
- provide certain London railway passenger services such as DLR, Tramlink and London Overground
- make road user charging schemes;
- make transfer schemes;
- provide travel concessions;

- issue penalty fares;
- promote private bills in parliament; and
- provide financial assistance (to a person or body doing anything which in the opinion of TfL is conducive to the provision of safe, integrated, efficient and economic transport facilities or services to, from or within Greater London).

The general transport duty is a duty on the Mayor to develop and implement policies and proposals for the promotion and encouragement of safe, integrated, efficient and economic transport facilities to, from and within Greater London.

Appendix 3

Table of Actions: Implemented Actions

Business Function	Extreme Weather or Climate Risk	Summary of Actions (as set out in first report)	Timescale over which actions were planned	Progress on Implementation of Actions	Assessment of extent to which actions have mitigated risk	Benefits/challenges experienced
TfL Road Network and Bus operations	Increase in rainfall especially during winter periods	Mitigation already under way - drainage plan, gully and pumping station renovation. Interdependency with Thames Water, maps of flooding hotspots on the TLRN and bus stations and garages at risk of flooding.	Ongoing	Pumping station work complete. Hotspots, drainage plan, gullies - A review of the highway drainage strategy was carried out. See report page 14.	This review identified critical locations where flooding would have the greatest impact on the road network. It identified a number of improvement actions, looking at CCTV monitoring, maintenance and supplementary cleansing, roles, training and relationships with other key organisations.	The review has informed the drainage plan, helping to prioritise and fund the upgrade measures.
Rail, Tube - Rail short circuiting preventing train operation, flooded under-track crossings, cable damage	Increase in rainfall especially during winter periods	Some assumption that these impacts will be short term disruption. Mitigation includes accurate weather forecasts, planning and response	Ongoing	London Underground carried out a Comprehensive Flood Risk Review covering all sources of flood risk to all of its assets. See report pages 12 and 25.	The review provides a technical report to the Business that makes a statement on the current tolerability of safety risk and the current business risk exposure. It makes recommendations on optimisation of risk exposure in the future, by providing advice on steps necessary to manage and mitigate future flood events. It provides a dedicated Flood Risk Management *Geographical Information System* (GIS) to facilitate flood risk management.	The review provides a quantified input to the business case for targeting specific mitigations.
Rail and underground tunnels	Tidal and fluvial (and drainage) flooding	High level of mitigation already exists. Network management, tunnel mitigation work, emergency preparedness, flood plans	Ongoing			

Business Function	Extreme Weather or Climate Risk	Summary of Actions (as set out in first report)	Timescale over which actions were planned	Progress on Implementation of Actions	Assessment of extent to which actions have mitigated risk	Benefits/challenges experienced
Diverse range of TfL business areas, including London Underground, Rail, buses, trams	Extreme high temperature	Optimising service patterns to minimise trains halting in tunnels. Improving heat loss from trains, air conditioned trains on sub-surface lines, Victoria line tunnel ventilation. „Stay Cool" communication campaign, specify white bus roofs, install upper deck cooling systems on all new buses, relocate street traffic control equipment	Ongoing work deals with excess heat from line upgrades. Further work needed in future decades to prepare for climate change.	Most of these actions are ongoing, our 'business as usual' approach to managing extreme weather. For tunnel and station ventilation, see report pages 12- 13. We have doubled Victoria Line ventilation shaft capacity. We have installed air cooling units at Green Park and Oxford Circus. We have introduced air cooled New Bus for London and trains on the sub surface lines.	The measures have mitigated current heat risk from more frequent train service and on new buses.	There are benefits to passenger comfort. There are challenges relating to increased energy use in fans and motors. We are looking at opportunities to extract waste heat from the Underground system.
Rail, Underground and Roads – Earthworks stability e.g. embankments and cuttings	High rainfall or drought affecting the degree of soil moisture in earthworks	LU Asset management plan, use plant species that can withstand expected adverse conditions, cyclic and reactive landscape maintenance regime in place.	Asset Management Plans and will be reviewed regularly	See report page 12. A full assessment of all earthworks assets that was carried out in 2011, so there is now an excellent understanding of the full earthworks asset catalogue and the condition of all existing slopes on the London Underground network.	As a results of the assessment, all earthworks with high risks received effective mitigation action.	LU engineers have considered not just the technical aspects of the work, but how it can be undertaken in a way that will enhance the environment and maximise sustainability, e.g. by ensuring the use of existing fill materials in earthwork remedial works' design and construction, and with sensitivity to the surrounding environment.
TLRN, bus network, transport network platforms, rail and tram tracks, signals	Extreme ice and snow	Winter Maintenance Plans and a robust Winter Maintenance Programme. Road users informed of real time hazards via the London Streets Traffic Control Centre through Visible Message Signs and updates on TfL website which serves to modify road user behaviour through improved communications. Adopt components used in countries which already experience extreme temperatures. Increase network	Ongoing (seasonal)	These plans are ongoing as part of seasonal preparedness and are performing well. See report page 8. London Overground has installed points and track heaters at depots as part of its process to extend the service from four to five car trains. See report page 10.	Our plans mean we have been assessed as achieving good resilience performance compared to other transport providers in London during periods of cold weather and ice.	The benefits include provision of continued services for our customers.

		intelligence and extend hotspot database. Salt alternatives to be investigated. Collaboration with London boroughs to improve London wide resilience including compilation of resilience networks, mutual aid and consideration of pan London salt stocks				

Appendix 4: Table of Actions: New and Continuing Actions

Further or New Actions Planned	Risks Addressed by Actions	Timescale for New/Further Actions Planned
Addressing the risks identified in the London Underground Comprehensive Flood Risk Review	Natural and man made flood risks	Varies according to which mitigations are specified and delivered by different parts of the business during the next year.
TfL is doing a trial of material viability for different porous asphalts under London's road use conditions See report page 14	Pluvial flood risk	By end of 2016
London Underground has commissioned a design guide containing the latest understanding of clay cuttings and embankments. This will help to deliver a new understanding of analysis and failure methods to inform future upgrade works.	Flood and heat (freeze/thaw) risks	By end of 2015
Continuing to deliver the highways asset management plan	Flood risks	Ongoing
Continuing to deliver the Rail and Underground asset management plan	All climate risks	Ongoing
Continuing to specify new projects and services with regard to climate projections	All climate risks	Ongoing

Table of Detailed Impacts related to Assets																		
Weather type	**Extreme hot weather**			**Drought**			**Rain/flooding**			**Cold/freeze**			**Snow**			**Wind**		
Potential change	***Higher temperatures and increased frequency of hot weather***			***Longer periods of drought and increased frequency of drought***			***Heavier rain and increased frequency of high rainfall***			***Lower temperatures and increased frequency of cold/freezing weather***			***Heavier snow and increased frequency of snowfall***			***Stronger winds, gustier winds and increased frequency of high winds***		
Assets	**Risks**	**Reactive mitigation**	**Long term mitigation**	**Risks**	**Reactive mitigation**	**Long term mitigation**	**Risks**	**Reactive mitigation**	**Long term mitigation**	**Risks**	**Reactive mitigation**	**Long term mitigation**	**Risks**	**Reactive mitigation**	**Long term mitigation**	**Risks**	**Reactive mitigation**	**Long term mitigation**
Ground	Trams - tarmac melts in hot weather impacting on rails. Shrinkage of clays causing fissures.			Ground Subsidence causing structures to move, more burst water mains	Monitoring	Correction	Surface flooding, trams suffer badly	Improved drainage, flood-proof equipment, build walls around depots	Don't build equipment rooms with sunken floors	Ballast heave	Inspections							
Tracks	Buckled rails, delays, derailments, changes to track alignment, increased risk of fire affecting wooden sleepers	Heat duties, additional track inspections, speed restrictions	Continuously welded rail, different track design standards	Can affect track bed causing alignment variations, deterioration of wooden sleepers	Speed restrictions, monitoring, more sleepers required		General rain damage to track bed, inundation, wet beds, debris washed into switches and crossings, abnormal wear on rail head due to sediment	Clear drains more frequently, drainage inspections, increased lubrication of points	Larger drains	Broken rails, frozen points, frozen tram track gullies, rail shrinkage and damage	De-icing, point heating, de-stressing, continuously welded rail	Heated rails, more investment in ploughs etc, different track form design, different systems	Tram track gullies blocked, derailments, poor conductivity, rolling stock stuck in drifts. Can't run when can't see head of rail.	Tram snow ploughs, run all night, DLR has heated rails on inclines.		Debris blown on to tracks, greater density of leaf fall	Speed restrictions	
Tunnels				Ground Subsidence causing structures to move	Monitoring	Correction	Scour of tunnel roofs, blockage of drains, failure of pump systems, flooding from water mains, changes in stresses on tunnel walls	Clear drains more frequently, liaison with Port of London Authority, inspections	Larger drains								Problems with operating ventilation systems causing fire risk		
Bridges and viaducts	Expansion causing over-stressed bearings, compromising stability	More frequent inspections	New standards for weight limits	Ground Subsidence causing structures to move	Monitoring	Correction	Scour, pressure of water	Shut bridge, build up concrete around supports	Scour-resistant foundations	Contraction, cracking of brickwork due to freeze thaw	Assessment	Repairs	Snow can drift more on exposed bridges/viaducts					

Embankments and cuttings	Shrinkage of soils causing damage, increased fire risk	Inspections		Ground Subsidence causing structures to move. Increased risk of fire.	Monitoring	Correction	Slippage caused by rain storms, stability affected by the way vegetation is managed (worse in cuttings)	Piling, shoring up	Earth retaining structures	If dried out, freeze/thaw causes problems	Assessment	Repairs							
Drainage				Caking of drainage sediments	Increased maintenance		Blocked drains, drains unable to cope with floods, pollution from overflows, drainage assets may not be in correct positions if groundwater rises	Clear drains more frequently, particularly after heavy rain	Larger drains	Blocked drains	Clear drains more frequently	Larger drains	Melting snow can inundate drains						
Power supply (non-rail infrastructure)	Heat haze distortion. Equipment failure. Overloading (more air con). More regular brownouts	Ventilation	Cooling, replacement with higher spec components, smart grid solutions				Flooded cable routes etc., power failure			Excess demand, more cable failures			Power supply can be affected particularly in rural areas			Power failure			
Sub stations	Heat haze distortion. Equipment failure	Ventilation, monitoring temperature of substations (e.g. on DLR)	Cooling, replacement with higher spec components				Floods can knock out substations, e.g. Pudding Mill Lane on DLR	Improve local drains	Flood protection				Outdoor Network Rail substations may be a problem						
Third rail systems	Can buckle and fall over. Third rail more susceptible to changes in temperature.	Temporary speed restrictions	More modern and sophisticated design				Short circuit, flooded under-track crossings, cables not designed for immersion in water (electrolysis)	Improve local drains	Larger drains, pumps (expensive)				East London Line has flat-topped rail but no problems on DLR	Deicing trains					
Overhead line electrification	Sags, dewiring	Speed restrictions					Running rail is the return - failure of power supply						Can ice up, weight of snow can lead to power failures	Run all night		Fatigue of lineside structures	Inspections		

Signalling system	Heat haze distortion. Equipment failure. Point equipment drying out. Shrinkage and ageing of wiring. Increased risk of fires damaging cable runs. Overheating signalling equipment rooms.	Ventilation. More expensive higher quality equipment. More off-the-shelf equipment, better specification of equipment. Increased maintenance.	Cooling, replacement with higher spec components	Ground Subsidence causing signal structures to move			Track circuit failure, obscured visibility, speed restrictions, timeouts, failure of axle counters and point machines. Lubricant washed off points.	Clear drains more frequently, increased maintenance	Larger drains	Frozen points	Point heating is normally provided in open sections	Point heating is normally provided in open sections	Signal operating temperature range?, can't view the signal. Point heaters don't work in snow.	Performance issue as for safety the red signal aspect is the lower aspect so that it cannot be obscured by a build up of snow	Cab signalising and removal of equipment in location cases wherever possible.	Signal structure movement - unlikely for structures in past 20 years as foundations are significant	Examine old structures	Strengthen old structures, replace with cab signalling
Comms systems	Equipment failure	Ventilation. More expensive higher quality equipment. More off-the-shelf equipment, better specification of equipment.	Cooling, replacement with higher spec components				Roof canopies, cable conduits. Temporarily lose radio in very heavy rain.	Appropriate containment								Movement of CCTV cameras and comms equipment		
Control centres	Equipment failure, failure of air conditioning, flat roof cracking and expansion	Ventilation. More expensive higher quality equipment. More off-the-shelf equipment, better specification of equipment. Remote monitoring.	Cooling, replacement with higher spec components				Building on floodplains, flooding of flat roofs	Protecting control centre	Moving control centre	Cracking of brickwork due to freeze/thaw, increased heating required								

Depots	UV degradation of exposed equipment e.g. Cables, shed roofs. Staff affected, hot trains, track buckling. Interface between depot and main line. Flat roof cracking and expansion.	More care and attention					Building on floodplains (e.g. Beckton depot for DLR)	Protecting depot	Moving depot	Cracking of brickwork due to freeze/thaw, increased heating required, rainwater harvesting pipes may burst			Running trains all night can mean depots get iced up. Heavy snow loading on roofs.	Park vehicles over points, run trains around depots. Inspect roofs more regularly.		Damage to signage.		
Rolling stock	Train reliability lower in hot weather, signal computers need cooling. On-train staff risk. Windows cracking on trains. Trains heating up due to solar gain.	Cab air con, window modifications, improved maintenance. Detraining.	Cooling, replacement with higher spec components. Locate equipment better where there is ventilation.	Can't wash trains if hosepipe bans		Plan for water independence e.g. rainwater harvesting	Electrical systems impacted	Inspection	Improved packaging	Train reliability lower in cold weather, doors get stuck, wheel-rail lack of traction, can't wash train if frozen			Vents etc get blocked by snow, train horns and door pockets, blocked by snow. Equipment on train roofs can be affected.	Cold weather plan (welly booting). Winterisation plan for each type of rolling stock.		Containers blown off freight trains, blocking tracks, train resistance to wind loading		
Maintenance	Fatigue, sunburn, heatstroke. Increased inspections required, harder for workforce to get to site	Undertake route maintenance in different ways, precautions.		Drought orders affecting ability to work			Can't do maintenance in heavy rain, can't open equipment cases or do track welding			Plant and tools not working			Inability to maintain and inspect due to access restriction, staff clearing snow, staff stranded	Plan maintenance away from winter period	Snow clearing equipment	Crane use and working on steep embankments may be stopped		

Station assets (approaches, signs, lifts, PA, interchanges, etc.)	Equipment failure and fatigue (wear out faster), melting asphalt on roofs, flat roof cracking and expansion. Expansion of nosing stones and tactile strips.. Shrinkage of clays causing damage to station structures. Failure of air conditioning.	Ventilation, increased maintenance	Cooling, replacement with higher spec components				Flooding of roads outside stations, people with wet feet and umbrellas can damage lifts, structural instability in certain areas, flooding of lift shafts due to rising groundwater		Change architecture	Cracking of brickwork due to freeze/thaw, increased heating required, cracking of roofs, glass breaking, equipment becomes more brittle			Snow on roofs, stairs, platforms, slips trips and falls. Where do you put all the snow?			Canopies broken/blown off, wind tunnel effects could lead to station closures, damage to signage		
Green assets (trees, other vegetation)	Lineside fires, different vegetation types and animals.	Clearing, vegetation control		Early leaf fall, trees collapse onto route	Inspection	Removal or pruning	Vegetation grows faster	Cut back more					Snow building up					
Boundary issues (e.g. on-street running of trams, level crossings)							Neighbouring road system can flood and impact on stations, neighbouring developments can cause dewatering leading to movement						Responsibility for clearing wider environment. Buses/cars blocking trams. Tramlink have to grit the roads.			Third parties can maintain infrastructure that could blow onto track		
People (passengers and staff)	Overheating, increased assaults, reduced concentration, more people wandering in front of trams, passenger illness causing delays	Ventilation	Cooling,	Drought orders affecting ability to work			Staff unable to get to work. Slips, trips and falls. Wet and cold personnel unable to work			Water mains freeze affecting staff facilities			Slips, trips and falls. Staff getting to work. Staff fatigue. Running out of grit.	Provide tools to do the job - shovels etc.		Potential for injury to passengers		

Appendix 6 - London Underground Comprehensive Flood Risk Review

London Underground undertook a Comprehensive Review of Flood Risk (LUCRFR) from 2013-15. This was established to review all significant sources (*both natural and non-natural*) of flooding risk to all of LU's vulnerable assets. The scope involved evaluation of risk in both safety and business terms. The project commenced in May 2013 and is due to complete in June 2015. *London Underground* (LU) last generally evaluated their flood risk exposure in 1999 through the *Flood Mitigation Project* (FMP) which has informed project flood mitigation designs since it reported.

The LUCRFR project scope is substantial and considers all the major flood hazard modes (*tidal, fluvial, pluvial, groundwater, reservoirs, sewers and water mains, etc.*) and quantifies the magnitude of the threat that each hazard mode poses to LU assets vulnerable to inundation. It considers both accidental and deliberate initiation of non-natural flood events. All hazard modes *bar* water mains, have been either explicitly or implicitly modelled by external bodies (*Environment Agency, British Geological Survey, Lead Local Flood Authorities, etc.*) which have made their hydraulic modelling results available to LU. Water main bursts are being hydraulically modelled by the LUCRFR project *in-house* for high-consequence sites; with that modelling data then being used as a statistical guide for qualitative assessment of hazard magnitude at the lower consequence sites (*which form the bulk of the vulnerable assets*).

The LUCRFR project will provide a technical report to the Business that makes a statement on the current tolerability of safety risk and the current business risk exposure. It will make recommendations for the optimisation of risk exposure in the future, by providing advice on steps necessary to manage and mitigate future flood events. It will also provide a dedicated Flood Risk Management *Geographical Information System* (GIS) to facilitate the management of this important hazard category in the future.

Case Study/Example - Victoria Station (as upgraded)

The *Victoria Station Upgrade* (VSU) project has been progressing in parallel with the LUCRFR, which has latterly provided detailed visibility of flood risk to the VSU project, so that it can inform urban realm and flood mitigation designs – including *mitigation-type* recommendations aligned with the Business' developing corporate strategy on this important matter.

The LUCRFR output provided a detailed technical report exploring each flood hazard mode in turn and examining residual risk to the Business. For example, River Thames tidal/fluvial flooding hazard is already protected against by EA-monitored Thames Tideway defences. These strategic defences offer vulnerable parts of London 1 in 1000 years return period flood protection; this level of protection exceeds the probabilistic limit set by LU standards for this particular hazard mode, so *residual risk* is deemed acceptable without further analysis. There is consequently no mitigation design-driver resulting from the tidal/fluvial threat to VSU. In contrast, the threat from burst water mains was less clearly resolved by previous studies and a probabilistic limit for such a complex threat cannot reasonably be set. The LUCRFR project therefore modelled this hazard mode in detail, both hydraulically and (*subsequently*) in risk terms. This provided a high resolution understanding of hazard magnitude (*flood depth*) and probability of occurrence, consequences (*in terms of safety and business impacts*) and the product of those variables – risk (*presented in monetised terms*). This

risk value can then used by the VSU project to develop appropriately *cost-beneficial* flood mitigation design options, that can meet statutory requirements and LU standards – *thus* to render residual safety risk *As Low As Reasonably Practicable* (ALARP) and residual business risk '*acceptable*' in terms of railway reliability and performance.

The above detailed analysis of the burst water mains hazard mode, revealed that one of the existing station entrances was not fully protected against the requirements set by LU standards and that current VSU flood mitigation designs for it would (*very likely*) also be inadequate. Indeed, the magnitude of the hazard at this point was shown to be very high and will require specialist flood mitigation beyond the capability of typical stop-logs/flood-boards. The LUCRFR project is currently advising the VSU project with regard to quantitative cost benefit analysis (QCBA) of specific mitigation options, and on the general subject of appropriate flood mitigation *types*. This last point is in the context of the Business' corporate push to replace its dependence on the potentially unreliable use of stop-logs. To that end, the Business is exploring a change to *fixed-in place* protection devices rather than *remotely-stowed* ones, and for the more significant hazard magnitudes – a shift to the *tension-fabric* technology currently being rolled-out by the New York Subway (*in response to the Superstorm Sandy impacts*).

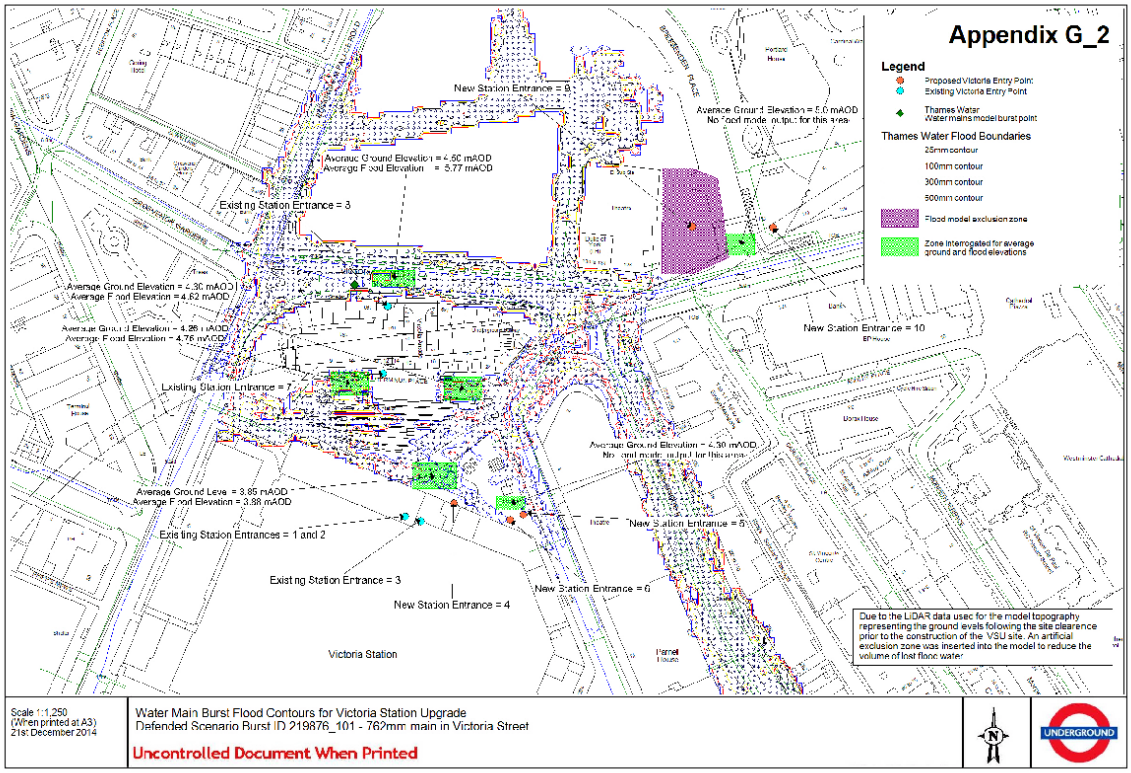


Figure x – Burst water mains hydraulic model output

Figure 1 above provides a graphical representation of the flood extents and depths associated with one of the water mains burst scenarios modelled by the LUCRFR project. It identifies the deep water that may occur in Victoria Street in the event of a proximate burst to a 750mm dia Thames Water asset. The estimated probability of occurrence of this event is approx 1 in 500 years, which is clearly and quite correctly rare. However, the consequences must also factor into the quantification of risk, and they are relatively high. So the risk posed by such an event produces a significant monetary impact on the railway..

This approach to flood risk management is only possible because of sophisticated modelling and data management software and hardware. The benefits for the Business arise on many levels in the context of asset management and risk control. The requirement to demonstrate to the *Office of Rail Regulation* (ORR) how the Business maintains the residual safety risk from flood ALARP is streamlined through these tools and developments; because it becomes an automatic bottom-up aggregation exercise based on individual asset assessments - this renders more objective, reliable and searchable outputs. In addition, the Business' *Project Management* systems are being augmented and revised by the LUCRFR project, to ensure that appropriate 'project gates' exist whereby flood risk is automatically assessed and appropriately mitigated if required.