Summary: Climate change and interdependency risks for London's land based transport sector

Chapter for ARP4 reporting

May 2024

This page left intentionally blank for pagination.

Mott MacDonald
St Vincent Plaza
319 St Vincent Street
Glasgow G2 5LD
United Kingdom

T +44 (0)141 222 4500
mottmac.com

Summary: Climate change and interdependency risks for London's land based transport sector

Chapter for ARP4 reporting

May 2024

Mott MacDonald Limited. Registered in
England and Wales no. 1243967.
Registered office: Mott MacDonald House,
8-10 Sydenham Road, Croydon CR0 2EE,
United Kingdom

Issue and Revision Record

Revision	Date	Originator	Checker	Approver	Description
A	29/02/2024	JB/FC/HD/SH	NVD, KM	JB	First draft
B	19/04/2024	KM/FC/HD/SH	JB	BB	Second draft
C	17/05/2024	KM	JB	JB	Final issue

Document reference:

Contents

Figures

Glossary

Term	Definition
Adaptation	The process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. (TfL ARP3)
Cascading impacts	Cascading impacts occur when impacts in one or more parts of an interconnected system may trigger impacts in other parts of the system. For example, flooding can cause direct damages to power infrastructure which then cascades through to other sectors such as transport, increasing risk across the system. (CCRA3 Technical Team).
Climate hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. (IPCC AR5).
Climate risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services) and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence. (IPCC SR1.5).
Codependency	Areas where the transport sector both contributes to the interdependency risk as well as being impacted.
Downstream interdependency	Transport operations are also critical for other sectors, such as health (for example, ambulances requiring road access), education (for example, travel to/from school) and employment.
Emerging interdependency	An interdependency that could not currently be realised because the infrastructure asset or pathway is not currently present (eg electrified fleets) but is expected to be in place within the time periods used in the climate assessment (2050s, 2080s).

Term	Definition
Interdependency	For the purposes of this project, an interdependency is defined as an organisational interface where a climate induced risk is shared by multiple sectors, leading to increased vulnerability.
Intradependency	Impacts to one part of the land based transport sector (LBTS) can also cascade across the sector as London's LBTS depends on the smooth running of each LBTS organisation. For example, rail station closures due to flooding could increase road traffic and affect bus service reliability, or flooding of network management control centres could result in major network disruption. In addition, flooding of transport networks can affect the ability of staff to reach their workplaces and so affect service reliability.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation. (IPCC AR5)
Upstream interdependency	The London LBTS and its operations are also impacted by other sectors. For example, power supply, telecommunications, water supply and wastewater services. If these are vulnerable to climate change, then London LBTS operations will also be affected. London's LBTS is also dependent on its supply chain to operate efficiently. If the supply chain is vulnerable to climate change impacts, operations will be affected.

1 Climate change and interdependency risks for London's land based transport sector

London's road and rail sector collaborated on a joint project (led by Transport for London) to improve understanding of its upstream interdependencies, as part of the fourth round of the Adaptation Reporting Power (ARP4).

1.1 Introduction

1.1.1 Project context

Transport for London (TfL), Network Rail, National Highways, High Speed 2 (HS2), High Speed 1 (HS1), the Department for the Environment, Food and Rural Affairs (Defra) and others have continued to work together as part the Transport Adaptation Steering Group (TASG) to deliver joined-up approaches to their ARP4 submissions. This project is a continuation of these attempts to take a collaborative approach to climate adaptation and resilience across London. This collaborative approach to sharing knowledge and best practice has been recognised within the London Climate Resilience Review.

1.1.2 Interdependencies

Climate hazards that impact on one organisation's assets can lead to cascading impacts to other organisations, known as interdependencies.

The congested nature of London's infrastructure increases both the likelihood and potential magnitude of cascading impacts. This means that a multitude of organisational interdependencies must be considered, where assets or processes beyond the land based transport sector (LBTS) may be impacted by climate hazards and impact the transport sector.

"London can be viewed as a system made up of many interdependent and interconnected parts. London's transport infrastructure is dependent on energy infrastructure which is dependent on water infrastructure and vice versa; disruption to one part of the system has cascading effects. These interdependencies extend beyond London's boundaries, so we have considered impacts and solutions beyond London." London Climate Resilience Review Interim Report, pg. 8[1].

Understanding and managing climate hazards in relation to these organisational interdependencies is one of the London LBTS' biggest challenges. Therefore, a key focus for the LBTS as part of ARP4 is to:

- Identify both upstream and downstream interdependencies that exist between transport and assets and services in different infrastructure sectors (eg water and drainage, energy and telecommunications)
- Identify how climate hazards (eg flooding, drought and heatwaves) affecting upstream interdependencies will impact the delivery of transport services.

[1] London Climate Resilience Review Interim report

1.1.3 Project aim and approach

This project combines system mapping with a climate interdependency risk assessment for the London LBTS' upstream interdependencies and draws on guidance from the UK Government and Defra. Stakeholder engagement has taken place throughout the project to codevelop an understanding of existing interdependencies, climate hazards and potential actions to reduce climate interdependency risks. Many of these findings and actions will be applicable beyond London and for the wider LBTS. In particular, using a systems approach to codevelop an understanding of interdependencies with stakeholders from across multiple sectors can highlight opportunities to co-fund investments in climate adaptation which benefit all parties.

Using a systems approach for interdependency analysis has provided the platform for the climate interdependency risk assessment which follows a standard methodology consistent with Defra's reporting guidance and the ARP3 assessment. Further detail on the project method and the approach used for the climate interdependency risk assessment can be found in the full project report.

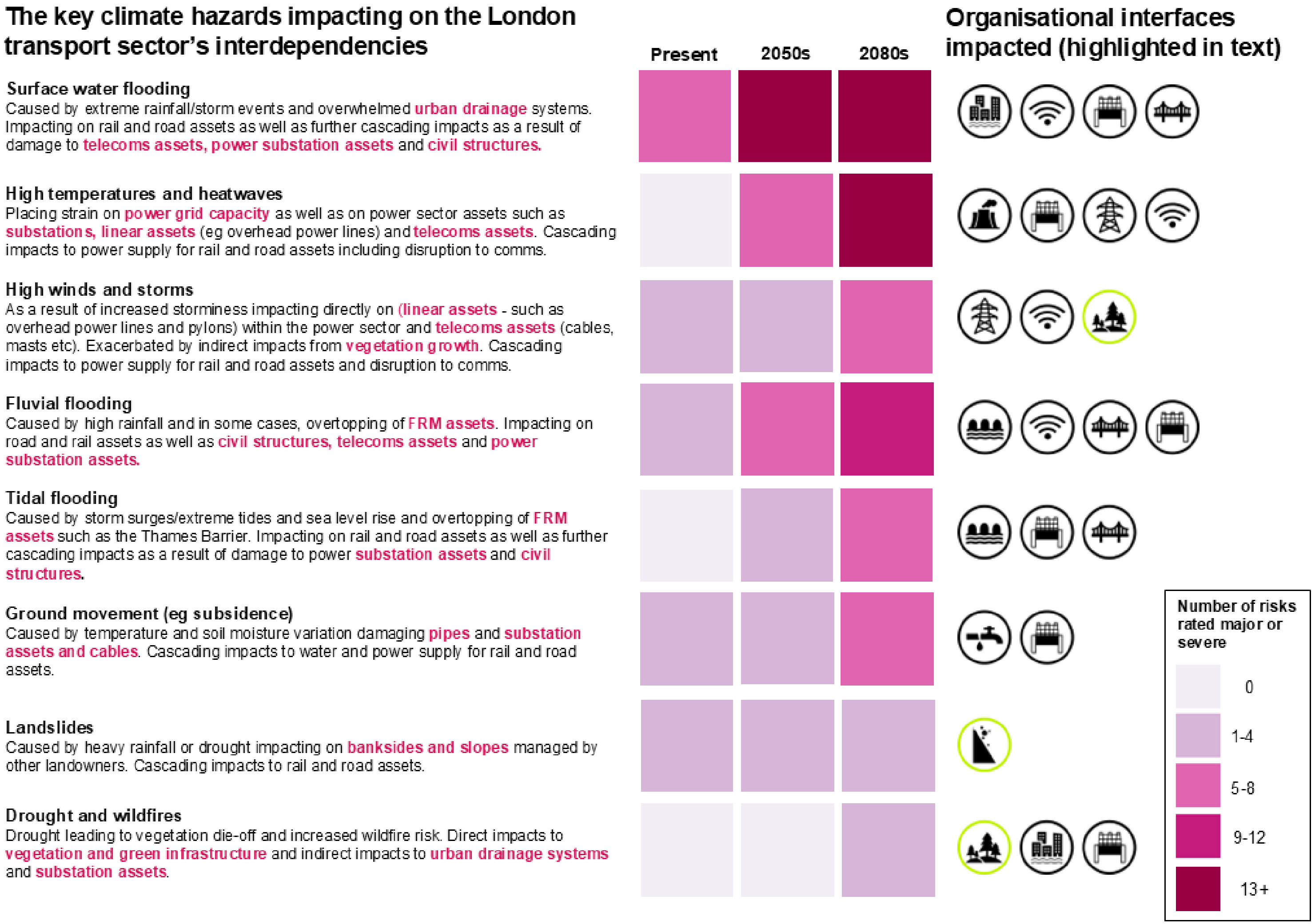
1.2 Findings

A total of 114 climate interdependency risks have been identified and scored against the likelihood of this pathway occurring and the potential magnitude of an impact or consequence across three time horizons: present day; 2050s; and 2080s. The full risk assessment has been included as an appendix to the ARP4 reports. This section discusses the key findings relating to the climate interdependency risks and trends most relevant to the LBTS. A summary of the findings by sector with further detail is presented in the full report.

1.2.1 Key risks for the London LBTS

Figure 1.1 summarises the key findings from the risk assessment. Key climate hazards are shown along with the interdependencies (or interfaces) that are most impacted for each climate hazard. Analysis of the risk assessment shows the number of risks which meet the threshold of "major" or "severe" for each of the main climate hazards.

Figure 1.1: Trends in total risk severity for each interface across the three time horizons. Organisational interfaces are highlighted in pink where referenced in the description of the key climate hazards



Climate hazards

The climate interdependency risk assessment has identified the following key climate hazards:

- Surface water flooding driven by higher and more intense rainfall
- Fluvial flooding caused by higher rainfall in upstream catchments
- Landslides driven by higher and more intense rainfall and drought impacts on soil moisture
- High temperatures impacting on the power and telecoms sectors, along with impacts from wind and associated debris
- Sea level rise coupled with storm surges and extreme high tides mean that tidal flooding remains a significant risk for London.
- Ground movement (eg through subsidence) may lead to widespread impacts on subterranean assets across multiple sectors but is considered a medium-risk due to the slow onset of impacts
- Drought and wildfires represent an emerging risk, with the latter a particular concern for the power sector.

Groundwater flooding has the potential to impact significantly on subterranean assets across multiple sectors, with a reduction in chalk stream abstractions upstream potentially increasing this risk[2]. However, understanding of these impacts is currently limited and this lack of confidence is reflected in the scoring, where it is grouped with fluvial flooding and impacts from increased average rainfall. Frozen precipitation and low temperatures are anticipated to reduce in significance over time, as projections indicate a warming trend in winters through the 21st century.

Interdependencies

The main findings from the climate interdependency risk assessment are:

- Power sector interfaces score highly due to high levels of interdependency and the multiple climate hazards affecting power assets
- Urban drainage and civil infrastructure interfaces also score highly due to likelihood scores for flood hazard impacts and high consequence scores
- The telecoms interface is a medium level risk, although this may vary significantly according to each LBTS organisation's individual configuration. However, reduced confidence in these scores is noted due to the limited information available from both the telecoms sector and the LBTS regarding vulnerability. The telecoms sector's dependency on the power sector is also noted but not assessed directly within this project
- Impacts from vegetation and pipe bursts generally received lower scores due to evidence of adaptation measures and lower consequence scores
- Impacts from flood risk management (FRM) assets were scored lower due to high levels of proposed adaptation for the Thames Barrier reducing likelihood, despite high consequence scores.

Overall trends suggest that surface water flooding already poses a major risk to London and this is only likely to increase in the future. Other hazards such as high temperatures and heatwaves, high winds, fluvial and tidal flooding will increase in severity into the 2050s. Climate interdependency risks increase significantly in the 2050s as decarbonisation, electrification and changes in climate hazards lead to greater impacts from the power sector. Impacts from

[2] Chalk streams systems (2023) – Mott MacDonald project commissioned by the Environment Agency to explore potential impacts and unintended consequences of chalk stream abstraction reductions upstream, including high-level assessment of risks to London Underground assets if groundwater levels increase in the Upper Lea Valley.

damage to civil structures, banksides and slopes and vegetation interfaces also increase within the 2050s and are primarily driven by increased precipitation. Rising sea levels into the 2050s and beyond may limit the ability of tidal flood defences to continue to protect LBTS assets situated within the Thames Estuary.

1.2.2 Summary of risk assessment findings by sector

Below is a summary of the key sectors or systems on which the LBTS is dependent and the key climate hazards and impact pathways which may create cascading risks to the LBTS.

Power

Power grid capacity and resilience can be impacted during periods of high demand, such as for cooling during extreme high temperatures. Climate hazards such as flooding and high temperatures also impact on the resilience of linear and substation assets as part of transmission and distribution networks. Climate hazards to the power sector are also considered within the wider context of net zero, with the decarbonisation of heating and the increased electrification of assets and fleets into the 2050s increasing vulnerability. Cascading failures could impact on power supplies critical for operation of track infrastructure, signage and street lighting on highways and roads, as well as air conditioning and cooling within built environments such as stations and depots.

Telecoms

Both fluvial and surface water flooding present risks to telecoms assets, such as data centres, exchange centres and street cabinets. Telecoms masts and cables may also be susceptible to damage from high winds. Failures could affect the ability of transport staff to communicate with passengers and in rare cases could impact communication with emergency responders. High temperatures also present risks to the telecoms sector and the high level of dependency on the power sector (eg to provide cooling) is noted. Engagement with the telecoms sector has been limited in comparison to other sectors and there is less information regarding how climate change will affect the frequency and magnitude of outages of the telecoms network in the future. This suggests a key area for further investigation and collaboration and provides a lower level of confidence in our risk scores.

Water

Ground movement caused by reductions in soil moisture content and temperature variation can lead to pipe bursts. Pipes are also directly impacted by low temperatures, although this risk is assessed to decrease over time as temperatures rise. Bursts can lead to track, road and station closures through flooding and tunnel ingress, as well as interruption to supply events. Other wider risks to water resources and water quality are considered to have a less significant impact on the LBTS and have not been included within the risk assessment. Prioritisation of water supplies for public services and statutory requirements to maintain supply (eg through bottled water) means that drought risk impacting on water availability to built environments is not considered as a key risk to the LBTS. The overwhelming of the combined network during periods of heavy rainfall is also considered within the urban drainage interface.

Environmental management

Tidal and fluvial flooding present risks to the operation of FRM assets such as the Thames Barrier and upstream flood defences. Both drought and high rainfall can reduce slope stability and cause landslides on banksides and hillslopes which are managed by private landowners. Similarly, lineside vegetation managed by private landowners can be impacted by increased leaf and tree fall due to a lengthened growing season coinciding with earlier and more intense storm events. This can lead to speed restrictions, track closures and health and safety risks on roads and for built environments (eg station platforms). The management of vegetation, particularly during drought periods (where water restrictions may impact on maintenance and lead to die-off) is considered to be an emerging risk due to the planned increase in green infrastructure as an adaptation measure.

Land use and planning

Extreme rainfall events leading to higher levels of urban runoff can be exacerbated by periods of drought, reducing soil infiltration, and sea level rise and high tides increasing tidal locking of outfalls. This will increase the likelihood of the urban drainage and combined sewer network becoming overwhelmed, leading to surface water flooding which may cause track, road and station closures. Within the area of urban planning and maintenance, flood or weathering related damage to civil infrastructure, such as bridges and tunnels, may also impact on transport infrastructure. As discussed above, the adoption of green infrastructure practices across London will bring benefits to infiltration and urban cooling but must be carefully managed to avoid maladaptation through damage to road surfaces, blocking of drainage systems and increasing wildfire risk.

1.3 Co-dependencies

In several cases, TfL and other members of the LBTS also own assets which may contribute to areas of interdependency identified above. These function as a two-way relationship where the LBTS also contributes to the interdependency and the management of risk.

Key examples of these co-dependencies include:

- **Vegetation management** – LBTS stakeholders also maintain their own lineside and roadside green infrastructure assets. Pruning and management of vegetation takes place as part of maintenance programmes. Management of green infrastructure is significant for climate change adaptation due to the shading provided by trees which helps to mitigate against the impacts of high temperatures on track infrastructure and rolling stock. TfL also manages green infrastructure as part of the Healthy Streets approach[3] to improve shading on streets. If vegetation is not managed appropriately this can impact on the LBTS and other sectors
- **Civil structures** – LBTS assets, such as tunnels, roads and bridges, can also be damaged and lead to impacts to pipes or cables owned by other stakeholders such as Thames Water and Affinity Water
- **Urban drainage capacity** – LBTS stakeholders maintain their own drainage assets which also contribute to the overall capacity of the system. This means that the potential for the combined network to become overwhelmed is also dependent in part on the LBTS maintaining their own drainage assets to reduce the total volume of runoff. Water quality impacts from overflowing drainage and highways runoff can also constitute a significant downstream interdependency for catchment management. This is an issue especially in outer London where the drainage network empties directly into rivers, rather than into treatment plants.

1.4 Downstream interdependencies

Downstream interdependencies may arise if rail or road services are impacted by a climate hazard and are unable to deliver goods or services as required for other users. These interdependencies were not included within the scope of the risk assessment. However, they were still collated and discussed with stakeholders during focus groups to understand the cascading impacts from the transport sector to other sectors. These are categorised as follows:

[3] TfL (2018) How green infrastructure contributes to the Healthy Streets Approach. Available through: TfL Healthy Streets Planning

- **Impacts on staff availability** – disruption or closures to rail or road networks leading to cascading impacts across multiple sectors[4], including but not limited to power, water and telecoms, if staff are unable to get to work
- **Supply chain impacts** – the transport network is critical to providing supplies of fuel, chemicals and other materials which are required for the operation of assets such as power stations, treatment works, ports and airports
- **Waste disposal** – many other sectors rely on the transport sector and the maintenance of highways and roads for waste disposal from sites. Inability to dispose of waste may lead to public health and environmental risks
- **Access for emergency services** – closures to highways and roads will impact on the ability of emergency response units to respond in a timely manner with resulting impacts to health and safety
- **Access to health services** – closures to highways and roads will impact on hospitals due to delayed admission or access for patients
- **Access to airports** – Over 2M passengers a year use public transport to travel to Heathrow Airport, with many of these journeys dependent on LBTS rail or road assets[5]. Road or rail closures can lead to economic impacts through delayed or missed flights
- **Train operating companies (TOCs)** – track or station closures may mean that TOCs cannot run their services
- **Local businesses** – kiosks and shops inside stations or nearby may be impacted by station closures with resulting economic impacts to communities
- **Power grid back-up capacity** – Greenwich power station, owned by TfL, and other embedded generation operated by the LBTS can provide back-up capacity for the wider grid during times of high demand.

1.5 Prioritised actions

A total of 52 actions were co-created by stakeholders to reduce the risk from climate hazards to the key organisational interfaces. A prioritisation exercise was informed by stakeholders and used to summarise priority actions and the recommended timescales for delivery.

The prioritisation framework identifies high priority actions that can be implemented over the short (one year), medium (two to four years) and longer term (five+ years). Priority actions do not include a cost-benefit analysis and will require additional consideration of funding mechanisms for implementation.

The objective for delivering these priority actions is two-fold:

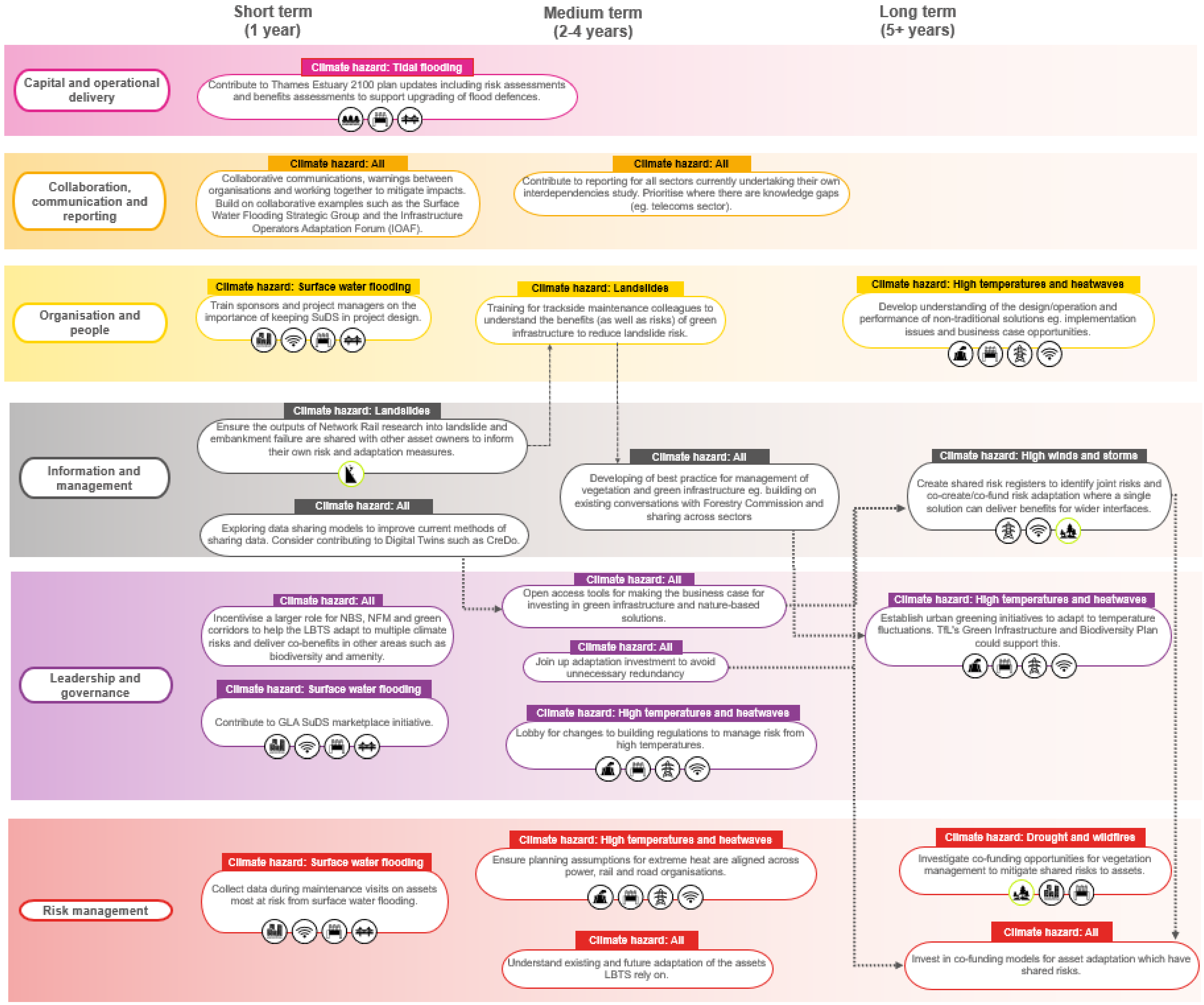
1. Deliver more impactful actions to address the key climate interdependency risks identified in this study.
2. Reduce redundancy across organisations from duplicated investments in adaptation.

Figure 1.2 summarises our priority actions for reducing climate interdependency risks. It follows the climate interdependency risk infographic (see Figure 1.1) through linking the relevant climate hazards and organisational interfaces to the recommended actions. This indicates potential stakeholders who could be involved in implementing actions.

[4] Potential feedback to the LBTS (eg from staff availability) is not assessed within this project as it represents an 'intradependency' within the LBTS.

[5] Heathrow-Airport-Travel-Report-2019.pdf

Figure 1.2: Infographic showing prioritised actions for key climate interdependency risks



Short-term actions include those which are within the LBTS level of control, considered to have sufficient skills and capacity available to implement and align with current regulatory and planning cycles. Medium-term actions focus on areas which are already in development but may require additional capacity building, stakeholder engagement or regulatory support to implement efficiently. Longer term actions include those where there is no precedent and require a greater level of coordination, resourcing and co-funding.

Delivering the shorter-term actions would build collaboration and communication across organisations to help facilitate delivering the longer term actions. For example, sharing outputs from current research on landslide and embankment failure could help inform adaptation measures within organisations (short-term action). This could help inform training for trackside maintenance colleagues to understand the benefits and risks of green infrastructure to reduce landslide risk (medium-term). This could then inform the development of best practice for vegetation and green infrastructure (medium-term), which feeds into the establishment of urban greening initiatives to adapt to future climate hazards (longer-term action).

Establishing a shared risk register and, beyond that, the collective recognition of risks and funding of solutions across sectors, will require support beyond TfL and the TASG from regulatory bodies and increasing alignment of regulatory planning and investment cycles and determinations. For example, at present, organisations identify risks and seek funding for risk reductions discretely to their relevant regulator. Where there is a shared or common risk that can be addressed for multiple organisations or sectors at the same time, it is proposed that a joint investment approval process that allows regulatory bodies to make joint determinations, underpinned by a robust shared risk register, would be effective. This avoids redundancy of solutions and delivers a more effective and efficient solution for customers overall.

1.6 Summary and recommendations

Overall, the project presents both a significant contribution to ARP4 submissions for London's LBTS and also provides a new approach to assessing interdependencies and climate hazards. Combining a systems approach with the established climate risk assessment process has ensured an innovative and rigorous process to the collation and analysis of climate interdependency risks. Undertaking stakeholder engagement across all stages of the project has created a co-learning process which has developed cross-sectoral relationships and a shared understanding of the climate interdependency risks facing London’s infrastructure.

Outputs from this assessment have focused on the key organisational interfaces which have been identified as priorities by stakeholders. This presents a more pragmatic approach than a purely hypothetical assessment of all potential cascading impacts across a system, which has typified previous analyses of climate and interdependency risk. At the same time, the system mapping that has been undertaken ensures that the value of collective thinking and “brainstorming” of potential risks is not lost but has been synthesised to a more manageable output.

The findings provide a platform for further exploration of climate change and interdependency risks for the London LBTS. However, the varying levels of confidence in risk scoring (eg lower for telecoms risks), and the need to review this scoring periodically as more data becomes available, is also noted. Nevertheless, this project presents a summary of much of the available evidence on cascading interdependency risks to key infrastructure assets for the London LBTS.

Developing a more complete understanding of how climate interdependency risks will impact on London beyond the LBTS will require the support of actors beyond TfL and the TASG. The following recommendations are higlighted:

- Greater regulatory commitment to coordinating cross-sectoral working groups. TfL and the TASG have taken a lead in this regard to the benefit of the transport sector and other sectors. However, the "pulling power" of one organisation or sector to convene and address a multisectoral problem is limited. Making the ARP4 a requirement rather than a voluntary process would go some way to addressing this

- The creation of opportunities for co-funding appraisals for climate adaptation across regulatory groups in each sector
- Standardising the use of data sharing tools to support in identifying pressure points across the entire system. Stakeholders highlighted that this approach needs to be streamlined to minimise wasted time in configuration leading to redundant efforts
- Dissemination of best practice guidance for the maintenance and management of green infrastructure given its prominence in climate adaptation
- Conducting a cost-benefit analysis for the recommended actions to further support the prioritisation of actions and highlight the potential for solutions benefitting both the transport sector and others
- This project sets a precedent in multisector collaboration to identify climate interdependency risks for the London LBTS. However, to fully assess cascading interdependencies across multiple sectors in London would require in-depth knowledge of likelihood and consequence for assets and services in other sectors, eg the exact nature of vulnerability between all power and all telecoms assets. This is beyond the scope of a project funded by the transport sector alone, although it is recommended that a co-ordinated approach should be undertaken once all sectors have matured in their understanding of interdependencies.

mottmac.com