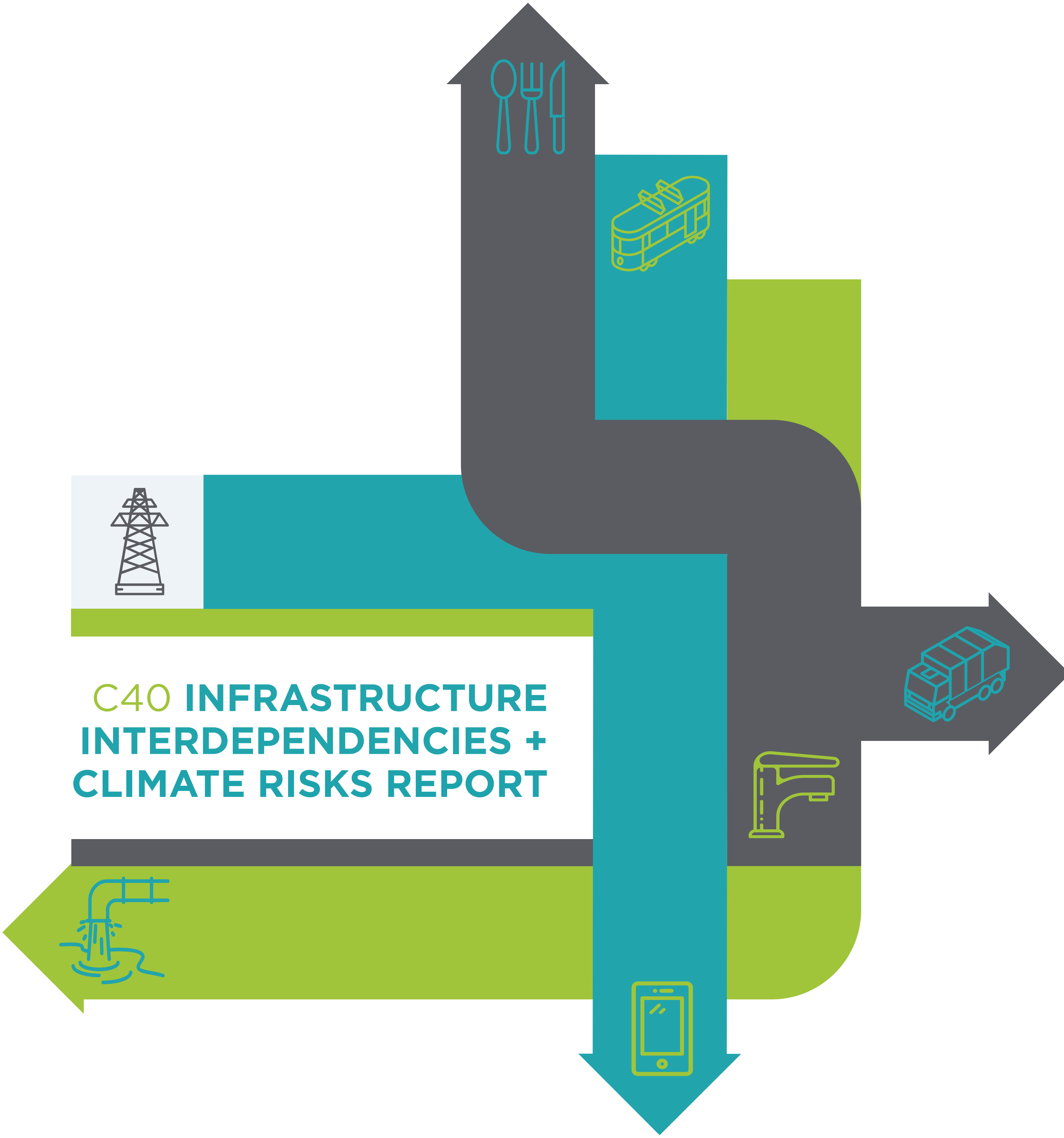
C40 INFRASTRUCTURE INTERDEPENDENCIES + CLIMATE RISKS REPORT



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Interdependencies + Climate Risk

Executive Summary:

Modern urban infrastructure systems for the energy, transportation, telecommunications water/wastewater, solid waste, and food sectors are highly interdependent. Climate change is projected to cause adverse ripple effects in these systems due to an increase in the magnitude and frequency of extreme weather events such as coastal and inland flooding, heat waves, droughts, and wildfires.

This report summarizes the efforts of a sample of city governments and other public agencies around the world to understand the cascading impacts of climate change on interconnected infrastructure systems at the urban scale. It highlights how the identification of infrastructure interdependencies and climate impacts can serve as a first step in reducing risks to systems.

Various categories of infrastructure interdependencies are reviewed and summarized, such as physical, cyber-based, and geographic, interdependencies. Of these, infrastructure systems with critical interdependencies (caused by automation, resource constraints or the nature of the services provided) are at a higher risk of failure from climate hazards.

Approaches used by city governments to understand and communicate sectoral interdependencies have ranged from initial engagement or relationship-building with infrastructure owners through traditional educational seminars to more hands-on, interactive workshops in which participants from various sectors have mapped interconnections through discussion and drawings.

To assess and communicate climate risks to interdependent infrastructure systems, city agencies have used geospatial mapping techniques that show the exposure of infrastructure assets to climate hazards. Further, local agencies have also performed qualitative vulnerability assessments in which the sensitivity and adaptive capacity of infrastructure are described. In other instances, quantitative risk assessments which monetize the cost of climate impacts on infrastructure have helped make the case for climate adaptation solutions. In some instances, the identification of specific failure points in interconnected infrastructure systems (e.g., weak links in contiguous shoreline protection infrastructure, or temperature thresholds beyond which damage to infrastructure is more likely) have helped tailor the development of adaptation strategies.

Data-sharing among city agencies and infrastructure organizations (e.g., on climate science, assets characteristics, governance structures, etc.) has been crucial in facilitating strategic planning for climate impacts. City agencies that have undertaken collaborative risk assessments using the above approaches have been successful in developing and prioritizing preliminary adaptation strategies to mitigate the impacts of climate change on interdependent infrastructure systems. From this analysis, a handful of best practices and recommendations for city agencies have been identified in the process of engaging infrastructure organizations and facilitating collective action, conducting preliminary analyses of climate risks to interdependent infrastructure, and developing/implementing tailored adaptation strategies. A useful next step in this research is to explore how the analysis of sectoral interdependencies and climate risks can be further refined, and how it can lead to on-the-ground implementation of risk mitigation solutions.

1. Report Background

This report was commissioned by the C40 Cities Climate Leadership Group to help cities take action to become more resilient to the effects of climate change. Cities are at the forefront of experiencing climate impacts and there is a widespread need for municipal agencies to understand and mitigate climate risks to urban infrastructure and services and the communities they serve. This report highlights ways in which local agencies are working with infrastructure sectors to understand:

- How city governments depend on infrastructure sectors over which they have no control;

- How various infrastructure systems depend upon each other to operate, hence creating interdependencies and the potential for cascading failures from external disruptions;
- How interdependent city-owned as well as private infrastructure and services will be affected by changing weather patterns;
- How city governments and various infrastructure sectors can reduce risks to an acceptable level on a mutually prioritized basis.

2. Project Conception

This study topic was first conceived by municipal staff members from Toronto and Amsterdam who are leading work in their respective cities to understand climate risks and interdependencies. While numerous local agencies have been able to conduct climate risk assessments of infrastructure over which they have operational control, it is often challenging for agencies to engage external sectors in such efforts.

After seeing preliminary success in engaging external sectors on local climate adaptation planning, staff from Toronto and Amsterdam developed a scope for a study from which best practices from a sample of cities across the world could be shared on how local governments are working with external sectors to analyze and mitigate climate risks across multiple interdependent infrastructure systems.

The study was conducted by AECOM, and includes the development of case studies from five pre-selected cities, and a series of infographics explaining the general concept of interdependencies and climate risks. It is anticipated that the outputs of this study will serve as a resource for other cities undertaking climate adaptation planning efforts in collaboration with external infrastructure sectors.

C40 identified the following cities[1] for detailed case studies as they are in different stages of engagement with external infrastructure organizations to mitigate climate risks.

- Amsterdam, Netherlands
- Bogota, Colombia
- Johannesburg, South Africa
- Melbourne, Australia
- Toronto, Canada

3. Report Summary

This report summarizes the efforts of the aforementioned six cities as well as other public agencies[2] around the world to understand the cascading impacts of climate change on interconnected infrastructure systems at the urban scale. It highlights how the identification of infrastructure interdependencies and climate impacts can serve as a first step in developing efficient and collaborative climate adaptation strategies.

The purpose of this study is to identify and showcase techniques used by city governments around the world to engage with the infrastructure organizations on which they depend, but over which they have little or no jurisdiction, in order to mitigate climate risks.

The rest of the report is organized as follows: Section 4 of the report introduces the concept of interdependencies among infrastructure sectors and organizations. Section 5 provides examples of approaches used by city governments to understand and communicate sectoral interdependencies. Section 6 gives an overview of methods being used to assess and communicate climate risks to interdependent infrastructure systems, with a focus on specific failure points in one or more critical infrastructure systems that can lead to cascading failures in others. Section 7 describes the importance of data sharing between public and private sectors to facilitate better strategic planning for climate impacts. Section 8 presents examples of how collaborative risk assessments have led to the conceptualization and prioritization of risk mitigation strategies. Section 9 summarizes best practices and lessons learned from each of the previous sections on understanding infrastructure sectoral interdependencies and climate risks to interdependent systems, as well as adaptation strategy development. Section 10 presents recommendations for potential research topics building on the results of this study. Appendix A contains detailed case studies of five cities that have explored climate risks to interdependent systems and developed preliminary adaptation strategies to mitigate such risks. Highlights from these five cities are also included throughout the report in applicable sections. Appendix B shows a series of infographics depicting general sectoral interdependencies and cascading consequences of disruption to specific sectors from climate impacts.

1 It should be noted that this list of cities is not exhaustive, and there are other cities around the world that are also analyzing infrastructure interdependencies and cascading climate risks. However, the listed five cities were prioritized due to resource constraints.

2 Due to limited resources, examples of other public agencies are primarily drawn from North America, leveraging the findings of prior research and projects conducted by C40 and AECOM.

4. The Concept of Interdependencies Among Infrastructure Sectors and Organizations

For the purposes of this report, infrastructure is broadly defined as a network of built components and processes that function synergistically to produce and distribute a reliable flow of goods and services (Rinaldi, Peerenboom, & Kelly, 2001). Physical infrastructure sectors considered in this report include energy, telecommunications, transportation, water supply, wastewater treatment, solid waste management, buildings, and food systems, as they are critical to the security, economic prosperity and social well-being of communities.

It should be noted that city governments also operate social infrastructure (i.e., services and programs that support quality of life) such as recreation, day care, outreach to homeless persons, newcomer/ immigrant services, etc. However, as social infrastructure relies heavily on physical infrastructure, and the first-order impacts of climate change typically occur on physical infrastructure, the examination of social infrastructure is considered outside the scope of this study, though it is touched upon in sections describing cascading impacts of disruption to physical systems.

Modern infrastructure systems are highly interdependent on each other, containing multiple connections, feedback and feedforward paths, and intricate branching. Infrastructure interdependencies can be categorized into four main types: physical, cyber, geographic, and logical (Rinaldi, Peerenboom, & Kelly, 2001).

Physical interdependencies occur when commodities or services offered by one system are required by another infrastructure to operate, and vice versa. E.g., a power generation plant and a rail network may be interdependent if the network operates on electricity, and the power plant relies on rail for fuel delivery.

Cyber interdependencies exist when the state of infrastructure depends on information technology systems. E.g., computerized control systems – powered by electricity – relay information to electricity grids, power generation facilities, transportation network signaling systems, and many other infrastructure systems. Of all types, cyber interdependencies are relatively new and a result of the pervasive computerization and automation of infrastructure over the last several decades.

Geographic interdependencies occur due to the potential impact of a local environmental event on infrastructure systems located in close spatial proximity. Events such as fires, floods, or earthquakes can cause disruption to geographically interdependent infrastructure. E.g., pipes and telecommunications infrastructure often follow similar corridors or conduits, and a washout, earthquake, or structural collapse of foundations can cause multiple systems in close proximity to fail.

Logical Interdependencies (i.e., cascading consequences) arise when disruptions to a system cause second-order impacts via connections that are not physical, cyber, or geographic in nature. This category of interdependencies includes the cascading effects on the environment, society, and economy that are triggered by failure in one system. The extent of these effects depends on the magnitude of the disruption, the degree of coupling between the primarily impacted system and secondary systems, and their adaptive capacity. For example, if a storm event causes significant damage to a major transportation facility (e.g., a bridge), and alternative transit options are limited, this can impact commuter and freight activity as well as emergency services, particularly if repairs to the facility are time-intensive.

Criticality of Interdependencies and Resulting Impacts

As stated in previous sections, technological advances, such as computerization and automation, have increased the efficiency, reliability and services provided by infrastructure systems. However, technology has also contributed to the tighter coupling of interdependent infrastructure (Rinaldi, Peerenboom, & Kelly, 2001). Additionally, one infrastructure sector may be critical to another due to the nature of its operations, as no viable substitutes or alternatives are available for its services. E.g., transportation services cannot operate without energy, and energy generation facilities cannot operate without the reliable delivery of fuels.

In other instances, external factors such as efforts to reduce costs by city governments can lead to reduced redundancies in infrastructure systems or support services, and therefore result in stronger interdependencies among systems. E.g., cuts to inventories of spare parts, mobile radios, vehicle fleet and emergency response staff may reduce a city's ability to respond to and recover from emergencies.

Networks of infrastructure sectors with critical interdependencies are at a higher risk of failure from external shocks or stresses, including climate hazards such as coastal or inland flooding, extreme heat, drought, or wildfires. It is important to understand the extent of interdependencies and climate related risks faced by infrastructure systems so that adaptation solutions can be developed and prioritized accordingly.

Local governments can play a key role in coordinating climate adaptation planning efforts across multiple sectors at the local scale. The following sections describe approaches taken by selected city and other public agencies to understand infrastructure sectoral interdependencies and their climate impacts.

5. City Approaches to Understanding Infrastructure Interdependencies

City governments are responsible for their community's economic, social, and environmental well-being, and can play a central role in local scale climate adaptation planning. The resilience of modern infrastructure systems in the face of climate impacts is integral to maintaining thriving communities. Yet, many infrastructure systems such as energy, telecommunications, food etc. are often privately owned, and it can be challenging for city agencies to engage with these sectors in an integrated, mutually beneficial way on adaptation planning issues.

Interviews conducted with the five case study cities chosen for this study and reports from other public agencies indicate that increasing awareness among individual infrastructure sectors about climate impacts on interdependent systems has been an effective way to break down silos and encourage collaboration. Below are some examples of approaches city governments have used to facilitate shared understanding of interdependencies among multiple infrastructure owners through initial engagement approaches such as educational seminars and networks, as well as interactive workshops.

Initial Engagement with Infrastructure Sectors

Efforts by the Cities of Toronto and Melbourne show how representatives from infrastructure sectors can be convinced to come to the table as a first step in initiating discussions on infrastructure interdependencies.

City of Toronto, Canada: For over a decade, staff members at the City of Toronto have pursued a bottom-up approach to climate adaptation planning. They have led efforts to increase awareness among infrastructure sectors about the impacts of climate change to their operations as a way to engage them. In 2007, City staff organized an expert panel of researchers, scientists, and insurance sector representatives to educate various internal departments on climate change vulnerabilities and risks. The media was also invited, and this event represented a turning point in garnering greater support for climate adaptation within the city. In 2011 the City sponsored a day-long public climate adaptation symposium which attracted approximately 100 internal and external stakeholder organizations. This established the mandate for a cross-sectoral coalition, which led to the formation of an ad hoc group known as the Toronto WeatherWise Partnership, comprising approximately 75 business, academic, community, and infrastructure organizations. In addition, the City also worked with a non-government organization known as CivicAction, which provided convening capacity to engage the private sector on climate adaptation issues. Through a series of meetings, the WeatherWise Partnership was provided educational seminars from experts from a variety of sectors including food, health, finance, transportation, telecommunications, and electricity. As a next step, the Partnership voted to select the electricity sector as the focus of a climate risk assessment, resulting in the identification of a City-led project team which convened an educational seminar on climate impacts to the electrical sector. The team also surveyed the tolerance of critical infrastructure customers to power disruption, which indicated low adaptive capacity. Additionally, it facilitated Toronto Hydro's (an electrical utility serving the city) risk assessment of transmission and distribution assets, which led to the identification of potential risk reductions strategies.

This early work demonstrated the value of City staff engaging with external sectors on climate adaptation. This example of the electrical sector helped foster collaborative relationships with additional infrastructure sector representatives, and as a result, some of these sectors have voluntarily participated in subsequent climate change risk assessments. More information on this effort is provided in the City of Toronto's case study in Appendix A.

City of Melbourne, Australia: The City of Melbourne created a network of organizations involved in actively managing the climate change risks faced by inner city Melbourne. The network, known as the Inner Melbourne Climate Adaptation Network (IMCAN), brought together representatives of State Government departments, scientific and academic research groups, water authorities, local councils, industry groups and businesses, and emergency service organizations. IMCAN was conceived because the City recognized the need for inter-organizational and inter-sectoral cooperation to address shared climate change risks.

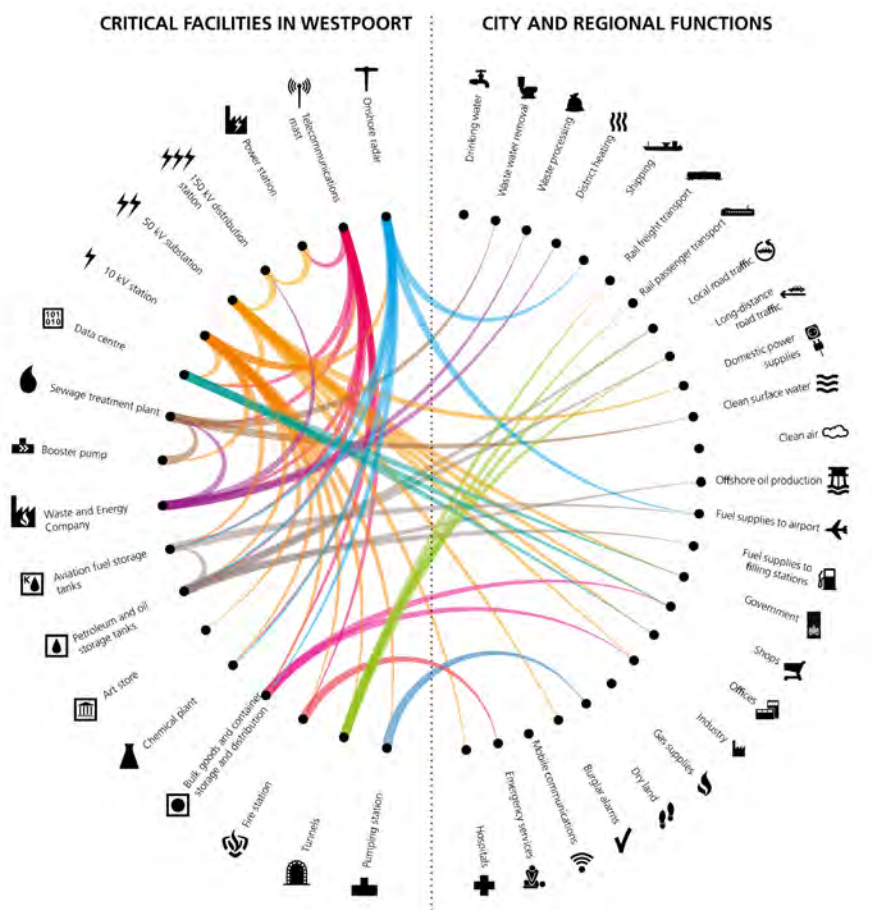
Further, it formalized individual discussions on adaptation that were already taking place between many local organizations. See Appendix A for more information on the origins and activities of IMCAN.

Interactive In-person Workshops on Mapping Interdependencies

The case studies from the City of Amsterdam and Toronto highlight formats for interactive, in-person workshops in which sectoral interdependencies can be mapped in real-time.

City of Amsterdam, The Netherlands: The City of Amsterdam participated in the Westpoort Harbour district pilot study, the purpose of which was to test a multi-layer safety approach to addressing flood risks. The City and a local water resource management corporation called Waternet met with 15 different publicly and privately owned companies across multiple sectors (e.g. electricity, sewage treatment, telecoms, district heating, chemical industries, recycling, etc.) as part of the engagement process. Through workshops, working sessions, and round tables, study participants conducted exercises to map interdependencies between different infrastructure systems, and identify weak links or points of potential failure, the results of which are shown in Figure 1 below. An example of an interdependent system can be seen by following the links from the 10 kV substation. If the substation goes out of service due to an extreme flood event, it would disrupt electricity supply to the booster pumping station, which in turn would stop the inflow of wastewater into the sewage treatment plant, lead to potential backflow of wastewater into various facilities in the city, and contaminate clean surface waters. More information on the outcomes of the City of Amsterdam's engagement process can be found in Appendix A.

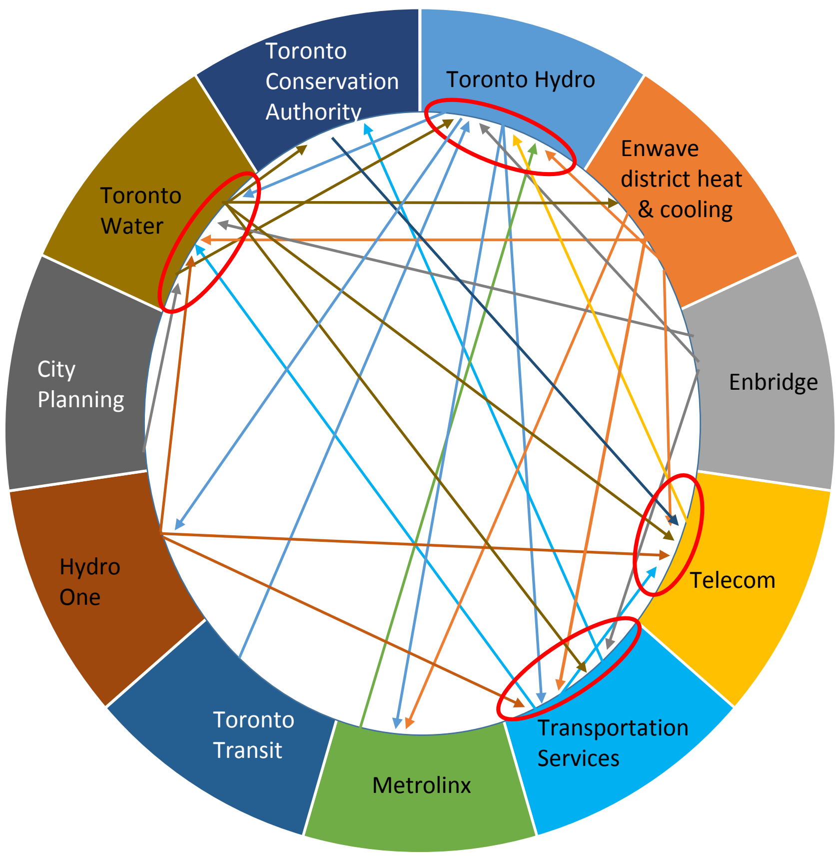
Figure 1: Westpoort Harbour District Pilot Study Interdependencies Mapping Exercise Results



Source: Waterproof Amsterdam, 2013.

City of Toronto, Canada: A City-led High Level Risk Assessment (HLRA) included workshops in which a climate risk and interdependencies identification exercise was conducted for ten internal and external organizations from the transportation, water and other utilities sectors. The results of the exercise are shown in Figure 2. The figure highlights general interdependencies of infrastructure sectors like energy and telecommunications. The arrows in the image originate from the dependent entity and point to the service-providing entity. For example, Enbridge Gas (a natural gas provider) and EnWave (a district energy supplier) both depend on Toronto Hydro for electricity to run pumps, electrical controls, and other equipment. Toronto Hydro itself is not dependent on these two utilities, but does rely on other infrastructure such as the road transportation network for workers to access its facilities. A full description of the HLRA and its adaptation strategy outcomes is provided in Appendix A.

Figure 2: Toronto High Level Risk Assessment Interdependencies Mapping Exercise Results



Source: Concept adapted by the City of Toronto with permission from MUST Urbanism (2016).

6. City Approaches to Understanding Climate Change Impacts to Interdependent Systems

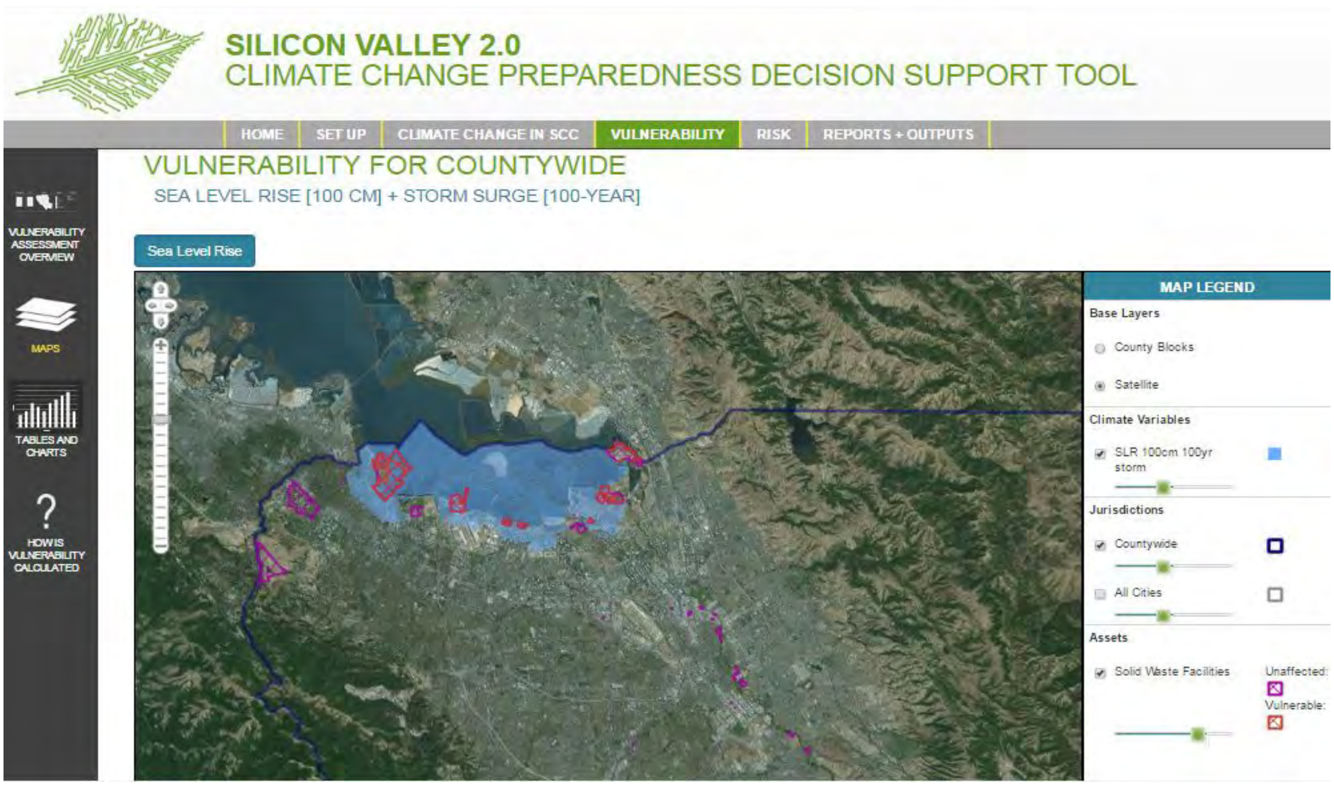
Several local agencies across the world have initiated the process of climate adaptation planning by conducting vulnerability and risk assessments of communitywide assets, including infrastructure systems. These assessments have helped them understand the nature of climate impacts. In many cases, climate change is projected to amplify the magnitude and/or frequency of extreme weather events like coastal or inland flooding, extreme heat, drought, and wildfires. The extent of impacts to exposed infrastructure systems depends on their sensitivity and adaptive capacity, as well as their interconnectedness, and is referred to as the vulnerability of systems. Vulnerability assessments have revealed that infrastructure failure can have not only structural, design, maintenance, and interdependency-related causes, but also organizational, financial, and governance-related triggers. The broader risks to failed infrastructure are a function of the likelihood of extreme events and their socio—economic and environmental consequences. City governments that have successfully understood preliminary climate risks to interdependent infrastructure have often done so via the use of interactive geospatial mapping tools, and quantitative or qualitative analyses, as shown below. As vulnerability and risk assessments weren't the main focus of the research done on the five case study cities in this project, this section showcases efforts of other local governments in establishing a preliminary understanding of climate risks to interdependent systems.

Use of Mapping and Other Visual Aids to Showcase Climate Exposure and Vulnerability

Examples from the County of Santa Clara and the City and County of San Francisco show how maps can be used to communicate infrastructure exposure to climate hazards. Examples from the Cities of Eugene and Springfield[3] and the County of Santa Clara provide a methodology for how climate vulnerability and risk assessments of infrastructure can be conducted in varying levels of detail.

County of Santa Clara, California: As part of the Silicon Valley 2.0 project, the County of Santa Clara conducted a comprehensive climate vulnerability and risk analysis to identify high-risk assets and services. In this analysis, the County developed an interactive, online climate exposure, vulnerability and risk visualization tool that allows users to see the impacts of climate hazards on assets. The tool produces maps which show various infrastructure assets in the building, energy, transport, water, wastewater, solid waste, and telecommunications sectors, and the extent to which they are projected to be exposed to hazards such as sea level rise, storm surge, precipitation, wildfire, and extreme heat. In addition, the tool also rates the vulnerabilities of the assets and quantifies the broader economic impacts of disruption to these assets. See Figure 3 for a sample output map from the tool showing the exposure of solid waste facilities to end-of-century sea level rise coupled with a 100-year storm event. Figure 4 summarizes statistics on the acreage of solid waste facilities impacted, and provides a vulnerability rating based on the magnitude of exposure and sensitivity.

Figure 3: Silicon Valley Decision Support Tool Exposure Analysis



Source: Silicon Valley 2.0 Decision Support Tool, County of Santa Clara, 2015.

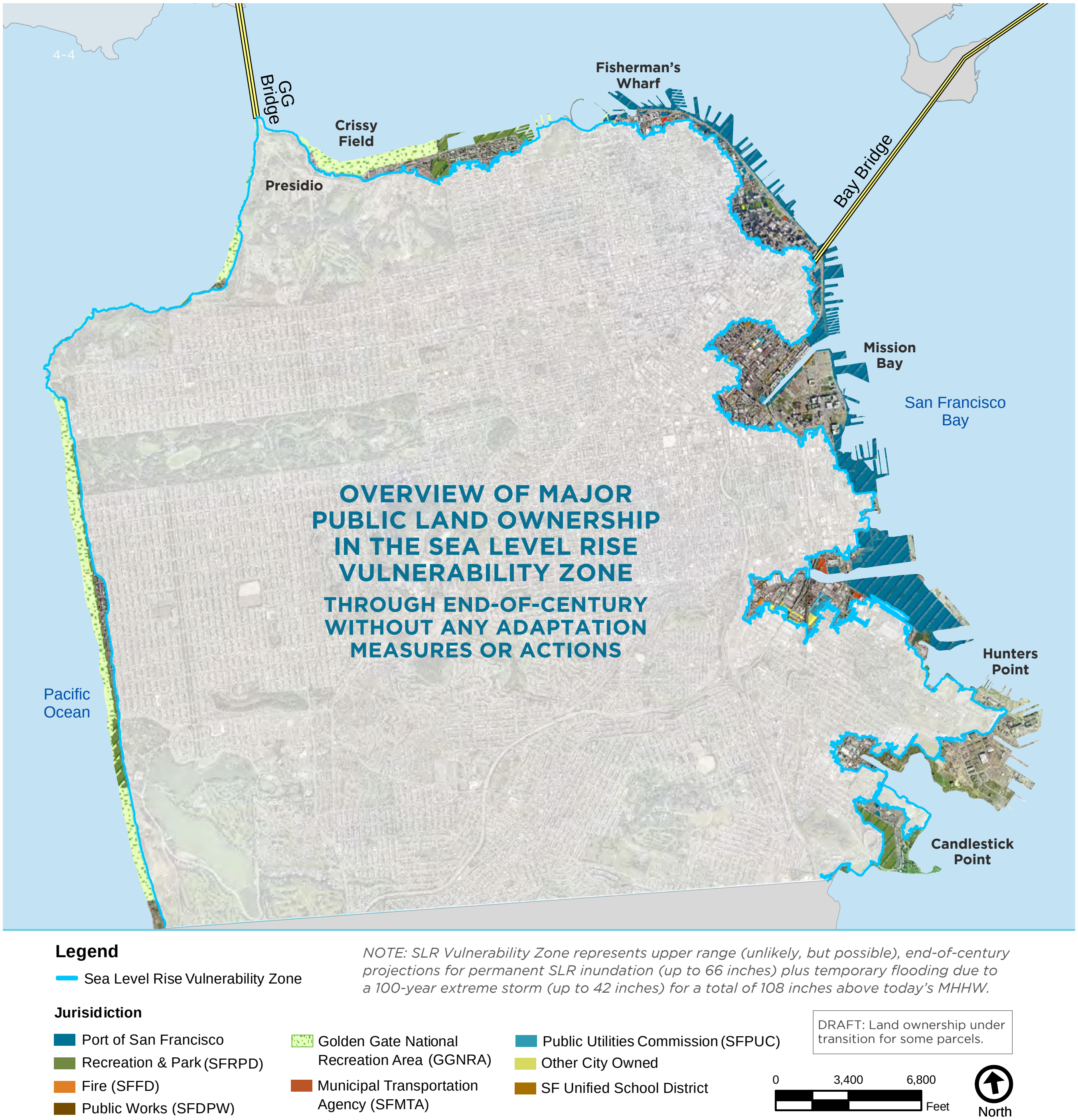
3 These cities were showcased in the C40 Cities 100 Report, which presents a hundred solutions for climate action in cities.

Figure 4: Silicon Valley Decision Support Tool Vulnerability Analysis

Source: Silicon Valley 2.0 Decision Support Tool, County of Santa Clara, 2015.

City and County of San Francisco, California: In its Sea Level Rise Action Plan, the City and County of San Francisco included maps of its shoreline highlighting coastal and bayside infrastructure within the city's defined sea level rise vulnerability zone, and identified assets by agency with ownership and regulatory jurisdiction. Helping agencies geospatially visualize the exposure of their infrastructure to climate hazards has been an effective way for the City to engage them collectively in adaptation planning. See Figure 5 for a map of San Francisco's sea level rise vulnerability zone, which shows assets projected to be exposed to approximately 66 inches of sea level rise coupled with a 100-year storm (up to 42 inches).

Figure 5: San Francisco Sea Level Rise Vulnerability Zone by Land Ownership



Map Disclaimer: The inundation maps and the associated analyses are intended as planning level tools to illustrate the potential for inundation and coastal flooding under a variety of future sea level rise and storm surge scenarios. The maps depict possible future inundation that could occur if nothing is done to adapt or prepare for sea level rise over the next century. The maps do not represent the exact location of flooding. The maps relied on a 1-m digital elevation model created from LiDAR data collected in 2010 and 2011. Although care was taken to capture all relevant topographic features and coastal structures that may impact coastal inundation, it is possible that structures narrower than the 1-m horizontal map scale may not be fully represented. The maps are based on model outputs and do not account for all of the complex and dynamic San Francisco Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or Open Coast. For more context about the maps and analyses, including a description of the data and methods used, please see the Climate Stressors and Impacts Report: Bayside Sea Level Rise Inundation Mapping Technical Memorandum, March 2014 and FEMA Open California Coast Sea Level Rise Pilot Study, San Francisco County, 2015.

Source: City and County of San Francisco Sea Level Rise Action Plan, 2016.

Quantitative and Qualitative Vulnerability and Risk Assessments

Cities of Eugene and Springfield, Oregon: Staff from the Cities of Eugene and Springfield, with support from Oregon Partnership for Disaster Resilience, conducted a high level climate vulnerability assessment with input from various infrastructure sector representatives. City staff met for six hours with each sector, and using a standard list of questions, collected information about the sensitivity and adaptive capacity of systems to specific hazards. A key finding from these discussions was that there is a high level of functional interdependencies among all sectors. Table 1 below shows a sample summary of the vulnerability assessment results for the food sector, which reflects the results of discussions with representatives from local grocery stores, local and regional wholesalers and distributors, food processing and storage facilities in Portland and Eugene, local food-growers, and local restaurants. The table highlights the functional dependency of the food sector on other infrastructure systems such as energy, transportation, and natural systems.

Table 1: Eugene and Springfield Food Sector Vulnerability Assessment Summary

Food Sector Summary Table	
Critical Interdependencies: Systems of all types are dependent on other systems in order to function. In order to operate, this sector is particularly dependent on:	**Crucial Vulnerabilities:** Each sector has a number of vulnerabilities. For this sector, the following are particularly notable:
▪ Electricity ▪ Transportation ▪ Fossil Fuels ▪ Natural Systems	▪ The majority of food consumed in Eugene-Springfield is stored in Portland and travels down I-5 by truck and trailer. ▪ Grocery stores stock only a three day supply of food. ▪ External influences on agriculture and transportation sector have an undue influence on the price and availability of food in Eugene-Springfield.
▪ Local growers are impacted by flooding but flood is not a significant concern to the local food sector as a whole. ▪ With the potential impact on electricity supply and the critical dependence on tractor trailers to distribute food from Portland to Eugene, winter storms can have a significant impact on the local food system. ▪ An earthquake will have catastrophic impacts to the system. Other hazards are of much lower concern.	

Source: Regional Climate and Hazards Vulnerability Assessment in Support of Eugene-Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan, 2014.

County of Santa Clara, California: As previously stated, the County of Santa Clara conducted a thorough vulnerability and risk assessment of infrastructure systems to multiple climate hazards in the Silicon Valley 2.0 project. The County recognized that decisions on the implementation of adaptation solutions for critical infrastructure are driven by the costs and benefits of adaptation options relative to the cost of no action, and a presentation of potential net costs is one of the most effective ways to gain buy-in from infrastructure owners. One of the outputs of this study was the quantification and rating of the economic consequences of no adaptation action for various assets in the County. E.g., as shown in Figure 6, the analysis determined that the overall fiscal revenue losses in the buildings and properties sector from riverine flooding would be extreme (over $90 million), whereas the losses from sea level rise without storm surge would be lower (between $4 and $18 million). For cells marked as "N/A", data were either not available or not applicable.

Figure 6: Outputs of Quantitative Economic Consequences Analysis in Santa Clara County

	SEA LEVEL RISE	SEA LEVEL RISE + STORM SURGE	RIVERINE FLOODING	WILDFIRE	EXTREME HEAT
Replacement Cost	High	Very High	Extreme	Extreme	N/A
Loss of Fiscal Revenue	High	High	Very High	Very High	N/A
Change in Operational Costs	N/A	N/A	N/A	N/A	Low
Interruption of Economic Activity	Moderate	High	Very High	High	N/A
Overall Economic Consequences	**High**	**Very High**	**Extreme**	**Extreme**	**Low**

Low	$1	to less than	$1,000,000
Moderate	$1,000,000	to less than	$4,000,000
High	$4,000,000	to less than	$18,000,000
Very High	$18,000,000	to less than	$90,000,000
Extreme	$90,000,000	or more	

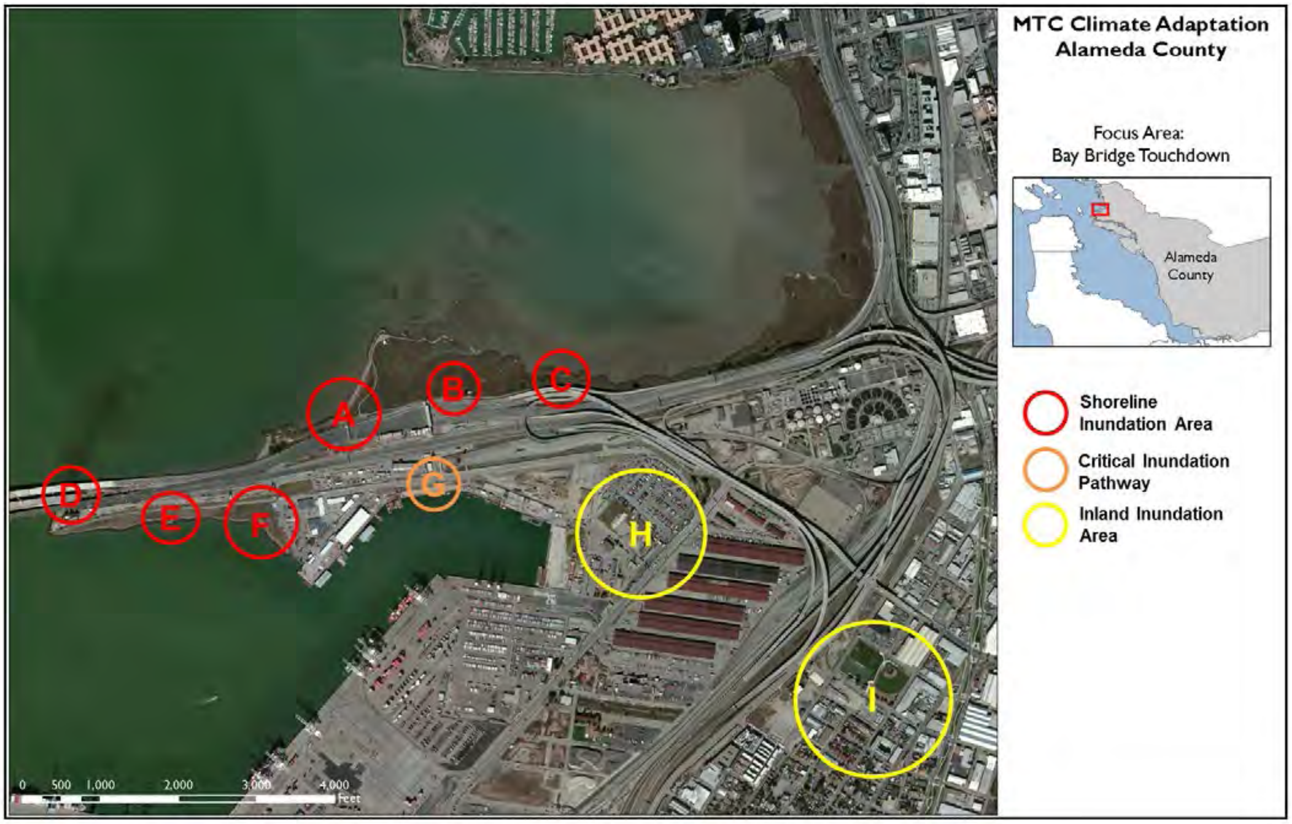
Source: Silicon Valley 2.0 Adaptation Guidebook, County of Santa Clara, 2015.

Failure Points that Lead to Cascading Impacts

In vulnerability assessments, an analysis of specific failure points in infrastructure systems can help inform targeted adaptation strategy development. While the research conducted for this study did not identify examples of cities that had identified weak links in detail, there are examples of sector-specific agencies that have used these methods to optimize the use of limited resources to mitigate climate risks. For example, transportation asset management agencies such as the San Francisco Metropolitan Commission (MTC) and the Federal Highway Administration (FHWA) have identified failure points in infrastructure systems that can lead to cascading impacts.

San Francisco Bay Metropolitan Transportation Commission (MTC): In the study on Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area, the Metropolitan Transportation Commission (MTC) identified infrastructure impact points or failure points based on three key factors: the magnitude of climate hazards projected to impact infrastructure, the time horizon of the impact, and the physical characteristics of the infrastructure such as elevation and condition. E.g., MTC carried out exposure mapping of the San Francisco Bay Bridge Touchdown area in Oakland, California to determine the specific magnitude of sea level rise and storm surge that would cause inundation and disruption to assets, given their elevation and other characteristics. As shown in Figure 7, a critical inundation pathway (marked in orange), which provides hydraulic connectivity from shoreline inundation areas (marked in red) to inland inundation areas (marked in yellow) to convey floodwaters, was identified within the Bay Bridge Touchdown area. The pathway had been formed by an engineered stormwater drainage area along a local road, designed to drain to the San Francisco Bay. Although intended for mitigating floodwater from precipitation and runoff, this drainage system can allow coastal floodwaters to propagate inland due to future sea level rise and storm surge. Understanding inundation pathways and locations of shoreline overtopping can help target adaptation strategies.

Figure 7: Example of Failure Point: Critical Inundation Pathway Connecting Shoreline Inundation Areas to Inland Inundation Areas



Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

Source: Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area Technical Report, 2014.

Federal Highway Administration (FHWA), USA: In its Post-Hurricane Sandy Vulnerability Assessment and Adaptation Analysis, the Federal Highway Administration (FHWA) examined the impacts of climate change on transportation assets such as highways, railroads, bridges, tunnels, and ports in the states of New York, New Jersey, and Connecticut. Failure thresholds that would cause the assets to go out of service, and in turn result in broader economic impacts via disruption to commuter and freight activity were identified. E.g., Table 2 shows maximum temperature thresholds used by Metro-North Railroad (a commuter rail service run by the Metropolitan Transportation Authority in New York State) beyond which rail buckling, wire sagging, and maintenance disruption can occur on railroads, and cause disruption to households and businesses if alternative routes are limited. Climate projections for the region show that extreme heat events exceeding 100°F are likely to occur approximately every 2.7 years by mid-century compared to every 10 years under current conditions. Without action, the frequency of rail buckling could be expected to increase significantly. The railroad has a daily weekday ridership of over 125,000, and closure of rail service would likely cause congestion on roadways as typical train commuters resort to driving and bus transit, and alternative train routes may experience overcrowding, resulting in lost productivity and possible delays in the delivery of goods and emergency services. This information on extreme temperature thresholds informed the development of strategies to prevent rail buckling, wire sagging, and disruption to maintenance.

Table 2: Temperature Thresholds for Rail Buckling, Wire Sagging, and Maintenance Disruption

Rail Buckling	Wire-Sagging	Track Maintenance Disruption
>100°F ambient temperature or >140°F rail temperature	>90°F ambient temperature for a maximum speed of 70 miles per hour (MPH, and 50 MPH at curves)	>95°F of ambient temperature

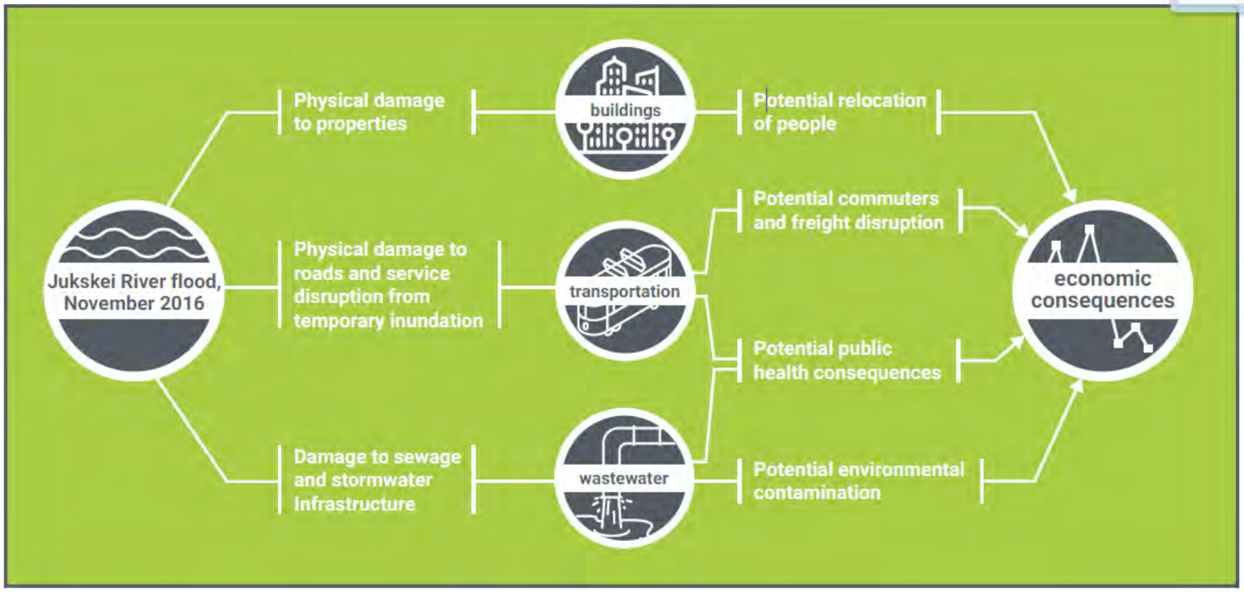
Source: Metro-North Railroad, 2015.

Approaches to Understanding and Communicating Cascading Risks

Once sectoral interdependencies and first-order vulnerabilities of infrastructure systems are better understood, it becomes easier to project the second- or third-order failures in dependent systems from climate hazards. The City of Johannesburg illustrates how various City departments were convened to understand the cascading impacts of flood events, and how such flood events might be exacerbated in the future due to climate change. Similarly, the City of Amsterdam investigated the cascading impacts of flood events on various economic sectors. These examples are supplemented with others from cities such as Sydney, Dallas and San Francisco, where cascading impacts on infrastructure systems from potential hazards were also communicated.

City of Johannesburg, South Africa: The City of Johannesburg's Department of Environment and Infrastructure Services (EISD) is leading a review and update of its 2009 Climate Adaptation Plan in collaboration with the Global Change and Sustainability Research Institute (GCSRI), based out of the University of the Witwatersrand (Wits University). In one of the workshops held during the Plan update process, researchers from GCSRI and practitioners from EISD led key junior and mid-level staff from internal City departments such as Housing, Roads, Public Health, Environmental Health, Biodiversity, Water, Waste, and Innovation through a facilitated co-learning exercise exploring topics related to climate adaptation. One activity included understanding the context in which adaptation occurs or may occur, such as in response to cascading impacts of recent weather related disasters. For example, a representative from the Health Department cited the impacts of a massive flood in November 2016 which damaged sewer infrastructure. This flood along the Jukskei River and the Alexandra Township and neighboring suburbs of the city led to the loss of life and property damage. It also sparked discussions on the potential relocation of those who experienced significant damage to their homes. During the storm, parts of the city's sustainable stormwater infrastructure and roads were also severely damaged. Through discussions held in this workshop, City departments recognized the potential cascading damages that can occur from extreme weather events which are likely to be exacerbated by climate change. Detailed examination of the recent flooding event are ongoing as part of the co-learning process for effective climate change adaptation in the City. Figure 8 shows a schematic of the direct impacts of the flood event as well as potential, indirect cascading impacts on populations, the environment, and the economy. More information on EISD and GCSRI's efforts to update the Plan can be found in Appendix A.

Figure 8: Schematic of Potential Cascading Impacts from Flooding Along the Jukskei River



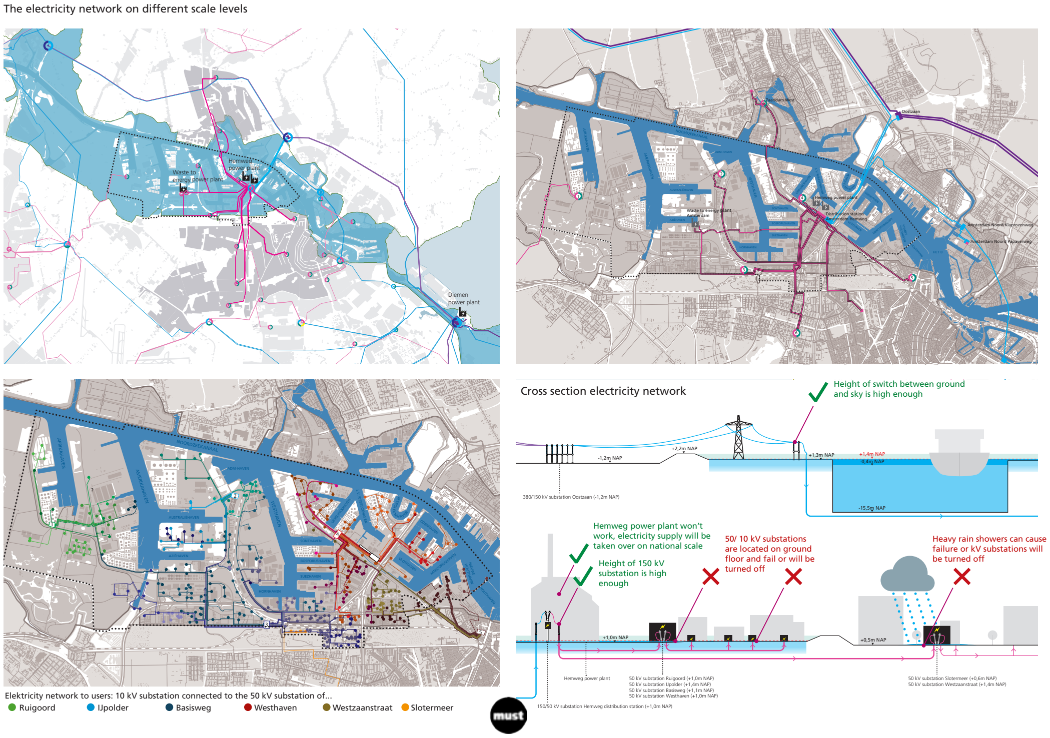
Source: Adapted by AECOM from EISD staff interviews, 2016.

City of Amsterdam, The Netherlands: As part of the workshops, working sessions, and round tables conducted under the aforementioned Westpoort Harbour district pilot study, participants investigated the critical infrastructure networks and evaluated flood risks for different components in the networks. Using infographics, the following networks and their interdependencies were examined:

- Electricity
- Wastewater
- District heating
- Telecommunications
- Pipelines
- Roads and railways

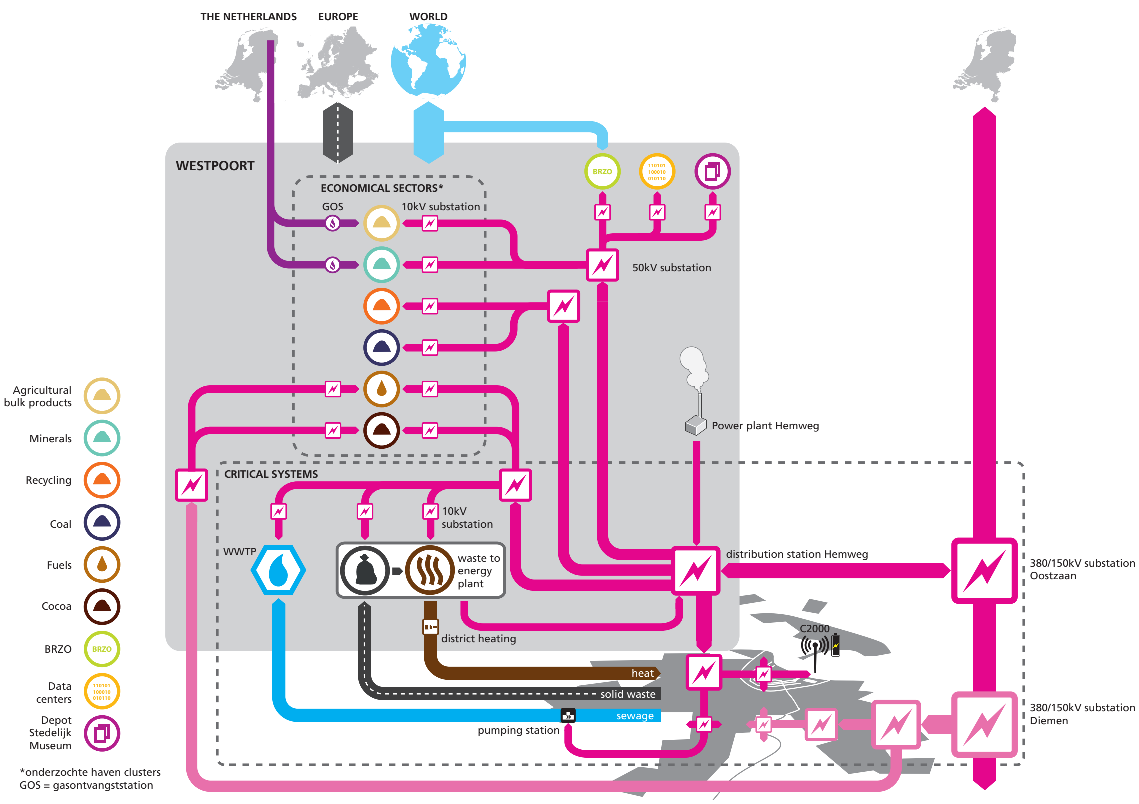
Further, the cascading economic impacts of disruption to these networks from flood events were discussed, specifically on sectors such as agricultural bulk products, minerals, recycling, coal, fuels, cocoa, chemical industries, and data centers. Figure 9 shows a representation of the electricity network in Westpoort Harbour District at different scales. In this figure, a cross-section shows the most vulnerable locations in the network. Figure 10 shows how all critical infrastructure networks and economic sector clusters in the Harbor are connected to the electricity network.

Figure 9: Electricity Network at Different Scales in Westpoort Harbour



Source: MUST Urbanism, 2016.

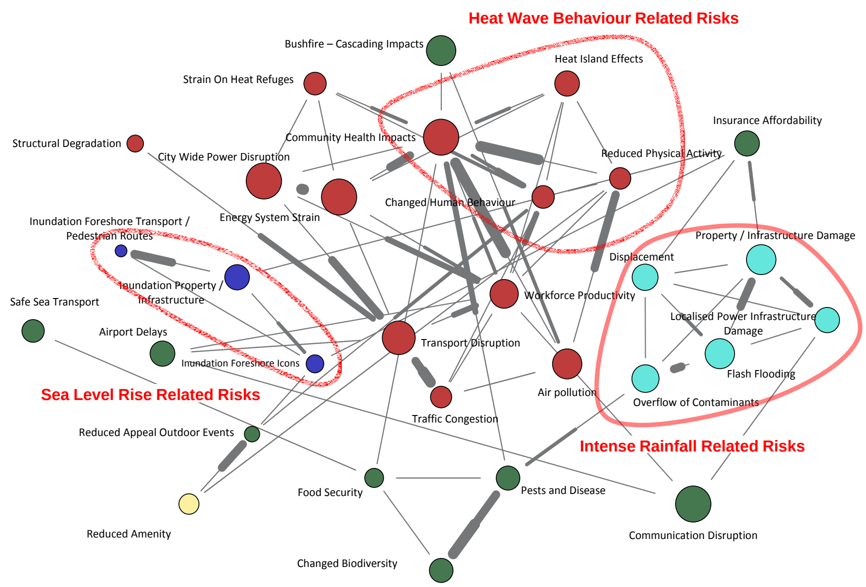
Figure 10: Dependencies of Infrastructure and Economic Sectors on Electricity



Source: MUST Urbanism, 2016.

City of Sydney, Australia: In its Climate Adaptation and Risk Study, the City of Sydney used the interconnectedness of infrastructure systems and services as one of the indicators in its evaluation of climate risks. To capture the community's understanding of infrastructure interdependencies and other risk indicators, the City issued an online survey to stakeholders it had previously engaged through workshops in the adaptation planning process. Figure 11 shows a graphical representation of the survey results. It demonstrates the community's perception of those risks which are central to causing other risks, and vice versa. In the figure, a thin line shows risks that are related. A thick line indicates a cascading risk, which warrants a more serious consideration of the originating risk. For example, respondents stated that air pollution (an originating risk) is a leading cause for reduced physical activity (cascading risk). The figure also highlights clustered risks marked by orange circles. For example, intense rainfall can cause a cluster of risks including property damage, power failures, displacement, and contamination, many of which are also linked to each other. The identification of these interdependencies is critical for developing targeted actions that are able to respond to (and cut across) multiple risk areas.

Figure 11: Graphical Representation of Risk Perception Survey Results



Source: City of Sydney Climate Risk and Adaptation Project Report, 2015.

Of the various risks shown in the above figure, the most central risks (both originating and cascading) are summarized in Table 3 below.

Table 3: Most Significant Risk Causes and Effects

Risk Causes	Risk Effects
Energy system strain	Community health impacts
City wide power disruption	Workforce productivity
Air pollution	Changed human behavior
Heat island effects	Reduced physical activity
Transport disruption	Transport disruption

Source: City of Sydney Climate Risk and Adaptation Project Report, 2015.

City of Dallas, Texas: As part of its 100 Resilient Cities Agenda Setting Workshop held in October 2015, the City of Dallas conducted a break-out table session on mapping cascading impacts for a number of different shocks and stresses. One of the fictional scenarios related to drought or failure in long term water supply.

Long term water supply scenario description: *Rapid population growth in the Dallas-Fort Worth-Arlington metropolitan area continues at record pace and forecasts outpace the region's long-term, water resource plan. This potential shortage is exacerbated by record drought conditions that strain current water supply. Lawsuits have limited the water authority's ability to develop additional lakes and reservoirs in East Texas and the region's long-term water supply is threatened. Business leaders warn local officials of plans to relocate manufacturing businesses and water-intensive industries out of the greater Dallas area unless solutions are reached quickly.*

Participants worked at their tables to deconstruct the scenario to identify relevant shocks and stresses, interdependencies between sectors, as well as cascading impacts. Finally, participants were asked to identify potential initiatives to strengthen the response effort so that a similar event in the future would have less of an impact. The goal was to help participants understand the broader repercussions of climate impacts beyond just first order physical impacts to assets and to understand interdependencies between different sectors. Participants discussed the undesirable and unanticipated impacts that lack of water or imposed water rationing could have across different sectors with potentially negative impacts on the local economy. Some examples include reduced energy production and blackouts, increasing water costs that disproportionately affect disadvantaged populations, and increased frequency of wild fires that might displace families or businesses and tax emergency services. Participants also discussed the consequences of a water shortage on Dallas' future ability to sustain the population growth that has fueled North Texas for decades. See Table 4 and Figure 12 for sample outputs of the exercise.

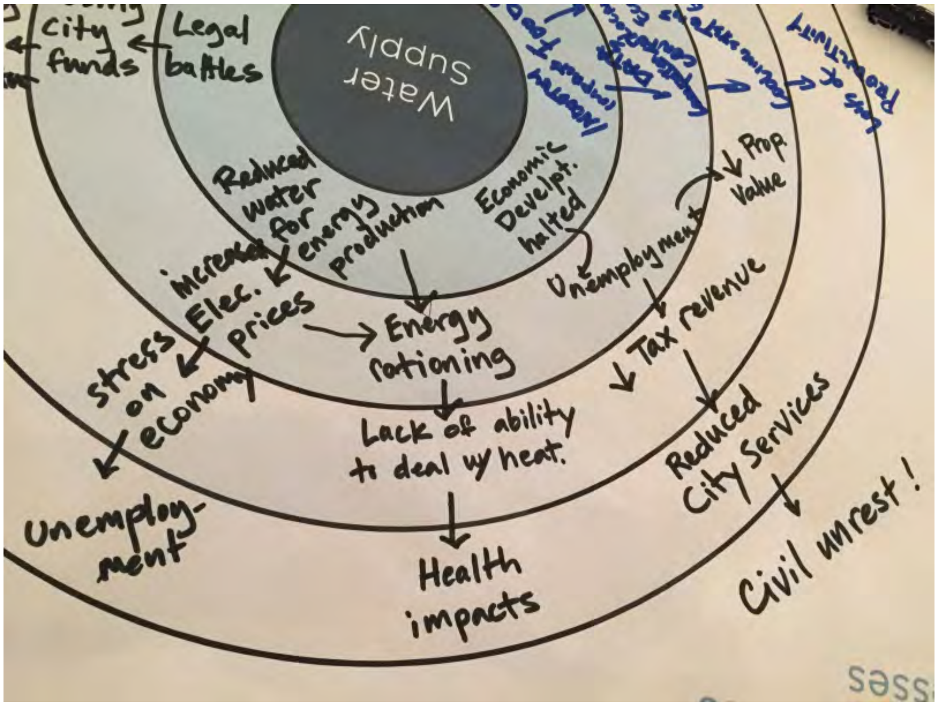
Table 4: Summary of Results from Cascading Impacts Exercise – Primary, Secondary Impacts and Potential Initiatives

Dimensions of Urban Resilience[4]	Primary Impacts of drought	Secondary Impacts of drought	Initiatives to mitigate drought impacts
Leadership & Strategy	▪ Water rights disputes	▪ Legal costs/strain on resources	▪ Collaborate with experts; best practices ▪ Landscape guidelines and policies
Health & Wellbeing	▪ Wild fires	▪ Loss of property value ▪ Loss of life ▪ Ecological damage	▪ Prioritization of use ▪ Sustainable, affordable housing
Economy & Society	▪ Depressed macro-economic conditions	▪ Reduced tax base, city bankruptcy and loss of income ▪ Job loss ▪ Business relocations ▪ Crime and civil unrest	▪ Tax incentives for companies using sustainable/ conservation practices ▪ Scale of water prices
	▪ Loss of agricultural production	▪ Increased food costs ▪ Food shortages	
	▪ Increased water prices	▪ Exacerbates inequity	
Infrastructure & Environment	▪ Water shortage	▪ Water restrictions ▪ Quality of life	▪ Rainwater harvesting ▪ Water efficiency investments ▪ Recycled municipal water
	▪ Reduced energy production capacity	▪ Energy shortages and blackouts	

Source: 100 Resilient Cities Dallas Agenda Setting Workshop Report, City of Dallas, and 100 Resilient Cities, 2016.

4 The Rockefeller Foundation's City Resilience Framework, which provides a lens to understand the complexity of cities and the drivers that contribute to their resilience, includes four key dimensions of urban resilience listed in Table 4.

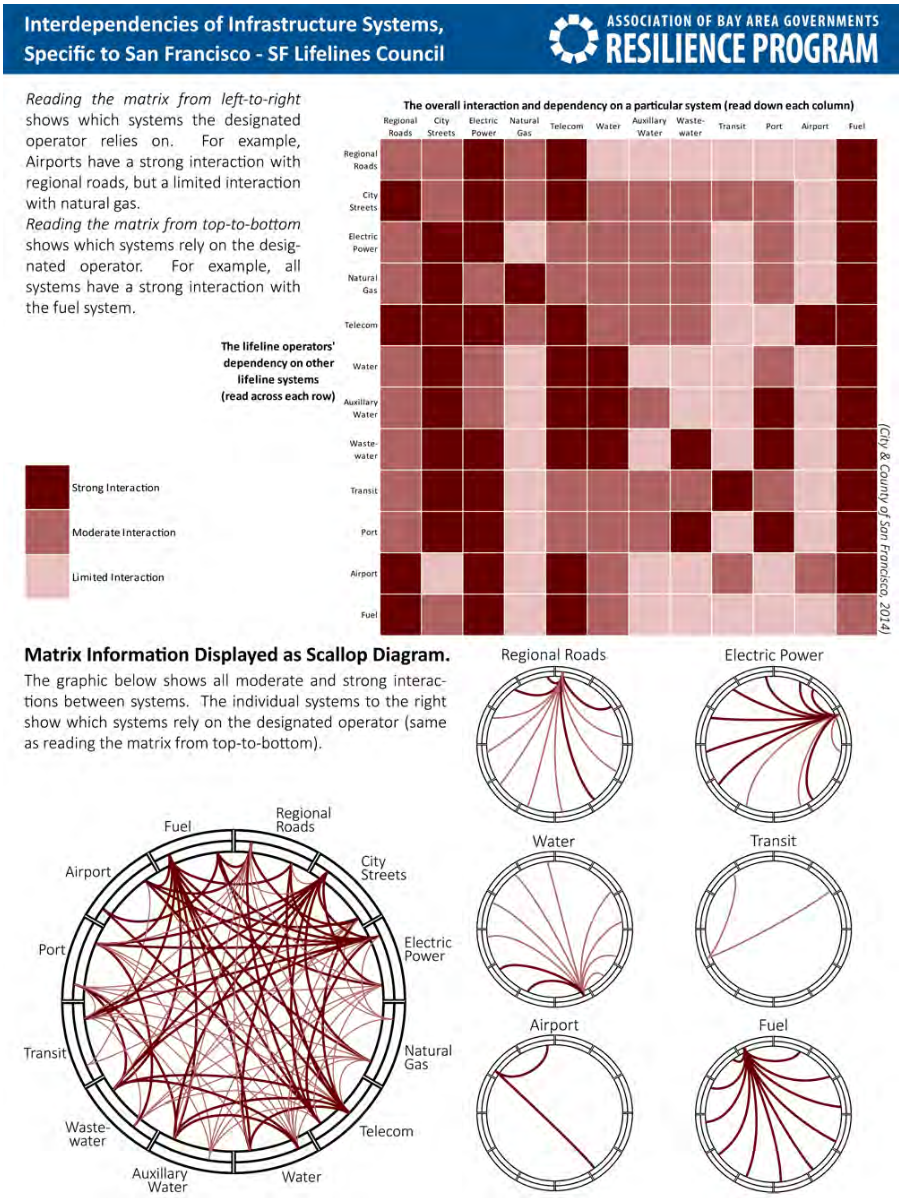
Figure 12: City of Dallas Cascading Impacts Exercise



Source: AECOM, 2016.

City and County of San Francisco, California:
In 2014, the City and County of San Francisco's Lifeline Council, made up of representatives from organizations managing infrastructure systems such as transportation, energy, water, wastewater, and telecommunications, published its first Lifelines Interdependence Study. For the study, past research and participant interviews were used to identify interdependencies between systems. The Association of Bay Area Governments (ABAG) used the results of this study to map interdependencies among infrastructure systems in its report entitled Cascading Failures: Earthquake Threats to Transportation and Utilities. Figure 13 below (taken from the ABAG report) shows the matrix of interdependencies between twelve important systems in which darker cells indicate tighter coupling, whereas lighter cells indicate limited interconnectedness. The vertical axis in this table describes designated operators of infrastructure systems, and the horizontal axis shows the systems on which the operators depend. This information is further displayed with lines in scallop diagrams. The sector from which the most number of lines (and the darkest lines) originate is one on which many other systems depend for operation. The matrix and scallop diagrams show that fuel services are most relied on by all other systems.

Figure 13: Interdependencies of Infrastructure Systems in San Francisco



Source: Adapted by the Association of Bay Area Governments from the City and County of San Francisco Lifelines Interdependency Study, 2014.

7. The Importance of Information Sharing to Understand Interdependencies and Cascading Risks

Data collection (both qualitative and quantitative) is a critical first step in identifying and analyzing climate risks to interdependent systems. Different kinds of data are required to inform various stages of climate adaptation planning, e.g., data may be needed on climate science projections; infrastructure characteristics (e.g., location, condition, elevation, interconnectedness), sensitivity, and adaptive capacity; and on the broader economic, social and environmental benefits provided by the infrastructure. Below are some examples of how public agencies have developed site-specific data to inform vulnerability and risk assessments and adaptation strategy development (New York City and the Southeast Florida Climate Compact), or overcome data access barriers through collaboration with infrastructure owners (the Cities of Bogota and Melbourne, and the County of Santa Clara).

Site Specific Climate Science Data to Inform Climate Adaptation Planning

New York City, New York: New York City is developing a broad range of climate adaptation policies and programs, as well as the knowledge base to support them. The knowledge base includes up-to-date sea level rise, coastal flooding, and other climate hazard projections; a framework for establishing a climate resiliency indicators and monitoring system; and various resiliency studies.[5] The City recognizes that both the knowledge base and the programs and policies it supports need to evolve as climate risks unfold in the future. The New York City Panel on Climate Change (NPCC) was formed in 2008 to contribute to this knowledge base. The NPCC is required to meet at least twice a year to review recent scientific data on climate change and its potential impacts, and to make recommendations on climate projections. These projections are due within one year of the publication of the Intergovernmental Panel on Climate Change Assessment Reports, or at least every three years. The NPCC also advises other City departments on a communication strategy to inform the public about its research. Initially formed as a scientific panel, the first NPCC was comprised of academic and private-sector experts in climate science, infrastructure, social science, and risk management. It established a climate risk management framework for the city's critical infrastructure throughout the extended metropolitan region. The first NPCC developed downscaled climate projections and derived new climate risk information, created adaptation assessment guidelines and protocols, and determined how climate protection levels would need to change to respond to evolving climate conditions. Subsequent panels have continued to refine climate science projections, with the latest one (released in 2015) providing projections through 2100 for the first time.

The Southeast Florida Regional Climate Change Compact, Florida: In 2014, the Southeast Florida Regional Climate Change Compact reconvened a previously formed Sea Level Rise Work Group for the purpose of updating regional projections for sea level rise based on new global projections, guidance documents and scientific literature released since the Work Group's first report. The objective of updating projections is to make regionally consistent and current information available to Climate Compact Counties and partners for vulnerability and risk assessments and adaptation strategy development. In the 2015 update, the baseline year for all projections was shifted from 2010 to 1992 to allow for easy translation of projections to future water surface elevations using local tidal station data, and to be consistent with guidance from federal agencies. The projections have also been extended to 2100 in recognition of the need for longer range guidance for major infrastructure and other long term investments.

Overcoming Data Access Barriers Through Collaboration

City of Bogota, Colombia: The City of Bogota has made GIS data available on its website for local climate and non-climate hazards (e.g. flooding, landslides, forest fires, earthquakes). Mapping information about residents/households and infrastructure systems are also provided to serve as the basis for conducting vulnerability and risk assessments. The information database is one component of the City's risk management framework, which includes a system of governance, policy instruments, and funding sources to support risk mitigation and climate adaptation actions. See Appendix A for a detailed description of this framework.

City of Melbourne, Australia: The IMCAN network led by the City of Melbourne was conceived as a "safe" space to facilitate the exchange of ideas and practices in climate adaptation. IMCAN is designed to be a network of peers involving trusted academics, scientists and adaptation practitioners who can share scientific and practical information on climate adaptation. More importantly, it has been a forum where different organizations were not only encouraged to talk about their successes, but also to be open about the issues and challenges they face. Discussions in the network are designed to allow challenges faced by an organization to be addressed through the sharing of ideas, support, and potential coordination of action with other organizations, without liability concerns. For more information on IMCAN's potential as a trusted forum for studying interdependencies and climate risks, see Appendix A.

County of Santa Clara, California: In the Silicon Valley 2.0 project, the County of Santa Clara requested geo-spatial data on physical asset characteristics (e.g., location, elevation, condition, etc.) from various infrastructure owners and operators, including energy service providers, to inform its climate vulnerability and risk assessment. However, confidentiality and security restrictions prevented Pacific Gas and Electric Company (PG&E), the local electric and natural

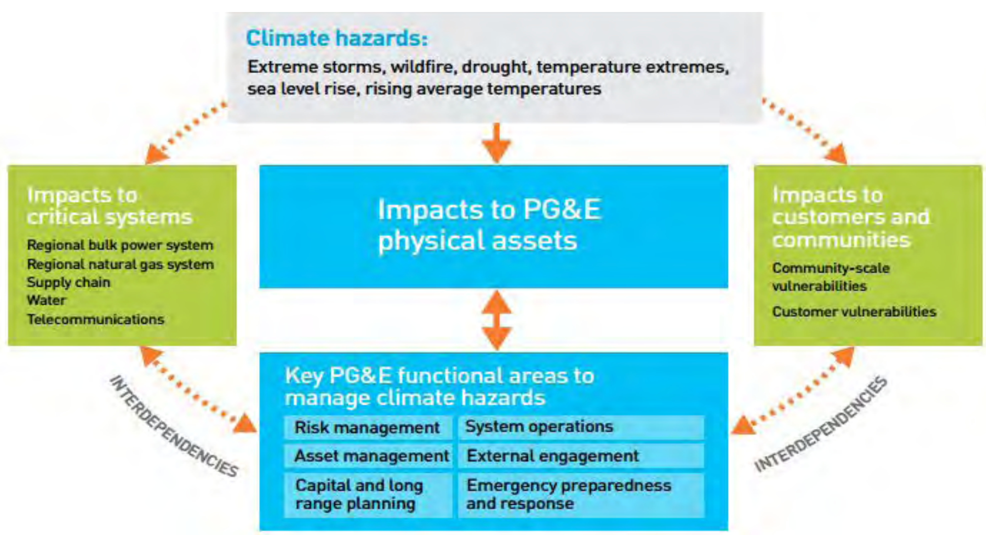
5 Building the Knowledge Base for Climate Resiliency: New York City Panel on Climate Change 2015 Report. <http://onlinelibrary.wiley.com/doi/10.1111/nyas.2015.1336.issue-1/issuetoc>

gas provider, from sharing certain data on assets such as substations and transmission/distribution infrastructure. Working together, the County and PG&E agreed that the most important priority was to equip PG&E to better understand the impacts of climate change on its assets and customers, as well as other infrastructure systems on which PG&E relies for business continuity, so that the energy provider could take necessary steps to mitigate such impacts.

PG&E joined the County's technical advisory committee, which also included members from other infrastructure sectors. PG&E reviewed a gap analysis conducted by the County to determine the extent to which climate adaptation efforts were already being planned and/or implemented by the company. Further, the County provided geospatial data on projections for sea level rise, storm surge, extreme precipitation, and wildfires to PG&E along with a suggested methodology for how to conduct an internal vulnerability and risk analysis.

The County's efforts reinforced the importance of addressing climate change impacts at PG&E, and contributed to the company's efforts to develop a formalized climate adaptation planning process. In fact, the Silicon Valley 2.0 project was among the first local multi-sector climate resilience initiatives in which PG&E participated. Building on this work, PG&E released its own companywide vulnerability assessment—highlighting key climate hazards and the nature of impacts, PG&E's proposed governance framework for incorporating climate adaptation into routine planning and operations, and examples of current and planned adaptation measures. Figure 12 shows a diagram of PG&E's interdependencies with other infrastructure sectors, as well as cascading impacts of climate hazards to the customers and communities it serves.

Figure 14: Climate Impacts Across PG&E's Value Chain



Source: Pacific Gas and Electric Company Climate Change Vulnerability Assessment and Resilience Strategies, 2016.

8. Examples of Collaborative Risk Reduction Resulting From Understanding Interdependencies

Based on the results of vulnerability and risk assessments, agencies leading climate adaptation planning have developed strategies to mitigate risks to interdependent infrastructure. Strategies may address physical, informational, or governance-related vulnerabilities and risks faced by infrastructure systems. The case studies below highlight examples of each of these strategy types. The City of Amsterdam shows examples of physical strategies (e.g., installing site-specific flood barriers) as well as governance-related strategies such as strengthening crisis management plans and procedures. The San Francisco Metropolitan Transportation Commission has identified a regional scale physical strategy (a living levee) to protect transportation assets and supporting infrastructure from sea level rise and storm surge. The City and County of San Francisco highlights both informational and governance-related strategies, including detailed studies of geographic areas with a cluster of infrastructure, and enhanced coordination among critical service providers.

City of Amsterdam, The Netherlands: As described in previous sections, the pilot study focusing on the Westpoort Harbour District in Amsterdam identified recommendations for improving its flood resilience using on a multi-layer safety approach at different scales. The layers included flood prevention through upgrades to shoreline defense systems such as levees, flood mitigation through upgraded design guidelines for existing and new development, and minimization of flood impacts through robust crisis management procedures. Participant organizations completed comprehensive mapping of infrastructure interdependencies in the District and across the city, which helped identify high-priority infrastructure systems and sites that need to be protected in the near and long terms, as well as opportunities for collaborative planning, action and investment. Proposed flood resilience strategies included strengthening the major riverine and coastal protection systems across the region, installing site-specific flood barriers, raising ground levels of sites and equipment, and strengthening crisis management plans/procedures.

San Francisco Bay Metropolitan Transportation Commission (MTC): In the study on Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area, MTC conducted a sea level rise vulnerability and risk assessment of key transportation assets in the San Francisco Bay Area, and developed adaptation strategies. In partnership with other transportation agencies such as San Francisco Bay Area Rapid Transit and the California Department of Transportation, as well as the San Francisco Bay Conservation and Development Commission, MTC prioritized at-risk assets, and developed adaptation strategies addressing their physical, informational, or governance-related risks using a multi-criteria strategy evaluation framework. The risk assessment and strategy selection methodology accounted for cascading impacts of disrupted transportation assets on the economy, environment and society. Further, risks were evaluated not just by accounting for direct impacts to transportation assets, but also impacts to other infrastructure systems that support transportation assets (e.g., substations distributing electricity to bridge operations). Similarly, the evaluation of adaptation strategies accounted for their ability to protect multiple infrastructure systems simultaneously. One such example of a physical adaptation strategy was to build a living levee along the touchdown of the San Francisco Bay Bridge, which would serve the dual purpose of protecting a vital transportation asset and its supporting components, as well as promoting coastal habitat restoration. An aerial view of the proposed living levee is shown in Figure 15.

Figure 15: Aerial Graphic of Proposed Living Levee Along the San Francisco Bay Bridge Touchdown in California.

Source: Climate Change and Extreme Weather Adaptation Options for Transportation Assets in the Bay Area Technical Report, 2014.

City and County of San Francisco, California: Through the San Francisco Lifeline Council's Interdependence study, it was evident that fuel-related services were the most relied on by all other infrastructure systems, and that roads, electricity, telecommunications, and water were all also critical to other systems. As an outcome from the study, the Council has designated priority routes through the city that are critical for multiple systems restoration in case of an extreme event, and is currently magnifying its study of cell sites, fuel supplies, and utility staging areas. As a next step, the Council plans to conduct more detailed studies of geographic "choke point" areas of the city where there are heavy concentrations of infrastructure and in which system damages, disruptions, interdependencies, and restoration challenges may also be more concentrated. Further, the Council will enhance coordination of disaster planning and preparedness efforts among lifeline system operators, the City and County of San Francisco, and other relevant entities. Finally, the Council will enhance coordination of mitigation efforts that could collectively improve lifeline system performance in the city after future disasters.

9. Summary of Best Practices and Lessons Learned in Understanding Interdependencies and Cascading Climate Risks

Based on a review of city efforts to understand climate risks to interdependent infrastructure, and develop and implement climate adaptation strategies, some best practices and lessons learned have emerged, which can be useful to other city governments that are considering initiating an adaptation planning efforts. These practices and lessons apply to three main stages: facilitating engagement and collective action, mapping climate change risks and infrastructure interdependencies, and enabling development and implementation of adaptation strategies.

Facilitating Engagement and Collective Action

- Gain support from the Mayor or City Council and Executive Management to catalyze action and build support for climate adaptation planning across a range of organizations, especially those over which the City has no jurisdiction or control.
- Engage a diverse, cross-sectoral range of organizations. This includes multiple scales of government (e.g., city departments, other local, state or federal public authorities), the private sector, and community organizations.
- Understand the existing context, roles, responsibilities, and decision making processes of the various organizations involved in general risk management and climate adaptation planning.
- Recognize that collective efforts to address interdependencies will be more effective and sustained when they help each organization fulfil its own objectives, and secure its own operations and assets.
- Engage academic and research institutions in risk management and adaptation planning efforts to enhance the robustness and credibility of such efforts.
- Create a safe space to promote the sharing of infrastructure risks. The need to be able to discuss specific risks, and collectively evaluate the implications for different organizations, requires that organizations be open about their practices. At the same time, provide privacy, legal and reputational protection for shared sensitive information.

Mapping Climate Change Risks and Infrastructure Interdependencies

- Map out the connections, links, dependencies and interdependencies between organizations, assets and operations. Recognize the criticality of links and directionality of failures. Determine failure points leading to cascading consequences.
- Use specific climate hazard scenarios (e.g., projected flood elevations from mid-century sea level rise coupled with a 100-year storm) to develop a detailed understanding of cascading risks faced by interdependent infrastructure. Recognize that different organizations may have different risk tolerances, but that it is helpful to work to a common scenario (or set of scenarios). Use information on impacts of past extreme events to visualize future cascading risks.
- Collect data on asset characteristics (location, elevation, condition, replacement cycle, replacement and maintenance costs, etc.), sensitivity, adaptive capacity, criticality in supporting the economy, environment, or society, etc. for a robust climate vulnerability and risk assessment. Data likely will not be perfect; proxy data are acceptable.
- Each organization should develop an understanding and prioritization of its own climate change risks as a useful pre-requisite to addressing interdependencies.

- Develop a common and shared understanding of collective climate change risks between the various organizations to provide a basis for cooperation and coordination.
- Identify areas of common risk between organizations, overlapping or common responsibilities for risk mitigation, and any gaps to addressing these risks.

Enabling Development and Implementation of Adaptation Strategies

- Look for opportunities to mainstream climate change risk and interdependency considerations into existing everyday asset management, risk management and disaster response practices.
- Define an evaluation, implementation, and monitoring plan for proposed adaptation strategies. Evaluation criteria can include the ability of strategies to reduce climate risks to multiple, interconnected infrastructure systems. The implementation plan should identify lead agency, funding, timeline, monitoring cycle, and performance metrics.
- Consider a wide range of adaptation strategies (e.g., long-term versus short-term, aggressive versus non-aggressive, low-cost versus high cost) based on the organization's projected risks and risk tolerance. Organizations with high risk tolerance can still implement low-cost, short-term, governance-based actions first (e.g., accounting for higher-magnitude storms in their emergency preparedness and response plan), and adapt their approach in the future.
- Update information about climate change projections, asset characteristics, exposure, sensitivity, adaptive capacity, and criticality on a regular basis, as it will directly inform the selection of adaptation strategies. In particular, information on climate change projections is evolving.
- Adaptation efforts that are grounded in mandatory policy or regulation at the local, regional, and national scales are more likely to be implemented than voluntary actions.

10. Next Steps

The findings of this study indicate that while a few city agencies around the world have recognized the importance of factoring infrastructure interdependencies into climate vulnerability and risk assessments, and some have analyzed the cascading impacts of climate change on interconnected systems, in many cases, this analysis needs refinement, particularly in identifying failure points among complex systems. Further, there is limited evidence as to whether and how such analyses have led to the development and implementation of risk mitigation strategies. In light of these findings, it is recommended that further research be conducted on the following topics such that city governments can incorporate results into their climate adaptation planning efforts.

- **Research on the potential of computer models to refine vulnerability and risk assessments:** Examples of climate exposure assessments reviewed in this study have primarily employed the use of static, two-dimensional mapping techniques to show the exposure of infrastructure systems to climate stressors. These assessments are typically supplemented by qualitative or quantitative vulnerability and risk assessments wherein the sensitivities of infrastructure and broader consequences to other systems, the economy, the environment, and society are analyzed. A more advanced form of analysis could include the use of computer models to show interdependencies among infrastructure systems. Such models can simulate the normal operations of interconnected systems, including flows of inputs such as energy, materials or labor. External shocks and stresses can be then be introduced to the model to visualize impacts on systems on a time-lapse basis. This type of modelling is highly sophisticated and requires substantive data such as extreme weather and sensitivity information for infrastructure components. A potential topic for future study is benchmarking of best practices in the use of this kind of modelling that provides time-lapse representations of climate hazards on infrastructure and interdependencies over time.
- **Research on identification of critical links and failure points:** While the cities examined in this study have successfully identified the nature of interdependencies among infrastructure, the level of analysis hasn't been detailed enough to be able to isolate critical links in networks or likely failure points. This kind of analysis requires acquiring more data on infrastructure characteristics and connections. Future research should focus on identifying examples of city agencies which have carried out granular analyses of failure points, as it would facilitate development of targeted adaptation solutions (e.g., defining minimum functionality requirements for critical links).

- **Research on how infrastructure interdependency and climate risk analyses are directly informing adaptation strategy development and implementation:** Cities that have incorporated infrastructure interdependencies into their climate vulnerability and risk assessments are in the early stages of adaptation strategy development. A library of best practices needs to be created on what kinds of adaptation strategies are emerging from engaging various infrastructure sectors, and what mechanisms are being put in place to implement them.
- **Research on investment models for adaptation strategy implementation:** If the impacts of climate change on interdependent infrastructure are highlighting shared risks, there is potential for pooling technical and financial investment resources among various infrastructure sectors to implement multi-benefit adaptation solutions. Future research should examine financing models for such solutions.

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Appendix A: Case Studies

City of Toronto Case Study: High Level Climate Risk Assessment and Interdependencies Exercise for Critical Infrastructure Sectors

Summary: The City of Toronto began considering climate change risks to interdependent infrastructure in 2016 by convening meetings, workshops and discussions between multiple internal city divisions and external infrastructure organizations in the water, transportation and utility sectors. A year-long city-led engagement process was structured around a High Level Risk Assessment exercise. The process allowed organizations to share general information about their own vulnerabilities and risks to climate change, and understand those of other organizations who depend upon them. In addition, this process allowed for the identification of sectoral interdependencies and highlighted how the risk mitigation responses of one organization to climate hazards could benefit others. It also established contacts and a common dialogue on shared risks. The process was commended by participants as the first of its kind in the region to tackle interdependencies, as well as a demonstration of leadership by the City of Toronto. Participants stressed the importance of and the need for continued collaboration and dialogue on interdependencies. They also cited the need for a forum where protections and controls on liability and legal repercussions are in place to allow for a fuller disclosure of specific vulnerabilities, risks, and actions.

Toronto is projected to experience an increase in the frequency of extreme weather events due to climate change. In recognition of these hazards, the City adopted the Climate Change Risk Management Policy (CCRMP) in July 2014. The CRRMP directs City divisions to systematically prioritize the identification, assessment, mitigation, monitoring and reporting of risks to infrastructure and services associated with climate hazards across the City's operations. The policy also directs staff to engage with residents, the private sector and broader public sector to share knowledge on climate change and work towards enhancing extreme weather resilience on a broader scale.

One of the initiatives to implement the CCRMP is to undertake a High Level Risk Assessment (HLRA) exercise in 10 different thematic areas:

1. Utilities (i.e. electricity, telecommunications, natural gas, district heating and cooling);
2. Transportation (i.e. public transit, highways, roads, railways, airports);
3. Water (i.e. water treatment and supply, wastewater collection and treatment, stormwater management);
4. Buildings (i.e. private and publicly owned);
5. Public safety (e.g. fire/police/ emergency medical services);
6. Liquid fuels;
7. Additional networks (waste management, social services, food supply);
8. Local economy/insurance/finance;
9. Health (e.g. healthcare facilities, clinics, outpatient care centres, and health oriented programs and services); and,
10. Natural environment.

The goal is that through the HLRA exercise, different actors (both internal city divisions and external organizations) responsible for service delivery within these thematic areas increase their understanding about climate change risks as well as the interdependencies between service providers. During

2016, this exercise was conducted in the first three thematic areas: utilities, transportation, and water.[1]

Staff at the City were able to identify and recruit appropriate points of contact at organizations within each thematic area based on previous interactions with them in a City-led climate adaptation focused network of individuals from infrastructure and other sectors called the Toronto WeatherWise Partnership. These contacts were primarily mid-level managers responsible for addressing impacts of extreme weather events on their organizations' operations, and were knowledgeable in the emergency planning and response functions of their organizations. The City invited all forms of participation in the exercise, including the option for organizations to observe initial meetings and then participate actively if they found the exercise to be mutually beneficial. This option was successful in engaging additional organizations.

The exercise started with a kick-off meeting among organizations across all three thematic areas to establish a common understanding of the objectives and the assessment process. Following the kick-off, city staff met individually with internal and external organizations within each thematic area to explore current and future weather impacts to infrastructure services.

Organizations within each thematic area then participated in individual sector-specific workshops where a high level review of risks faced by the sectors was presented, followed by discussions on cascading failures in other sectors due to critical interdependencies between infrastructure

Figure 1: Overview of Toronto's High Level Climate Change Risk Assessment Workshops in Three Thematic Areas

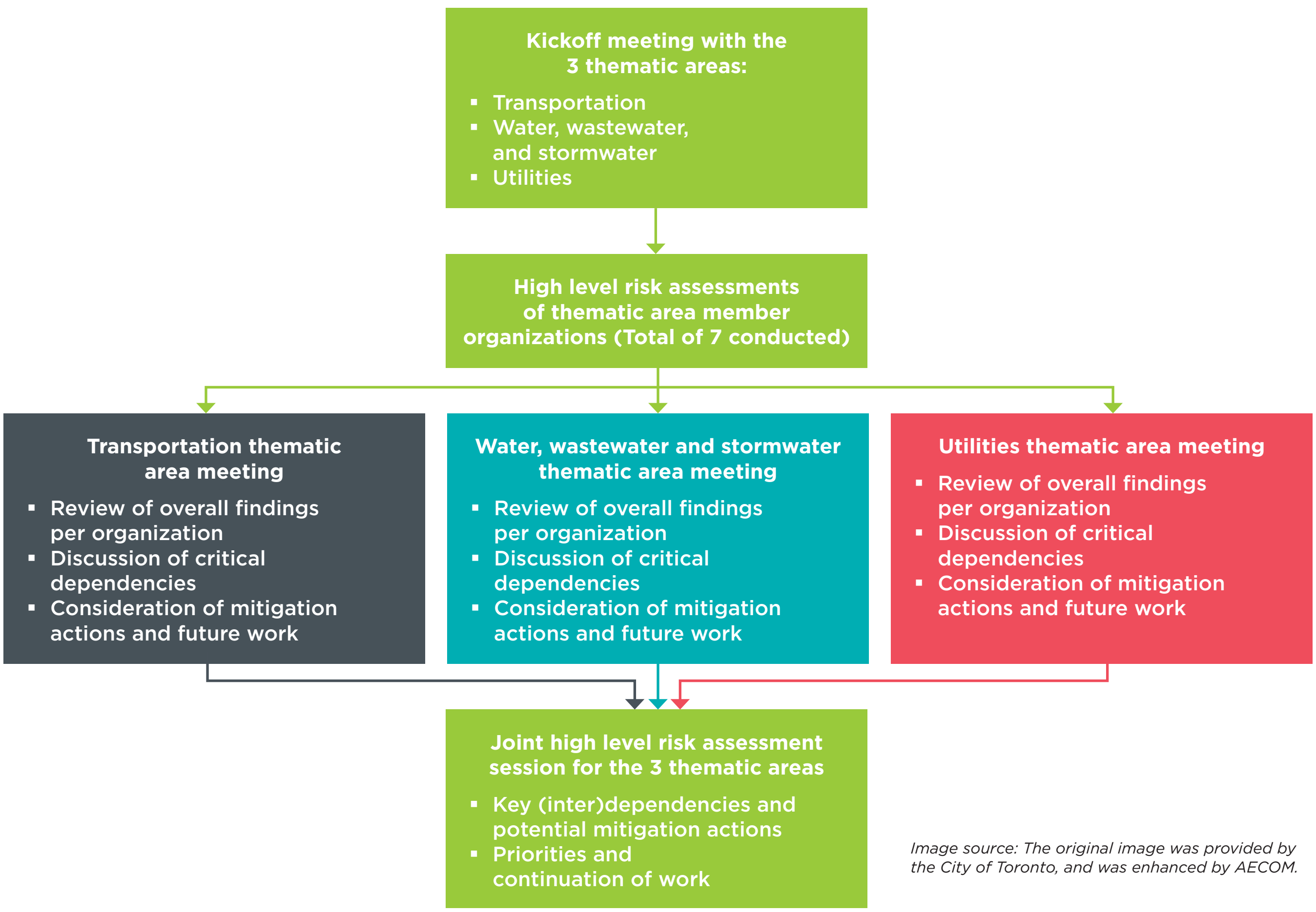


Image source: The original image was provided by the City of Toronto, and was enhanced by AECOM.

[1]The organizations engaged in the following thematic areas were:
- Utilities: Toronto Hydro, Hydro One, Independent Electricity System Operator, Enwave Energy Corporation, Enbridge Gas, Telus Communications, and Rogers Communications;
- Transportation: Toronto Transportation Services Division, Toronto Engineering and Construction Services, Toronto Transit Commission and Metrolinx;
- Water: Toronto Water, Toronto Engineering and Construction Services, Toronto City Planning, Toronto Public Health, Toronto and Region Conservation Authority, Enwave Energy Corporation.

The HLRA Exercise Structure

The following three climate hazard scenarios were used in the HLRA exercise to help stimulate the conversation on potential impacts and risks:

- Extreme high temperatures across the whole city
- An extreme rainfall event in a northeastern suburb
- A similar extreme rainfall event in the downtown area

Risks were rated within the following six categories that are loosely based on ISO 31000 Risk Assessment Standard:

- Premises/ infrastructure/ assets
- Cost (including reputation)
- Environment
- Logistics (e.g. supply chain, utilities and transport infrastructure)
- People (e.g. staff, clients of city services)
- Corporate processes and functions
- Service delivery

services. In these workshops, the primary points of contact for each organization were accompanied by their managerial and technical colleagues from other divisions. Senior staff at the City with direct experience in risk assessment, climate change adaptation planning, public health, conservation and broader city planning devoted considerable time to preparing for and facilitating these meetings. Finally, a joint workshop between organizations across the three thematic areas was held, during which key interdependencies between infrastructure services across thematic areas were validated, and potential mitigation actions and areas of future work were identified. An overview of the HRLA engagement process is shown in Figure 1.

Outcomes of the Risk Assessment and Infrastructure Interdependencies Exercise

The HLRA led to the identification of climate change impacts on various organizations, as well as their interdependencies and potential cascading effects on other organizations, infrastructure systems, and services. Figure 2 shows an example of an interdependencies mapping exercise conducted at one of the workshops for the utilities thematic area. It highlights general interdependencies of infrastructure sectors like energy and telecommunications, independent of climate change impacts. For example, Enbridge Gas (a natural gas provider) and EnWave (a district energy supplier) both depend on Toronto Hydro for electricity to run pumps, electrical controls, and other equipment. Toronto Hydro is not directly dependent on these two utilities, but relies on other infrastructure such as the road network to access its equipment, and the City's stormwater system.

Furthermore, a wide range of future activities, many with benefits to multiple organizations, that could be undertaken to mitigate climate change risks were identified. Examples include:

- Developing a better understanding of specific, localized flooding risks across the city. It was determined that a review of existing information and knowledge gaps on flood risks specific to infrastructure sectors such as water, transportation, utility services should be performed.
- Creating a centralized alert portal to notify various service providers of incidents involving water-main breaks in the city, which can erode pipe supports, damage other infrastructure systems, and create public safety hazards because they are located in common underground infrastructure corridors and access chambers.

A full list of multiple climate risk reduction actions was presented in a report to the Parks and Environment Committee on Nov. 2, 2016.[2]

Summary of HLRA Benefits

The HLRA exercise resulted in numerous benefits in terms of addressing climate change risks to interdependent infrastructure.

- It catalyzed dialogue about the risks faced by different organizations, sectoral interdependencies, and the potential for cascading impacts on key infrastructure service providers both within and external to the city.

[2] City of Toronto. (2016, November 2). Resilient City—Preparing for a Changing Climate, Status Update and Next Steps. Retrieved from www.toronto.ca/legdocs/mmis/2016/pe/bgrd/backgroundfile-98049.pdf

Figure 2: Interdependencies in the Utility Thematic Area through Toronto's High Level Risk Assessment Process

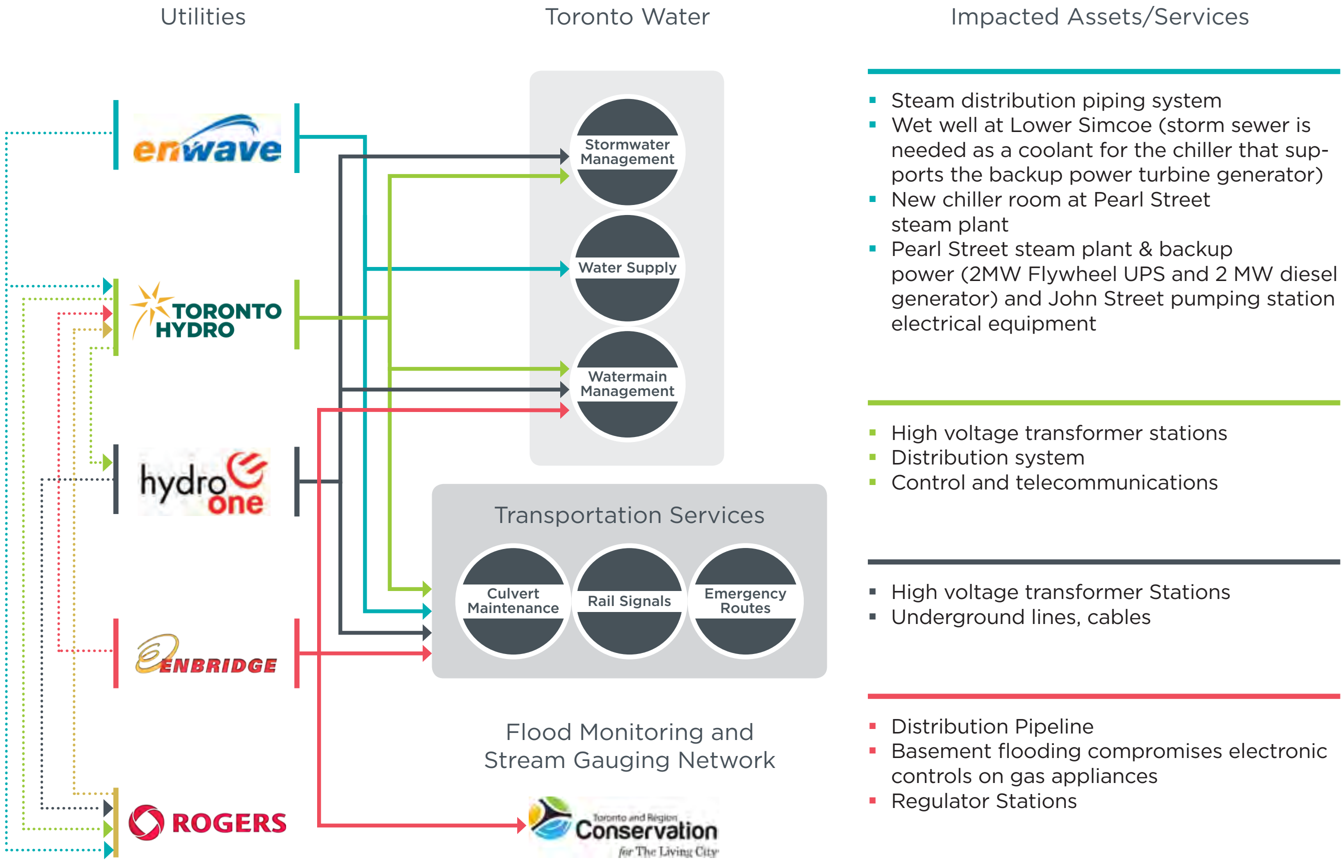


Image source: The original image was provided by the City of Toronto, and was enhanced by AECOM.

Note: The diagram does not represent all possible interdependencies among highlighted sectors. For example, the dependencies between the telecom sector and Toronto Water are not illustrated, even though these utilities may share common underground infrastructure corridors. It is presented for illustrative purposes, and represents a preliminary and working output from one HLRA workshop which has been shared publically.

- Prior to the exercise, participating organizations generally understood their own climate change risks, and had mitigation procedures in place; however, their understanding of the implications of one organization's activities on other dependent systems was limited. The HLRA process helped improve their understanding of interdependencies.
- This exercise also helped raise awareness among participants about specific climate change and extreme weather related risks.
- It resulted in a wide variety of helpful adaptation actions across many sectors. It is hoped that the learnings and outcomes will encourage other infrastructure organizations over which the City has no jurisdiction to get involved.
- Finally, the identification of a preliminary list of actions, coupled with the requirements for the City to report back on the progress on risk reduction activities on interdependent infrastructure systems, will stimulate collective efforts to address climate change risks and enhance resilience.

Recommended Improvements for Future HLRA Exercises

Staff at the City plan to continue this work in the three thematic areas, and initiate similar work in the seven other thematic areas. They, along with key infrastructure sector representatives who participated in the first HLRA exercise, have recommended the following improvements to maximize the potential of this exercise:

- Need for a common and detailed understanding of risks, as well as relative priorities for upgrades among the participating organizations.

- Need to establish roles and responsibilities to address shared risks. Several utilities often share common “housing infrastructure”, such as space within a building or in a common underground conduit or chamber. For such assets, the failures of protection systems in one system could cause damage to or failure of equipment in another. E.g., if a utility that owns a building allows another utility to install infrastructure in its basement, in the event of a flood, the building owner’s equipment may not be adversely impacted, but the equipment of the other utility in the basement could be damaged. Questions were raised, and remain unresolved, as to which organization needed to make the necessary upgrades to protect under such circumstances. As each organization is responsible for capital investments and maintenance work on its own infrastructure, the priorities for upgrades or protecting systems do not always align between organizations.
- Need to determine how to best facilitate disclosure of sensitive information integral to more comprehensively addressing risk identification and reduction while acknowledging security and reputational concerns of participating organizations. This must be done without compromising statutory, regulatory or contractual obligations that are in place regarding public disclosure and personal or corporate privacy.
- Need for new protocols, procedures or controls to safeguard the sharing of specific geographic or equipment related information with others in order to enhance their common understanding of risks and mitigation information. Without this, a full disclosure of information is not possible, impeding further collaboration and proactive planning on climate change risks.
- Need to review more specific hazard or failure scenarios in future work. The HLRA scenarios, while useful to initiate a high level conversation about cascading failures, were too broad to allow for a detailed engineering-level investigation of potential cascading failures (recognizing that the lack of full disclosure of risks, as previously raised, was also a related challenge). More detailed technical analysis is therefore required in some cases.
- Need to emphasize proactive and future infrastructure planning and management, rather than reactive event or emergency response.
- Need for the proactive participation of Provincial ministries, the provincial energy regulator, and other sectors such as telecommunications in discussions regarding interdependencies. Some of these groups are responsible for other infrastructure upon which utilities are dependent, and it could have been illuminating for these groups to have participated in the HLRA process to better understand the issues and challenges in coordinated climate change adaptation.

City of Amsterdam Case Study: Westpoort Harbour Pilot Study on Sectoral Interdependencies and Flood Risk Reduction

Summary: The City of Amsterdam, together with its partners in other levels of government such as the Ministry of Infrastructure and Environment, the Province of North Holland, regional water authorities, emergency management organizations, and businesses, examined flooding risks to interdependent infrastructure systems, assets and operations under the national Delta Programme. Launched in 2010, the Delta Programme set out to reexamine the flood protection afforded by Dutch dike systems. Interdependencies were investigated through a pilot study focused on the Westpoort Harbour, an industrial district located to the west of Amsterdam on the south bank of the River IJ and the North Sea shipping channel. Critical electrical, sewage, transportation, industrial and telecommunication facilities important to Amsterdam as well as the wider Dutch economy are located in the district. In this pilot study, flood hazards and consequences to different sectors were identified, and interdependencies between systems were mapped out. As a next step in this study, an adaptation strategy is being developed to identify critical networks, systems, and sites which must remain operational; develop technical and physical solutions to achieving these outcomes; clarify the roles and responsibilities of government and the private sector, and enable collaboration among them to implement risk reduction measures.

For many centuries, Dutch flood and coastal defense systems have primarily been composed of dikes, sluices, dams and water pumping stations around the country. These primary flood defense systems have worked so well that the Dutch generally no longer consider flood risks as a persistent threat to their society. However, improved technical investigations, engineering knowledge, examples of flood events abroad (e.g. Hurricane Katrina), rising sea levels, and other climate hazards have prompted authorities to reexamine their assumptions and reliance on traditional flood and coastal defense systems, particularly in the context of climate change. Therefore, in 2010, a new Delta Programme was launched to reexamine the protection and safety afforded by these primary flood defense systems. The national government, provincial governments, municipalities and regional water authorities across the country worked together with input from community organizations and the business community to evaluate whether a better approach to flood resilience than reliance on their trusted dike systems could and should be developed.

The Delta Programme, a national scale effort, has been complemented by various local scale adaptation planning efforts in Amsterdam, including the Program Amsterdam Water Resilient, which informed the development of the Delta Strategy for the Amsterdam metropolitan region. The Delta Strategy is a regional scale effort under the national Delta Programme framework which examines climate risks from not only coastal and riverine flooding, but also drought. Similarly, the Amsterdam Rainproof program[1] is another example of a local program which focuses on urban flooding risks and solutions. These local programs have been integrated successfully into the City's Sustainable Agenda[2], which addresses both climate mitigation and adaptation planning.

The Delta Programme used a new multi-layer safety approach which had been previously introduced in National Water Plan, a national policy plan, to enhance the resilience of Dutch cities and communities to flooding. This approach was based on a more comprehensive protection, safety, and recovery philosophy to enhance the flood protection and rapid recovery of affected areas:

1. Layer 1: Flood prevention through continued strengthening and upgrading of the protective dike and dam systems.
2. Layer 2: Flood consequence mitigation through integration of designs and measures at the neighbourhood and building scales to protect

[1] https://www.rainproof.nl/
[2] https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/agenda-duurzaamheid/

against flooding, accommodate flood waters, or avoid being flooded altogether. These measures include protecting critical assets with flood walls, raising the elevation of neighborhoods and buildings, and moving critical or electrical equipment above basements or ground floors.

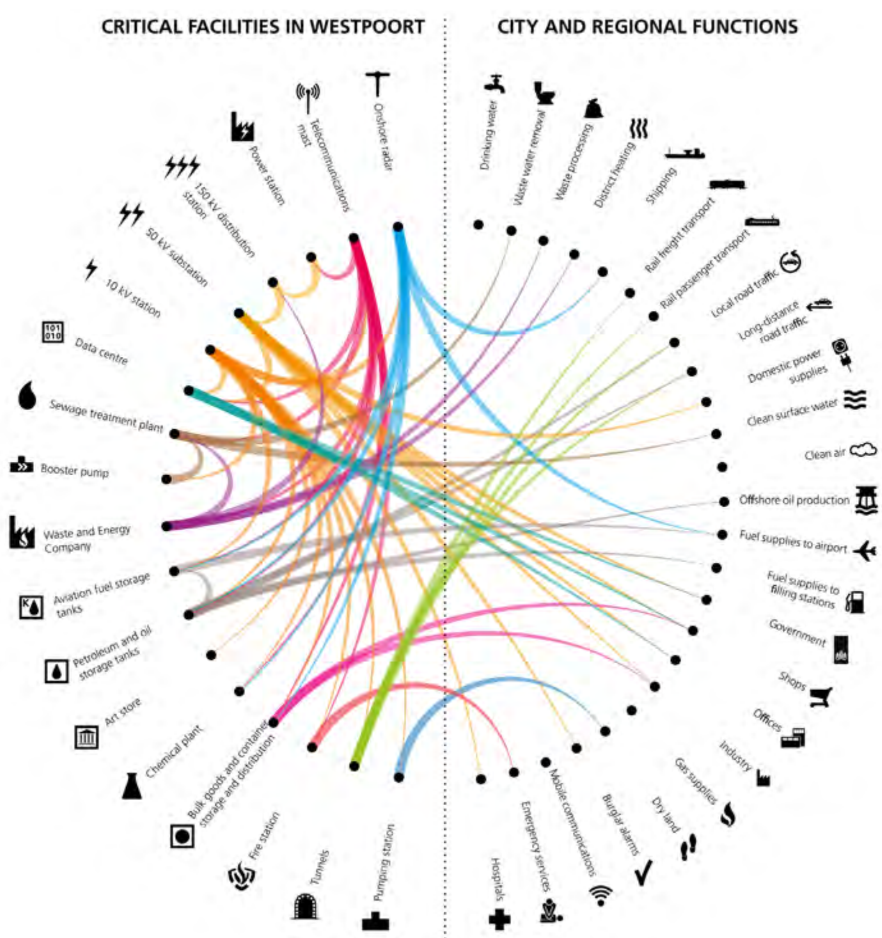
3. Layer 3: Flood consequence mitigation through improved crisis management in the event of a flood, including an evaluation of the robustness, adequacy and safety of evacuation routes and transportation infrastructure.

This multi-layer safety approach was evaluated and tested on the ground by conducting various pilot studies on regions and cities across the Netherlands through the Delta Programme. One pilot study, initiated in 2012, focused on the Westpoort Harbour district, an industrial district on the western side of Amsterdam where critical infrastructure, businesses and industry vital to the functioning of Amsterdam and the country's economy are located.

The Westpoort Harbour district houses a waste-to-electricity generation plant, major electrical transformer substations and distribution infrastructure, the city's sewage treatment facilities, chemical processing and storage facilities, fuel supplies for Schiphol International Airport (Amsterdam's main airport), and important telecommunications infrastructure and data centres, along with other transportation and logistics companies, industries and businesses. The Westpoort Harbour district is only 1 meter above current sea level, and is protected by dikes and sluices at Ijmuiden (North Sea entrance to the channel providing access to the district) and dikes along the Lek River and Lake Markermeer.

As part of the Westpoort Harbour district pilot study, Waternet, a local water resource management corporation, together with the City of Amsterdam, met with 15 different publicly and privately owned companies across multiple sectors (e.g. electricity, sewage treatment, telecommunications, district heating, chemical industries, recycling, etc.). The goal of these engagements was to raise awareness about flood risks and discuss the consequences of a flood event to business continuity. Through workshops,

Figure 1: Example of Mapped Infrastructure Interdependencies in the Westport Harbour District



Source:

working sessions, and round tables, study participants evaluated flood risks for different sites, infrastructure services and networks. They also conducted an exercise to map interdependencies between different infrastructure services, systems and networks, the results of which are shown in Figure 1. The left half of the figure shows infrastructure facilities located in the Westpoort Harbour district. The right hand side of the figure shows buildings, services, and amenities across the region that are served by the infrastructure facilities in the Westpoort district. An example of an interdependent chain can be seen by following the links from the 10 kV substation. If the substation goes out of service due to an extreme flood event, it would disrupt electricity supply to the booster pumping station, which in turn would stop the inflow of wastewater into the sewage treatment plant, lead to potential backflow of wastewater into various facilities in the city, and contaminate clean surface waters. On the other hand, drinking water facilities would not be impacted by such an event as they are not connected to the substation.

The pilot study identified recommendations for improving the flood resilience of the Westpoort Harbour district based on the multi-layer safety approach at different scales. First, overall protection could be enhanced by strengthening the major riverine and coastal protection systems across the region, while specific and critical sites in the district could be protected by installing flood barriers and raising ground levels of sites and equipment. The study also encouraged local companies and their employees to be more self-reliant in the event of a flood, e.g., through reviewing and strengthening crisis management and safe shutdown procedures.[3]

Challenges

- While initial progress on understanding interdependencies was made through the pilot study, this work is still ongoing and likely to be a long and intensive process due to the number and complexity of connections, jurisdictions, priorities, and existing levels of risk mitigation.
- Companies and organizations more or less understood their own vulnerabilities, but had less insight as to how failures in their operations could affect others.
- Similarly, they showed a tendency to make optimistic assumptions about the continuity of other services (e.g. energy, transportation) on which they depended, and had not fully considered how flood risks might actually affect or interrupt those services.

Next steps:

Participants from the pilot study identified the following future tasks for improving the resilience of the Westpoort Harbour district:

- Gathering more information on the characteristics, connections and interdependencies of various critical networks.
- Identifying the weakest links or points of likely failure for interdependent infrastructure systems.
- Identifying critical sites, services and networks which should be kept functional during a flood event, such as electrical power supply and sewage pumping services.
- Defining minimum functionality requirements for critical services. E.g., companies handling or producing hazardous chemicals should account for major flood scenarios in their emergency plans in order to avoid spill-over and cascading risks to human health and the environment.
- Clarifying the roles and responsibilities of various entities who should be involved in flood risk management, including national, provincial and local governments, and public and private corporations.
- Coordinating on developing flood mitigation solutions and financing mechanisms to optimize investments.
- Determining acceptable levels of flood risk faced by various levels of government, public authorities and private organizations with interdependent infrastructure systems to ensure a common risk tolerance level. E.g., an electrical utility can invest in waterproofing its electricity distribution infrastructure, but if its clients do not invest similarly in waterproofing their own equipment in their buildings, electrical supply could still be interrupted by a flood event.

This pilot study has helped to identify key infrastructure systems and sites that need to be upgraded and protected in the near term versus long term. It also highlighted opportunities for improving flood protection through collaborative planning and action when investments are made to upgrade or replace infrastructure over time as part of a regular capital improvement schedule. An adaptation strategy, which will include some of the tasks identified above, has been under development for the last year and a half, and study proponents expect to present a draft of the strategy to governing authorities and the public and private sectors in mid-2017.

[3] DHV, De Urbanisten, Deltares, City of Amsterdam. (2017). The Water-Resistant City. Applying multi-layer flood protection to the Amsterdam region.

 C40 Infrastructure Interdependencies and Cascading Climate Impacts Study

City of Melbourne Case Study: Use of Intra-Industry and Cross-Sectoral Networks and Forums to Identify Sectoral Interdependencies and Reduce Climate Risks

Summary: The Greater Melbourne Region is projected to be impacted by multiple climate hazards such as drought, extreme rain, high wind events, heatwaves, wildfires, and sea level rise. Several initiatives have been undertaken in the region to address risks to infrastructure systems posed by these hazards. The Melbourne Water Industry Climate Change Committee and the Inner Melbourne Climate Adaptation Network are showcased as examples in this case study of how collaborative networks can be used to engage different organizations as a first step in addressing common climate change risks to interdependent infrastructure systems. These forums have allowed organizations to share knowledge and understandings of individual and shared climate change risks, present their respective areas of responsibility in risk management, identify gaps in collaborative risk reduction efforts, and form the basis to take action on reducing risks.

Greater Melbourne is an urban agglomeration in southeastern Australia comprising 32 local municipalities. With a population of over 4.5 million, it is the second most populous metropolitan region in Australia. The City of Melbourne, one of the 31 local municipalities in this region, is the State of Victoria's capital city. Key climate change risks for Greater Melbourne stem primarily from four hazard categories: drought and reduced rainfall, intense rainfall and high wind events, extreme heatwaves and bushfires, and sea level rise. There have been numerous initiatives to address climate change impacts across the metropolitan region, including the development of Melbourne's 2016 Resilient City Strategy, and Melbourne Water's Flood Management Strategy for Port Phillip Bay and Westernport. In this case study, two specific ongoing initiatives were explored, which focus on harboring collaboration to address climate change risks faced by interdependent systems: Melbourne Water's Industry Climate Change Committee (MWICCC), and the Inner Melbourne Climate Adaptation Network (IMCAN) spearheaded by the City of Melbourne.

Melbourne Water's Industry Climate Change Committee (MWICCC)

Melbourne Water is a state owned water authority operating within and around Greater Melbourne. This authority acts in four key roles: providing drinking water, providing recycled water, treating wastewater, and managing floods, waterways and catchment lands. Melbourne Water established the Melbourne Water Industry Climate Change Committee (MWICCC) with three local water retailers for municipalities across Greater Melbourne, namely, City West Water, South East Water, and Yarra Valley Water. MWICCC usually meets once every two to three months. The objectives of the network are to share information and lessons on climate change risks and adaptation. Specifically, the terms of reference for MWICCC are to:

- Continue to improve the joint understanding of the implications of climate change for their businesses by sharing information on climate science, risks and adaptation efforts;
- Identify areas for joint research or activity between participating organizations;
- Work towards developing consistent data sets and risk assessment and adaptation approaches;
- Develop consensus-based internal and external communication strategies;
- Influence key stakeholders and policy;
- Champion new climate change adaptation processes or tools introduced to the industry; and,
- Share information on internal engagement and education strategies.

Melbourne Water Industry Climate Change Committee

One of the accomplishments of MWICCC on climate change was to develop an industry risk register, which contains a list of common risks facing their organizations.[1] In the development of the register, the four organizations worked together to prioritize common risks, understand where they were already undertaking cooperative action, identify any gaps to addressing common risks in their combined activities, and assign responsibilities for subsequent actions. A key factor contributing to the success of the industry risk register was that each organization had already developed its own understanding of the climate change risks it faced. Based on this understanding, they came to the table better prepared to identify areas of common concern, and to coordinate their efforts more effectively and efficiently.

An example of the type of risk these organizations face is the management of projected decreases in rainfall and increased occurrence of drought. Unlike Melbourne Water, the region's bulk water supplier, the three water retailers interface directly with water consumers and are better able to introduce consumption reduction initiatives that will help address water supply constraints experienced by Melbourne Water. Another overlapping risk example is the management of overflows from the sewer network during rainfall events. The network successfully organized seminars on climate change risks like these for the broader Victorian water industry with the aim of raising awareness, sharing information and lessons learned, facilitating industry dialogue and supporting industry action. The MWICCC continues to meet periodically to carry out the mandate specified in its terms of reference.

City of Melbourne's Inner Melbourne Climate Adaptation Network (IMCAN)

The Inner Melbourne Climate Adaptation Network (IMCAN), started in 2012, connects and facilitates communication between organizations involved in actively managing the risks associated with climate change impacts facing inner city Melbourne. IMCAN is an initiative of the City of Melbourne, which demonstrated its leadership in the climate adaptation space. It is an example of a bottom-up approach to addressing the need for inter-organizational and inter-sectoral cooperation, and served to formalize discussions on adaptation that were already taking place between many local organizations in the city. The network consists of members from state governments, scientific and academic organizations, water authorities including Melbourne Water, other municipalities, industry groups and businesses, and emergency service organizations.

IMCAN has met approximately two to three times a year since inception. Discussions in 2012 – 2014 were thematically structured around the different kinds of extreme weather events that were projected to be exacerbated by climate change in Melbourne (e.g. heatwaves, drought, extreme precipitation, and sea level rise). IMCAN participants have tested different discussion formats through the years, ranging from more traditional presentation and question and answer sessions to multiple guest speakers, roundtables and one-on-one interviews.

As a forum for information exchange, the network, by itself, has not developed adaptation projects. However, the relationships that have been built through the forum have led to joint projects to address projected climate change impacts around inner city Melbourne. For example, the City of Melbourne is currently working with Melbourne University and the

[1] Information compiled in the risk register is confidential and cannot be shared.

Inner Melbourne Climate Adaptation Network

Inner Melbourne Climate Adaptation Network

Royal Melbourne Institute of Technology (RMIT), the city's two main universities and large landowners, on a flood risk reduction project with the former and an urban heat island mitigation strategy with the latter. Additionally, through IMCAN, the Port of Melbourne, the insurance industry, and power sector have also engaged with the City on addressing climate change impacts through information sharing, project planning, and coordination.

A representative from the insurance industry reports that IMCAN has been a useful forum to learn about the efforts that various other organizations are taking to tackle climate change. More importantly, the network has allowed for greater coordination of activities to ensure that organizational efforts are not counter-productive. For example, the insurance industry is now working with the City of Melbourne to understand the mitigation measures it is putting in place to protect new development in low lying and flood prone areas. These efforts help assure the insurance industry that the new developments are not placing residents and businesses in flood zones which the insurance industry, by regulatory requirement, would be forced to insure. They also provide the insurance industry the necessary information to avoid having to set prohibitively high premiums in these areas.

The insurance industry has also been coordinating with the City on its efforts to mitigate urban heat island impacts. Traditionally, the City's strategy to address heat island impacts has been to increase the number of trees in the urban area. However, certain kinds of trees with shallow root systems are more susceptible to falling over in wind storms, increasing the risk of damage to adjacent properties, and in turn potentially raising insurance premiums. Consequently, the insurance industry is now working with the City to identify tree species which are stronger and less susceptible to being blown over. A key resource that the insurance industry can bring to the table is a significant amount of data about different kinds of risks in order to support better decision making.

One of the keys to the success of the IMCAN network is that it was conceived as a "safe" space to facilitate the exchange of ideas and practices in climate adaptation. IMCAN is designed to be a network of peers involving trusted academics, scientists and adaptation practitioners who can share scientific and practical information on climate adaptation. More importantly, it has been a forum where different organizations were not only encouraged to talk about their successes, but also to be open about the issues and challenges they face. The IMCAN network specifically excluded the consulting industry to preclude the possibility that organizations would be solicited for business opportunities when sharing information on challenges. Furthermore, the safe space is designed to allow weaknesses or challenges facing an organization to be addressed through the sharing of ideas, support, and potential coordination of action with other organizations.

The network relies on the continued and voluntary efforts of participants to dedicate time and other resources to support the information exchange and discussion. It has had success in engaging certain organizations more than others, and outreach and engagement efforts by the City to reach the latter, such as the transportation and telecommunications, are ongoing. Increasing participation in IMCAN by representatives from State ministries and agencies, who can be funders or regulators, has led to increased interest and participation from local municipalities and other organizations in this network (particularly in light of a new State Government that has led to a more supportive policy environment on climate change adaptation).

The IMCAN network has been an important forum for advancing climate adaptation in Melbourne and therefore it is potentially a space where the issue of climate change impacts to interdependent infrastructure systems could be addressed. The network has helped develop an initial understanding of how different organizations and responsibilities may be reliant on one another, or may be affected through extreme events causing cascading impacts. However, climate change risks from interdependencies have not been explicitly explored or mapped to date. Nonetheless, the established contacts, trust and progress thus far suggests that the IMCAN network would be an appropriate forum to pursue work on addressing climate change risks to interdependent systems as part of its work in the climate change adaptation space.

City of Johannesburg Case Study: Opportunities for Analyzing Sectoral Interdependencies in Climate Change Adaptation Plan Update

Summary: The City of Johannesburg developed a Climate Change Adaptation Plan in 2009, which identified a range of climate-related risks to its population. Cascading impacts to various infrastructure systems and food security were also discussed at a high level. However, due to a range of capacity, coordination, governance and finance-related challenges faced by the City, the Plan's actions have not been implemented to any significant degree since its adoption.

In 2016, the City initiated a new process to review and update this Plan. To avoid the pitfalls and implementation challenges of the 2009 Plan, it has partnered with a local university-based research institute in the update process. Through a co-learning and action research-oriented approach, the City and the institute hope to build a robust institutional foundation to support the implementation of the Plan. This update process provides the City an opportunity to explore and address climate change risks faced by interdependent infrastructure systems in collaboration with internal and external agencies.

The City of Johannesburg developed a Climate Change Adaptation Plan in 2009, which identified key risks and priorities for adaptation related to increased energy demand; increased water demand; as well as the impacts of urban flooding on water and sanitation infrastructure, electrical and telecommunications infrastructure, public and private property, personal safety and loss of life, and road safety and traffic.

Furthermore, in the investigations of climate change impacts and risks, the plan acknowledged the cascading impacts of floods and droughts, which, when combined with a range of other factors (e.g. lapses in infrastructure planning and monitoring), can result in damage to interdependent infrastructure systems, food insecurity, increased food prices, and potential loss of life, especially for the urban poor. The Plan sought to integrate climate change adaptation planning as a strategic consideration across City operations. It called for the creation of new dedicated task teams, the development of management systems to support the expansion of stakeholder engagement, ongoing risk assessments, the use of cost-benefit analysis to help identify solutions, the examination of financing options, and regular reviews of progress.

Implementation Challenges

Various challenges have, however, hampered the full implementation of the actions recommended in this Plan, such as a lack of dedicated support for longer-term adaptation planning in the face of more short-term and pressing development priorities like poverty alleviation and improvement of basic urban living conditions (e.g. housing, clean water, sanitation, etc.). Similarly, inadequate financing or other incentives were put in place to support full implementation. Insufficient stakeholder engagement and cross-sector participation in the development of the Plan was also cited as a challenge, thereby contributing to a lack of coordination and ownership by City departments essential to implementation. While the Plan was ambitious and far reaching, its scope was not sufficiently translated into tasks, targets and performance indicators to guide City staff in their day to day work. These reasons collectively contributed to the lack of significant progress on the Plan's proposed actions.[1]

Plan Update Process

In 2016, practitioners and leaders within the City of Johannesburg's Department of Environment and Infrastructure Services (EISD) undertook

[1] It should nonetheless be noted that the City has continued to develop programs, projects and infrastructure, such as stormwater resource management, road infrastructure upgrades and repairs. These projects will enhance the resilience of the city to climate change impacts, although they were not specifically recognized or carried out under the guise of climate change adaptation.

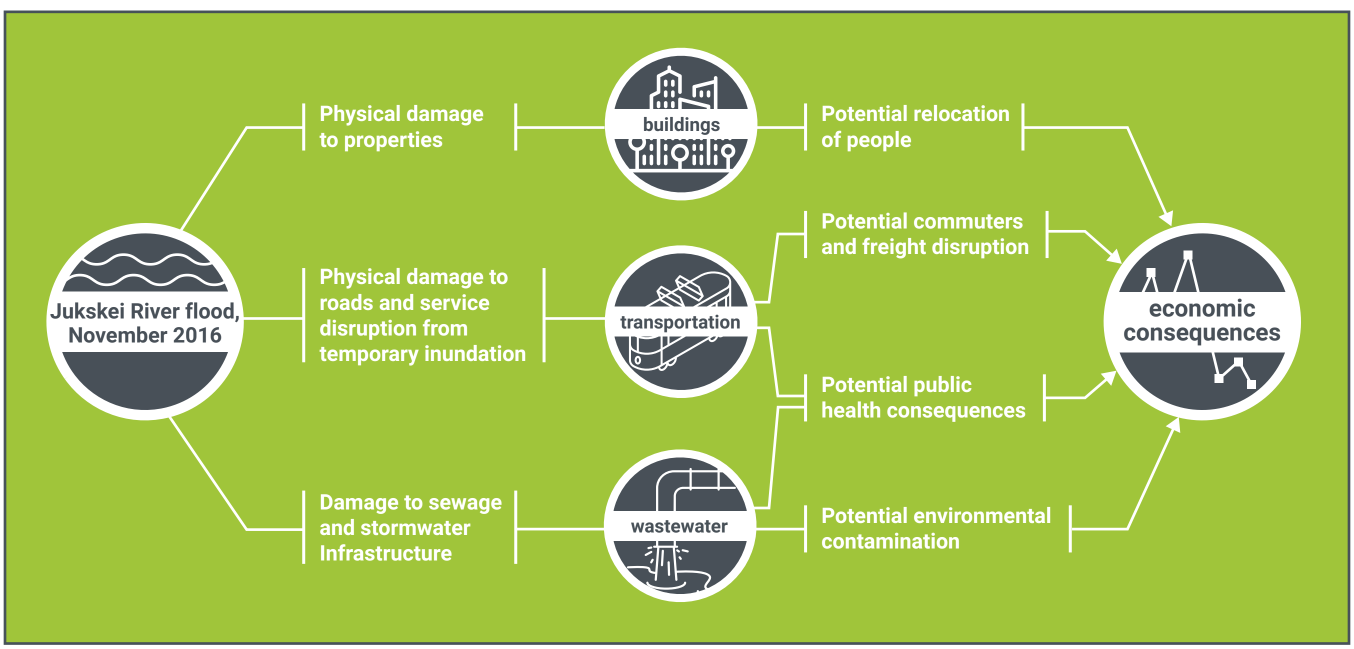
a new process to review and update the Plan. The City has engaged the Global Change and Sustainability Research Institute (GCSRI), based out of the University of the Witwatersrand (Wits University) in Johannesburg, to provide ongoing support, and together, GCSRI and the City are employing an approach based upon:

- Improving the understanding of the history, contexts and challenges facing the City;
- Co-learning about governance, decision-making and institutional processes in order to develop a more tailored, context-sensitive and implementable set of actions;
- Understanding, engaging and mobilizing internal and external stakeholders (e.g. city departments, businesses, NGOs) to own and assist in implementing the plan; and,
- Developing mechanisms to support and monitor implementation.

Stakeholder Engagement as Part of the Update Process

In one of the workshops held during the Plan update process, researchers from GCSRI and practitioners from EISD led key junior and mid-level staff from internal City departments such as Housing, Roads, Public Health, Environmental Health, Biodiversity, Water, Waste, and Innovation through a facilitated co-learning exercise exploring topics related to climate adaptation. One activity included understanding the context in which adaptation occurs or may occur, e.g., in response to cascading impacts of recent weather related disasters. For instance, a representative from the Health Department cited the impacts of a massive flood in November 2016 damaging sewer infrastructure. This flood along the Jukskei River and the Alexandra Township and neighboring suburbs of the City led to the loss of life and property damage in parts of the city. It also sparked discussions on the potential relocation of those who experienced significant damage to their homes. During the storm, parts of the city's sustainable drainage infrastructure and roads were also severely damaged. Through the dialogue and discussions held in this workshop, City departments recognized the potential cascading damages that can occur from extreme weather events which are likely to be exacerbated by climate change. Detailed examination of the recent flooding event are ongoing as part of the co-learning process for effective climate change adaptation in the City. Figure 1 shows a schematic of the direct impacts of the flood event as well as potential, indirect cascading impacts on populations, the environment, and the economy.

Figure 1: Schematic of Potential Cascading Impacts from Flooding along the Jukskei River



Source: AECOM, 2016.

Next Steps

One of the main outcomes of the workshops has been to set up a permanent interdepartmental task team and steering committee to drive the development and eventual implementation of the new revised Plan. Next steps include:

- An internal city stakeholder mapping exercise led by GCSRI and EISD to identify the most suitable champions across departments and sectors to lead adaptation efforts, support learning and capacity-building, and ultimately get internal traction for the new Plan.
- Outreach to external stakeholders to build support for the revised Plan, including local businesses and associations.[2]
- Embed GCSRI researchers directly into city departments to assist in specific co-learning activities. Such activities include a 'forensic' investigation of the November 2016 flood and a study on extreme heat and drought impacts. It is hoped that both the City and researchers will gain a better understanding through projects like these on the causes of cascading failures, outcomes and potential opportunities for climate adaptation.

The current process of revising the City of Johannesburg's Climate Adaptation Plan will be a potential and appropriate forum for identifying and addressing climate change risks faced by interdependent infrastructure and systems. The approach to revising the Plan will focus more on encouraging coordination and institutional capacity-building among internal infrastructure owners and operators. It is anticipated that the learnings gained by staff and policymakers during the process will lead to a more sustained effort in tackling both direct climate change impacts to urban systems as well as cascading impacts stemming from sectoral interdependencies.

[2] Although climate change mitigation activities have seen widespread uptake in the business community, the value of climate adaptation has not yet been accepted in a proactive manner. Hence, there is a need for adaptation-focused outreach to the business community.

City of Bogota Case Study: Opportunities to Mainstream Interdependency and Cascading Climate Risk Considerations into Bogota's Risk Management System

Summary: Bogota has adopted a multi-scale risk management system to support climate and non-climate risk management activities consisting of four key themes: governance, policy and planning, financing, and information dissemination This system formalized and institutionalized risk management and climate change activities already taking place across the metropolitan region under a comprehensive framework. It includes a number of decrees that mandate the organizations managing the city's infrastructure, sectors and services to work together to carry out risk knowledge development, risk reduction, emergency management, climate change adaptation and climate change mitigation activities at the metropolitan and local levels. A key output of the work done under the policy and planning theme was the District Plan for Risk Management and Climate Change, a roadmap to guide the public and private sector organizations working in risk management over the next 35 years. Altogether, the risk management system has the potential to mainstream the assessment of climate change risks to interdependent infrastructure systems.

Bogota, District Capital (D.C.) is the capital of, and largest city in, Colombia with a population of approximately 8 million. The District Capital (or metropolitan region) is divided into 20 separate districts, 12 urban, 7 mixed urban and rural, and 1 entirely rural. Bogota is located in the center of the country on a high plateau in the eastern range of the Andes Mountains. The main climate related hazards affecting the city are riverine flooding, wildfires, flash flooding, and landslides.

To address climate and non-climate risks , the City has developed and implemented a comprehensive risk management system called the District System for Risk Management and Climate Change - Sistema Distrital de Gestión de Riesgos y Cambio Climático). This system is based on four themes:

1. **Governance for risk management activities.** This established a series of councils or committees to oversee the planning, policy development, coordination and implementation of risk management and disaster recovery activities across the city.

2. **Development and implementation of plans and policy documents.** These include:

- District Plan for Risk Management and Climate Change for Bogota 2015-2050 (Plan Distrital de Gestión de Riesgo y Cambio Climático para Bogotá 2015 – 2050);
- Land Use Plan (Plan de Ordenamiento Territorial);
- Economic, Social, Environmental and Public Works Development Plan of Bogotá (Plan de Desarrollo Económico, Social, Ambiental y de Obras Públicas de Bogotá);
- District Emergency Response Strategy (Estrategia Distrital de Respuesta a Emergencias);
- Local Risk Management Plans (Planes Locales de Gestión de Riesgos).

Regulations have been passed enacting the policies contained within these documents.

3. **Financing.** Identification and dedication of funds to support projects in risk management, climate change adaptation, and climate change mitigation. Financing is made available through the District Fund for Risk Management and Climate Change (FONDIGER - Fondo Distrital para la Gestión de Riesgos y Cambio Climático). Currently, the fund is supported in part by the redirection of 0.5% of tax revenues collected by the metropolitan city administration.

4. **Development and dissemination of information about risks.** Agency responsibilities include the identification and characterization of various hazard and risk scenarios, analysis and monitoring of risks, and communication to City departments and external agencies, including through an online database of maps and documents.

[1] IDIGER. (2015). District Plan for Risk Management and Climate Change for Bogota, D.C., (2015-2050), Support Document. Bogota: Instituto Distrital de Gestión de Riesgos y Cambio Climático.
[2] Ibid.
[3] Examples of non-climate risks include earthquakes, disease, and terrorism.
[4] Note that the risk management system also encompasses climate change mitigation, or the reduction of GHG emissions.

Specific attention is drawn in this case study to the governance structure of the risk management system as well as a key planning document, the District Plan for Risk Management and Climate Change, to illustrate how the assessment of climate change risks to interdependent infrastructure systems can be integrated into the existing risk management system.

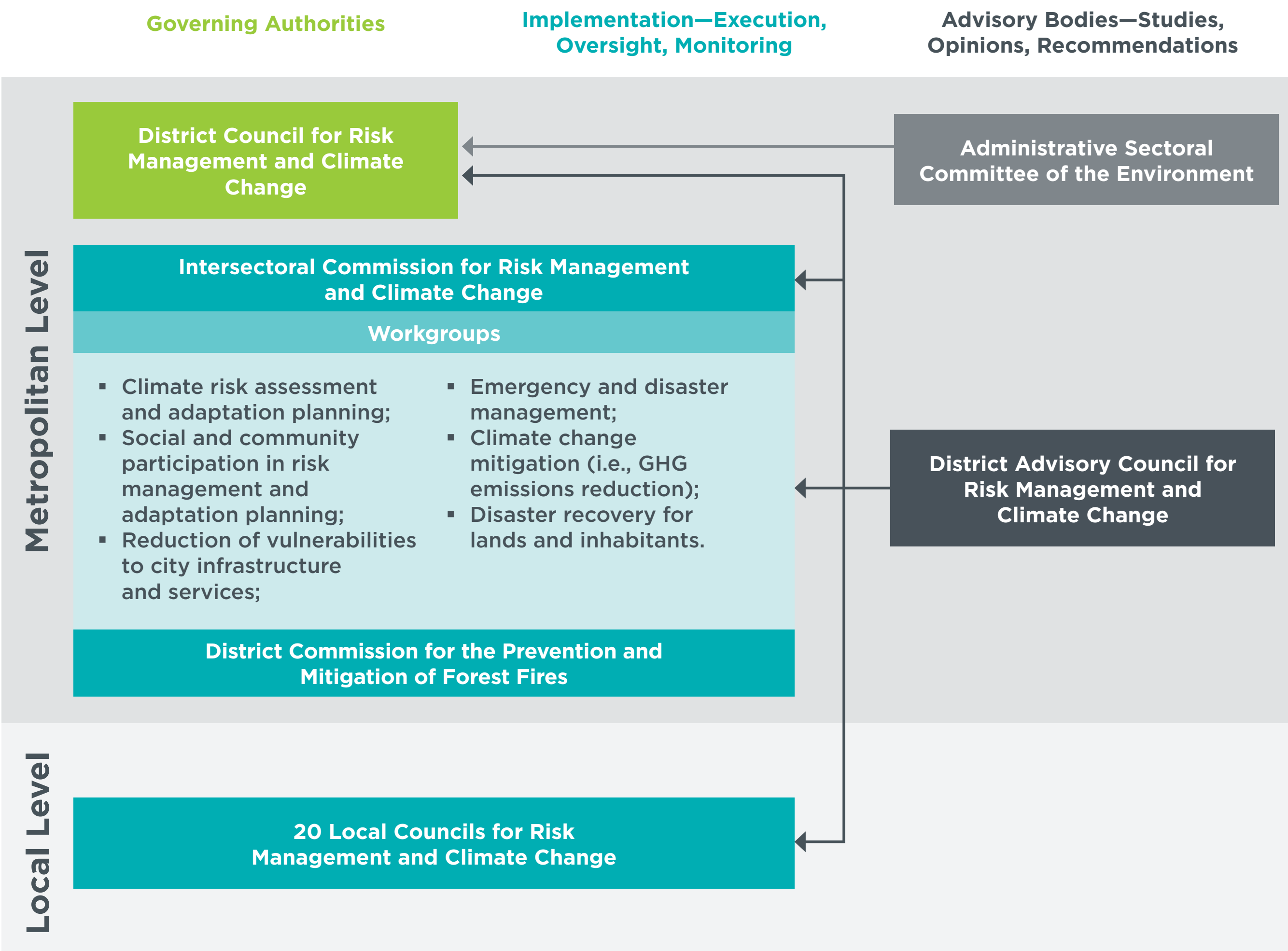
Governance Structure

The risk management system has a multi-tiered, multi-organizational and cross-sector governance structure. The roles and responsibilities of each organization are set out by decrees which mandate how they interact and coordinate with one another to develop and implement risk mitigation and climate change adaptation/ mitigation actions. Figure 1 shows the governance structure, which is explained in detail below.

Tier 1: At the top level, the District Council for Risk Management and Climate Change (CDGRCC -- Consejo Distrital para Gestión de Riesgos y Cambio Climático) is the central administrative decision-making body. It coordinates all risk management activities for the metropolitan region.

It has the power to adopt policies and make decisions to address risks across the city, and to guide, organize and control those activities. Key responsibilities

Figure 1: Governance Structure of Bogota's Risk Management System



Source: AECOM, 2016.

[5] Decree 172 of 2014, April 30, Legal Regime of District Capital of Bogota (http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i= 57274) Decree 2 of 2015 for the approval and adoption of The District Plan for Risk Management and Climate Change for Bogota 2015-2050 (http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=64901).

include high level planning for risks, and analyzing and approving the financial strategy to fund risk mitigation and disaster management/recovery work.

On matters of risk mitigation, the CDGRCC includes the Mayor, as well as the heads of 13 city departments including mobility, environment, housing, social integration, and the General Director of the Risk Management and Climate Change Department (IDIGER), which serves as secretariat for the CDGRCC. When the CDGRCC is convened to address issues of disaster preparedness, response, and recovery, the membership is broadened to include other relevant organizational managers in disaster response and recovery, e.g., from the energy company, the City's water and sewer service, telecommunications, metropolitan police, fire department, and the Colombian Red Cross.

An administrative Sectoral Committee of the Environment (Comité Sectorial de Desarrollo Administrativo de Ambiente) has been constituted to provide technical and professional advice to the CDGRCC on policy, plan, and program proposals on risk management and climate change.

> **Opportunity to mainstream interdependency and cascading climate risk considerations:** Given the CDGRCC's authority, the breadth of participation from various infrastructure sector representatives, technical resources at hand (e.g., from the Environment committee), it has the potential to pass policies mandating the study of climate change risks to interdependent infrastructure systems. Furthermore, as an administrator of funds, it can require the consideration of interdependencies and climate risks by agencies seeking funding for proactive risk mitigation work as well as reactive disaster recovery work.

Tier 2: The next level is the Intersectoral Commission for Risk Management and Climate Change (Intersectoral Commission - Comision Intersectorial de Gestión de Riesgos y Cambio Climático). Its purpose is to coordinate the implementation, monitoring and evaluation of the policies decided upon by the CDGRCC. The membership of the Intersectoral Commission is very similar to that of the CDGRCC, and includes representatives from the same infrastructure and service sectors previously identified, as well as the commander of the local army brigade.

To carry out its work, the Intersectoral Commission has the ability to convene workgroups that provide more detailed technical analyses and operational support. Currently, there are six different workgroups in place dealing with:

- Climate risk assessment and adaptation planning;
- Social and community participation in risk management and adaptation planning;
- Reduction of vulnerabilities to city infrastructure and services;
- Emergency and disaster management;
- Climate change mitigation (i.e., GHG emissions reduction)
- Disaster recovery for lands and inhabitants.

The District Commission for the Prevention and Mitigation of Forest Fires (Comisión Distrital para la Prevención y Mitigación de Incendios Forestales) also works closely with the Intersectoral Commission on common areas of risk reduction activity.

> **Opportunity to mainstream interdependency and cascading climate risk considerations:** The Intersectoral Commission and its supporting agency are well-positioned to take on the responsibility of stakeholder engagement and technical analyses to assess interdependencies and cascading climate risks, and develop collaborative risk reduction actions. .

Tier 3: The last tier of the governance structure is comprised of Local Councils for Risk Management and Climate Change (Local Councils - Consejos Locales de Gestión de Riesgos y Cambio Climático). In each of the 20 districts of the metropolitan region, the Local Council is responsible for on-the-ground implementation, as directed by the policies and plans adopted at higher levels (e.g., they are in charge of enacting policies and programs, organizing response drills, operating and strengthening the District's early warning system and emergency operating system, and enhancing awareness of these activities within the local area). Membership in Local Councils mostly mirrors the membership at the metropolitan level, but also includes representatives from community organizations involved in the risk management.

> **Opportunity to mainstream interdependency and cascading climate risk considerations:** The Local Councils can serve as implementing bodies for actions identified by the Intersectoral Commission to reduce climate risks to interdependent infrastructure.

Cross-tier Advisory Body: The governing authorities described above are advised by the District Advisory Council for Risk Management and Climate Change (District Advisory Council - Consejo Consultivo Distrital para la Gestión de Riesgos y Cambio Climático). The mandate of this Council is to conceptualize, develop, study and make recommendations on policies related to risk management and climate change across the metropolitan region and at regional and local scales. This more technically focused body is composed of mid-level managers or policy specialists from City departments including environment, risk and climate change, and planning, as well as representatives from the non-governmental sector, academia, the industrial/commercial/agricultural production sectors, real estate, and social and community organizations. Private sector interests are also represented through a member of the City's Chamber of Commerce, who also sits on the District Advisory Council.

> **Opportunity to mainstream interdependency and cascading climate risk considerations:** This Council would play a key advisory role in the design of policies and actions that can equip other councils to assess sectoral interdependencies and climate risks, and develop and implement risk reduction measures.

The District Plan for Risk Management and Climate Change 2015-2050

The District Plan is the key planning tool to direct the management of risks and climate change in Bogota. It sets out:

- The policy context for general risk management, climate change adaptation, and greenhouse gas reduction;
- An overview of the hazards (both natural and anthropogenic) and risks faced by the districts and their population;
- The vision, principles, approaches, goals, objectives, programs, and actions to address short term and long term risks.

The Plan outlines the roadmap of actions and targets for governing authorities and private and non-governmental partners. It is shepherded by the CDGRCC, who also oversees its ongoing implementation and refinement. However, the specifics of policy or program creation, implementation, communication and roll-out may also be taken on by the Intersectoral Commission, the District Advisory Council and Local Councils.

The Plan is a guide for action over the next 35 years for the various governing authorities. It also calls for the provision of funds (FONDIGER) to encourage and support these activities, the attribution of which is controlled by the CDGRCC at the metropolitan level. The stewardship and execution of the Plan's actions and funding is monitored through the Intersectoral Commission or one of its workgroups, IDIGER, or the Local Councils.

There are no punishment mechanisms (legal or financial) for non-compliance with the Plan. Therefore, it relies on cooperation and voluntary compliance by all actors, including the private sector, for implementation. It is anticipated that cooperation with the private sector will arise where the City and private sector share common interests and benefits.

Currently, the Plan is under revision by the CDGRCC in order to conform to the intentions of a newly elected Mayor. Notably, its short term goals, technical and financial feasibility are being reviewed in light of the policy objectives of the current government for its 2016 – 2020 mandate. The update process for the Plan involves all stakeholders in the District's Risk Management and Climate Change System.

> **Opportunity to mainstream interdependency and cascading climate risk considerations:** The Plan is an important policy instrument to orient a multitude of actors towards the common goals of risk management and climate change action. The Plan would also be an appropriate place to include efforts to collectively assess and collaboratively address risks from interdependent infrastructure systems and services.

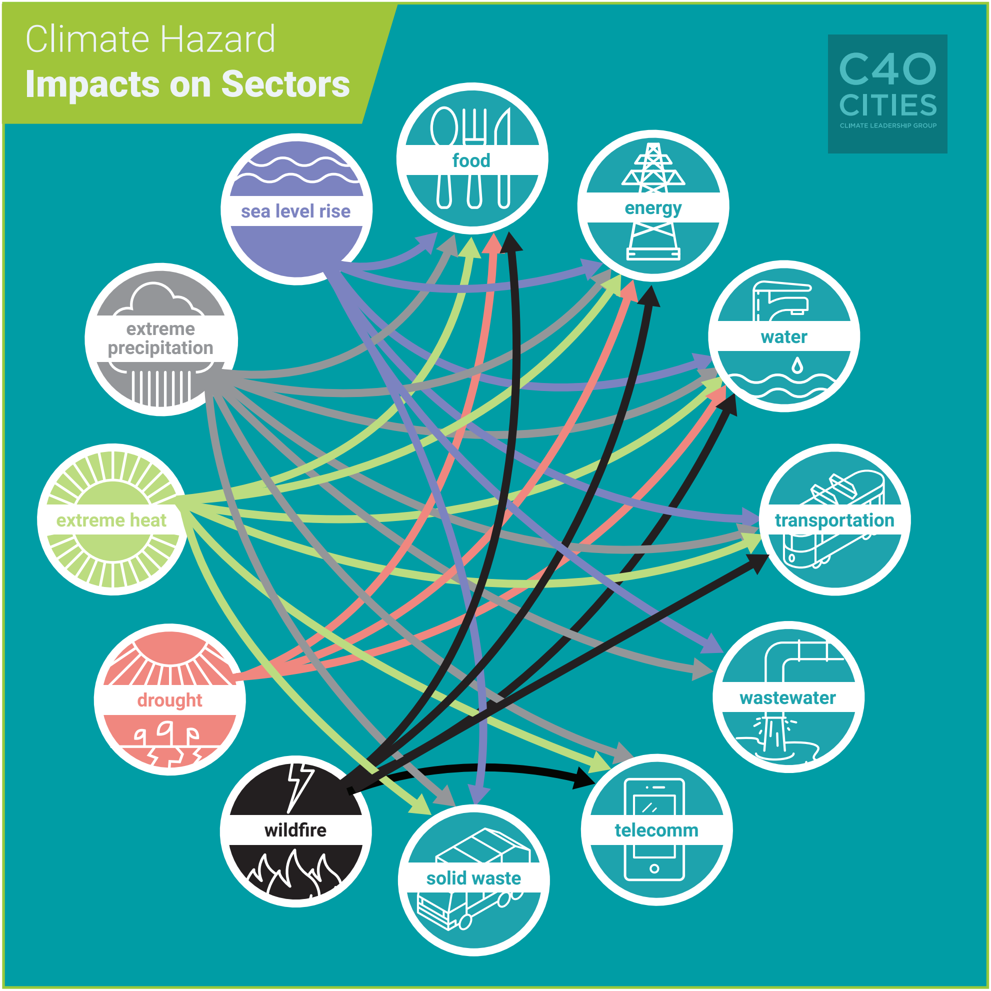
Potential Challenges faced by the Risk Management System

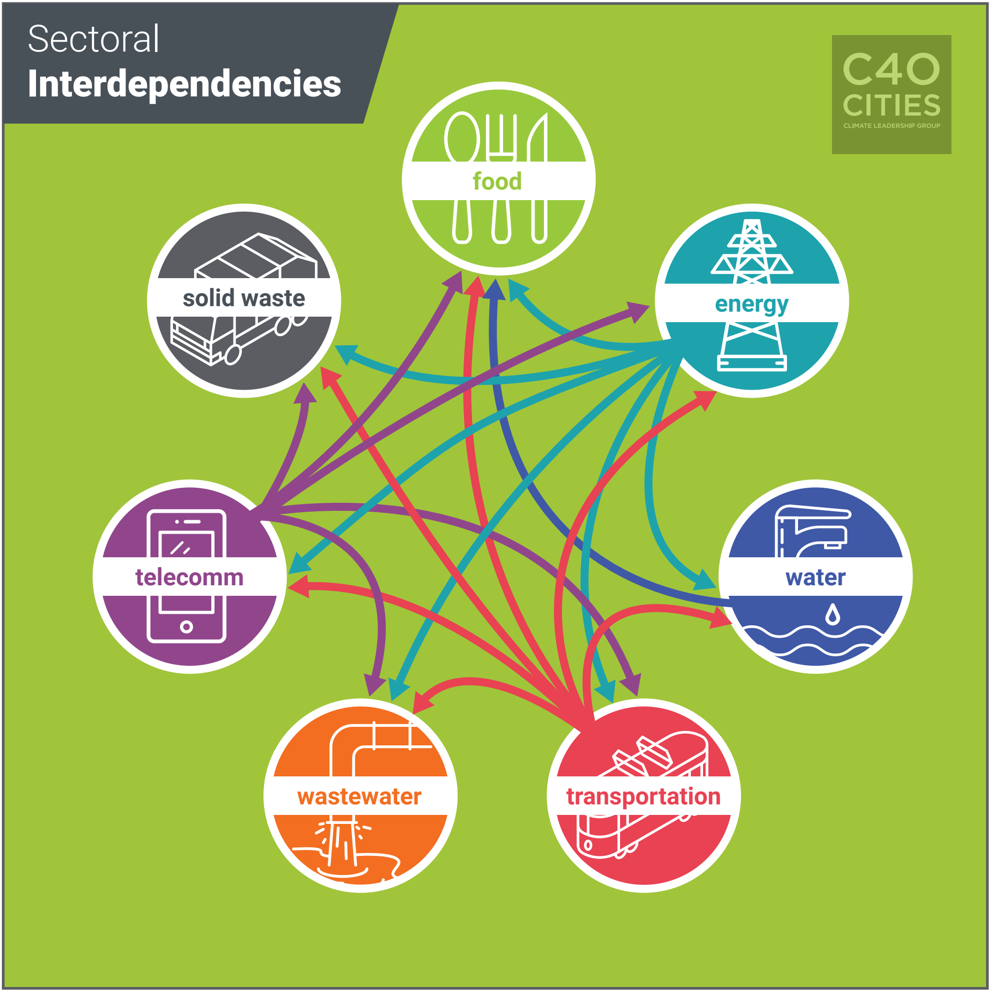
The governance structure of Bogota's risk management system and the District Plan have the potential to serve as effective platforms for the consideration of cascading climate risks to interdependent infrastructure sectors to be mainstreamed into the metropolitan region's risk management process. For this to be effective, it is recommended that the following challenges associated with this system be considered and addressed.

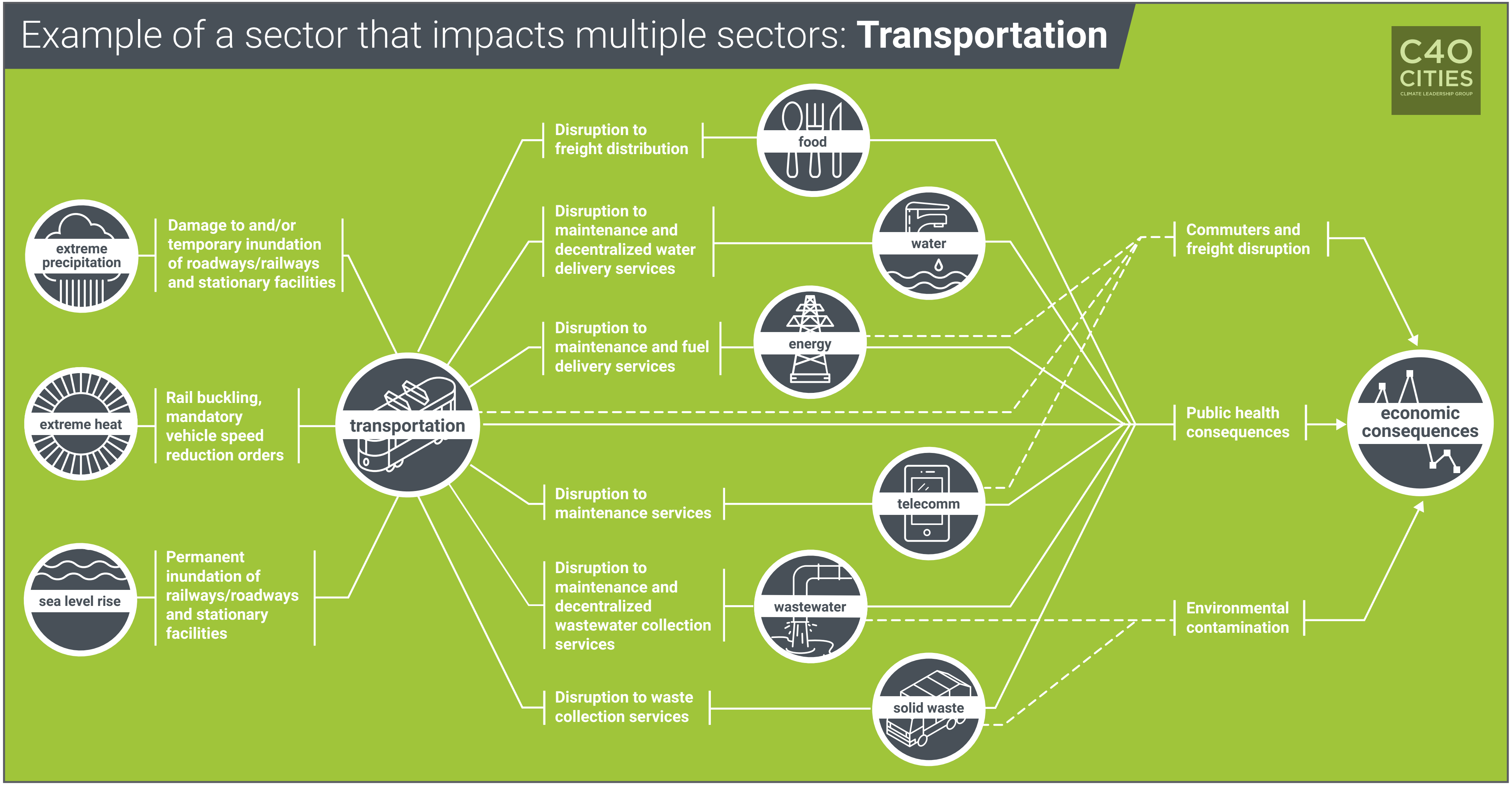
- The system may lend itself to bureaucratic and organizational inertia due to the sheer number of governing authorities and representatives, partner organizations, administrative and decision making processes.

- Achieving effective and meaningful participation on the part of all actors in the implementation of the District Plan is an ongoing challenge. Not only does the coordination of so many governing bodies and actors represent an organizational challenge, but without legal or consequential penalties, the participation of actors, especially in the private sector, remains voluntary. Participation is further hindered by the fact that the private sector has traditionally relied heavily on governments to mitigate risk, and have not historically been proactive participants.
- There are insufficient financial resources to solve all the problems of risk management and climate change, a circumstance which limits the scope of projects and actions outlined in the District Plan. One of the challenges faced by the CDGRCC is the identification of sustainable funding resources to meet the District Plan's goals and objectives.

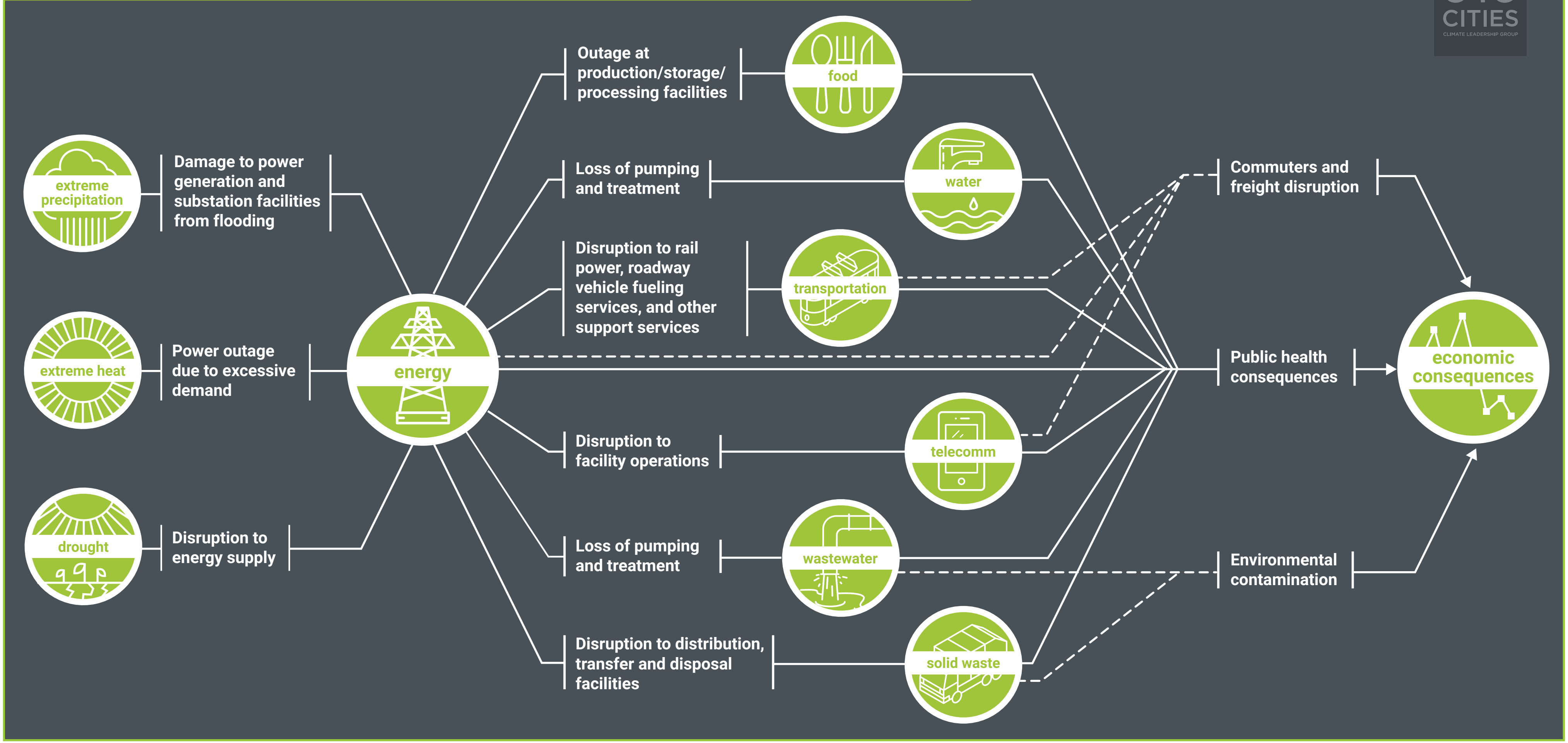
Appendix B: Infographics Explaining Infrastructure Sector Interdependencies and Cascading Climate Risks


Climate Hazard
Impacts on Sectors
C40
CITIES
CLIMATE LEADERSHIP GROUP
sea level rise
extreme precipitation
extreme heat
drought
wildfire
food
energy
water
transportation
wastewater
telecomm
solid waste

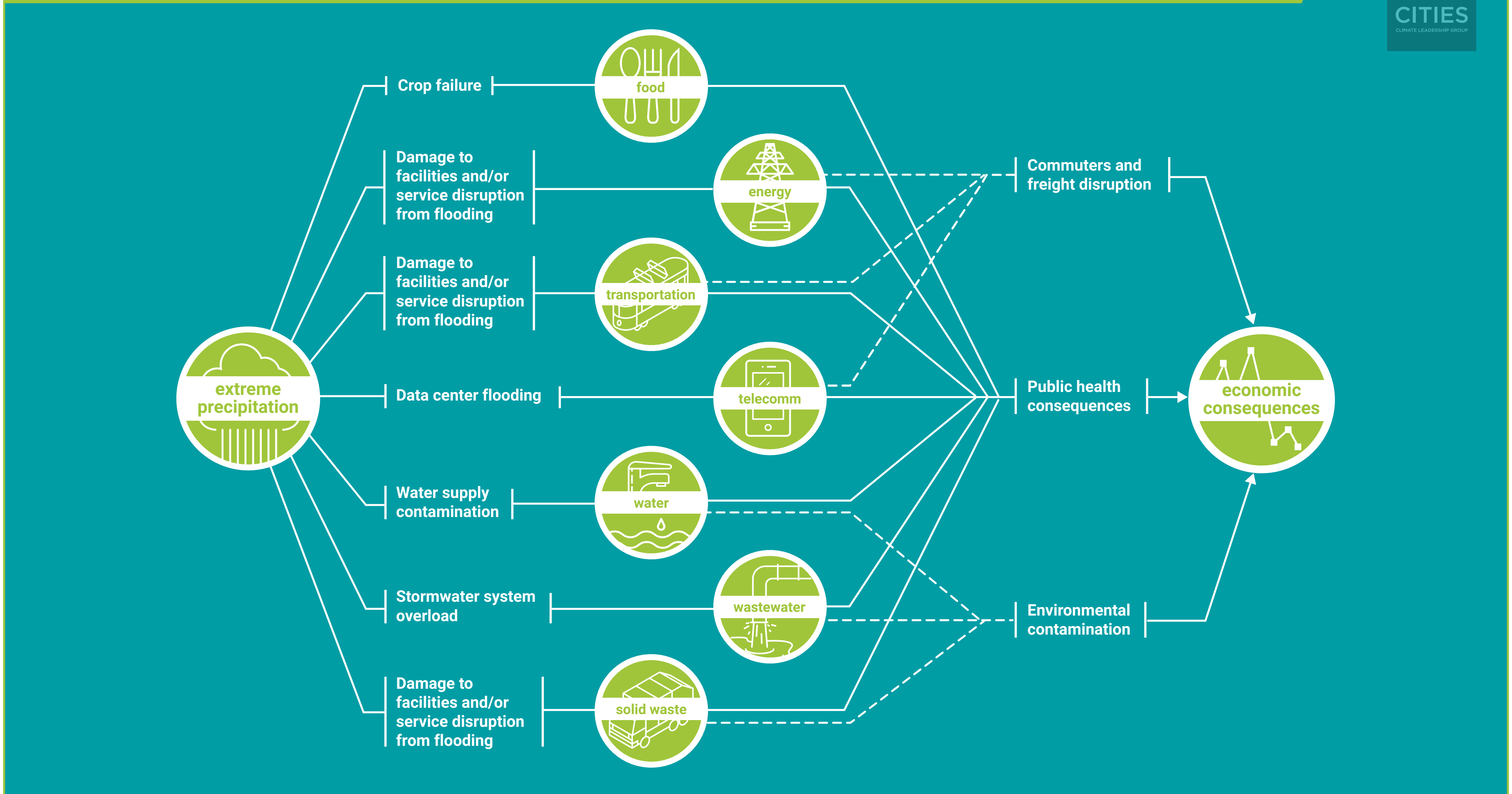

Sectoral
Interdependencies
C40 CITIES
CLIMATE LEADERSHIP GROUP
food
solid waste
energy
telecomm
water
wastewater
transportation

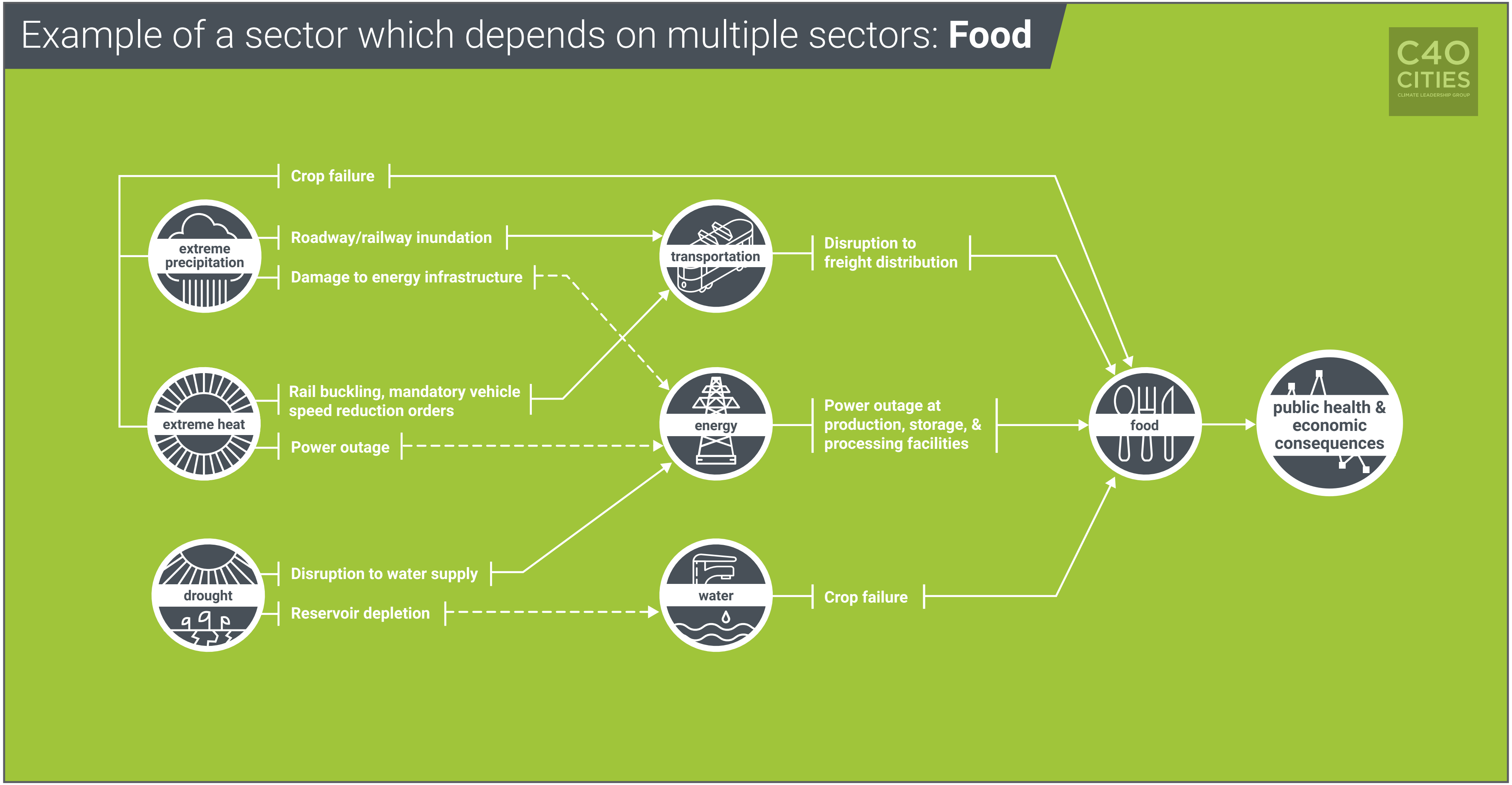

Example of a sector that impacts multiple sectors: Transportation
C40 CITIES
CLIMATE LEADERSHIP GROUP
extreme precipitation
Damage to and/or temporary inundation of roadways/railways and stationary facilities
extreme heat
Rail buckling, mandatory vehicle speed reduction orders
sea level rise
Permanent inundation of railways/roadways and stationary facilities
transportation
Disruption to freight distribution
food
Disruption to maintenance and decentralized water delivery services
water
Disruption to maintenance and fuel delivery services
energy
Disruption to maintenance services
telecomm
Disruption to maintenance and decentralized wastewater collection services
wastewater
Disruption to waste collection services
solid waste
Commuters and freight disruption
Public health consequences
Environmental contamination
economic consequences

Example of a sector that impacts multiple sectors: **Energy**



Example of a climate hazard that impacts multiple sectors: **Extreme precipitation**




Example of a sector which depends on multiple sectors: **Food**
C40 CITIES
CLIMATE LEADERSHIP GROUP
Crop failure
extreme precipitation
Roadway/railway inundation
Damage to energy infrastructure
transportation
Disruption to freight distribution
extreme heat
Rail buckling, mandatory vehicle speed reduction orders
Power outage
energy
Power outage at production, storage, & processing facilities
food
public health & economic consequences
drought
Disruption to water supply
Reservoir depletion
water
Crop failure