



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

ARP4 Interdependencies project report

May 2024

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# Issue and Revision Record

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# Glossary

<b>Term</b>	<b>Definition</b>
<b>Adaptation</b>	The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. (TfL ARP3)
<b>Cascading impacts</b>	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)
<b>Climate hazard</b>	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)
<b>Climate risk</b>	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)
<b>Co-dependency</b>	Areas where the transport sector both contributes to the interdependency risk as well as being impacted.
<b>Downstream interdependency</b>	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.
<b>Emerging interdependency</b>	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).

<b>Term</b>	<b>Definition</b>
<b>Interdependency</b>	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.
<b>Intradependency</b>	Impacts to one part of the land based transport system (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.
<b>Resilience</b>	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)
<b>Upstream interdependency</b>	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.

# Executive Summary

In accordance with the Climate Change Act 2008, Transport for London (TfL) voluntarily reports on the actions it is taking to adapt to climate change as part of its Adaptation Reporting Power (ARP) submissions. In the third round of reporting (ARP3), organisations worked together at the sector scale to develop common approaches to risk assessment and reporting of climate risks and adaptation actions. The challenge at ARP4 is to expand the analysis to explore how climate hazards impact on interdependencies between assets and services in different infrastructure sectors (eg transport, water and drainage, power and telecommunications).

London's land-based transport sector (LBTS) is already being affected by severe weather events that are becoming more frequent and more intense. Climate change will increase the likelihood of climate and weather-related hazards such as heatwaves, drought, rising sea levels, flooding (all sources), wildfires and subsidence. Climate hazards that impact on one organisation's assets can then lead to cascading impacts on other organisations. The congested nature of London's infrastructure increases both the likelihood and potential magnitude of these cascading impacts. Therefore, climate interdependency risks represent a complex problem for the LBTS as these risks cascade across organisational boundaries.

This project combines system mapping with a climate risk assessment for the LBTS' upstream interdependencies. This draws on guidance from the UK government and Defra<sup>1</sup> to use a systems approach to understand, analyse and respond to the complex problem of assessing interdependencies and climate risk. A high level of stakeholder engagement has taken place throughout the project to codevelop an understanding of interdependencies, climate hazards and risk reduction actions. The system mapping has provided the platform for the climate interdependency risk assessment which follows a standard methodology consistent with Defra's reporting guidance and work undertaken in ARP3.

The work represents a continuation and expansion of collaborative approaches to climate adaptation and resilience in London. This approach to sharing knowledge and best practice has been recognised within the London Climate Resilience Review and provides a strong platform to encourage multisector engagement beyond ARP4.

## Findings

A total of 114 climate interdependency risks have been identified and scored against the likelihood of this event occurring and the potential magnitude of an impact or consequence across three time horizons: present day; 2050s; and 2080s. Overall findings for the London LBTS and its upstream interdependencies are summarised below:

### 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 telecommunications 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.

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<sup>1</sup>See [HM Treasury Magenta Book: Central Government guidance on evaluation \(2020\)](#) and [HM Government Environmental Improvement Plan \(2023\)](#)

## Interdependencies

- 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 telecommunications 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 telecommunications sector and the LBTS regarding vulnerability. The telecommunications sector's dependency on the power sector is also noted but not assessed directly within this project.

## Trends across time horizons

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 climate hazards, such as high temperatures and heatwaves, high winds, and 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 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.

## Actions

Key risk reduction actions have also been identified for the LBTS along with proposed timings, with priorities to:

- **Continue to support cross-sectoral collaboration** beyond the LBTS and prioritise engagement where knowledge gaps exist, such as in the telecommunications sector
- **Improve data sharing** across organisations, with the ultimate aim of creating shared risk registers
- **Explore co-funding opportunities for resilience measures which deliver co-benefits**, particularly for green infrastructure solutions which can reduce the risk from multiple hazards, such as flood management and urban cooling
- **Share and develop best practice on the maintenance of green infrastructure** which presents an increasingly important adaptation solution yet remains poorly understood in regard to management and maintenance.

## Conclusions

Overall, the project presents both a significant contribution to ARP4 submissions for the LBTS and also provides a new approach to assessing climate interdependency risks. 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 risks facing London's infrastructure.

Outputs from this assessment have focused on the key interfaces which have been identified as priorities by stakeholders. This presents a more pragmatic approach than a purely hypothetical assessment of all potential cascading failures across a system, which has typified previous analysis 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.

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 Transport Adaptation Steering Group (TASG). We highlight the following recommendations:

- 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 ARP a requirement rather than a voluntary process would go some way to addressing this
- The creation of opportunities for co-funding of 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 leading to redundant efforts
- Dissemination of best practice guidance for the maintenance and management of green infrastructure given its prominence in climate adaptation.

Specific actions which could be taken forward by TfL in relation to key climate interdependency risks (telecommunications, pipe bursts, distribution network, flood defences) which have been identified through the risk assessment are also discussed.

# 1 Introduction

The project aims to provide a joined-up approach to support the assessment of interdependencies within ARP4 for the wider Transport Adaptation Steering Group (TASG).

## 1.1 Project context

The Climate Change Act 2008 gives the secretary of state the power to direct reporting authorities to produce reports on what they are doing to adapt to climate change and associated governance processes. The power is referred to as the Adaptation Reporting Power or ARP. The ARP identifies current and future climate risks, together with proposed adaptation measures, and reports on progress since previous ARP submissions.

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 of the 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.

## 1.2 Interdependencies

London's LBTS is already being affected by severe weather events that are becoming more frequent and more intense. Climate change will increase the likelihood of climate and weather related hazards, such as heatwaves, drought, rising sea levels, flooding (both surface water and fluvial), wildfires and subsidence. Climate hazards that impact on one organisation's assets can then lead to cascading impacts on other organisations, known as interdependencies.

The congested nature of London's infrastructure increases both the likelihood and potential magnitude of these cascading impacts. This means that multiple organisational interdependencies must be considered, where assets or processes beyond the 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.”***

London Climate Resilience Review Interim Report, pg. 8<sup>2</sup>.

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 and TASG in ARP4 is to:

- Identify both upstream and downstream interdependencies that exist between assets and services in different infrastructure sectors (eg transport, water and drainage, energy and telecommunications)

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<sup>2</sup> [London Climate Resilience Review Interim report](#)

- Identify how climate hazards (eg flooding, drought and heatwaves) affecting upstream interdependencies will impact the delivery of transport services.

### 1.3 Project aim and approach

This project supports TfL and the LBTS to update their ARP4 submissions through improving their understanding of interdependencies, climate hazards and risk reduction actions to enable a resilient transport network and continuity of service for users.

Climate interdependency risks represent a complex problem for the LBTS as these risks cascade across organisational boundaries. The UK Government recommends taking a systems approach<sup>3</sup> to understand, analyse and respond to complex problems. The system mapping presented in this report has provided the platform for the analysis of interdependencies and the climate interdependency risk assessment. Stakeholder engagement is central to this approach and has taken place throughout the project in the form of system mapping focus groups and three workshops.

This project report outlines the key findings and is structured as follows:

- Section 2 provides an overview of the project method across the system mapping and climate interdependency risk assessment
- Section 3 presents the results from the climate interdependency risk assessment for key LBTS interdependencies
- Section 4 discusses the proposed actions for climate interdependency risk reduction
- Section 5 presents the recommendations and next steps.

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<sup>3</sup>See [HM Treasury Magenta Book: Central Government guidance on evaluation \(2020\)](#) and [HM Government Environmental Improvement Plan \(2023\)](#) for example (accessed 16/06/2023).

## 2 Method

This project combines system mapping with a climate risk assessment for the LBTS' upstream interdependencies. This section outlines the approach used to identify interdependencies and climate risks for the LBTS and how those outputs were used to inform the risk assessment. The scoring method used for the risk assessment itself is also discussed.

Systems approaches provide a structured co-learning process, bringing together interested parties to work through complexity and uncertainty. This enables them to see the bigger picture, share knowledge and experience and consider different perspectives. This is key to informing more holistic considerations and recommendations that can account for interdependencies, identify and manage trade-offs and avoid unintended negative impacts from interventions.

In line with the Defra guidance, we have used <sup>4</sup> Participatory Systems Mapping (PSM) within our stakeholder engagement approach. PSM is used to develop a qualitative visual representation of a system through a facilitated co-learning process with stakeholders. It shows the elements that make up the system and how the behaviour of the system is affected by the causal relationships between these elements. It is a collaborative process that draws on experiences and knowledge from across a diverse group of perspectives. PSM promotes discussion between participants and builds a shared understanding of a system, which also encourages buy-in for further action planning.

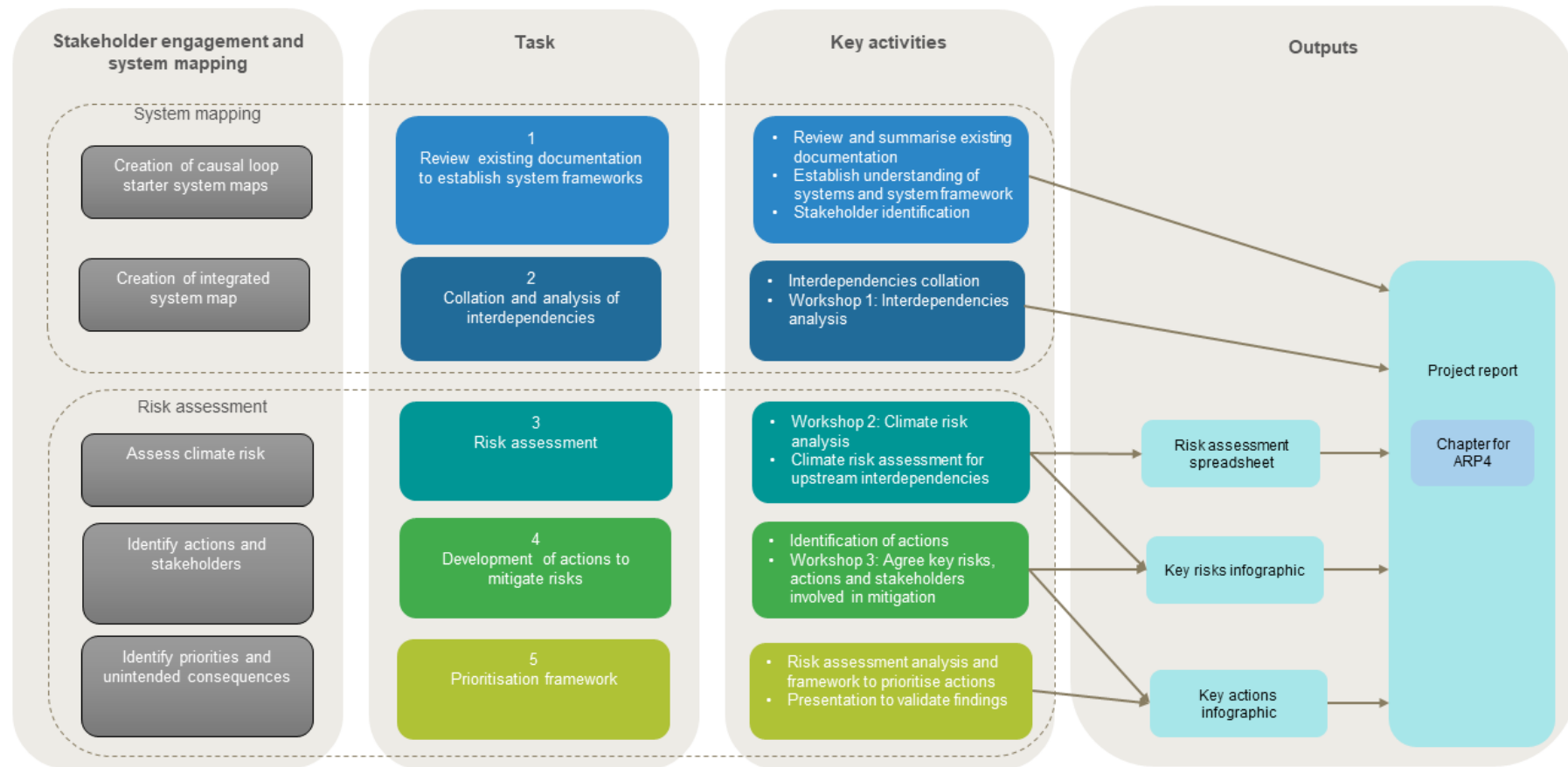
Using a systems approach for interdependency analysis has provided the platform for the climate interdependency risk assessment. The risk assessment follows a standard methodology consistent with Defra's reporting guidance and the ARP3 assessment.

The overall method is shown in Figure 2.1, highlighting the contribution of stakeholder engagement through the project, along with the key tasks and outputs in each step. A full list of the stakeholders who engaged with the project is presented in Appendix A.

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<sup>4</sup> Defra recommend using PSM for creating a shared understanding of environmental issues. See Defra: [Integrating a systems approach into Defra \(2022\), Section 2.2.3](#) (last accessed 16/06/2023).

**Figure 2.1: Project overview**



### 2.1.1 Step 1: Review of existing documentation to establish system frameworks

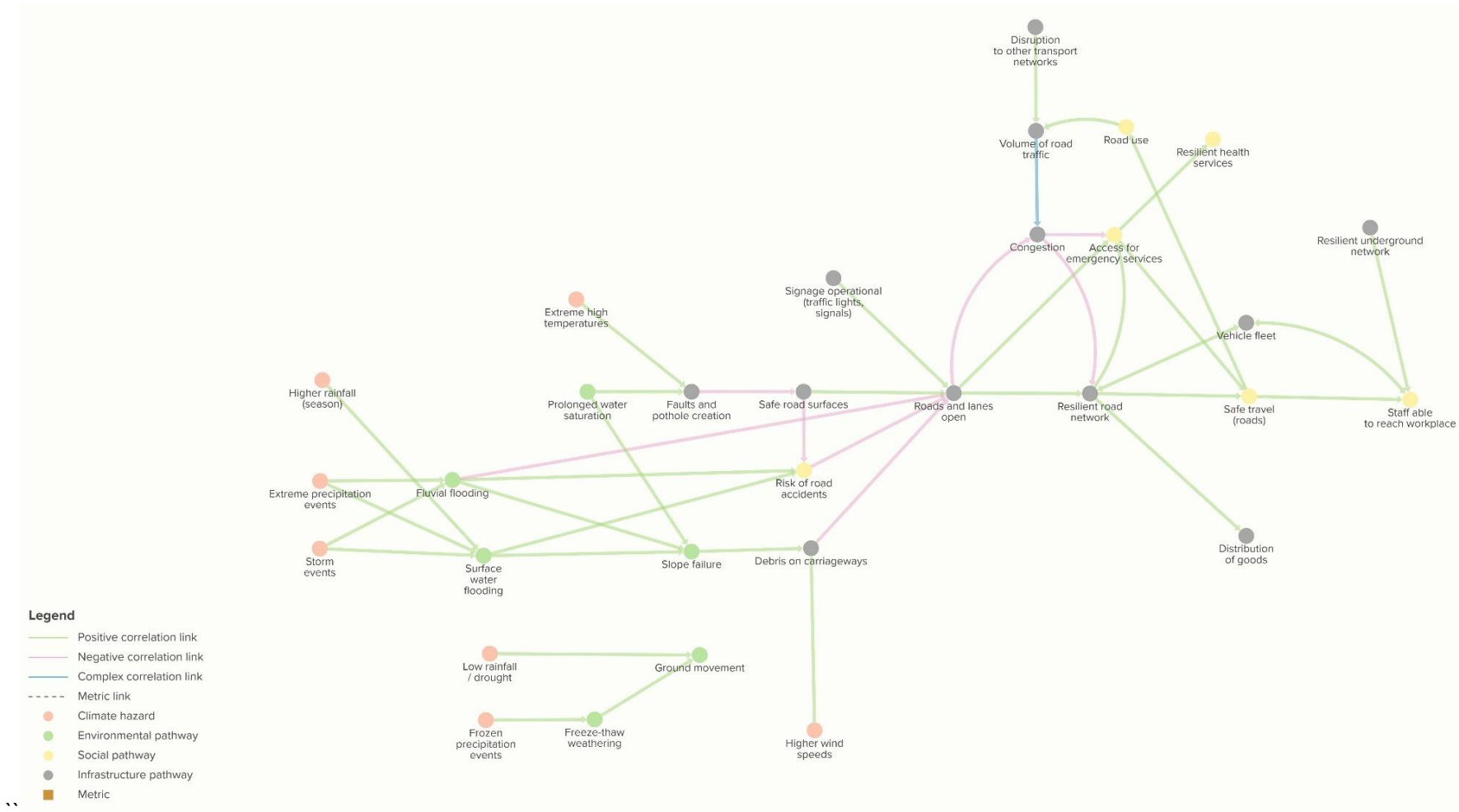
The first step of the PSM approach was to develop a high-level scoping map which delineated the boundaries of the system. This was created after a desk review of relevant documentation (see Appendix B for further details). This map helped to identify the key system areas and stakeholders to engage with.

Simple subsystem maps were then created for each relevant sector using an online, open-access software called Kumu. Maps were drafted for the following subsystems:

- Environmental management
- LBTS – rail and sponsored services (including underground)
- LBTS – roads
- Land use and planning
- Power
- Telecommunications
- Water.

Figure 2.2 shows a subsystem map for the LBTS road system in Kumu with key processes and climate hazards. Appendix C provides a description on how to read system maps.

Figure 2.2: Example subsystem map for LBTS - roads



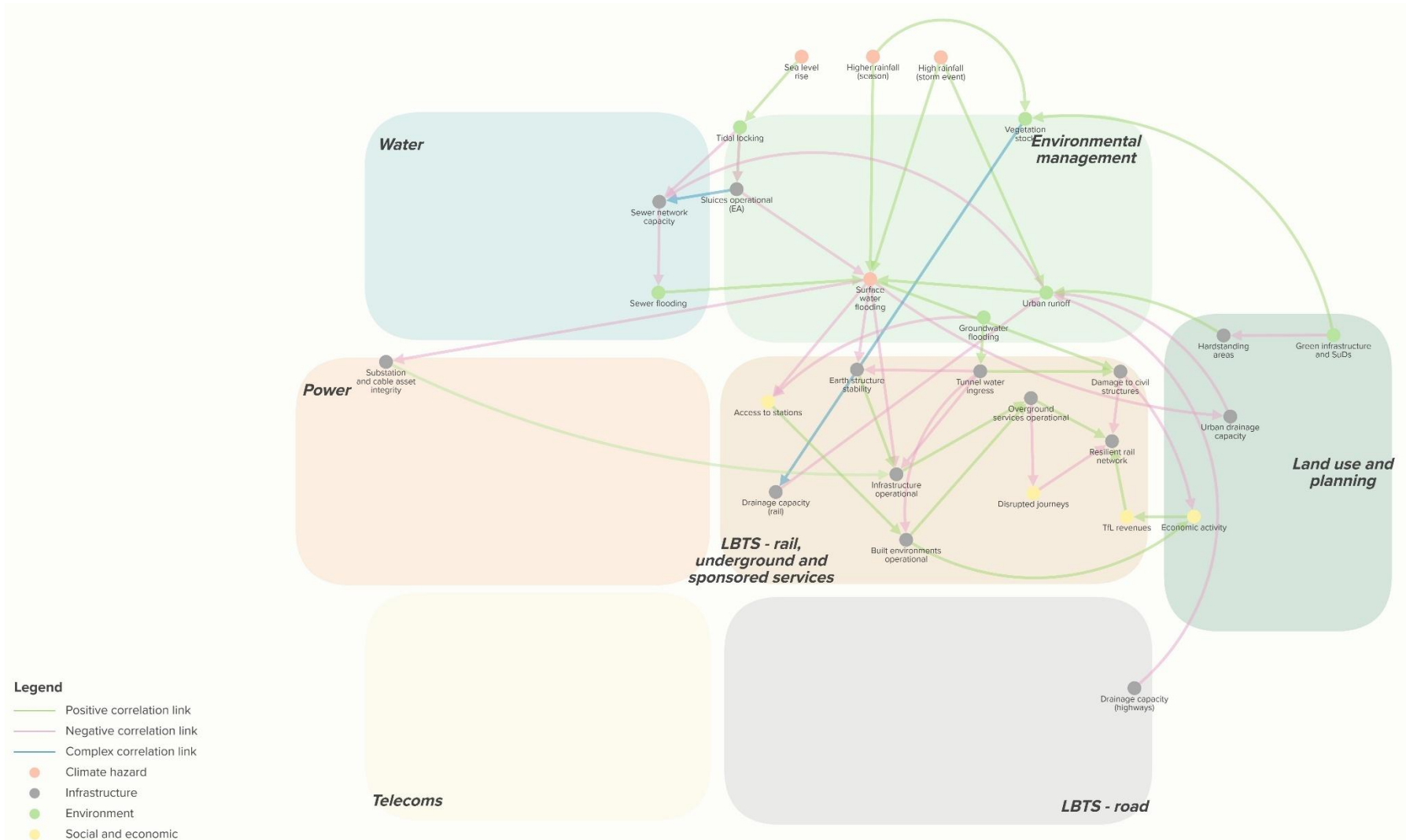
### **2.1.2 Step 2: Collation and analysis of interdependencies**

Online focus groups with stakeholders from each sector were held to review the subsystem maps drafted in Step 1. This step validated the relationships between elements and how they were impacted by climate hazards to identify interdependencies with the LBTS.

Participation in the focus groups was strong overall but varied across different sectors. Key omissions at this stage included the telecommunications sector, the Port of London Authority (PLA) and the aviation sector. Subsystem maps were, therefore, reviewed with internal experts for these sectors instead.

Once subsystem maps for each sector had been reviewed and updated, they were combined into an integrated system map for analysis. This included analysing the map to identify upstream and downstream connections and synthesising individual pathways into “hotspot” areas using filtering tools (see Figure 2.3).

**Figure 2.3: Hotspot map for drainage and flooding showing key climate hazards and interdependency pathways**



A range of stakeholders from across multiple sectors then attended the in-person “integration workshop” held in January 2024.

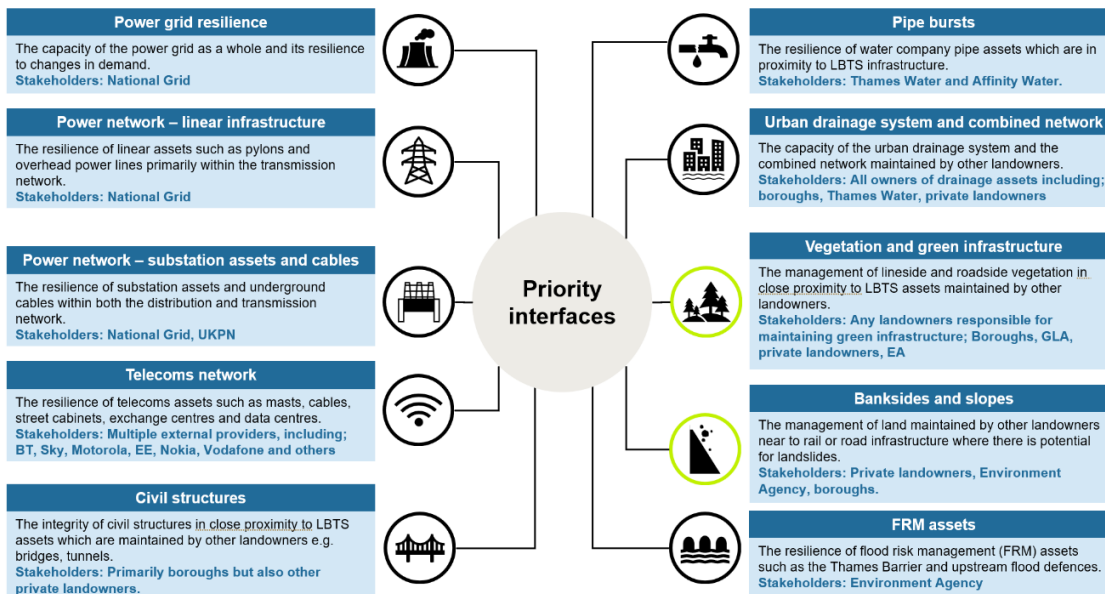
In the workshop, stakeholders were asked to review the interdependency hotspots and identify key impact pathways, from climate hazards through to key assets and processes in other sectors, and then the LBTS. The maps were also used to highlight key organisational interfaces (eg urban drainage capacity) which represented the point where the risk transferred to the LBTS from another sector.

**What is an integration workshop?**

*The purpose of an integration workshop is to bring together stakeholders from across the component subsystems to review the integrated system map. This allows stakeholders to move beyond siloed thinking and to share different perspectives together on system-wide concerns. Holding these events in person encourages conversations across the stakeholder group, developing relationships which can also bring value beyond the immediate project.*

This ensured a collaborative approach to collation of the interdependencies affecting the LBTS through including the perspectives, experiences and knowledge of stakeholders from across multiple sectors. Outputs informed the identification of 10 key organisational interfaces to summarise the LBTS’ priority interdependencies (Table 2.1).

**Table 2.1: List of organisational interfaces (green circles indicate interfaces linked to vegetation and the natural environment)**



Outputs from the integration workshop also led to the creation of an interdependency system map (Figure 2.4), summarising all interdependency pathways to be used within the climate interdependency risk assessment. Filtering tools were then applied to enable analysis centred around either organisational interfaces or climate hazard.

Figure 2.5 illustrates how the outputs from the system mapping enabled upstream interdependency risks to be identified for use in the risk assessment. This example filters on pipe bursts as a key organisational interface, which impacts on LBTS assets such as highways, roads and streets, rail infrastructure and built environments. The impact pathway includes ground movement caused by climate hazards, such as low rainfall or temperature variation, as well as more direct impacts from low temperatures on pipe bursts. The map also highlights key

stakeholders (in this example, Thames Water and Affinity Water) responsible for each interface through the coloured bars around each interface node.

The climate interdependency risk assessment was structured so that each individual causal pathway from left to right on the map (from **climate variable** through to **assets impacted**) represents a climate interdependency risk to be scored. The ID for each risk relates to its organisational interface (1-10) and which risk it represents within the pathway. In this example, there are nine risks (6A to 6I). Further detail on how to use the filtering functions of the system map can be found in Appendix C. Definitions and the categorisation of climate variables and assets were agreed with TfL in advance of the risk assessment and can be found in Appendix D.

Figure 2.4: Interdependency system map

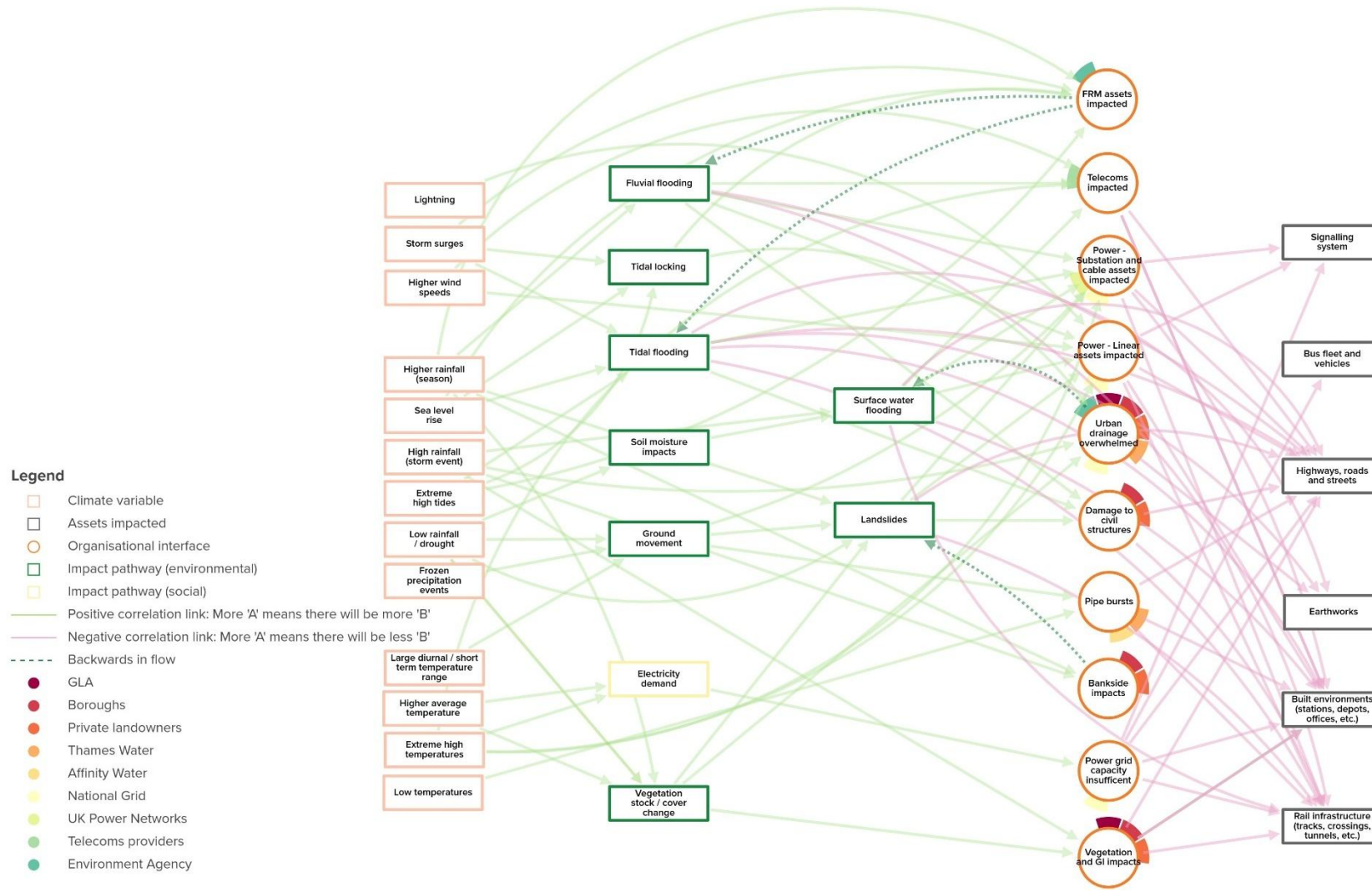
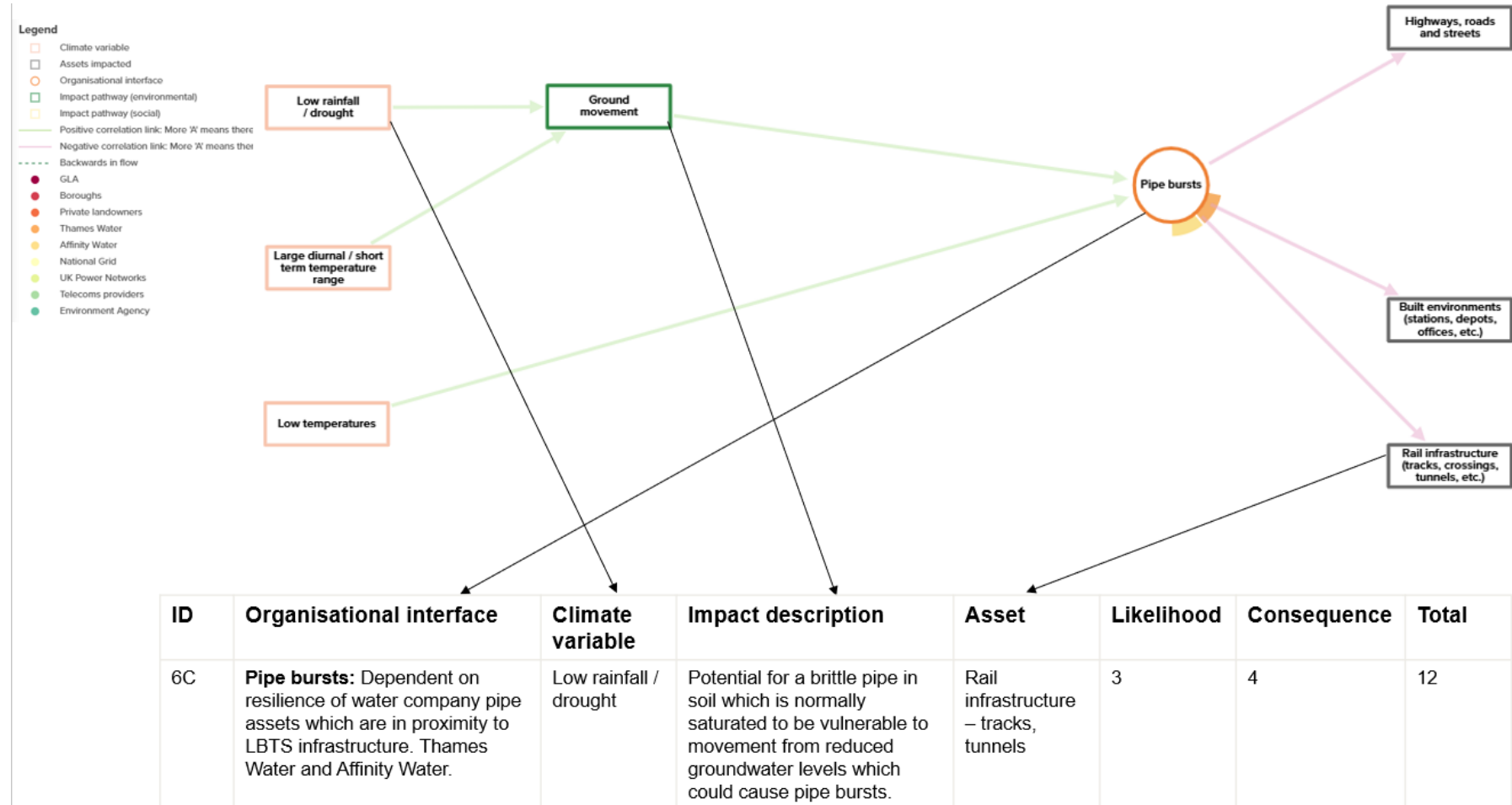


Figure 2.5: Interdependency pathway for climate hazards



### 2.1.3 Step 3: Climate interdependency risk assessment

Once the system mapping outputs had been used to structure the risk assessment, a high-level risk score was assigned for each interdependency pathway (Figure 2.66<sup>(OBJ)</sup>) in the form of a flow diagram for reading each interdependency risk row. This highlights where the system mapping outputs have been used to inform the risk assessment<sup>(OBJ)</sup>.

Stakeholders from the TASG then attended an online workshop in February 2024 to review the preliminary likelihood and consequence scores for each of the 10 interfaces within the risk assessment. Feedback and insights from stakeholders were used to inform the risk scoring for all three time periods, through their knowledge of adaptation actions and operational procedures which could affect the risk severity. This helped to ascertain the likelihood and consequences of upstream interdependencies impacting on the LBTS.

Further clarification calls were then held with non-LBTS stakeholders to review the risk severity associated with their relevant organisational interfaces. For example, climate interdependency risk scores relating to tidal flooding were reviewed with the Environment Agency to validate assumptions regarding the likelihood of climate hazards impacting on its assets.

### 2.1.4 Climate interdependency risk assessment scoring approach

The risk assessment was informed by the method used by TfL for its ARP3 Climate Change Risk Assessment. The risk to the LBTS was based on assessing the likelihood and consequence of the interdependency impact pathways occurring. Risks were assessed for three time horizons: current risk (2020s); risk in the 2050s; and risk in the 2080s. This methodology was discussed and agreed with TfL and presented to stakeholders at the workshops.

The likelihood score and the highest of the three consequence scores were multiplied together to calculate the overall risk severity:

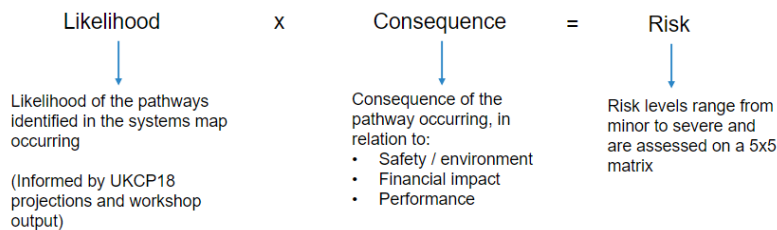


Table 2.2: summarises the thresholds for categorising the overall risk severity on a scale from “minor” to “severe”, in line with Network Rail’s ARP3.

**Table 2.2: Thresholds for categorising overall risk score**

		Consequence				
		Low (1)	Medium (2)	High (3)	Very High (4)	Critical (5)
Likelihood	Almost Certain (5)	moderate	major	major	severe	severe
	Likely (4)	moderate	moderate	major	major	severe
	Possible (3)	minor	moderate	moderate	major	major
	Unlikely (2)	minor	moderate	moderate	moderate	major
	Highly Unlikely (1)	minor	minor	minor	moderate	moderate

Figure 2.6: Overview of risk assessment approach



Notes: These headings are used in the climate interdependency risk assessment spreadsheet template

## Likelihood scores

The likelihood that the whole upstream interdependency pathway would be affected by climate hazards was scored using a five-point scale from “almost certain” to “highly unlikely”. The definitions of likelihood used were taken from the TfL ARP3 Climate Change Risk Assessment methodology. Table 2.3 shows the definitions used for the five-point likelihood scale.

**Table 2.3: Likelihood categories**

Score	Likelihood	Definition
5	Almost certain	The risk is in the process of materializing and may already be under active management as an event
4	Likely	Past events have not been fully resolved, effective mitigations not yet identified, control weaknesses are known and are being managed
3	Possible	Past events satisfactorily resolved, mitigations are in place or are on track to be in place, control improvements are under active management
2	Unlikely	Events are rare, required mitigations in place, controls are effective
1	Highly unlikely	No known event or if known extremely rare, extreme industry-wide scenarios

Source: TfL Climate Change Risk Assessment (ARP3)

Likelihood scores were assigned to each pathway based on professional judgement and scores for the 2050s and 2080s also considered whether there was any evidence of adaptation plans or measures that could decrease the likelihood. Evidence was identified from:

- The current climate baseline and UKCP18 data
- Reviewing ARP3 reports, risk assessments and climate change adaptation plans
- Reviewing publications by the UK Climate Change Committee (CCC), particularly its 2023 adaptation report to the UK Parliament and the sector briefings produced for UK government’s third Climate Change Risk Assessment (CCRA3)<sup>5</sup>
- Insights provided by the TASG stakeholders in the February 2024 workshop and in follow up conversations with other sectors

## Consequence scores

TfL’s ARP3 scored consequence on a single five-point scale from “critical” to “low”.

Consequence scores were broken down into three categories to provide a more detailed consideration of different types of consequences, in line with Network Rail’s ARP3<sup>6</sup>. The three consequence categories were agreed with TfL as safety/environment, performance and financial consequences. Table 2.4 shows the definitions of consequence used in the five-point scale in this project. These definitions were developed based on those used by Network Rail in its ARP3 risk assessment, TfL’s corporate risk assessment methodology and from discussion and agreement with members of the TASG and TfL.

Consequence scores were assigned using professional judgement that was informed from the same sources as the likelihood scores, specifically stakeholder engagement and a literature review of ARP3 reports and CCC reports.

<sup>5</sup> <https://www.ukclimaterisk.org/publications/type/briefings/>

<sup>6</sup> Network Rail Third Adaption Report December 2021

**Table 2.4: Consequence categories and definitions**

Score		Safety/environment	Financial <sup>7</sup>	Performance
5	Critical	Life changing/multiple health issues leading to prosecution. Multiple fatalities leading to prosecution. Major long-term/large-scale environmental harm leading to prosecution	£££££	Unplanned and severe disruption to more than one main route resulting in station/road/track closures and negative media coverage of TfL
4	Very high	Significant health issue leading to adverse regulatory outcome. Single fatality leading to adverse regulatory outcome. Significant long-term/large-scale environmental harm leading to adverse regulatory outcome	££££	Unplanned disruption on more than one route for over a week resulting in station/road/track closures
3	High	Moderate health issue leading to regulatory action. Major injuries leading to regulatory action. Moderate environmental harm leading to potential regulatory action	£££	Unplanned disruption on at least one route for up to a week resulting in station/road/track closures
2	Medium	Minor health issue with potential for regulatory action. Minor injuries with potential for regulatory action. Minor localised/short-term environmental harm with potential for regulatory intervention	££	Unplanned disruption on one route for up to a day
1	Low	Minor health issue. Minor injuries or minor localised environmental harm	£	Planned disruption on one route for up to a day

Source: Adapted from TfL Climate Change Risk Assessment (ARP3) and Network Rail ARP3

### 2.1.5 Climate projections

Climate projection data was used primarily to inform scoring across the different time horizons used in the risk assessment. In line with the climate projections used to inform the TfL ARP3 Climate Change Risk Assessment, data for the CRA in this project was obtained from the United Kingdom Climate Projections 2018 (UKCP18). UKCP18 projections are developed by the Met Office and are the latest set of climate projection data for the UK. Projection data was obtained for one medium-high greenhouse gas emissions scenario, RCP6.0, to be consistent with TfL's ARP3 report. Projection data was obtained for the 2050s and the 2080s for both temperature and precipitation variables. For sea level change, data for a high greenhouse gas emissions scenario, RCP8.5, was obtained for the same time periods. RCP8.5 was used for sea level data because the UKCP18 Marine Projections do not include data on sea level rise for the RCP6.0 scenario. The 90th percentile values were used from data from the probabilistic projections UKCP18 product. Values for 20-year and 100-year return periods were used from data from the probabilistic extreme's product from UKCP18.

Probabilistic projection data, with the exception of sea level rise, was obtained for the London administrative region, as available from the UKCP18 user interface. Due to data availability from location of tide gauges, sea level rise data was obtained for the closest gauge to London, Sheerness.

The climate hazards of higher wind speed and lightning were also included in the risk assessment. The Met Office's UKCP18 factsheet on wind was used to summarise expected changes in near surface wind speeds across the 21<sup>st</sup> century and the associated confidence in those projections<sup>8</sup>. Projections for lightning were not available so a description for projected trends over the 21<sup>st</sup> century was derived from TfL's recommended list of climate hazards.

<sup>7</sup> Financial consequence scores were determined from a professional judgement about the relative cost to TfL of a pathway occurring rather than a quantitative assessment based on cost calculations.

<sup>8</sup> [ukcp18-fact-sheet-wind\\_march21.pdf \(metoffice.gov.uk\)](https://www.metoffice.gov.uk/ukcp18-fact-sheet-wind_march21.pdf)

The key climate projection headlines for London over the 21<sup>st</sup> century are:<sup>9</sup>

- Warmer, wetter winters and hotter, drier summers
- Increase in frequency of extreme weather events, eg heatwaves and storms
- Sea level rise.

More detail on the climate baseline and projection data used in this project can be found in Appendix E. It includes a summary of which climate hazards were used to inform the risk assessment and where they were sourced.

#### 2.1.6 Key assumptions for risk assessment

- **Worst case scenarios** – during the second workshop, stakeholders were encouraged to consider worst case scenarios when scoring consequences under RCP 6.0 for the 2050s, eg locations and examples which could be more severe. This relates to 90<sup>th</sup> percentile, aligning to ARP3 and ARP4 risk assessments.
- **Adaptation** – if evidence of present or planned adaptation was found, either in reviewed documents or from discussions with stakeholders, then this was considered in the likelihood scoring. Evidence of adaptation was assumed to moderate the likelihood of the impact pathway occurring and/or the consequence of it occurring, for example due to upgrading assets, changing maintenance or operation regimes, or installing sustainable drainage systems (SuDs). If there was no evidence of adaptation found then an unadapted future was assumed, noted in the narrative and reflected in the likelihood and/or consequence scores, for example if it was assumed that assets would be replaced like-for-like and that current maintenance and operation procedures would continue.
- **Scoring of cascading interdependencies** – to create a manageable scope for the risk assessment, we have limited our assessment to score direct risks from interdependencies, eg where the impacts cascade directly from one sector such as water to transport, rather than power to water to transport. To fully risk assess cascading interdependencies across multiple sectors 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 telecommunications assets. This is beyond the scope of a project funded by the transport sector alone, although we recommend that this approach is taken once other sectors have matured in their understanding of interdependencies.
- **Coverage** – the risk assessment does not cover every possible interdependency but instead focuses on the key interfaces that have been highlighted as being of greatest concern for the London LBTS through the system mapping. The risk assessment focuses on upstream interdependencies with other sectors rather than those within the LBTS which are well understood. While the scope of the risk assessment scoring is on upstream interdependencies, co-dependencies and downstream interdependencies are discussed within the narrative in Sections 3.8 and 3.9.

#### 2.1.7 Step 4: Development of actions to reduce risks

A longlist of risk reduction actions was collated by the project team in response to the findings from the risk assessment. These considered actions such as collaborative approaches to data sharing and governance, targeted investments in resilience measures, the sharing of best practice and exploration of co-funding approaches. All stakeholders were then invited to attend an online workshop in March 2024.

Key climate interdependency risks to organisational interfaces and a visualisation of the impact pathway from the system map were presented, along with a draft list of risk reduction actions.

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<sup>9</sup> [SPF City Pack\\_editable\\_template \(metoffice.gov.uk\)](#)

Stakeholders were asked to help develop a list of risk reduction actions for the LBTS using a Miro board, grouped in accordance with the categories from the ARP3 adaptation plan. To encourage innovative thinking, we added an additional “magic wand” category where we asked stakeholders to consider actions they would like to see implemented regardless of barriers. A follow-up form was sent to participants to review the co-developed list of actions and to provide an indicative low, medium or high priority score against each action for the different climate interdependency risks identified.

### 2.1.8 Step 5: Prioritisation framework

Figure 2.7 summarises our prioritisation framework to identify key actions to reduce climate interdependency risks:

- Step 1 identified a longlist of actions for reducing risks which was informed by Workshop 3
- Step 2 applied the prioritisation criteria following the method used by Climate Adapt<sup>10</sup> to create a shorter list of priority actions
- Step 3 identified the timing of the priority actions by assessing the level of stakeholder engagement, skills and resources, and regulatory support required.

This allowed each action to be reviewed against a set of prioritisation criteria to provide a structured method for identifying key actions and recommended delivery for the LBTS. The final list of prioritised actions was reviewed and agreed with TfL.

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<sup>10</sup>[Climate adapt](#)

Figure 2.7: Overview of method for prioritising actions for reducing climate interdependency risks

Step 1: Identify actions for reducing climate interdependency risks													
Climate hazard		Key interdependency risk			Level of control				Recommended action				
e.g. surface water flooding		Identify key risks from climate assessment			Identify if the risk is within LBTS control or influence				What should be done to mitigate the risk?				
Step 2: Prioritising actions													
Criteria		Sub-criteria											
Risk level		Timeframes: Is the risk current or emerging?											
Risk level		Severity: Is the risk rated major or severe ?											
No regret		Actions which are worthwhile whatever the extent of future climate change will be											
Low-regret		Actions with relatively low associated costs but benefits for risk mitigation under climate change could be relatively high											
Win-win options		Actions which deliver the desired results in terms of minimising risks but also have significant contribution to other social, environmental or economic goals across organisations.											
Flexible or adaptive options		Actions that can be adjusted easily if circumstances change compared to initial projections											
Multiple benefit options		Actions which provide synergies with other outcomes such as climate change mitigation, disaster risk reduction, environmental management or sustainability.											
Step 3: Use framework to identify timing of priority actions													
Timing of priority actions													
Is the action within the LBTS level of control?													
Are skills and capabilities currently available to deliver this action?													
Are the actions aligned with the current regulatory cycle?													
Risk type	Recommended action	Categorisation	Risk Level	Prioritisation criteria					Prioritisation	Timing of priority actions			Outcome
				No regret	Low regret	Win-Win	Flexible or adaptive options	Multiple benefit options		T1 (engagement)	T2 (resourcing)	T3 (policy)	
General	Create shared risk registers to identify joint risks and co-create/co-fund risk mitigation where a single solution can deliver benefits for wider interfaces.	Information management	N.A.						High	No	No	No	Long term

Click or tap here to enter text.

## 3 Findings

A total of 114 climate interdependency risks have been identified and scored across three time horizons – present day, 2050s and 2080s – with the full risk assessment provided as a separate spreadsheet. This section summarises our key findings and discusses the climate interdependency risks and trends which are of most relevance to the LBTS.

We summarise below the key sectors or systems on which the LBTS is dependent and the key climate hazards identified through the stakeholder engagement, risk assessment and reviews of relevant documentation (such as ARP3 reporting and CCRA3 research).

### 3.1 Power

Primary risks relate to power grid capacity and resilience during periods of high demand, such as for cooling during extreme high temperatures. Other risks relate to the resilience of linear and substation assets as part of transmission and distribution networks to climate hazards, such as flooding and high temperatures<sup>10</sup>. Power sector risks are also considered within the wider context of climate mitigation. Decarbonisation of heating and the increased electrification of assets and fleets into the 2050s increases vulnerability. Cascading failure 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.

### 3.2 Telecommunications

Primary risks relate to damage to telecommunications assets, such as data centres, exchange centres and street cabinets, due to flooding. There is also concern about the potential for damage to telecommunications masts and cables due to high winds. Failures could affect the ability of transport staff and emergency responders to communicate and, in rare cases, could impact communication with emergency responders. However, engagement with the telecommunications 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 telecommunications network in future<sup>11</sup>. This suggests a key area for further research and collaboration and provides a lower level of confidence in our risk scores.

### 3.3 Water

Primary risks relate to pipe bursts as a result of ground movement caused by reductions in soil moisture content and temperature variation<sup>12</sup>. Pipes are also directly impacted by low temperatures, although this 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 the built environment is not considered as a key risk to the LBTS. The

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<sup>11</sup> [CCRA3-Briefing-Telecoms-and-ICT.pdf](#)

<sup>12</sup> <https://www.ukclimaterisk.org/publications/water-sector-briefing/#section-2-key-messages>

overwhelming of the combined network during periods of heavy rainfall is also considered within the urban drainage interface.

### 3.4 Environmental management

Primary risks relate to the operation of flood risk management (FRM) assets, such as the Thames Barrier and upstream flood defences, and the potential impacts from tidal and fluvial flooding. Banksides and hillslopes near to rail and road infrastructure can also be managed by private landowners, with the potential for both drought and high rainfall to reduce slope stability and cause landslides. Similarly, lineside vegetation can be managed by any private landowners and may be impacted by increased leaf and tree fall due to a lengthened growing season coinciding with more storm events. These impacts 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. This increases the potential for maladaptation due to damage to road surfaces, the blocking of drainage systems and wildfire risk.

### 3.5 Land use and planning

Primary risks relate to maintenance of the drainage network and the contribution of urban runoff during periods of intense rainfall, 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, carbon sequestration and urban cooling but must be carefully managed to avoid unintended consequences outlined in Section 3.4.

### 3.6 Summary of key findings and risks

Figure 3.1 below presents an infographic summarising the key findings from the climate interdependency risk assessment. The highest severity climate interdependency risks are shown along with the organisational interfaces which are most impacted for each of these. Analysis of the climate interdependency risk assessment shows the number of risks which meet the threshold of “major” or “severe” for each of the main climate hazards identified. This provides a high-level overview of how risk profiles change over the three time horizons assessed – present day, 2050s and 2080s. A breakdown of the analysis for each of the climate interdependency risks and organisational interfaces is provided in Appendix F.

Figure 3.1: 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.

## The key climate hazards impacting on the London transport sector's interdependencies

### Surface water flooding

Caused by extreme rainfall/storm events and overwhelmed **urban drainage** systems. Impacting on rail and road assets as well as further cascading impacts as a result of damage to **telecoms assets, power substation assets** and **civil structures**.

### High temperatures and heatwaves

Placing strain on **power grid capacity** as well as on power sector assets such as **substations, linear assets** (eg overhead power lines) and **telecoms assets**. Cascading impacts to power supply for rail and road assets including disruption to comms.

### High winds and storms

As a result of increased storminess impacting directly on (**linear assets** - such as overhead power lines and pylons) within the power sector and **telecoms assets** (cables, masts etc). Exacerbated by indirect impacts from **vegetation growth**. Cascading impacts to power supply for rail and road assets and disruption to comms.

### Fluvial flooding

Caused by high rainfall and in some cases, overtopping of **FRM assets**. Impacting on road and rail assets as well as **civil structures, telecoms assets** and **power substation assets**.

### Tidal flooding

Caused by storm surges/extreme tides and sea level rise and overtopping of **FRM assets** such as the Thames Barrier. Impacting on rail and road assets as well as further cascading impacts as a result of damage to power **substation assets** and **civil structures**.

### Ground movement (eg subsidence)

Caused by temperature and soil moisture variation damaging **pipes** and **substation assets and cables**. Cascading impacts to water and power supply for rail and road assets.

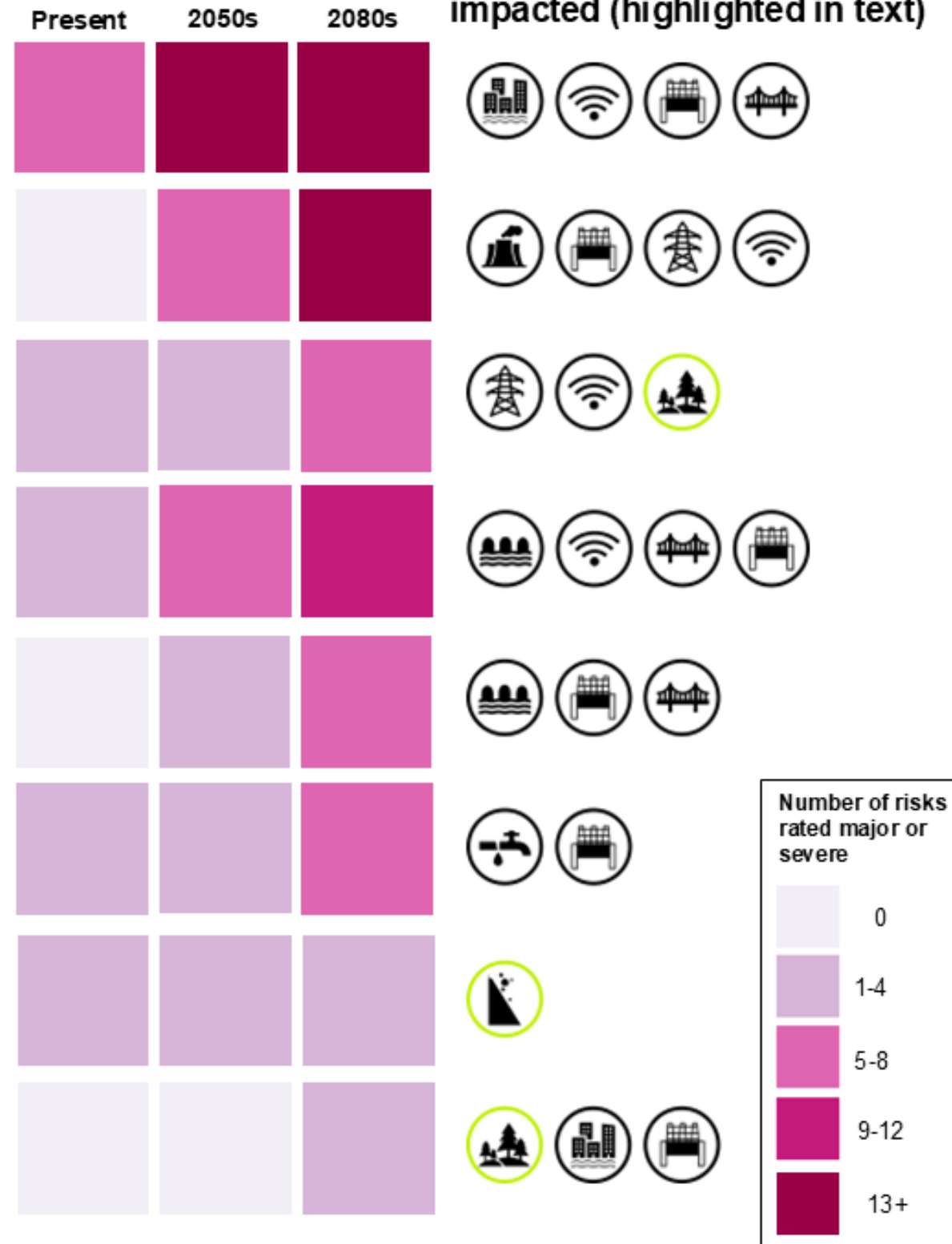
### Landslides

Caused by heavy rainfall or drought impacting on **banksides and slopes** managed by other landowners. Cascading impacts to rail and road assets.

### Drought and wildfires

Drought leading to vegetation die-off and increased wildfire risk. Direct impacts to **vegetation and green infrastructure** and indirect impacts to **urban drainage systems** and **substation assets**.

## Organisational interfaces impacted (highlighted in text)



Overall findings from the risk assessment are also summarised below:

### **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 also impact the power and telecommunications sectors, along with impacts from high winds and associated debris
- Sea level rise, coupled with storm surges and extreme high tides, suggest 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 was acknowledged as a concern although knowledge of potential impacts on assets was limited. This lack of confidence is reflected in the scoring where it is grouped with fluvial flooding and impacts from increase average rainfall
- Climate hazards, such as frozen precipitation and low temperatures, are anticipated to reduce in significance over time, as projections indicate a warming trend in winters through the 21<sup>st</sup> century.

### **Interdependencies**

- 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 hazards and high consequence scores
- The telecommunications interface has been scored as 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 telecommunications sector and the LBTS regarding vulnerability. The telecommunications 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 FRM assets were scored lower due to high levels of proposed adaptation for the Thames Barrier reducing likelihood, despite high consequence scores.

### **Trends across time horizons**

- 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 and fluvial and tidal flood, are not considered major at present, but will increase into the 2050s
- Climate interdependency risk increases significantly in the 2050s as decarbonisation, electrification and changes in climate hazards lead to greater impacts from the power sector
- Impacts from 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.

## 3.7 Priority upstream interdependencies for the LBTS

This section provides greater detail on the interdependencies themselves and is structured around the 10 organisational interface categories as defined above in Table 2.1. The narrative below provides a summary of the highest severity risks for each interface from the risk assessment for the 2050s, along with key assumptions and trends. Summary tables refer to L (likelihood) and C (consequence) scores, where the highest of three consequence scores used to calculate the total risk severity is presented.

Visualisations of each interface are included in Appendix G and can be read along with the sections below.

### 3.7.1 Interface 1: Power grid resilience

#### 3.7.1.1 Explanation of interface and key pathways

The resilience of the power grid is essential to providing reliable electricity supply for the London LBTS. This is primarily dependent on the National Grid electricity transmission network maintaining capacity. However, as decarbonisation increases, the proportion of renewable energy supplied to the grid from new distributed generators connecting directly into the distribution network may also impact on the resilience of the grid<sup>13</sup>.

Climate interdependency risks relate to increases in high temperatures<sup>14</sup> which can increase cooling loads in summer. This may lead to a shift in the demand profile from a winter heating to a summer cooling system, placing strain on grid capacity. In future scenarios, this is also likely to be coupled with overall increased demand due to decarbonisation (eg large-scale switch from gas boilers to heat pumps). If grid capacity is insufficient to cope with demand peaks during heatwaves, then this could lead to short-term blackouts and loss of power required for LBTS assets.

Previous examples of this relationship include the 9 August 2019 power outage, which led to traffic light failures in London<sup>15</sup>. However, it is worth noting the complexity of the relationship between power and transport and the multiple factors and elements within the system that may be affected<sup>16,17</sup>. For example, impacts to rail infrastructure from the power outage noted above were caused in part by lightning strikes, but also by failure within other elements of the system, which were not the responsibility of National Grid. This included the failure of several smaller embedded generation power stations and vulnerabilities within the Thameslink train fleet, which required a manual reset after shutdown. This highlights how decarbonisation and electrification are likely to increase vulnerability within both the power and transport sectors. Although it is unlikely that this same scenario would be replicated, there remains the potential for other pathways of vulnerability to emerge as climate hazards occur more frequently and energy systems become more complex and integrated.

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<sup>13</sup> Climate Change Committee, March 2023 <https://www.theccc.org.uk/publication/delivering-a-reliable-decarbonised-power-system/>

<sup>14</sup> In the short- to medium-term, extreme winter conditions may also exacerbate network resilience concerns as more people move to using heat pumps for winter heating. However, this has not been included within the risk assessment due to higher levels of uncertainty and the expectation that risks from low temperatures will decrease over time.

<sup>15</sup> [Transport chaos across England and Wales after major power cuts | Energy industry | The Guardian](#)

<sup>16</sup> [Report following railway power disruption on 9 August 2019 | Office of Rail and Road \(orr.gov.uk\)](#)

<sup>17</sup> [GB power system disruption on 9 August 2019: Final report \(publishing.service.gov.uk\)](#)

### 3.7.1.2 Summary

**Table 3.1: Highest risk severity for 2050s for power grid resilience**

ID	Climate variable	Impact description	Asset	L	C	Total
1A	Extreme high temperatures	Higher cooling loads placing greater strain on the grid leading to cascading impacts to power supply for rail	Rail infrastructure – tracks, boundaries, crossings	4	4	16
1B	Extreme high temperatures	Higher cooling loads placing greater strain on the grid leading to cascading impacts to power supply for roads	Highways and roads – predominantly street lighting, traffic lights and signage	4	4	16

The highest severity risk relates to cascading impacts to power supply as a result of extreme high temperatures impacting on grid capacity. The severity is driven by higher likelihood in the 2050s due to the increasing dependency of electrified vehicles and systems and roads, eg smart motorways increasingly reliant on electricity. This also leads to high consequence scores for health and safety due to potential loss of power for active traffic management and variable road signs. Loss of power for critical rail infrastructure is also a significant risk if overhead line electrification (OLE) cannot be maintained, leading to performance impacts from track closures and loss of service.

Other climate interdependency risks which have been scored are:

- Loss of power to signalling systems leading to track closures and service disruption
- Loss of power or inability to maintain electric vehicle fleets if charging points are no longer able to operate
- Loss of power to the built environment, which may impact staff health and wellbeing (eg lack of air conditioning), as well as to cold storage and supply chains (eg loss of cooling in depots).

## 3.7.2 Interface 2: Power network – linear infrastructure

### 3.7.2.1 Explanation of interface and key pathways

Impacts to linear infrastructure within the power network operated by National Grid could also lead to cascading impacts to power supply for the London LBTS. These assets include pylons and overhead power lines, which can be located outside of London as part of the wider transmission network. Due to London being a net importer of electricity, impacts may occur in geographically disparate locations, which then cascade through to assets in London.

Climate hazards that impact this interface include:

- Extreme high temperatures, which can impact on asset integrity, in particular the sagging of transmission lines, with much of the older network only designed to be resilient to 30°C. However, newer assets are designed to be resilient to 40°C, reducing likelihood scores (as informed by National Grid stakeholders)
- Increased lightning strikes, which can directly impact linear infrastructure and prevent staff from responding to incidents
- Higher wind speeds during storm events leading to debris, which can damage overhead power lines and cables
- Higher average rainfall over a season leading to increased catchment runoff, and higher river levels leading to fluvial flooding, which can damage linear assets

- Surface water flooding, which may be exacerbated by preceding low rainfall/drought conditions and hardened soils, in combination with storm events, leading to flash flooding. This can impact foundations for linear infrastructure as well as access for maintenance or response.

### 3.7.2.2 Summary

**Table 3.2: Highest risk severity for 2050s for power network – linear infrastructure**

ID	Climate variable	Impact description	Asset	L	C	Total
2M	Higher wind speeds	High winds and storms impacting on linear infrastructure (overhead power lines, cables), both directly and indirectly via debris, which may be exacerbated by increased vegetation growth. Cascading impacts to power supply for rail infrastructure (eg tracks)	Rail infrastructure – tracks, boundaries, crossings	4	4	16
2N	Higher wind speeds	High winds and storms impacting on linear infrastructure (overhead power lines, cables), both directly and indirectly via debris, which may be exacerbated by increased vegetation growth. Cascading impacts to power supply for highways and roads	Highways and roads – predominantly street lighting, traffic lights and signage	4	4	16

The highest severity risks identified are in relation to higher wind speeds and debris impacting on overhead power lines and cables. These risks are also dependent on the management of vegetation, which may be the responsibility of other landowners beyond the power sector. Consequence scores assume a loss of power and are, therefore, considered to be similar to those outlined in Section 3.7.1 for power grid capacity and resilience. However, the overall scores are different due to a difference in likelihood and adaptation responses within the power sector and the climate variables involved (eg wind rather than temperature).

Scores for the present day are highest for climate interdependency risks impacted by high wind speeds, with fluvial flood risk also of moderate concern. Risk severity generally trends upwards for both likelihood and consequence in the 2050s and 2080s.

### 3.7.3 Interface 3: Power network - substation assets and cables

#### 3.7.3.1 Explanation of interface and key pathways

Impacts to power network assets, such as substations and underground cables (of which London has a higher proportion relative to overground cables), can also lead to cascading impacts to power supply for the London LBTS.

These assets are vulnerable to a high number of climate hazards, including:

- Extreme high temperatures impacting on asset integrity within substations and performance thresholds for transformers, circuit breakers and cables, which may be temperature limited
- Frozen precipitation leading to more freeze-thaw weathering and erosion, leading to ground movement and impacts to structural foundations and asset integrity for substations and underground cables
- Larger diurnal or short-term temperature variation causing ground movement and impacts to structural foundations and substation asset integrity

- Higher average rainfall over a season leading to increased catchment runoff, and higher river levels leading to fluvial flooding, which can damage substation assets. This also includes the potential for groundwater flooding and impacts on power tunnels that carry cables as part of the transmission and distribution network
- Surface water flooding caused by a combination of low rainfall/drought and hardened soils, in combination with storm events, leading to flash flooding, impacting on asset integrity and access
- Storm surges, sea level rise and extreme tides, separately or in-combination, causing tidal flooding if FRM assets are overtopped, impacting on asset integrity and access.

### 3.7.3.2 Summary

**Table 3.3: Highest risk severity for 2050s for power network – substation assets and cables**

ID	Climate variable	Impact description	Asset	L	C	Total
3A	Extreme high rainfall in a single event	Extreme rainfall leading to surface water flooding. Can be exacerbated if occurring in summer after a period of low rainfall or drought leading to reduced soil moisture. Impacting on asset integrity and access. Cascading impacts to power supply for rail infrastructure (eg tracks)	Rail infrastructure – tracks, boundaries, crossings	4	4	16
3B	Extreme high rainfall in a single event	Extreme rainfall leading to surface water flooding. Can be exacerbated if occurring in summer after a period of low rainfall or drought leading to reduced soil moisture. Impacting on asset integrity and access. Cascading impacts and loss of power for road signage	Highways and roads – predominantly street lighting, traffic lights and signage	4	4	16
3E	Extreme high temperatures	Extreme high temperatures impacting on asset integrity within substations and performance thresholds for transformers, circuit breakers and cables, which may be temperature limited. Cascading impacts to power supply for rail infrastructure (eg tracks)	Rail infrastructure – tracks, boundaries, crossings	4	4	16
3F	Extreme high temperatures	Extreme high temperatures impacting on asset integrity within substations and performance thresholds for transformers, circuit breakers and cables, which may be temperature limited. Cascading impacts and loss of power for road signage	Highways and roads – predominantly street lighting, traffic lights and signage	4	4	16

The highest severity climate risks relate to extreme high temperatures and variables leading to surface water flooding. Likelihood scores are lower relative to those for linear assets, to account for redundancy within the network and the LBTS' own distribution assets (eg substations, cables owned by TfL), which mean that supply can be more easily switched if required. This increased resilience results in impacts which are more localised and shorter in duration.

The high temperature scenarios reflected in 3E and 3F also present the potential for wider in-combination impacts with power grid capacity and resilience. For example, in an extreme

scenario where high cooling demand was placed on the grid, both the higher demand and the impacts to asset integrity could increase the overall risks to power supply for the LBTS.

We see a trend for risk increase across all time horizons, which can be attributed to both projected climate change (increase in temperatures, droughts, precipitation) and a lack of adequate action.

### 3.7.4 Interface 4: Telecommunications network

#### 3.7.4.1 Explanation of interface and key pathways

Many LBTS operations are dependent on the telecommunications network operated by external providers, such as BT, Sky, EE, Motorola and others. The resilience of this external network is then essential for enabling communications between staff and from staff to the public. In some cases, communications with emergency services are also reliant on the external network. However, not all LBTS organisations will be equally affected by a telecommunications outage, as there are some examples of telecommunications systems which are entirely separate from external providers (eg the GSM-R system used by the Elizabeth line<sup>18</sup>). Impacts to the LBTS are broadly categorised as the loss of ability to communicate with staff and road users on highways and road, and with staff and passengers in built environments (especially stations).

Climate hazards which impact telecommunications include:

- Fluvial flooding caused by increased catchment runoff and higher river levels leading to damage and functioning of telecommunications assets (exchange centres, street cabinets, data centres) critical to the network
- Surface water flooding, caused by combination of low rainfall/drought and hardened soils followed by storm events and flash flooding, leading to damage to telecommunications assets (exchange centres, street cabinets, data centres) critical to the network
- High winds and storms impacting on telecommunications assets (masts, cables) critical to the network
- Extreme high temperatures impacting on assets such as underground cables and cooling requirements for exchange and data centres.

It is also noted that the telecommunications sector has a high level of dependency on the power sector (eg to provide cooling) and the three interfaces discussed above, although the scoring of these risks is beyond the scope of this risk assessment.

#### 3.7.4.2 Summary

**Table 3.4: Highest risk severity for 2050s for telecommunications network**

ID	Climate variable	Impact description	Asset	L	C	Total
4B	Extreme high rainfall in a single event	Extreme rainfall leading to surface water flooding. Can be exacerbated if occurring in summer after a period of low rainfall or drought leading to reduced soil moisture, leading to damage to telecommunications assets (exchange centres, street cabinets) critical for communications and passenger safety	Built environments - buildings, stations, depots, head offices and property/developments	4	4	16

<sup>18</sup> Digital Railway - Telecommunications Technologies for the Elizabeth Line - An Infrastructure Manager's Perspective - Crossrail Learning Legacy

ID	Climate variable	Impact description	Asset	L	C	Total
4F	High average rainfall over season	Fluvial flooding caused by increased catchment runoff and higher river levels leading to damage to telecommunications assets (exchange centres, street cabinets) critical for communications and passenger safety	Built environments - buildings, stations, depots, head offices and property/developments	4	4	16

Due to lack of information surrounding each LBTS organisation's relationship with external telecommunications providers, and a lower level of engagement with stakeholders from within the telecommunications sector, risk scores are provided with a lower level of confidence.

The highest risk severities have been assigned to both surface water flooding and fluvial flooding risks to telecommunications assets, with consequence scores driven by health and safety concerns. For example, failure of communication systems in stations preventing information from reaching passengers and safe evacuations. The potential for cascading disruption across multiple stations means that performance impacts are assessed to be higher for built environments on the rail network than for highways and roads. However, there are also safety risks on high speed roads and the potential that emergency services cannot be called on time.

It is worth noting that there are currently changes in the way that telecommunications and emergency communications networks are being configured, with the current Tetra trunk network being replaced by Long Term Evolution (LTE), as well as the copper wire (Public Switched Telephone Network (PSTN)) comms networks being discontinued. However, it is expected that prioritisation of service would take place for emergency service communications if a shared network was used. This has been reflected in risk scores related to emergency service callouts.

Increasing severities from present day through to the 2050s and 2080s are primarily driven by higher likelihood scores associated with projections increasing for wind, temperature and precipitation. Some adaptation has been noted in regard to resilience measures (eg "Cells on wheels" moveable masts which can be used during a hazard event<sup>19</sup>). In addition, potential adoption of the Future Rail Mobile Communication System (FRMCS)<sup>20</sup> would provide industry standardisation which may benefit joint adaptation approaches, although this could also lead to a more concentrated risk position.

### 3.7.5 Interface 5: Civil structures

#### 3.7.5.1 Explanation of interface and key pathways

The congested nature of infrastructure within London means that many LBTS assets are in close proximity to civil structures owned by boroughs or other private landowners. Impacts to these structures can then trigger cascading impacts to rail and road infrastructure through debris being washed into tunnels or onto carriageways and access roads, forcing road, track and station closures.

Climate hazards that impact this interface include:

- Higher average rainfall over a season, leading to increased catchment runoff and higher river levels causing fluvial and/or groundwater flooding, leading to damage to civil structure foundations and asset integrity through tunnel water ingress or sudden bridge collapses in extreme cases

<sup>19</sup> Cell on Wheels (COW) | Mobile Base Station ([icsindustries.com.au](http://icsindustries.com.au))

<sup>20</sup> ETSI - Railway Telecommunication | Rail Communications Standards | FRMCS

- Frozen precipitation and freeze-thaw weathering leading to ground movement and damage to civil structure foundations and asset integrity (eg bridges, subways)
- Large diurnal and short-term temperature changes causing weathering and erosion leading to ground movement and damage to civil structure foundations and asset integrity.

Fluvial flooding and tidal flooding are considered as the primary flood risk due to their erosion power and ability to move material at a larger scale than surface water flooding.

### 3.7.5.2 Summary

**Table 3.5: Highest risk severity for 2050s for civil structures**

ID	Climate variable	Impact description	Asset	L	C	Total
5C	High average rainfall over season	Higher average rainfall over season, leading to increased catchment runoff and higher river levels causing fluvial and/or groundwater flooding, leading to damage to civil structure foundations and asset integrity through tunnel water ingress or sudden bridge collapses in extreme cases. Damage to track infrastructure potentially leading to closure	Rail infrastructure - tracks, tunnels, boundaries, structures	4	5	20
5D	High average rainfall over season	Higher average rainfall over season, leading to increased catchment runoff and higher river levels causing fluvial and/or groundwater flooding, leading to damage to civil structure foundations and asset integrity through tunnel water ingress or sudden bridge collapses in extreme cases. Damage to highways, roads and streets potentially leading to closure	Highways, roads, streets, access points, carriageways, pavements, cycleways, street lighting, traffic lights and signage	4	4	16

The highest severity risk for this interface relates to impacts from fluvial flooding and the potential to erode or damage civil infrastructure and wash debris onto roads and tracks leading to high consequence scores for health and safety. Likelihood scores are high due to the many roads and tracks that are in close proximity or traverse structures owned by other organisations within London. Consequence scores are slightly higher for rail infrastructure due to the assumption that a lower proportion of road assets are dependent on third party civil infrastructure.

General trends for present, 2050s and 2080s are for likelihood scores to increase driven by increased precipitation and fluvial flooding.

### 3.7.6 Interface 6: Pipe bursts

#### 3.7.6.1 Explanation of interface

Pipe bursts are a key upstream interdependency for the LBTS, with the sector dependent on the resilience of water company (primarily Thames Water and Affinity Water) pipe assets which are in proximity to LBTS infrastructure. In general, stakeholders highlighted that Thames Water assets are located nearer to rail infrastructure and Affinity Water to highways infrastructure.

Climate hazards that impact this interface include:

- Low temperature events which lead to low water temperatures increasing pipe brittleness and vulnerability to bursts

- Greater diurnal and short-term temperature variation due to an increase in both cold and hot temperature extremes. These impacts can cause both deterioration of pipes through movement of the ground around pipes or direct impacts to the assets themselves
- Low rainfall and drought can also lead to soil moisture changes and ground movement as a result of reduced groundwater levels, impacting on brittle pipes. The high proportion of clay soils within London are also more vulnerable to changes in soil moisture.

Bursts on water mains and distribution network assets are a particular concern in London due to the congested nature of infrastructure. Asset age and material (eg high proportion of cast iron mains) also increase their susceptibility to bursts. Examples of these risks occurring include the burst water main on Blackfriars Road in January 2020 which temporarily closed Southwark tube station and diverted bus routes. Impacts of pipe bursts on the LBTS can be categorised primarily as:

- Bursts which lead to surface water flooding events leading to the closure of highways and roads, as well as stations if access roads are impacted
- Bursts which impact directly on track infrastructure or lead to tunnel water ingress and closure of tracks
- Bursts which cause interruption to supply (ITS) events for built environments (eg offices, stations) where water is not available for customers or staff.

### 3.7.6.2 Summary

**Table 3.6: Highest risk severity for 2050s for pipe bursts**

ID	Climate variable	Impact description	Asset	L	C	Total
6A	Large diurnal temperature range	Increased diurnal temperature variation and cycling causes ground movement and direct impacts to pipes leading to bursts. May impact directly on track infrastructure or lead to tunnel water ingress and closure of tracks	Rail infrastructure - tracks, tunnels, boundaries, structures	3	4	12
6D	Low rainfall / drought	Low rainfall and drought can also lead to soil moisture changes and ground movement as a result of reduced groundwater levels, impacting on brittle pipes. May impact directly on track infrastructure or lead to tunnel water ingress and closure of tracks	Rail infrastructure - tracks, tunnels, boundaries, structures	3	4	12

- The highest risk severities are associated with an increase in climate driven changes to soil moisture and ground movement leading to high likelihood scores. Consequence scores primarily relate to performance impacts for infrastructure if tunnels or tracks become flooded as a result of bursts
- However, as with all interdependencies assessed, in many cases climate hazards exacerbate existing risks to pipes and may not be the primary cause of the failure. In particular, the location of bursts on the network determines consequences, as a burst in proximity to a busy part of the line or station would have greater impacts
- Scores for this interface are comparably lower than others due to the prominence of managing leakage and bursts within Affinity Water and Thames Water's adaptation plans. However, as these plans do not extend beyond 2050 the risk is assessed to increase again

beyond this point. Likelihood scores also increase for drought/low rainfall and diurnal temperature variation risks due to projections indicating an increase in these climate variables. Conversely, low temperature risks decrease over the time period due to warming temperatures.

### 3.7.7 Interface 7: Urban drainage system and combined network

#### 3.7.7.1 Explanation of interface and key pathways

If urban drainage systems and the combined network are overwhelmed, this can lead to surface water flooding impacting on the LBTS. This interface covers all external organisations that own drainage assets above ground and considers the combined sewer network owned by Thames Water and other organisations that operate in Central London. This interface considers urban drainage capacity but also the requirements for better maintenance and accurate data on the network, which were highlighted as a key issue. In recognition of the intersectoral challenge posed by surface water flooding, TfL and other organisations, such as Thames Water, the Greater London Authority (GLA) and the Environment Agency, already work together as part of the London Surface Water Flooding Strategic Group.

Climate hazards that impact this interface include:

- Low rainfall and drought leading to reduced soil moisture and hardened ground, which is more susceptible to surface water flooding during high rainfall storm events. This leads to high levels of urban runoff impacting on urban drainage
- An increase in sea level rise, extreme high tides and storm surges, either individually or in combination, leading to elevated tide levels. This can lead to tidal locking limiting outfalls and sluices used to discharge from the drainage and sewer network, reducing drainage capacity and contributing to surface water flooding
- Higher average temperatures could also lead to a lengthened growing season and increased vegetation growth and die-off in drought impacting on maintenance of drainage network (due to blocking of gullies) and contributing to surface water flooding.

Surface water flooding can cause significant disruption to the LBTS' operations with impacts grouped under the following categories:

- Impacts to earthworks (road and rail embankments and cuttings) potentially causing collapse and loss of service
- Impacts to built environments by preventing access to stations and workplaces, as well as leading to health and safety risks through increased slips, trips and falls
- Impacts to infrastructure through flooding of tracks and tunnel water ingress leading to loss of service
- Impacts to the road network through closures and diversions required, as well as slippery surfaces leading to a rise in accidents.

#### 3.7.7.2 Summary

**Table 3.7: Highest risk severity for 2050s for urban drainage system and combined networks**

ID	Climate variable	Impact description	Asset	L	C	Total
7K	Sea level rise/extreme high tides/storm surges	Tidal locking limiting outfalls and sluices from drainage and sewer network, contributing to surface water flooding. Impacts to built environments and access to stations and workplaces	Built environments - buildings, stations, depots, head offices and property/developments	4	4	20

ID	Climate variable	Impact description	Asset	L	C	Total
71	Sea level rise/extreme high tides/storm surges	Tidal locking limiting outfalls and sluices from drainage and sewer network, contributing to surface water flooding. Impacts to infrastructure (tracks, tunnel water ingress) and loss of service	Rail infrastructure - tracks, tunnels, boundaries, structures	4	4	20

Urban drainage and surface water flooding cover a number of complex system interactions with climate risks. Primarily, surface water flooding occurs during periods of intense rainfall on impermeable surfaces such as concrete or hardened soils. However, due to many of London's drainage network outfalls being located along the Thames Estuary, potential in-combination interactions with higher tides are expected to increase in frequency. This is already noted as an issue by Thames Water and can lead to sewer flooding as well<sup>21</sup>.

Likelihood scores for these risks assume that tidal locking occurs in conjunction with a period of high rainfall and runoff. Consequence scores are weighted towards performance impacts and are highest for built environments and infrastructure which, if flooded, may lead to disruption and loss of service, in addition to health and safety risks.

Scores generally increase from the present day through to the 2080s due to the projected increase in climate hazard, although they are balanced somewhat in the 2050s due to planned uptake of Sustainable Drainage Systems (SuDS) as an adaptation measure (eg 7000ha of SuDS planned as part of Thames Water's Drainage and Wastewater Management Plan (DWMP)).<sup>22</sup>

### 3.7.8 Interface 8: Vegetation and green infrastructure

#### 3.7.8.1 Explanation of interface and key pathways

Green infrastructure assets are owned and managed by stakeholders such as London Boroughs, the Environment Agency and private landowners. Vegetation can provide benefits through shading, carbon sequestration, runoff attenuation and improvements to soil health and structure. Trees in urban areas can also provide an amenity and recreation benefit and improve air quality. However, if these assets are poorly managed and in close proximity to rail or road infrastructure, then they can negatively impact on operations.

Climate variables that impact this interface include:

- Higher average temperatures and higher average rainfall leading to an extended growing season. This increases the likelihood of leaves being on trees when autumn and winter storm events occur, increasing the overall risk of leaf fall onto tracks, roads and station platforms. This can also increase the growth of vegetation and tree roots which can damage road surfaces or impact on building structures
- Higher wind speeds leading to more tree and leaf fall onto tracks (which could cause problems to wheel adhesion and risk derailment), roads and station platforms.

There is also the potential for maladaptation in the planting of trees and other green infrastructure as part of LBTS and external initiatives and strategies (eg the London Plan) to increase shading. However, if vegetation is not managed appropriately then this leads to an increase in likelihood for the hazards above.

Impacts to the LBTS can be categorised as:

<sup>21</sup> [Flooding Resilience - Technical Appendix](#)

<sup>22</sup> [Thames Water DWMP 2025-2050 technical-summary.pdf \(thameswater.co.uk\)](#)

- Impacts to built environments through the risk of leaf fall onto station platforms presenting a safety risk through increased slips, trips and falls
- Impacts to highways and roads through larger debris on carriageways leading to road closures and disruption, and leaf fall reducing tyre adhesion and so increasing accident risk. Tree roots and growth may also damage road surfaces leading to additional maintenance costs
- Impacts to infrastructure as a result of tree fall onto tracks leading to line closures and disruption and fines, eg Network Rail can be fined by train operating companies if trains cannot run. Leaf fall can also reduce wheel track adhesion and damage wheels, leading to speed restrictions and delays.

### 3.7.8.2 Summary

**Table 3.8: Highest risk severity for 2050s for vegetation and green infrastructure**

ID	Climate variable	Impact description	Asset	L	C	Total
8D	Higher average rainfall and higher average temperatures combined with storm events	Increased length of growing season to coincide with autumn/winter storm events leading to increased risk of leaf fall onto tracks, reducing wheel track adhesion and causing delays if the line is closed due to a tree across the tracks	Rail infrastructure - tracks, tunnels, boundaries, structures	4	4	16

The highest risk severities for this interface are associated with the risks of leaf fall onto tracks, with consequence scores driven by performance impacts due to delays. Likelihood scores are increased due to policy drivers for “greening” London, although evidence of adaptation measures to manage impacts from tree and leaf fall are also considered (eg fences to trap leaves).

However, risk severity still increases across the time horizons due to projected changes for in-combination climate hazards whereby higher rainfall and temperatures lead to an extended growing season to coincide with storm events.

## 3.7.9 Interface 9: Banksides and slopes

### 3.7.9.1 Explanation of interface and key pathways

In some cases, LBTS assets, such as tracks and roads, run adjacent to riverbanks or slopes which are managed by other organisations, such as London Boroughs, the Environment Agency and other private landowners. Damage to these slopes or banks (eg in the form of landslides) can cause impacts to the LBTS. This is a particular concern within London due to the high proportion of clay soils which are prone to landslides in times of heavy rainfall or after drought.

Climate hazards which impact on this interface include:

- High average rainfall over a season which may increase soil moisture leading to landslide risks
- Low rainfall/drought leading to low soil moisture and reduced vegetation cover, impacting on slope stability and increasing landslide risk.

### 3.7.9.2 Summary

**Table 3.9: Highest risk severity for 2050s for banksides and slopes**

ID	Climate variable	Impact description	Asset	L	C	Total
9A	High average rainfall over season	Higher rainfall may increase landslide risk. Landslide impacts to critical rail infrastructure (eg tracks, tunnels)	Rail infrastructure - tracks, tunnels, boundaries, structures	4	4	16

The highest risk severities for this interface were associated with landslide risks caused by either low rainfall/drought conditions or high rainfall. Rail infrastructure was given higher consequence scores due to the relatively greater performance impacts and disruption associated with route closures on rail networks, with the assumption that road users would have more alternative diversion options.

The general trend is towards increased risk from present day to the 2080s due to the lack of identified adaptation across the non-LBTS organisations and increasing projections for precipitation.

### 3.7.10 Interface 10: FRM assets

#### 3.7.10.1 Explanation of interface and key pathways

Many organisations within the LBTS have critical assets located along the Thames Estuary that are protected by flood defences, such as the Thames Barrier operated by the Environment Agency and The Embankment. However, climate change might require these defences to be used more frequently and their levels to be raised which increases the likelihood of tidal flooding events impacting on the LBTS. This interface also considers FRM assets which are required in upstream areas where fluvial and flash flooding in valleys can also occur.

The climate hazards that impact on this interface are sea level rise, storm surges and extreme high tides. These have been grouped within the risk assessment based on their in-combination contribution to tidal flooding as a hazard. If overall tide levels rise beyond the level accounted for within the design of the Thames Barrier and other defences within the Thames Estuary 2100 plan, then overtopping would occur.

#### 3.7.10.2 Summary

**Table 3.10: Highest risk severity for 2050s for FRM assets**

ID	Climate variable	Impact description	Asset	L	C	Total
10D	Sea level rise/extreme high tides/storm surges	Tidal flooding caused by higher tide levels leading to overtopping of FRM assets and defences impacting on earthworks, eg stability of rail and road embankments and cuttings	Earthworks	2	5	10

The highest risk severities were associated with overtopping of FRM assets impacting on earthworks leading to tidal flooding and damage to road and rail assets. Consequence scores are driven by performance and financial impacts due to the potential for large scale damage across the estuary if key flood defences were to fail. Scores have assumed that adaptation measures included within the Thames Estuary 2100 plan will be implemented (eg flood

defences downstream of the Thames Barrier will have been raised by a further 1m to 1.5m by 2070) and, therefore, the likelihood is considered to be low. Similarly, fluvial flood risk scores have assumed the implementation of the River Thames Scheme<sup>23</sup>.

This means that the risk profile does not increase significantly across the 2050s time horizon as, although projections for sea level rise increase, further adaptation measures are expected to manage the increasing hazard. However, high consequence scores mean that overall risk will increase significantly if tidal flood defences are not funded or implemented as currently planned.

Other impacts to the LBTS that have been scored include:

- Impacts to highways and roads through closures
- Impacts to infrastructure, such as tunnels, tracks and crossings, causing line closures and service disruption
- Impacts to built environments through station closures and damage to control centres, depots and stations.

### 3.8 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 organisational interface and 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. Other benefits include water attenuation and lowering of the urban heat island effect. TfL also manages green infrastructure as part of the Healthy Streets approach<sup>24</sup> 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 its 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.

### 3.9 Downstream interdependencies

Downstream interdependencies may arise when rail or road services are impacted by a climate hazard compromised 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,

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<sup>23</sup> River Thames scheme - GOV.UK ([www.gov.uk](http://www.gov.uk))

<sup>24</sup> TfL (2018) How green infrastructure contributes to the Healthy Streets Approach. Available through: [TfL Healthy Streets Planning](#)

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:

- **Impacts on staff availability** – disruption or closures to rail or road networks leading to cascading impacts across multiple sectors, including but not limited to power, water and telecommunications 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 two million passengers a year use public transport to travel to Heathrow Airport, with many of these journeys dependent on LBTS rail or road assets<sup>25</sup>. 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.

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<sup>25</sup> [Heathrow-Airport-Travel-Report-2019.pdf](#)

## 4 Prioritised actions

A total of 52 actions were co-created by stakeholders to reduce the risk from climate hazards to the key organisational interfaces and adapt to climate change. This section summarises our priority actions and the timescales we recommend for delivery.

The longlist of actions is outlined in Appendix H and has been grouped following the TfL's ARP3 categorisation, with the number of actions in each category indicated below:

- Capital and operational delivery (5)
- Collaboration, communication and reporting (5)
- Information management (10)
- Leadership and governance (15)
- Organisation and people (6)
- Risk management (11)

We have applied our prioritisation framework (see Figure 2.7) to identify high priority actions that can be implemented over the short- (1 year), medium- (2-4 years) and longer-term (5+ years). Our 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 twofold:

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 4.1 summarises our priority actions for reducing climate interdependency risks. It follows the climate interdependency risk infographic (see Figure 3.1) through linking the relevant climate hazards and organisational interfaces to the recommended actions. This indicated potential stakeholders that could be involved in implementing actions.

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 of vegetation and green infrastructure (medium-term), which feeds into the establishment of urban greening initiatives to adapt to future climate hazards (longer-term action).

We highlight the importance of green infrastructure related actions. Interventions, such as tree planting, SuDS and other nature-based solutions, form an essential part of the net zero agenda and adaptation to multiple climate risks, such as flooding and heat. Additional benefits can also be derived, such as improved air quality, amenity and biodiversity. Therefore, these actions scored highly against the prioritisation criteria, as they represent win-win and/or multiple benefit

options and can be seen as priority investments. However, actions to address maintenance and management are just as important to avoid any unintended consequences for other climate hazards or organisations. For example, discussions with the GLA and previous engagement between the transport sector and Forestry Commission have pointed to potential adaptation through planting tree species that do not hold leaves during the storm season<sup>26</sup>. Developing a clear set of principles for green infrastructure management for London's asset owners would also provide guidance on the relative prioritisation of different trade-offs (eg safety v carbon sequestration or biodiversity). These actions need to be deployed in the most effective way possible to ensure adaptation to a variety of climate related risks.

Creating a culture of multi-sector collaboration can avoid unintended consequences from adapting to one climate risk in one organisation whilst creating a risk to another organisation's asset. For example, stakeholders referenced an example where the diversion of flood water from temporary works within the transport sector led to the collapse of a National Grid-owned tower along a riverbank. Therefore, we also highlight the need to improve sharing of data between the LBTS group and other sectors. In this regard, risks from pipe bursts in the water sector could be addressed through an improved understanding of network vulnerabilities. This could be achieved through using existing data exploring vulnerabilities to flooding within the TfL network (such as outputs from the London Comprehensive Review of Flood Risk), coupled with Thames Water's own network map which shows key receptors and their locations relative to pipe assets.

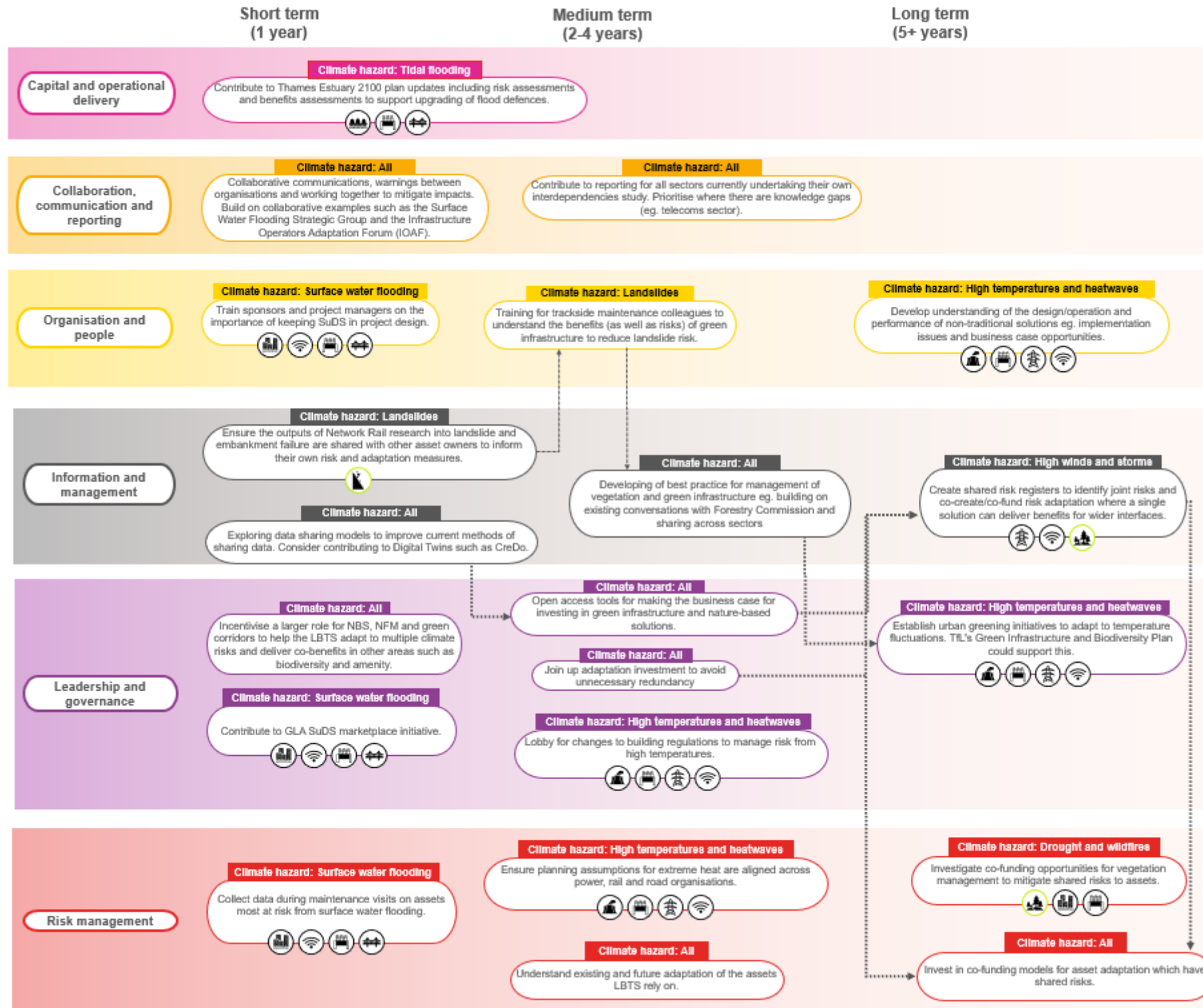
In the long term, our assessment has shown the need for a shared risk register or database. This will support cross-sectoral collaboration and help organisations to recognise the challenges that climate impacts can have across multiple sectors at any one time. Through a shared risk register, opportunities to respond to and mitigate risks can be jointly identified and solutions co-created and co-funded. This approach would also support the delivery of more co-ordinated investments in climate adaptation and resilience, leading to greater efficiency.

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 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, we propose 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 enables a more granular understanding of common benefits. It also avoids redundancy of solutions and delivers a more effective and efficient solution for all customers.

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<sup>26</sup> A presentation by the Forestry Commission on climate-adapted trees at a TASG meeting in 2020 led to a Network Rail and TfL workshop on climate-adapted trackside trees in 2021. This, in turn, led to TfL submitting a request to the Rail Safety and Standards Board (RSSB) to develop a set of high-level, overarching principles for trackside green infrastructure management. Findings have shown that research and guidance for the transport sector is currently limited.

Figure 4.1: Infographic showing prioritised actions for key climate interdependency risks



## 5 Conclusions and next steps

### 5.1 Summary and recommendations

Overall, the project presents a significant contribution to ARP4 submissions for the LBTS and also provides a new approach to assessing climate interdependency risks. 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 risks facing London's infrastructure.

Outputs from this assessment have focused on the key interfaces which have been identified as priorities by stakeholders. This presents a more pragmatic approach than a purely hypothetical assessment of all potential cascading failures across a system which has typified previous analysis 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, we also note the varying levels of confidence in risk scoring (eg lower for telecommunications risks) and the need to review this scoring periodically as more data becomes available. Nevertheless, this project presents a summary of much of the available evidence on climate 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. We highlight the following recommendations:

- 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 of 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.

We also recommend conducting a cost-benefit analysis for the recommended actions to further support the prioritisation of actions and highlight the potential for multi-benefit solutions benefitting both the transport sector and others.

### 5.2 Next steps

Our immediate recommendations for next steps for TfL are to encourage implementation of the short-term actions identified in Section 4 which are applicable to all members of the LBTS.

Specific actions which could be progressed in the short-term to address priority interdependencies include:

- Further engagement with the telecommunications sector which is currently beginning its own ARP4 reporting progress with support from the Electronic Communications Resilience and Response Group (ECRRG), which engaged with this project. Undertaking an internal review of TfL's own vulnerabilities would also be a starting point and would support the reporting process for the telecommunications sector
- Further engagement with Thames Water on mapping network vulnerabilities for TfL roads and rail
- Data sharing and collaboration with UK Power on specific vulnerabilities within TfL's distribution network
- Supporting the Environment Agency with ongoing work to assess the risks and benefits of upgrading the Thames Barrier and other flood defences
- Investigating the issue of groundwater flooding further. For example, the potential impacts of any chalk stream abstraction reductions upstream and any associated increase in groundwater levels and risks to subterranean assets.

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 telecommunications assets. This is beyond the scope of a project funded by the transport sector alone, although we recommend that a coordinated approach should be undertaken once all sectors have matured in their understanding of interdependencies.

## A. Stakeholder summary

**Table A.1: List of stakeholders that engaged with the project (attendance highlighted in grey)**

Stakeholder	System mapping focus groups	Workshop 1 - System mapping integration	Workshop 2 - Climate risk assessment	Workshop 3 – Risk reduction actions	Other (eg follow-up calls, forms, email exchanges)
Transport for London	Grey	Grey	Grey	Grey	
HS2	Grey		Grey	Grey	
HS1	Grey	Grey	Grey	Grey	
Department for Transport	Grey	Grey	Grey	Grey	
National Highways	Grey	Grey	Grey	Grey	
Network Rail	Grey	Grey	Grey	Grey	
Office of Rail and Road	Grey		Grey	Grey	
Defra	Grey				
National Grid	Grey	Grey		Grey	
UK Power Networks		Grey		Grey	
Environment Agency	Grey	Grey			Dark Grey
Greater London Authority	Grey	Grey			Dark Grey
Affinity Water		Grey		Grey	Dark Grey
Thames Water	Grey	Grey			Dark Grey
Heathrow Airport					Dark Grey
Electronic Communications Resilience and Response Group (ECRRG)					Dark Grey
Motorola					Dark Grey

## B. Documents reviewed

**Table B.2: Documents reviewed**

<b>Title</b>	<b>Type of document</b>	<b>Available online</b>
TfL Adaptation Reporting Power Submission 2021	PDF	Y
TfL Adaptation Risk Assessment	Excel	Y
Network Rail Third Adaptation Report - December 2021	PDF	Y
HS2 Climate Change Adaptation and Resilience	PDF	Y
National Highways Preparing for climate change on the strategic road network - third adaptation report under the Climate Change Act	PDF	Y
Affinity Water - Climate Change Adaptation Report 2021	PDF	Y
Affinity Water Adaptation Report Addendum Report Part 2 Climate Change Interdependencies MM Document	PDF	Y
PLA - Climate Change Adaptation Report Third Round Update	PDF	Y
Climate Change Adaptation Report National Grid Electricity Transmission July 2021	PDF	Y
Third Round Climate Change Adaptation Report National Grid Gas October 2021	PDF	Y
Thames Water Climate Change Adaptation Report for 2015-2020	PDF	Y
CCC Understanding climate risks to UK infrastructure Evaluation of the third round of the Adaptation Reporting Power - July 2022	PDF	Y
Cadent Climate Change Adaptation Report Third Round Response December 2021	PDF	Y
UKPN Climate Change Adaptation Report 16 December 2021	PDF	Y
TechUK Report to DEFRA under the Adaptation Reporting Power Third Round December 2021	PDF	Y
Heathrow Climate Change Adaptation Report Third Round Progress Report January 2022	PDF	Y
ITRC Resilience study research for NIC Systems analysis of interdependent network vulnerabilities Final Report April 2020	PDF	Y
LoTAG Adaptation Risk Workshop slides	PPT	N
Borough workshop outputs	Excel	N
Interdependencies categories for risk assessment (climate assessment)	Excel	N
NIC System analysis of interdependent network vulnerabilities	PDF	Y
WSP Interacting risks in infrastructure, the built and natural environments	PDF	Y
Defra Summary of responses and government response	Webpage	Y
Defra NAP3 and the fourth strategy for climate adaptation reporting	PDF	Y
Defra NAP3: Annex 1: Climate risks and opportunities	PDF	Y
SGN Third Round Climate Adaptation Report 2021	PDF	Y
Environment Agency Adaptation Report: Living better with a changing climate	PDF	Y
NHS-UK health security agency: Health and care adaptation report 2021	PDF	Y

## C. How to read and use system maps

Two system maps have been created for the purposes of this project.

1. The **integrated system map** which includes all key interdependencies and processes across the various sub-systems. Variations of this map were used within the system mapping focus groups and the integration workshop to collate and analyse interdependencies. Nodes or processes which were not considered to be relevant to the LBTS have not been included. This map functions as a stakeholder engagement tool and a record of conversations that took place across the project and is not intended as a final project deliverable in itself.
2. The **climate interdependency risk system map** which contains only the relevant upstream interdependencies and simplified impact pathways used in the climate risk assessment. We recommend using this map in conjunction with the reviewing the risk assessment spreadsheet and summary findings in Section 3.

### C.1 Guide to using the integrated system map

#### C.1.1 Basic principles

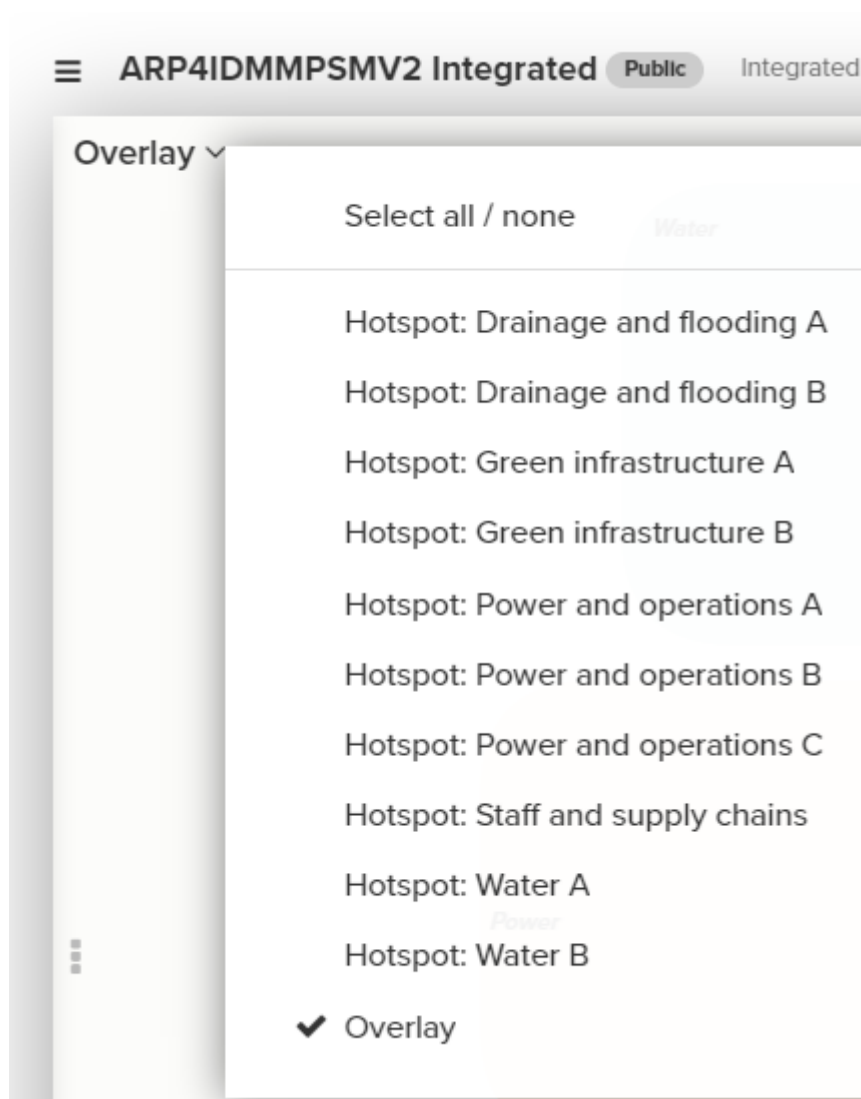
System maps comprise of nodes and links. To read a system map, it is important to understand the nodes and links in the following ways:

- **Nodes** represent system functions or factors of which there can be more or less. For example, there can be more or less disrupted journeys, or an increase/decrease in the number of staff able to reach their workplace. Categories of nodes are shown in the legend and classified by colour and shape. In this case, nodes have simply been classified as climate hazards, infrastructure, environment and social and economic according to their role within the system. More information on each node is provided on a panel to the left of the map which can be opened by clicking on three dots on the left of the map (close to the “L” of Legend). The panel may be closed by clicking these dots when it is open – which creates more space for the map to be seen. When you click on a node, these three dots appear to vibrate, drawing attention to their location.
- **Links** represent correlations. Positive correlation links are shown using green arrows (more of A leads to more of B), negative correlation links using red arrows (more of A leads to less of B) and complex correlations using blue arrows. Complex interactions (or those which are uncertain due to lack of information) are shown in blue and represent interactions where there is no clear correlation one way or the other. Note that, therefore, green does not necessarily equal good and red does not equal bad.

#### C.1.2 How to use the map – exploring the system

The integrated system map covers a total of seven sub-system areas identified through document review and the stakeholder engagement process. The map is structured so that the key LBTS sub-systems are at the centre of the map, with the other sub-systems around them. When the map is opened, the viewer is presented with the overlays for the sub-systems only. The key interdependency “hotspots”, which were used for analysis during the integration workshop, can then be selected using the filter in the top left of the page (Figure C.1).

Figure C.1: “Hotspot” filter



### C.1.3 How to read the map – detailed analysis

Hovering over a node will background all nodes not immediately linked to that node, thereby indicating the links relevant to that node. This effect is held by clicking the node and then the focus button (a circle with four marks like a compass) on the right-hand side of the map. Once the focus mode has been activated, then the focus can be expanded or contracted with the arrows that have appeared. Clicking on the focus button again will exit the view.

When a node has been selected, clicking on the focus button in the right-hand menu gives two options: to look at 1) the downstream impacts of the node; or 2) the nodes upstream which impact the selected node. These can be selected using the node impacts and node impacted by buttons at the bottom right of the screen, respectively.

## C.2 Guide to using the climate risk interdependency system map

### C.2.1 How to use the map – exploring the risk assessment

The definitions of the categories and how these have been used to structure the risk assessment are also discussed in Section 3 of the main report. The basic principles and

approaches to exploring this system map are the same as for the integrated system map outlined above.

However, the main difference in this map is that there are multiple filters present. These can be found in the top left of the map. They can be used as follows:

- 1. Headings** – this filter is set to show all nodes by default. However, this filter can be used to analyse the nodes according to their headings within the risk assessment spreadsheet (eg pathways, hazards, asset types).
- 2. Interface** – this allows users to filter by organisation interface (Column B in the risk assessment spreadsheet). Appendix H shows how this filtering has been applied to each of the interfaces.
- 3. Risk** – this allows users to filter by climate risk instead. This approach has informed the key risks infographic and discussions at Workshop 3 with the wider group to understand how multiple interfaces can be impacted by the same risks and, therefore, mitigated by similar actions.

The stakeholders button in the bottom right of the screen can also be toggled on and off to remove the stakeholder tagging around the interface nodes.

## D. Categories used in risk assessment

**Table D.3: Categorisation of climate variables**

<b>Climate variable</b>	<b>Other climate variables included</b>
Extreme high rainfall in a single event	Storm event. Heavy rain/cloudburst
Extreme high temperatures	Extreme high temperature (in the short-term, eg a few days) Long, hot, dry summer
Extreme high tides	
Frozen precipitation	Snow Ice Hail Sleet Change in freeze-thaw cycles
High average rainfall over season	High rainfall over a season or longer Increase in mean annual precipitation
Higher average temperatures	Higher average temperature (in the long-term, ie over a season or longer)
Higher wind speeds	Likely increase in the frequency and intensity of high wind events (with some uncertainty) Change in wind and storminess
Large diurnal temperature range	Large diurnal temperature range (in the short-term, eg a few days)
Lightning	Increases in the number of lightning days are projected for all four seasons, with the largest projected increases occurring in summer, associated with storms
Low rainfall/drought	Increase in the number of dry days per year, especially in summer Drier summers Low rainfall (over a long period of time but not necessarily leading to water use restrictions) Drought (three or more dry winters, leading to water supply restrictions) Increase wildfire risk
Low temperatures	Extreme low temperature (in the short-term, eg a few days)
Sea level rise	Extreme high tides
Storm surges	Changes in storm frequency
The following climate variables were not recorded as being of significant risk to interdependencies and were not included within the risk assessment	Fog Change in extreme winter temperature Other extreme weather events Change in solar radiation exposure Adhesion Sun glare

**Table D.4: Categorisation of asset types**

<b>Asset type</b>	<b>Other assets</b>
Built environments - buildings, stations, depots, head offices and property/developments	Control centres Plants Fixed plants Portable transportable plant Depot plant Substations Station assets (approaches, signs, lifts, PA, interchanges, etc.) Devco types Tenanted estate Comms system Mechanical, electrical and communications ITS Tech and networks
Bus fleet and vehicles	
Highways, roads, streets, access points, carriageways and pavements	Cycleways Street lighting Access points
(Rail) Infrastructure - tracks, tunnels, boundaries, structures	Bridges and viaducts Structures (eg bridges, footbridges, cycle bridges, bridge components, culverts, signals, gantries, retaining walls, buildings, road restraint systems and tunnels) OLE Level crossings, on-street running of trams Civils' structures On track machines - renewals On track machines - seasonal and incident On track machines - track treatment On track plan and mobile plant Third rail systems Deep tube tunnels Sub-surface tunnels
Earthworks	Geotechnical (eg embankments and cuttings)
Signalling system	
Rolling stock	Impacts to rolling stock from climate hazards are largely direct and have, therefore, been excluded from the interdependency risk assessment
People*	Impacts on customers and workforce (eg roadworkers, traffic officers, etc.) H&S/Welfare Maintenance staff and equipment Passengers TfL staff
Included as part of organisation interface nodes due to co-dependency, eg urban drainage, vegetation impacts and substation assets (see Section 2.4)	Drainage (eg gullies, outfalls and culverts, soakaways, ponds, pipes and ditches and channels) Power distribution Electrical Power supply (excluding rail) Power supply (non-rail infrastructure) Vegetation Green assets (trees, other vegetation)

\*Impacts to customers and staff safety are captured within the health and safety impacts in the consequence scoring. Similarly, increased congestion through cascading disruption within the transport sector is covered within performance impacts and is a relevant consequence for all interdependencies identified.

## E. Climate baseline

### E.1 Climate change in the context of London

#### E.1.1 Influences on climate in London

London, as part of Southern England, is within the part of the UK closest to continental Europe. Therefore, the city can be subject to continental weather influences that bring cold spells in winter and hot, humid weather in summer.

Due to London's location within a relatively sheltered area, between the Chiltern Hills to the north and the North Downs to the south, the regional climate is slightly milder than the rest of Britain. More specifically for London, the city is influenced by the urban heat island (UHI) effect.<sup>27&28</sup> The UHI effect is most conspicuous overnight in cold spells with light winds from late autumn to early spring, when temperatures in central London can be over 5°C higher than in the outer suburbs and surrounding rural areas.**Error! Bookmark not defined.**

Following the Clean Air Act of 1956 and a decline in heavy industry, there has been an increase in sunshine duration over the London area, particularly during the winter months.

#### E.1.2 Current climate - general trends

General trends in the area, based on observed data for the period 1981-2010, include:

- Mean annual temperature in London is 11.01°C
- January is the coldest month, with mean temperature of 5.01°C for the period
- July is the warmest month, with mean temperature of 18.12°C for the period
- Peak rainfall events are observed during autumn months
- Mean annual rainfall for the period is 638.61mm
- Average number of days with ground frost is 91 days per year.

#### E.1.3 Current temperature

Based on observed data from 1980-2010, January is the coldest month, with a mean monthly temperature of 5.01°C. July is the warmest month, with a mean monthly temperature of 18.12°C over the same period.

At the Greenwich Observatory station, situated within central London, the average annual maximum temperature was observed to be 15.34°C for 1981-2010, while the annual average minimum temperature was observed to be 7.84°C for the same period.<sup>29</sup>

The highest daily maximum temperatures recorded in the south and southeast of England were recorded at Heathrow Airport and St James's Park, where both locations reached 40.2°C on 19 July 2022.**Error! Bookmark not defined.**

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<sup>27</sup> The UHI effect is a phenomenon describing the elevated temperatures felt in towns and cities compared to rural surroundings. These effects are as a result of the heat retained by artificial surfaces that is slowly released. Therefore, higher temperatures are experienced. This effect occurs in combination with other impacts, such as the reduced cooling effect of vegetation in urban areas, in addition to the compounding effect of anthropogenic heat.

<sup>28</sup> Greater London Authority (2023) Heat. Available at: Heat | London City Hall [Accessed: December 2023]

#### E.1.4 Current precipitation

Rainfall is generally well distributed throughout the year, with an autumn peak. In addition, there are significant amounts in the summer associated with showery, convective rainfall. This is due to the additional heat from the London UHI leading to shower development in summer.

Due to the city's sheltered location between the Chiltern Hills and the North Downs, observed annual average rainfall in London is lower than the south and southeast region of England. For the 1981-2010 period of observed values at Greenwich Observatory, July was the month with the lowest average rainfall at 34.55mm, while October had the highest average rainfall at 61.06mm.<sup>29</sup>

Intense rainfall events have been recorded throughout London, with a noteworthy example occurring in Hampstead, Greater London, where 169mm rainfall fell within 2.5 hours on 14 August 1975.

#### E.1.5 Current sea level and observed sea level rise

In London, the risk from sea level rise (SLR) is growing. The high-water mark at London Bridge has increased by 1.5m since 1780.<sup>30</sup>

The rivers Thames and Lea are the two main tributaries in London, where the land elevation rises to an eroded hilly landscape towards the north and south of the city. This concentrates landward-encroaching SLR from the North Sea to the riverbanks of the Thames.<sup>31</sup>

The key structure protecting the city of London from increasing tide levels and storm surges is the Thames Barrier. The barrier opened in 1982 following an extreme flooding event in 1953. The aim of the barrier is to prevent high tides and storm surges from travelling upstream and damaging infrastructure and people in central London. It is expected to be operational until 2070, at which time it must be replaced.<sup>31</sup> The Thames Barrier was not intended to protect against sea level rises caused by climate change. At time of construction, the barrier was expected to be used two to three times per year. This has increased, whereby the current annual usage is six to seven times.<sup>32</sup>

#### E.1.6 Projected climate summary

The overall projected climate change trends for London over the 21<sup>st</sup> century include:

- There is an increased chance of warmer, wetter winters and hotter, wetter summers
- There is an increased risk of sea level rise.

In line with the scenario used for the Transport for London Climate Change Risk Assessment, climate projection data came from the United Kingdom Climate Projections 2018 (UKCP18) for

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<sup>29</sup> Met Office (2023) UK Climate Averages. Available at: [Greenwich Park \(Greater London\) UK climate averages - Met Office](#) [Accessed: December 2023]

<sup>30</sup> Carbon Brief (2014) Risk and uncertainty: Calculating the Thames Barrier's future. Available at: [Risk and uncertainty: Calculating the Thames Barrier's future - Carbon Brief](#) [Accessed: December 2023]

<sup>31</sup> Pace, S. (2021) Urban infrastructure inundation risk from permanent sea-level rise scenarios in London (UK0, Bangkok (Thailand) and Mumbai (India): A comparative analysis. Available at: [download \(lu.se\)](#) [Accessed: December 2023]

<sup>32</sup> Environment Agency (2014) The Thames Barrier. Available at: [The Thames Barrier - GOV.UK \(www.gov.uk\)](#) [Accessed: December 2023]

one greenhouse gas emissions scenario, RCP6.0<sup>33</sup>, for the 2050s and 2080s time periods for both temperature and precipitation. For sea level change, data was available only for RCP8.5 and was obtained for the same time periods. The UKCP18 projections were developed by the UK Met Office using the Met Office Hadley Centre climate model, and a selection of other global climate models, and are the latest set of climate projections for the UK.

The projections presented are both probabilistic projections and probabilistic extremes, outlined in Table E.5. Probabilistic projections present a range of values for the climate variable, based on the output of multiple runs of the climate models.

Probabilistic projection data, with the exception of SLR, was obtained for the London administrative region, as available from the UKCP18 user interface. Due to data availability from location of tide gauges, SLR data was obtained for the closest gauge to London, Sheerness.

Due to availability, probabilistic extreme data values were obtained at the 25km spatial resolution on the UKCP18 tool, grid reference 537500, 187500 to represent London.

**Table E.5: Climate projection data obtained for the risk assessment**

Climate variable	Data source	Emissions scenario	Time period	Spatial scale	Value
Summer (JJA) minimum air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Summer (JJA) maximum air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Summer (JJA) maximum air temperature extreme	UKCP18 - Probabilistic projections of climate extremes (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Grid reference: 537500, 187500	20- and 50-year return periods
Summer (JJA) mean air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Winter (DJF) minimum air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Winter (DJF) maximum air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Winter (DJF) mean air temperature	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Summer (JJA) mean precipitation	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile
Winter (DJF) mean precipitation	UKCP18 – Anomalies for probabilistic projections (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Administrative region	90 <sup>th</sup> percentile

<sup>33</sup> RCP6.0 is a pathway that describes trends in long-term global emissions of greenhouse gases (GHGs), short-lived species and land use/land cover change leading to a medium stabilisation scenario of radiative forcing. It is representative of an increase in global mean surface temperature of 2.8°C by 2081-2100.

Climate variable	Data source	Emissions scenario	Time period	Spatial scale	Value
1-day total summer (JJA) precipitation	UKCP18 - Probabilistic projections of climate extremes (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Grid reference: 537500, 187500	20- and 50-year return periods
1-day total winter (DJF) precipitation	UKCP18 - Probabilistic projections of climate extremes (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Grid reference: 537500, 187500	20- and 50-year return periods
5-day total summer (JJA) precipitation	UKCP18 - Probabilistic projections of climate extremes (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Grid reference: 537500, 187500	20- and 50-year return periods
5-day total winter (DJF) precipitation	UKCP18 - Probabilistic projections of climate extremes (25km) over UK, 1961-2100	RCP6.0	2050s, 2080s	Grid reference: 537500, 187500	20- and 50-year return periods
Annual sea level change (m)	UKCP18 – Sea level anomalised for marine projections around UK coastline, 2007-2100	RCP8.5	2050s, 2080s	Tide gauge location: Sheerness	90 <sup>th</sup> percentile

### E.1.7 Projected temperature change

Three temperature variables were analysed: changes in the mean seasonal air temperature; maximum air temperature; and minimum air temperature. These are presented in Table E.6. Data was obtained for seasonal values for summer (June, July, August) and winter (December, January, February). The projections are shown in Table E.6 and summarised graphically below (Figure E.2 and Figure E.3).

It should be noted that these projected mean, maximum and minimum temperatures are the modelled data for the typical range of future temperatures during each season, and that peaks and troughs in actual observed data will occur outside of these, resulting in heatwaves and cold snaps. The general trend is an increase in seasonal temperatures. While winters, on average, will become warmer, the Met Office consider that cold snaps may still occur to the same low temperatures that have been experienced in past decades. However, it may be that these occur less frequently.

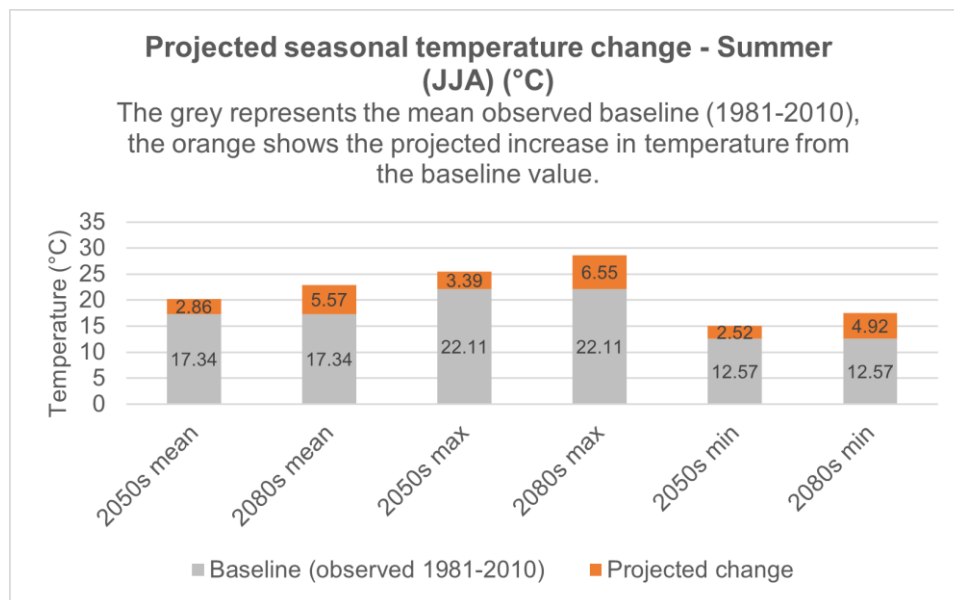
**Table E.6: Projected temperature change**

Climate variable	Season	Observed baseline mean seasonal temperature (1981-2010) (°C)	2050s (2040-2069) projected temperature change (°C) under RCP6.0, 90 <sup>th</sup> percentile	2080s (2070-2099) projected temperature change (°C) under RCP6.0, 90 <sup>th</sup> percentile
Air temperature (mean)	Summer (JJA)	17.34	+2.86	+5.57
Air temperature (max)	Summer (JJA)	22.11	+3.39	+6.55
Air temperature (min)	Summer (JJA)	12.57	+2.52	+4.92

Climate variable	Season	Observed baseline mean seasonal temperature (1981-2010) (°C)	2050s (2040-2069) projected temperature change (°C) under RCP6.0, 90 <sup>th</sup> percentile	2080s (2070-2099) projected temperature change (°C) under RCP6.0, 90 <sup>th</sup> percentile
Air temperature (mean)	Winter (DJF)	5.24	+2.09	+3.61
Air temperature (max)	Winter (DJF)	8.11	+1.99	+3.41
Air temperature (min)	Winter (DJF)	2.36	+2.34	+4.09

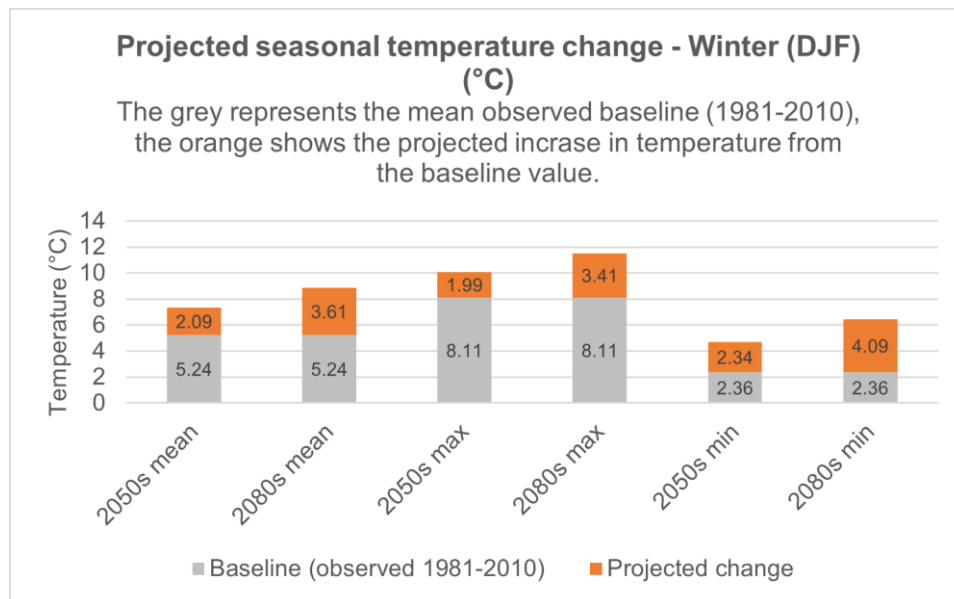
Source: UKCP18

**Figure E.2: Projected temperature change (summer)**



Source: UKCP18

**Figure E.3: Projected temperature change (winter)**



Source: UKCP18

### E.1.8 Projected temperature extremes

Seasonal temperature extremes were obtained for the summer months (JJA), presented in Table E.7.

The trend shows an increase in temperature extremes across all return periods and with increasing intensity through time. In London, this is likely to result in more intense and longer heatwave events in future decades, which may occur more frequently within any given year.

**Table E.7: Projected temperature extremes for the summer season (JJA) for 1-in-20-, 50- and 100-year return period events for a 1981-2000 modelled baseline based on RCP6.0, 90<sup>th</sup> percentile**

Climate variable	Modelled baseline (1981-2000) (°C)	2050s (°C)	2080s (°C)
20-year return period			
Maximum summer air temperature (JJA)	35.05	38.82	42.04
50-year return period			
Maximum summer air temperature (JJA)	35.92	39.72	43.05
100-year return period			
Maximum summer air temperature (JJA)	36.50	40.29	43.69

### E.1.9 Projected precipitation change

Table E.8 provides the baseline precipitation data for summer and winter (observed mean seasonal rainfall, mm) as well as the projections of how much this is anticipated to change by (percentage change) under RCP6.0 by the 2050s and 2080s.

**Table E.8: Projected precipitation change**

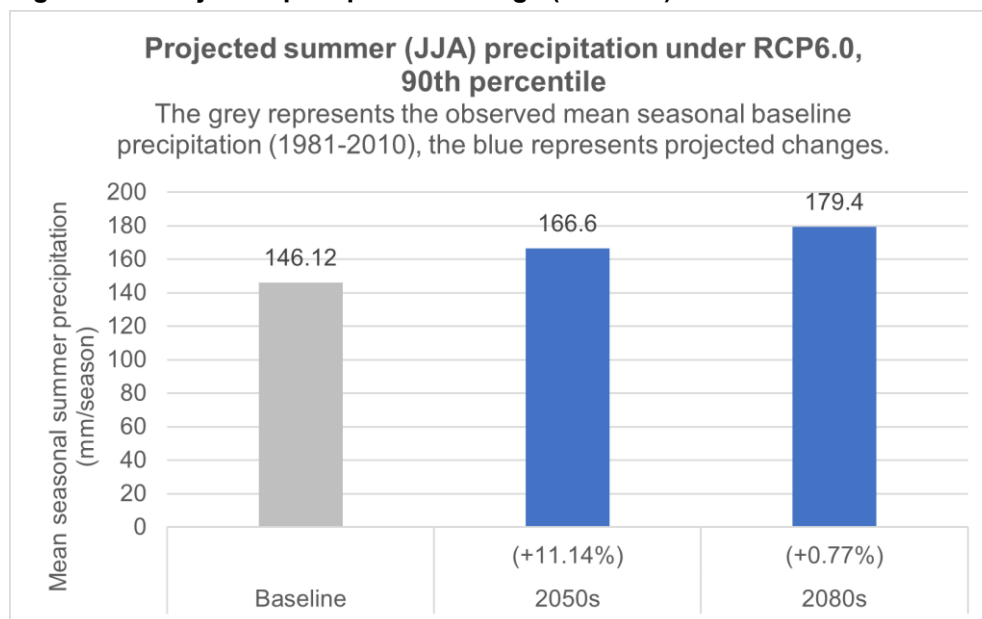
Climate variable	Season	Observed mean baseline seasonal precipitation (1981-2010) (mm)	2050s (2040-2069) projected precipitation change (%) under RCP6.0, 90 <sup>th</sup> percentile	2080s (2080-2099) projected precipitation change (%) under RCP6.0, 90 <sup>th</sup> percentile
Precipitation (mean seasonal)	Summer (JJA)	146.12	+11.14	+0.77
Precipitation (mean seasonal)	Winter (DJF)	162.59	+18.78	+33.45

Source: UKCP18

Figure E.4 and Figure E.5 respectively show the projected mean seasonal summer and winter rainfall in mm and include the percentage change in relation to the baseline period.

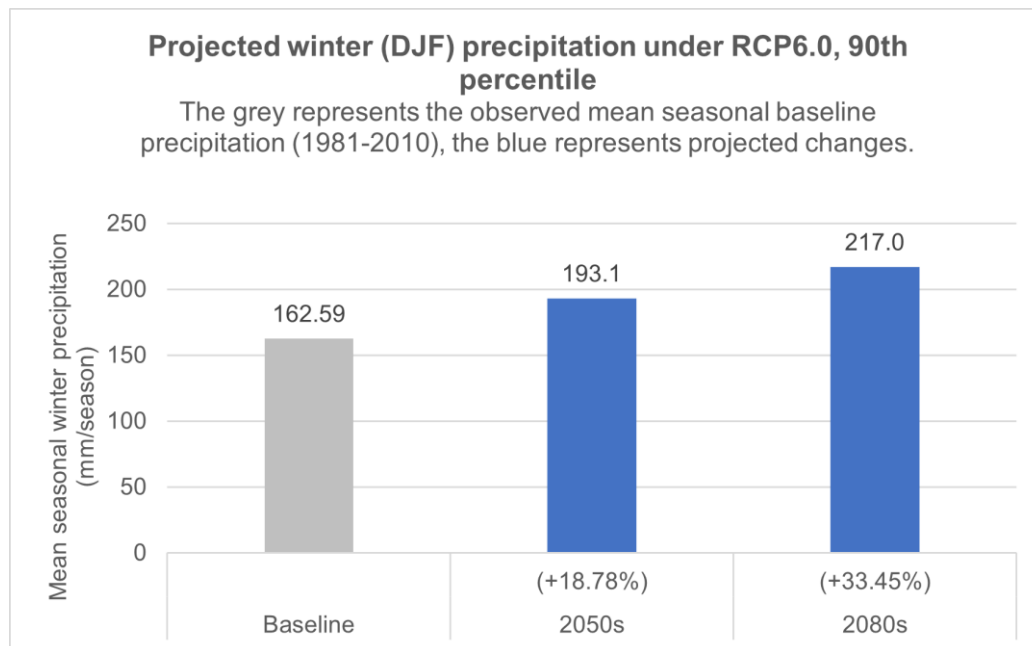
The observed mean total annual rainfall was 640.08mm for the London administrative region between 1981 and 2010. A +3.65% change is projected in mean total annual rainfall for the 2050s and a +5.69% change is projected for the 2080s.

**Figure E.4: Projected precipitation change (summer)**



Source: UKCP18

**Figure E.5: Projected precipitation change (winter)**



Source: UKCP18

The projected trend in rainfall shows that both summers and winters are expected to be wetter in the 2050s and 2080s. For winters, the rate of change increases through time from the 2050s to the 2080s. For summers, the rate of change decreases through time. This means that over time, despite both summer and winter experiencing wetter conditions, winter is expected to see a greater increase in seasonal average rainfall compared to the seasonal baseline, than that of summers.

There are few projections for snowfall, however, with a trend of warmer winters it may be that snow events become less frequent. The capacity of a warmer atmosphere to carry more water could potentially lead to heavy snowdrifts of wetter snow, as “wet” Atlantic storms meet cold Arctic weather fronts.<sup>34</sup>

### E.1.10 Projected precipitation extremes

In addition to the averages projected by climate models, rainfall events are projected to become more intense due to a warmer atmosphere being able to carry more water.

Projections of total precipitation over a one-day and five-day period, associated with a 1-in-20-, 50-year and 100-year return period, have been extracted from the UKCP18 probabilistic extremes tool and estimated for a baseline period and future RCP6.0 scenario for the 2050s and 2080s. Results for summer are presented in Table E.9 and Table E.10. Results for winter are presented in Table E.11 and Table E.12

Projections show an increase in intense and multiday precipitation events for both summer and winter seasons. Results in the below tables indicate that one-day precipitation events are more intense during summer across all return periods than during winter. Contrastingly, five-day precipitation events are projected to be more intense during winter. The trend towards increases

<sup>34</sup> National Snow and Ice Data Center (2024) Snow. Available at: [Science of Snow | National Snow and Ice Data Center \(nsidc.org\)](https://www.nsidc.org/) [Accessed: January 2024]

in multiday precipitation amount is likely to increase the likelihood and magnitude of fluvial flooding in London across both seasons.

**Table E.9: Projected one-day precipitation extremes for the summer season (JJA) 1-in-20-year, 50-year and 100-year return period events for a modelled 1981-2000 baseline based on RCP6.0, 90<sup>th</sup> percentile**

Climate variable	Modelled baseline (1981-2000) (mm)	2050s (mm)	2080s (mm)
20-year return period			
One-day total precipitation summer (JJA)	49.12	50.89	53.83
50-year return period			
One-day total precipitation summer (JJA)	61.81	64.05	67.65
100-year return period			
One-day total precipitation summer (JJA)	72.86	75.36	79.36

**Table E.10: Projected five-day precipitation extremes for the summer season (JJA) 1-in-20-year, 50-year and 100-year return period events for a modelled 1981-2000 baseline based on RCP6.0, 90<sup>th</sup> percentile**

Climate variable	Modelled baseline (1981-2000) (mm)	2050s (mm)	2080s (mm)
20-year return period			
Five-day total precipitation summer (JJA)	68.2	72.82	78.52
50-year return period			
Five-day total precipitation summer (JJA)	75.59	80.85	87.46
100-year return period			
Five-day total precipitation summer (JJA)	81.24	86.87	94.15

**Table E.11: Projected one-day precipitation extremes for the winter season (DJF) 1-in-20-year, 50-year and 100-year return period events for a modelled 1981-2000 baseline based on RCP6.0, 90<sup>th</sup> percentile**

Climate variable	Modelled baseline (1981-2000) (mm)	2050s (mm)	2080s (mm)
20-year return period			
One-day total precipitation winter (DJF)	33.18	36.96	40.44
50-year return period			
One-day total precipitation winter (DJF)	41.40	45.96	50.06
100-year return period			

Climate variable	Modelled baseline (1981-2000) (mm)	2050s (mm)	2080s (mm)
1-day total precipitation winter (DJF)	48.77	53.92	58.62

**Table E.12: Projected Five-day precipitation extremes for the winter season (DJF) 1-in-20-year, 50-year and 100-year return period events for a modelled 1981-2000 baseline based on RCP6.0, 90<sup>th</sup> percentile**

Climate variable	Modelled baseline (1981-2000) (mm)	2050s (mm)	2080s (mm)
20-year return period			
Five-day total precipitation winter (DJF)	68.24	76.44	84.19
50-year return period			
Five-day total precipitation winter (DJF)	75.49	84.38	92.97
100-year return period			
Five-day total precipitation winter (DJF)	80.88	90.14	99.32

### E.1.11 Projected sea level rise

Table E.13 summarises the projected sea level rise from UKCP18 marine data, relative to the observed baseline (1991-2010) derived from the National Oceanography Centre. It shows that sea level is projected to increase by 0.43m in the 2050s and up to 0.82m in the 2080s. **Figure E.6: Projected sea level rise**

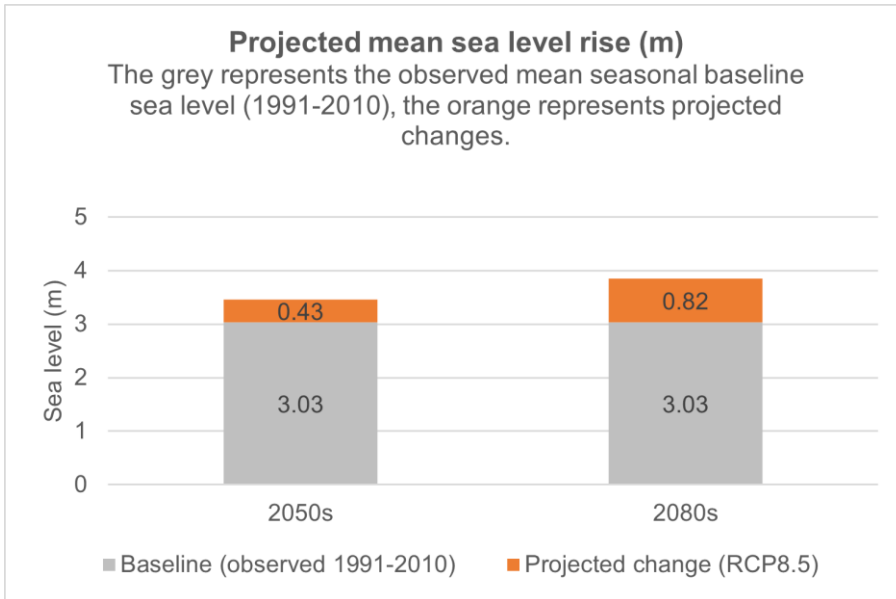
Figure E.6 summarises these increases graphically. For both the observed baseline and future projections, the closest available tide gauge, Sheerness, was used to represent SLR in London.

**Table E.13: Projected annual sea level change (m) relative to an observed 1991-2010 baseline, based on RCP8.5, 90<sup>th</sup> percentile**

Climate variable	Observed baseline mean sea level (1991-2010)	2050s (2040-2069)	2080s (2040-2069)
Sea level (m)	0.13	+0.43	+0.82

Source: National Oceanography Centre (baseline); UKCP18 (projections)

**Figure E.6: Projected sea level rise**



Source: National Oceanography Centre (baseline); UKCP18 (projections)

## F. Risk assessment analysis

Figure F.7: Summary of risk scores by interface

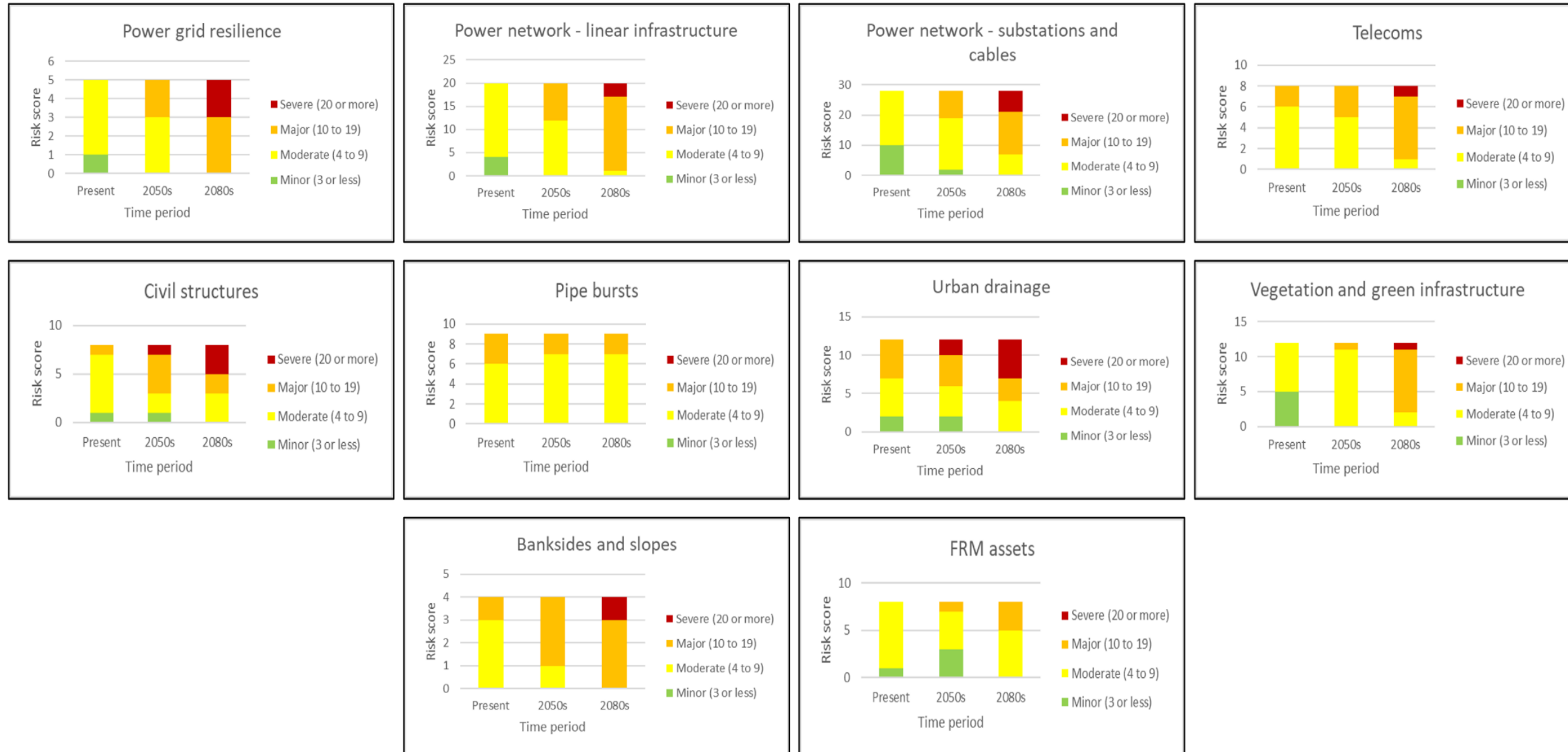
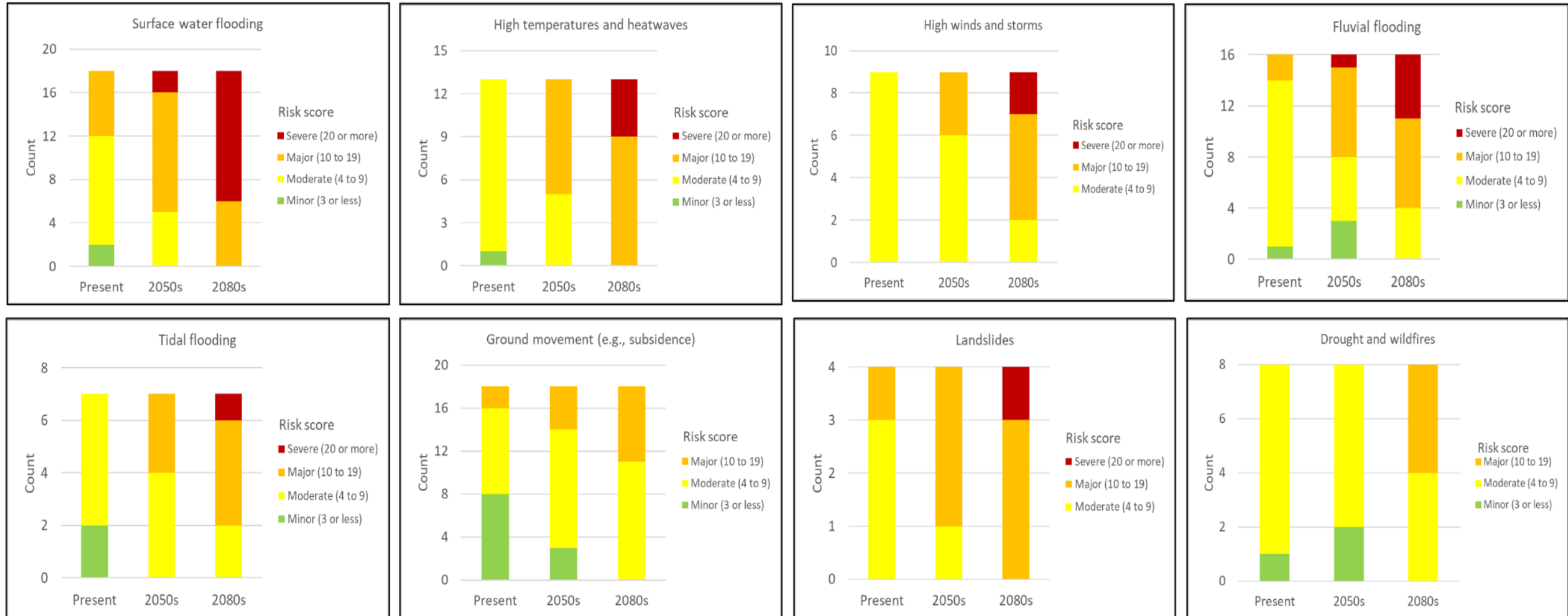


Figure F.8: Summary of risk scores by climate hazard



## G. System map visualisations

Figure G.9: Interface 1: Power grid resilience

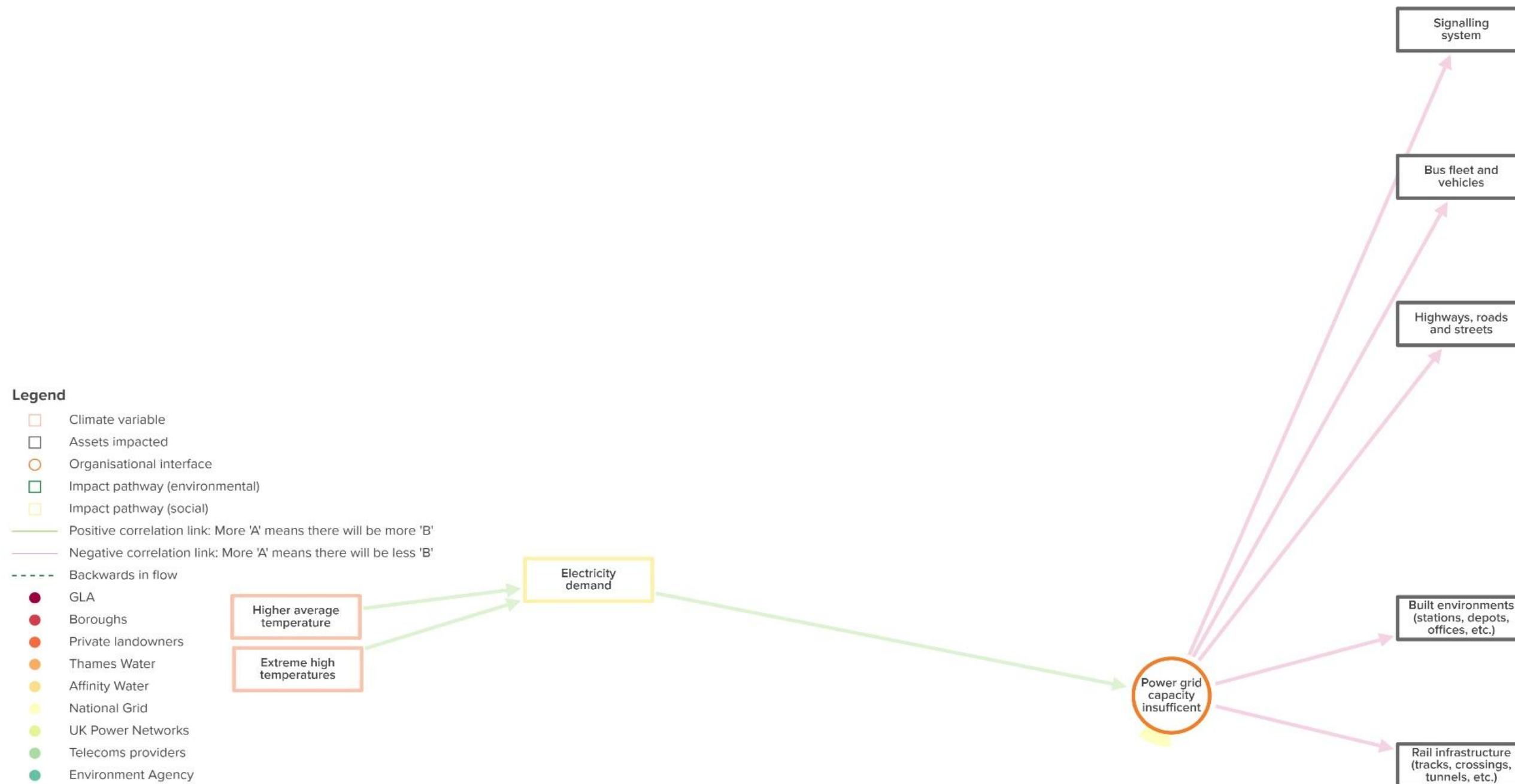


Figure G.10: Interface 2: Power network - linear assets

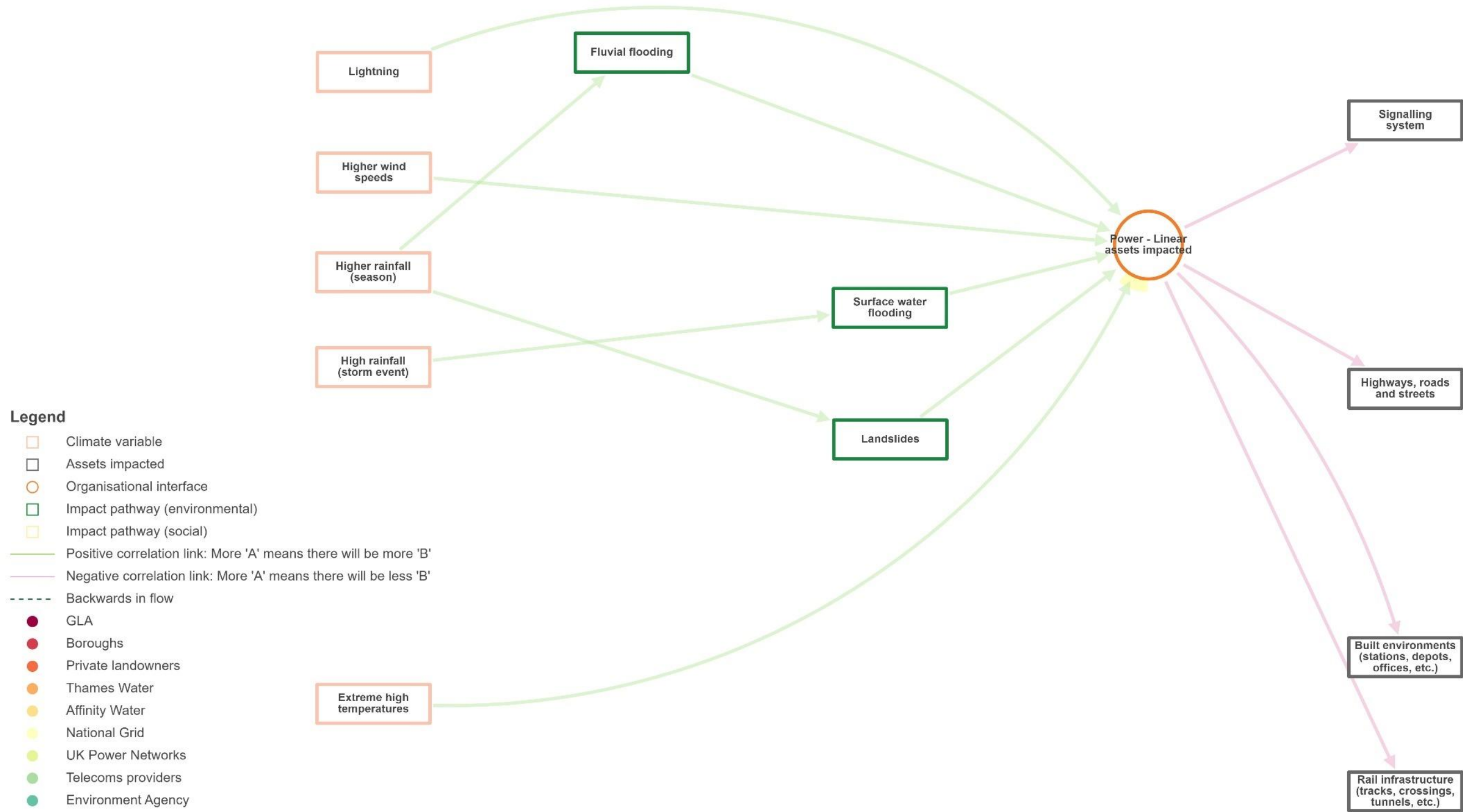


Figure G.11: Interface 3: Power network – substation assets and cables

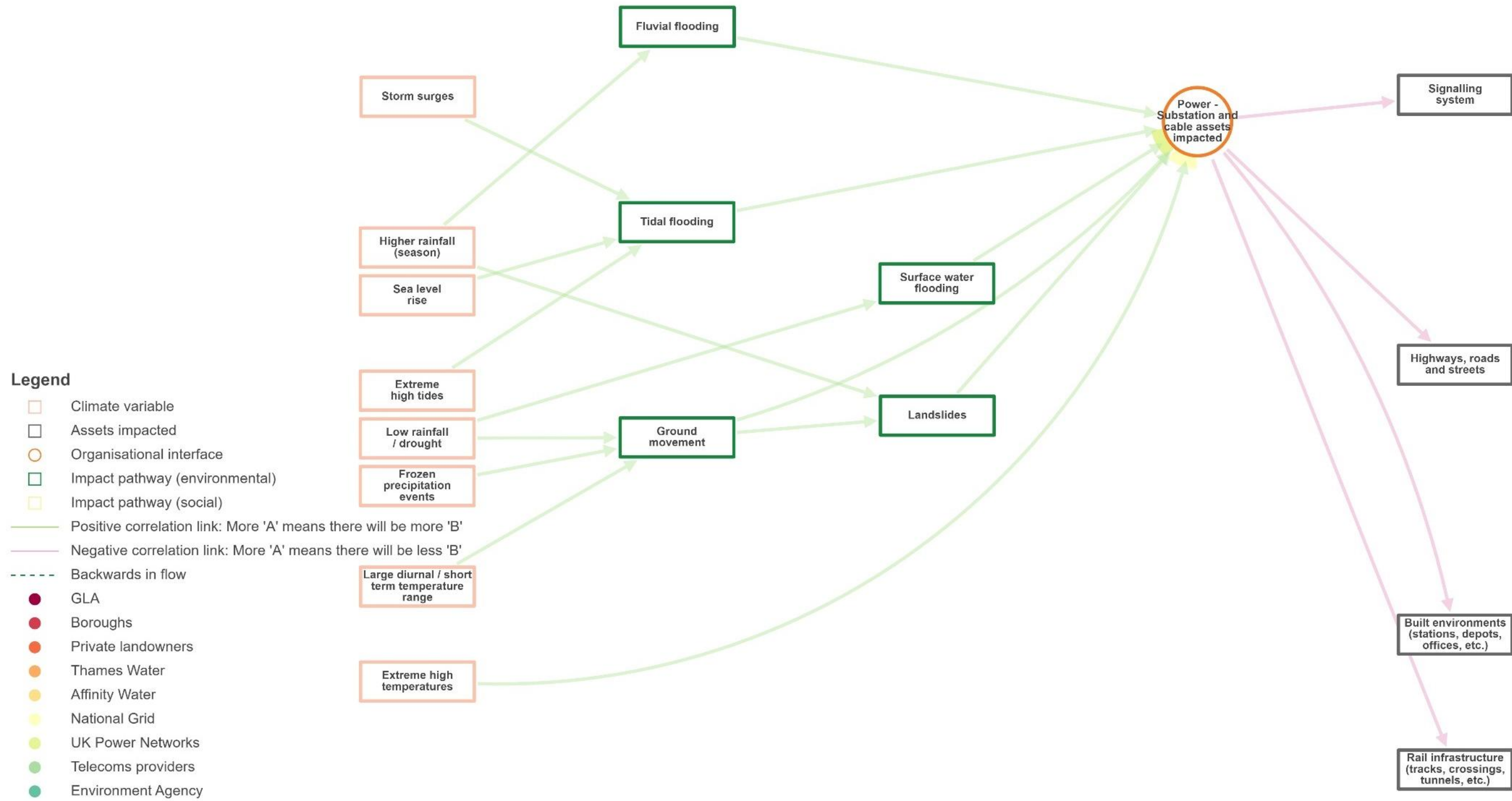


Figure G.12: Interface 4: Telecommunications

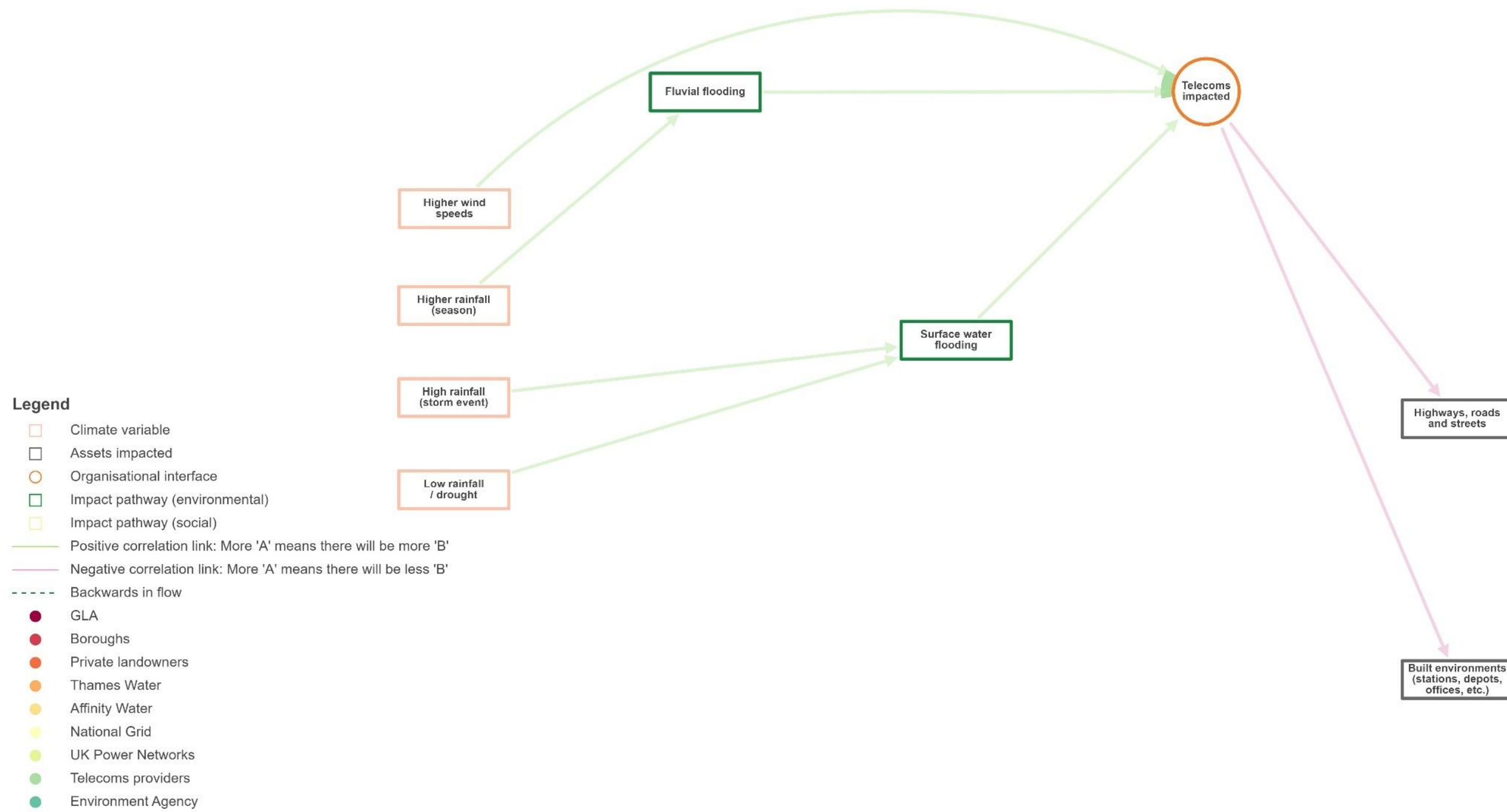


Figure G.13: Interface: Civil structures

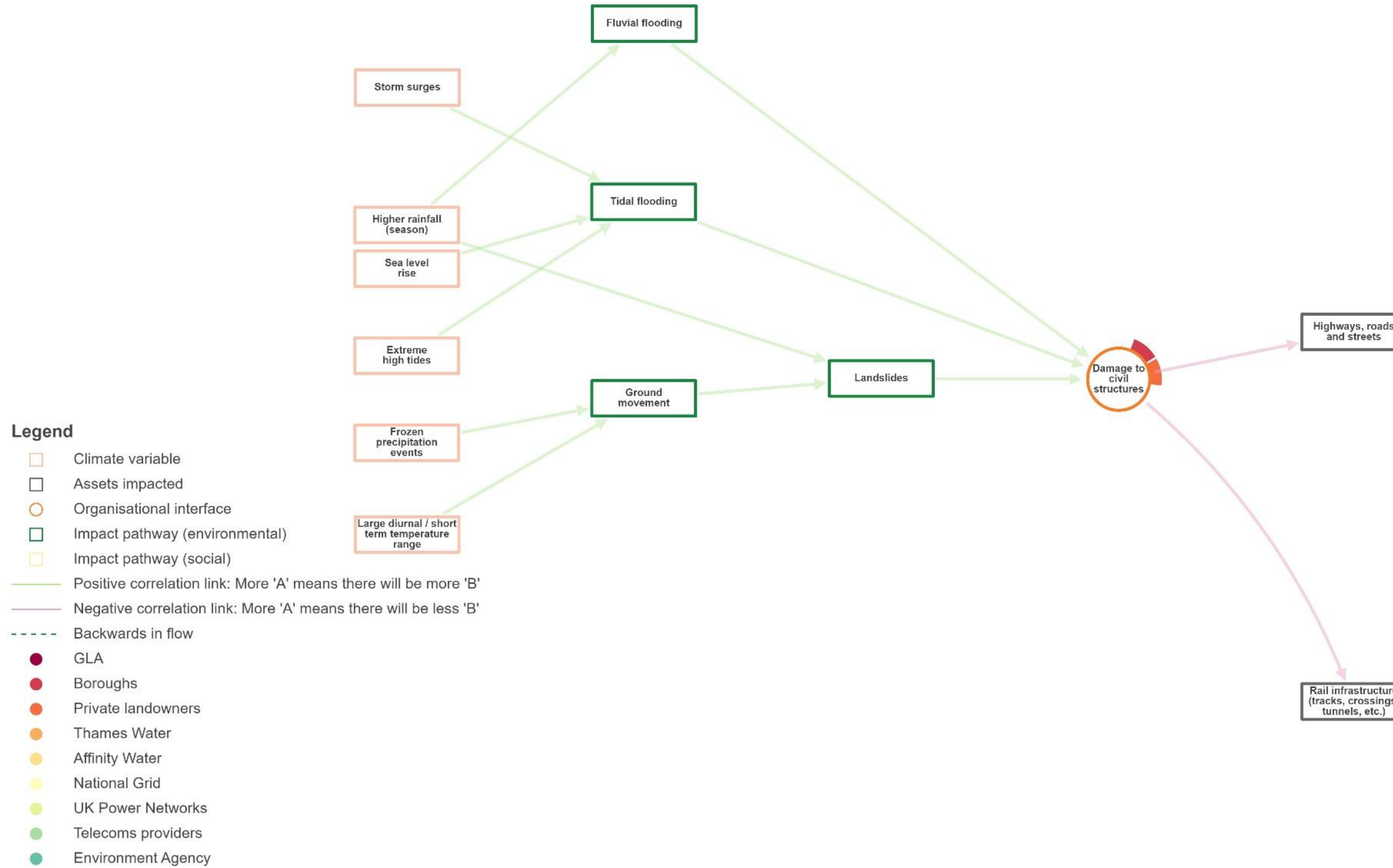


Figure G.14: Interface 6: Pipe bursts

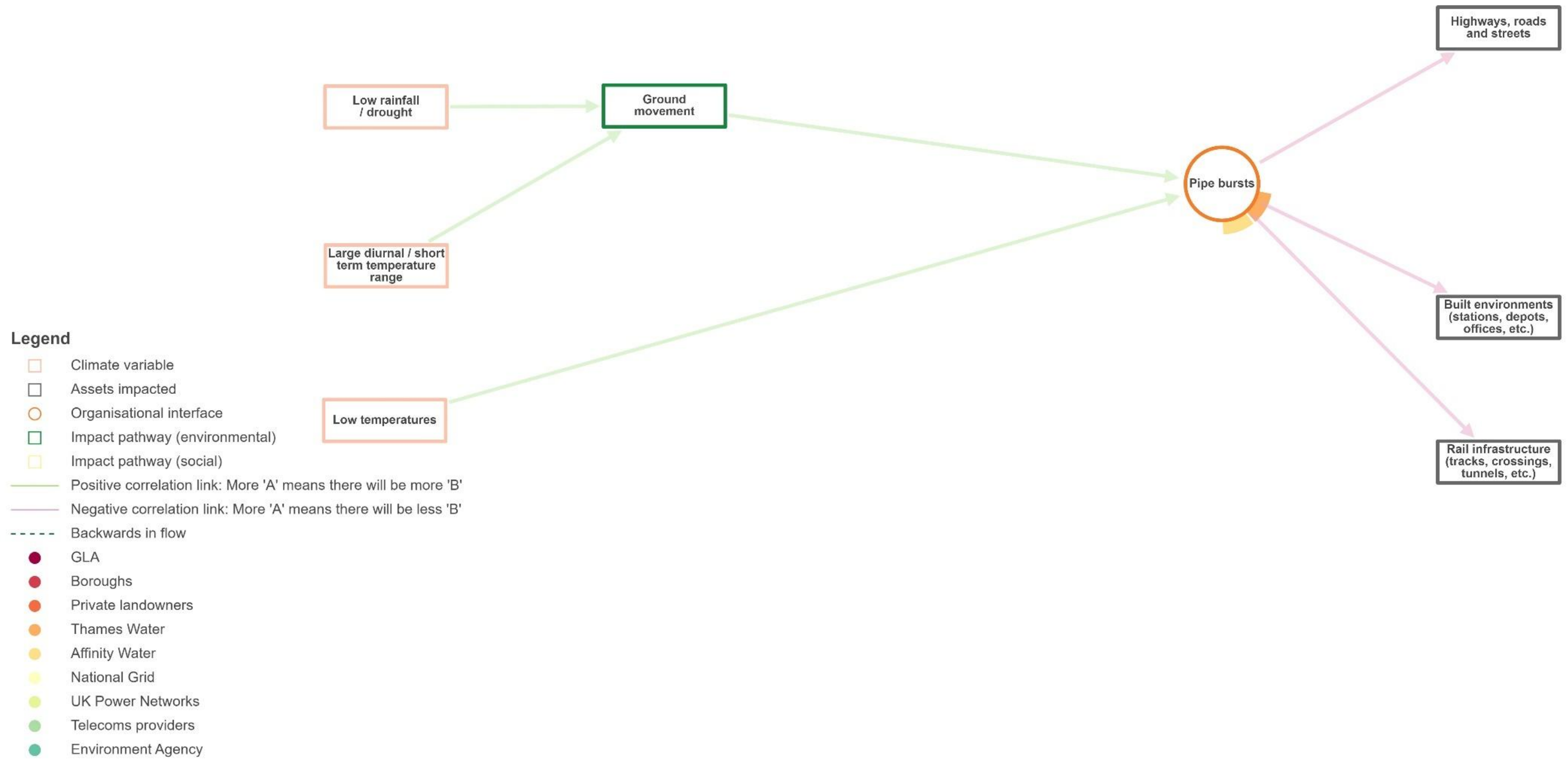


Figure G.15: Interface 7: Urban drainage system and combined network

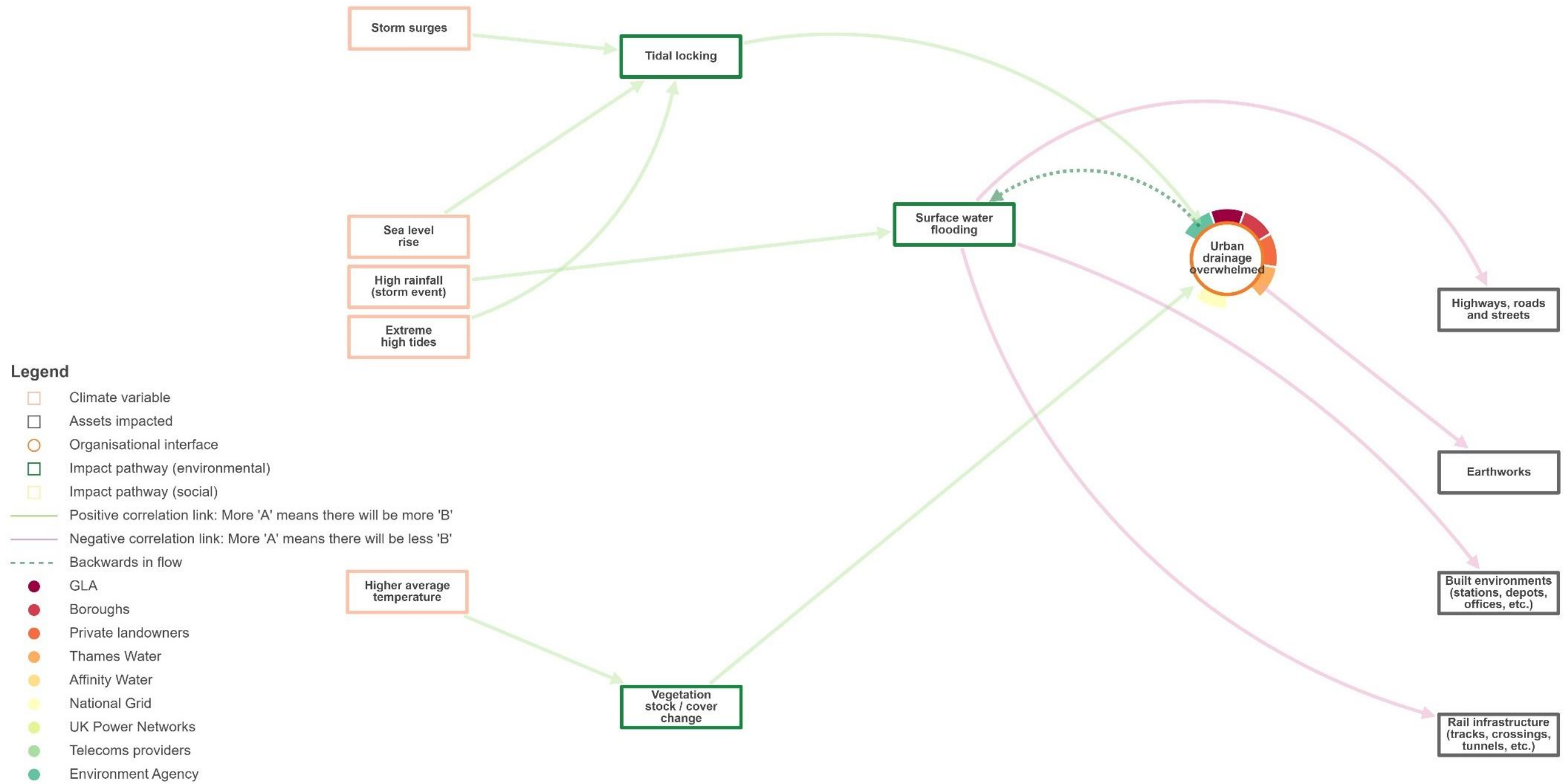


Figure G.16: Interface 8: Vegetation and green infrastructure

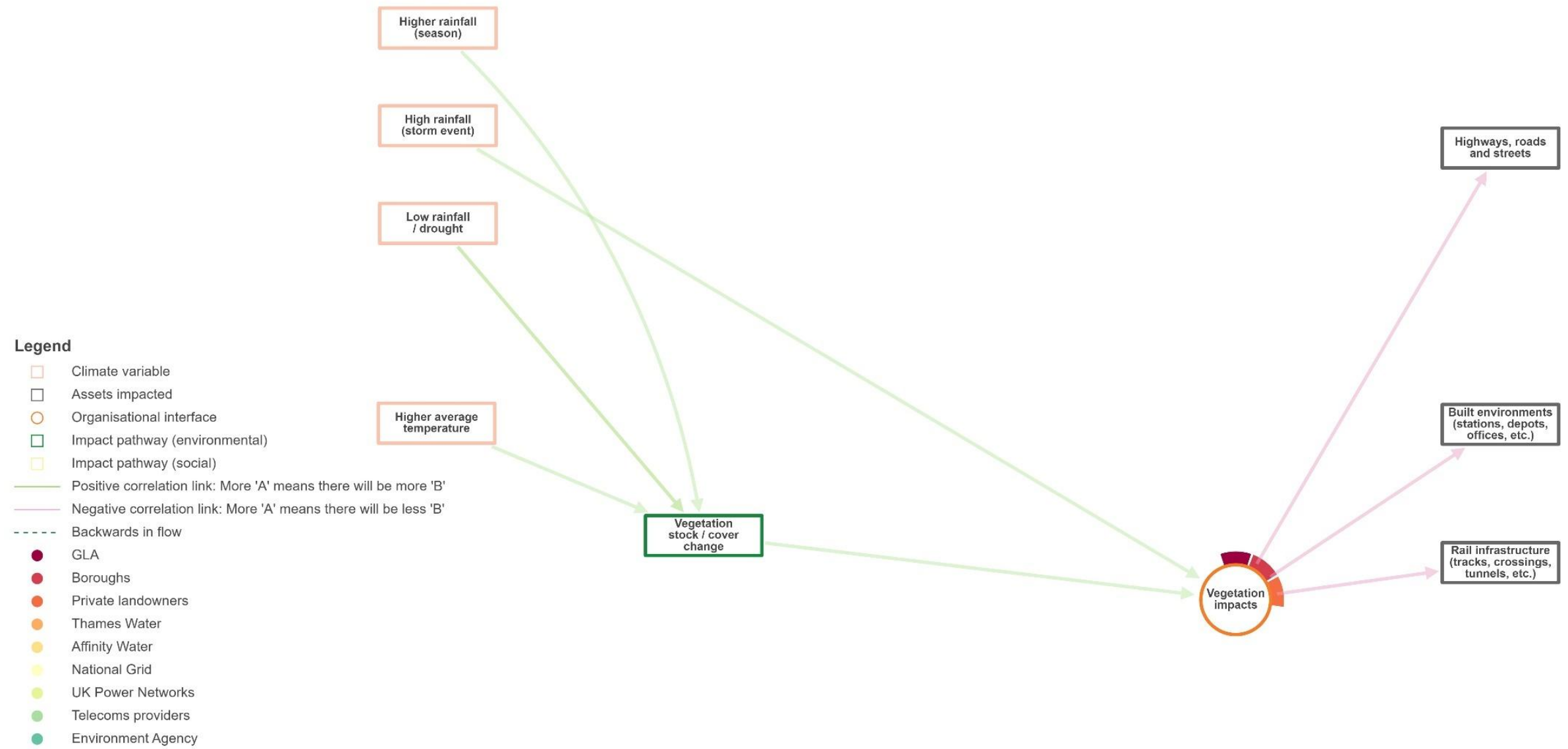


Figure G.17: Interface 9: Banksides and slopes

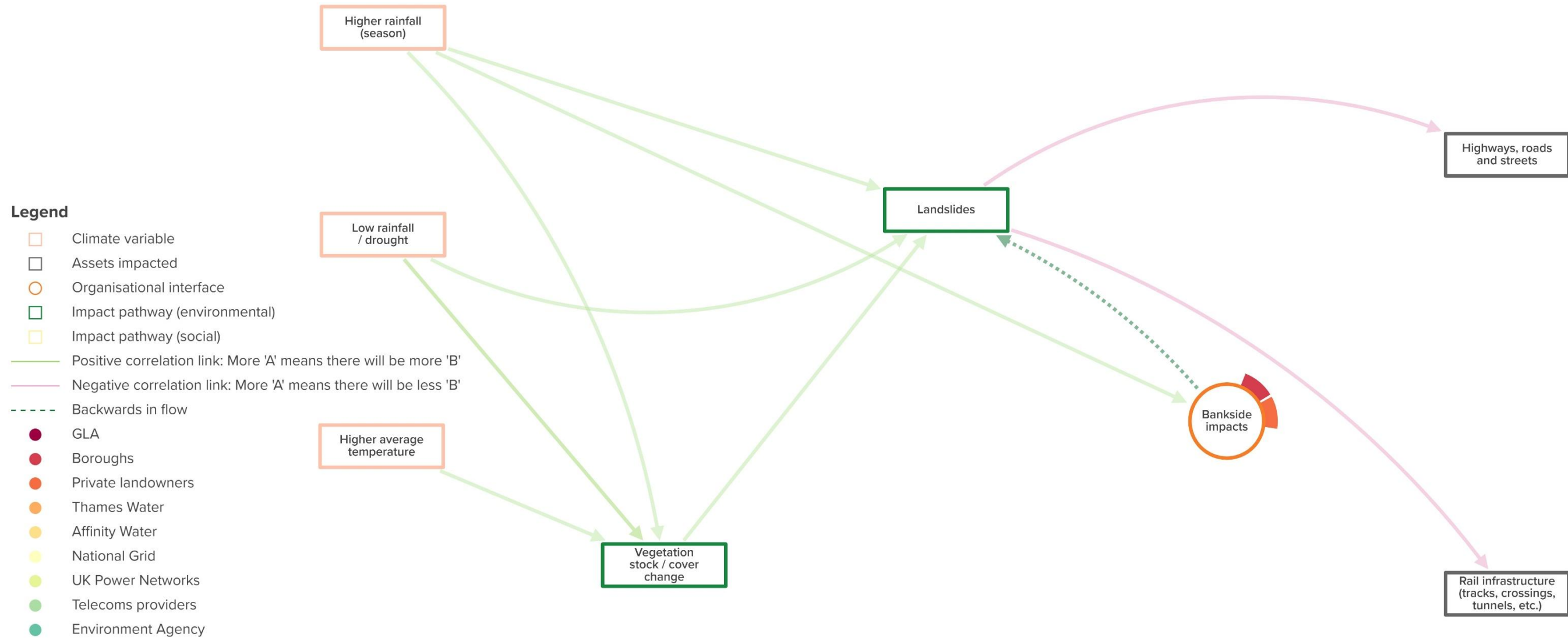
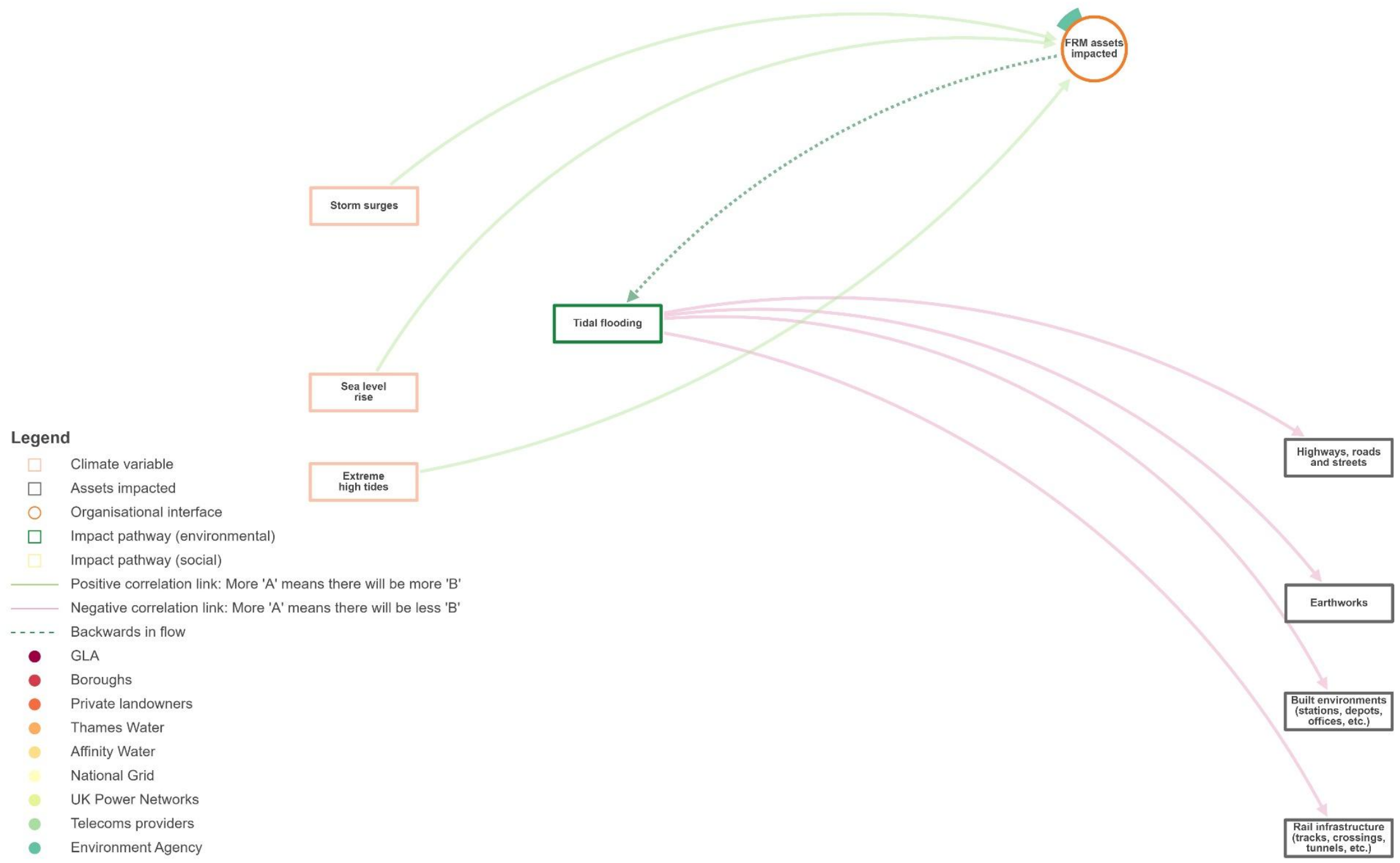


Figure G.18: Interface 10: FRM assets



## H. Prioritisation framework

Table H.14: High priority actions with scoring criteria

Risk type	Recommendation action	ARP3 category	No regret	Low regret	Win-win	Flexible or adaptive	Multiple benefits	Is this action likely to be within the LBTS' level of control?	Are skills and capabilities likely to be currently available to deliver this action?	Is this action aligned with the current regulatory cycle?	Outcome	Organisational interface
General – applicable to all climate hazards	Collaborative communications and warnings between organisations to work together to adapt to impacts. Build on collaborative examples, such as the Surface Water Flooding Strategic Group and the Infrastructure Operators Adaptation Forum	Collaboration, communication and reporting						Yes	Yes	Yes	Short-term, medium-high priority	All
General – applicable to all climate hazards	Explore data sharing models to improve current methods of sharing data. Consider contributing to Digital Twins, such as CreDo	Information management						Yes	Yes	Yes	Short-term, high priority	All
General – applicable to all climate hazards	Incentivise a larger role for nature-based solutions, natural flood management and green corridors to help the LBTS adapt to multiple climate risks (eg flooding, heat) and deliver co-benefits in other areas such as biodiversity and amenity	Leadership and governance						Yes	Yes	Yes	Short-term, medium-high priority	All
Landslides	Ensure the outputs of Network Rail research into landslide and embankment failure are shared with other asset owners to inform their own risk and adaptation measures	Information management						Yes	Yes	Yes	Short-term, medium-high priority	Banksides and slopes
Surface water flooding	Contribute to GLA SuDS marketplace initiative	Leadership and governance						Yes	Yes	Yes	Short-term, medium-high priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding	Train sponsors and project managers on the importance of keeping SuDS in project design	Organisation and people						Yes	Yes	Yes	Short-term, medium-high priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding	Collect data during maintenance visits on assets most at risk from surface water flooding	Risk management						Yes	Yes	Yes	Short-term, high priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Tidal flooding	Contribute to Thames Estuary 2100 plan updates, including risk assessments and benefits assessments, to support upgrading of flood defences	Capital and operational delivery						Yes	Yes	Yes	Short-term, high priority	FRM assets, power network – substations and cables, civil structures
General – applicable to all climate hazards	Contribute to reporting for all sectors currently undertaking their own interdependencies study. Prioritise engagement where there are knowledge gaps (eg telecommunications sector)	Collaboration, communication and reporting						Yes	No	Yes	Medium-term, high priority	All
General – applicable to all climate hazards	Join up adaptation investment across sectors to avoid unnecessary redundancy	Leadership and governance						No	No	Yes	Medium-term, high priority	All

Risk type	Recommendation action	ARP3 category	No regret	Low regret	Win-win	Flexible or adaptive	Multiple benefits	Is this action likely to be within the LBTS' level of control?	Are skills and capabilities likely to be currently available to deliver this action?	Is this action aligned with the current regulatory cycle?	Outcome	Organisational interface
General – applicable to all climate hazards	Open access tools for making the business case for investing in green infrastructure and nature-based solutions	Leadership and governance						No	Yes	No	Medium-term, high priority	All
General – applicable to all climate hazards	Understand existing and future adaptation of the assets LBTS rely on	Risk management						No	Yes	Yes	Medium-term, high priority	All
High temperatures and heatwaves	Lobby for changes to building regulations to manage risk from high temperatures	Leadership and governance						No	Yes	No	Medium-term, medium-high priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Ensure planning assumptions for extreme heat are aligned across power, rail and road organisations	Risk management						No	No	Yes	Medium-term, high priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High winds and storms	Develop best practice for management of vegetation and green infrastructure, eg building on existing conversations with the RSSB and the Forestry Commission and sharing across sectors	Information management						Yes	No	Yes	Medium-term, high priority	Power network – substations and cables, telecommunications, and vegetation and green infrastructure
Landslides	Training for trackside maintenance colleagues to understand the benefits (as well as risks) of green infrastructure management to reduce landslide risk	Organisation and people						Yes	No	Yes	Medium-term, high priority	Banksides and slopes
General – applicable to all climate hazards	Create shared risk registers to identify joint risks and co-create/co-fund risk reduction where a single solution can deliver benefits for wider interfaces	Information management						No	No	No	Long-term, high priority	All
General – applicable to all climate hazards	Invest in co-funding models for asset adaptation which have shared risks	Risk management						No	No	No	Long-term, medium-high priority	All
High temperatures and heatwaves	Establish urban greening initiatives to adapt to temperature fluctuations. TFL's Green Infrastructure and Biodiversity Plan could support this	Leadership and governance						No	No	No	Long-term, medium-high priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Develop understanding of the design/operation and performance of non-traditional solutions, eg implementation issues and business case opportunities	Organisation and people						No	No	No	Long-term, medium-high priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
Drought and wildfires	Investigate co-funding opportunities for vegetation management to adapt to shared risks to assets	Risk management						No	No	No	Long-term, medium-high priority	Vegetation and green infrastructure, urban drainage, and power network – substations and cables

**Table H.15: Medium to low priority actions. Note timing of options not included.**

Risk type	Recommendation action	ARP3 category	No regret	Low regret	Win-win	Flexible or adaptive	Multiple benefits	Outcome	Organisational interface
General – applicable to all climate hazards	Invest in growing self-generation capacity and/or backup-power arrangements at critical sites	Capital and operational delivery						Medium priority	All
General – applicable to all climate hazards	Share details of risks with the designers of future projects to ensure designs cater for the future climate	Collaboration, communication and reporting						Medium priority	All
General – applicable to all climate hazards	Support NIC recommendations around statutory adaptation duty for regulators	Leadership and governance						Medium priority	All
General – applicable to all climate hazards	Produce adaptation pathways across infrastructure assets	Leadership and governance						Medium priority	All
General – applicable to all climate hazards	Training to develop understanding of SuDS performance, implementation issues and new opportunities for business case	Organisation and people						Medium priority	All
Ground movement (eg subsidence)	Conduct further studies using shared data and models to highlight vulnerabilities within the pipe network	Information management						Medium priority	Pipe bursts, power network – substations and cables
Ground movement (eg subsidence)	Establish governance of building site management and wastewater to improve understanding on where it's redirected and how it's managed	Risk management						Medium priority	Pipe bursts, power network – substations and cables
High temperatures and heatwaves	Ensure cooling measures (eg A/C) do not increase carbon emissions	Capital and operational delivery						Medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Inform and educate communities and organisations regarding energy use during peak times	Organisation and people						Medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Review and update design standards for infrastructure (eg for power lines and cables) in line with recent climate projections	Leadership and governance						Medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High winds and storms	Undertake LiDAR studies and engage in data sharing on vegetation risk	Risk management						Medium priority	Power network – substations and cables, telecommunications, and vegetation and green infrastructure
Landslides	Increase understanding of asset risk factors to landslides and then understand exposure locations	Risk management						Medium priority	Banksides and slopes
Surface water flooding	Engage with the GLA collaborative streetworks opportunity	Capital and operational delivery						Medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding	Use London Surface Water Flooding Strategic Group planned data sharing agreement as a facilitator for sharing data on surface water flood risk	Information management						Medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding	Continue to co-fund and implement actions from Surface Water Flooding Strategic Group including development of SuDS Opportunity Modelling	Information management						Medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures

Risk type	Recommendation action	ARP3 category	No regret	Low regret	Win-win	Flexible or adaptive	Multiple benefits	Outcome	Organisational interface
General – applicable to all climate hazards	Provision of risk maps by asset owners	Information management						Low-medium priority	All
General – applicable to all climate hazards	Improve local understanding of the value of habitats and green spaces in London	Leadership and governance						Low-medium priority	All
General – applicable to all climate hazards	Training requirements that include communities, STEM outreach, stewardship	Leadership and governance						Low-medium priority	All
Drought and wildfires, ground movement (eg subsidence)	Develop a community role in delivery of urban greening to retain water moisture and reduce risk of drought and groundwater movement	Collaboration, communication and reporting						Low-medium priority	Pipe bursts, power network – substations and cables, vegetation and green infrastructure, urban drainage.
High temperatures and heatwaves	Share data regarding LBTS organisations' current and planned embedded generation contributions to power grid through joint study with National Grid and UKPN	Information management						Low-medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Calculate projected energy needs for LBTS and share with energy sector	Risk management						Low-medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High temperatures and heatwaves	Align safety considerations and best practices for maintenance/replacement/construction programmes. Social research on expectations on transport sector during periods of extreme weather (eg what is the expected service level during a 40C heatwave and does it align across sectors?)	Leadership and governance						Low-medium priority	Power grid resilience, power network – substations and cables, power network – linear infrastructure, and telecommunications
High winds and storms	Work with building regulations and planning to ensure wind impact is considered in new development	Leadership and governance						Low-medium priority	Power network – substations and cables, telecommunications, and vegetation and green infrastructure
Landslides	Undertake LiDAR studies on bankside risk and landowner mapping	Risk management						Low-medium priority	Bankside and slopes
Surface water flooding	Share high-level forward capital works plans across infrastructure sectors	Capital and operational delivery						Low-medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding, Fluvial flooding	Investigate opportunities to improve resilience at the community scale.	Organisation and people						Low-medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding, fluvial flooding	Support in CreDo Transport Use Case dependencies analysis	Collaboration, communication and reporting						Low-medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures
Surface water flooding, fluvial flooding, tidal flooding	Align flood risk and reduction strategies with outputs from CreDo. Contribute to data sharing for digital twins where possible	Information management						Low-medium priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures, FRM assets
High winds and storms	Lobby for changes to planning laws and regulators on appropriate location of cables	Leadership and governance						Low priority	Power network – substations and cables, telecommunications, and vegetation and green infrastructure.
Surface water flooding	Establish one lead authority to coordinate response to surface water flood risk	Leadership and governance						Low priority	Urban drainage, telecommunications, power network – substations and cables, and civil structures

Risk type	Recommendation action	ARP3 category	No regret	Low regret	Win-win	Flexible or adaptive	Multiple benefits	Outcome	Organisational interface
Ground movement (eg subsidence)	Share and maintain a skills-based database to resource the response to pipe bursts	Risk management						Low priority	Pipe bursts, power network – substations and cables

