2.1 RISK MITIGATION IN CRITICAL INFRASTRUCTURE

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

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2.1

RISK MITIGATION IN CRITICAL INFRASTRUCTURE

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COORDINATING RISK MITIGATION

NATIONAL STRATEGY FOR CRITICAL INFRASTRUCTURE

The *National Strategy for Critical Infrastructure (2009)* (the Strategy) sets out Canada's approach to strengthening the resilience of critical infrastructure (CI). The Strategy defines CI as the "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government."[1] CI can be stand-alone or interconnected and interdependent within and across provinces, territories and national borders. Disruptions of CI could result in catastrophic loss of life and injuries, adverse economic effects, and significant harm to public confidence.

The Strategy advances coherent and complementary actions among federal, provincial, and territorial initiatives and among the ten CI sectors: energy and utilities, finance, food, transportation (Figure 1), water (Figure 2), government, information and communication technology, health, safety, and manufacturing.[2] A Lead Federal Department (LFD) is responsible for each sector and for bringing together a network of stakeholders and representatives from within each sector. The Strategy is built around three strategic objectives: 1) building partnerships among federal, provincial and territorial governments and CI sectors, 2) implementing an all-hazards risk management approach, and 3) advancing the timely sharing and protection of information among partners.[3]

Between 2018 and 2020, Public Safety Canada led an examination of the Strategy to determine if there was a need to update Canada's overall approach to CI resilience. The examination's findings recommended a renewal process, which will take place over the next three years (2021–2023).[4] The renewal of the Strategy is an opportunity to shed light on what is working well, what needs to be improved, and what our vision for the future should be, as Canada faces an evolving list of risks and threats.

1. BUILDING PARTNERSHIPS

As detailed in the *Emergency Management Framework for Canada*,[5] strengthening the resilience of CI requires complementary and coherent action by all partners to promote the most effective use of resources and execution of activities. Harmonizing approaches to strengthening the resilience of CI at all levels will enable efforts to facilitate timely and effective prevention, mitigation,

Figure 1: Trains and rail lines provide critical transportation infrastructure (Photo: Public Safety Canada).

preparedness, response and recovery measures to deal effectively with disruptions. The Strategy recognizes that each responsible jurisdiction, department and agency, as well as CI owners and operators, will take action as they deem appropriate for strengthening the resilience of CI in Canada. To be successful, however, the implementation of the Strategy requires the collaboration of federal, provincial, territorial and CI sector partners and the establishment of engagement mechanisms to facilitate this collaboration.[6]

2. IMPLEMENTING AN ALL-HAZARDS APPROACH

The Strategy promotes the application of risk management and sound business continuity planning. Risk management refers to the "continuous, proactive and systematic process to understand, manage and communicate risks, threats, vulnerabilities and interdependencies across the CI community." A comprehensive risk management process requires that federal, provincial and territorial governments collaborate with their CI partners to develop all-hazards risk analyses that take into account accidental, intentional and natural hazards. While governments promote a common approach to strengthening the resilience of CI, and share tools, lessons learned and best practices, CI stakeholders are ultimately responsible for implementing their own risk management approach given their situation.[7]

As part of the Strategy, federal, provincial and territorial governments conduct exercises and assist in the coordination of regional exercise planning across jurisdictions and with CI sectors. Exercises help partners with an assessment of their CI and recommend improvements to their plans, which ensure an effective response and recovery in the face of a CI disruption.

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3. SHARING AND PROTECTING INFORMATION

Information sharing and information protection play a key role in collaborative efforts to strengthen the resilience of CI. Improved information sharing, within existing federal, provincial and territorial legislation and policies, enhances the timely exchange of information on risks and the overall status of critical assets, so that CI owners and operators, governments and others can assess risks and take appropriate action.[8] Information exchange is crucial before, during and after a disruption or emergency, as it enables a "common operating picture" among all levels of government and CI sectors an improved approach across the range of prevention, mitigation, preparedness, response and recovery.[9]

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Due to the many interdependencies in Canadian CI, the inappropriate release of sensitive information poses a risk for a province or local authority and Canada as a whole. There are some exemptions from disclosure for reasons of national security and public safety, existing under federal, provincial and territorial access to and freedom of information legislation.[10] A consequential amendment to the *Access to Information Act*, as part of the Government of Canada's *Emergency Management Act*, gave clear protection to sensitive information provided by CI owners and operators. Governments continue to ensure an appropriate level of protection to sensitive emergency management and CI information.[11]

THE NATIONAL CROSS SECTOR FORUM ACTION PLAN FOR CRITICAL INFRASTRUCTURE

The *National Cross Sector Forum Action Plan for Critical Infrastructure* (the Action Plan) acts as a blueprint for how the Strategy is implemented to enhance the resilience of Canada's CI. Since the publication of the Strategy in 2009, four supporting action plans (2010–2013; 2014–2017; 2018–2020; and 2021–2023) have been released, each outlining concrete steps towards advancing the three objectives set out in the Strategy.[12]

The first Action Plan (2010–2013) set out the roles and responsibilities of the federal government, provincial and territorial governments, and CI owners and operators along with action items in the areas of partnerships, risk management and information sharing.[13] Within years one and two, partners focused on the development of sector networks and the National Cross Sector Forum (NCSF) as well as improved information sharing. Initial activities in support of risk management were also undertaken at this time. During subsequent years, effective sector networks and improved information has enabled further risk management activities (e.g., development of sectoral risk profiles, guidelines for risk assessments) and emergency management planning and exercises.[14]

Public Safety Canada currently conducts all-hazard risk assessments through the physical-based Regional Resilience Assessment Program and the Canadian Cyber Security Tool and cyber assessment program. This includes working with provinces and territories to determine priority sites for physical assessment and identifying and implementing measures to increase the impact and reach of the cyber and physical programs. Public Safety Canada also produces risk assessment products based on specific hazards (flood, wildfire, earthquake, hurricane, etc.) or in response to potential or occurring emergencies with potential to disrupt CI.

To continue supporting the advancement of the Strategy's three strategic objectives until the release of the renewed national approach to CI resilience, Public Safety Canada (PS) has created the *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*. The Action Plan (2021–2023) reaffirms the Government of Canada's commitments to work closely with CI sector partners, provinces and territories towards a more secure and resilient Canada. The Action Plan (2021–2023) also continues to support the three strategic objectives identified in the Strategy and builds upon progress made through past action plans, identifies new activities based on the changing threat environment, and will support a collaborative approach to enhance the security and resilience of Canada's CI.[15]

ALIGNMENT WITH THE SENDAI FRAMEWORK

The work under the Strategy and subsequent Action Plans for CI contribute to the Sendai Framework for Disaster Risk Reduction's seven global targets. The work directly contributes to (18) Target (d) and is critical for achieving Targets (a), (b), (c), and (g).

In the Sendai Framework, item 18 (d) states: "Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030."[16]

While in most clauses of the Sendai Framework CI is bundled with all other assets, one commitment is specific to CI. Item 33 (c) states: "To achieve this, it is important: . . . To promote the resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide life-saving and essential services."[17]

ENGAGEMENT MECHANISMS

The following section outlines activities and action items that support the risk management principles outlined in the Strategy's strategic objectives. The purpose of the activities is to strengthen Canada's CI resilience by helping to prevent, mitigate, prepare for, respond to, and recover from disruptions. Additionally, they are designed to foster collaboration and information sharing among all levels of government, private sector partners, and allied countries.[18]

THE NATIONAL CROSS SECTOR FORUM

The Strategy and Action Plan (2010–2013) established the National Cross Sector Forum (NCSF) to maintain a comprehensive and collaborative Canadian approach to enhance the resilience of CI, by providing a standing mechanism for discussion and information exchange within and between levels of governments and CI sectors. Membership is drawn from the ten sector networks and is representative of a wide-ranging number of CI owners and operators, associations, and provincial and territorial governments.[19] Typically, one to three senior-level members of each sector network represents the CI sector at the NCSF.

The NCSF membership has developed terms of reference for the NCSF, including the designation of three chairs—the Deputy Minister of Public Safety, one industry representative, and one provincial/territorial representative. The chairs work with members to set agendas, determine the frequency of meetings and manage the business of the NCSF.[20] The Critical Infrastructure Division, Public Safety Canada, serves as the NCSF's secretariat, where the Division's staff provide strategic advice, support information sharing, develop the cross-sector risk profile, and provide general support to the NCSF.

THE MULTI-SECTOR NETWORK

The MSN provides a platform to examine Canada's CI priorities from a cross-sector and multi-jurisdictional perspective, facilitate the timely exchange of relevant information on CI risks and emerging issues, and foster cross-sector partnerships among CI owners and operators.[21] It brings together working-level representatives from each of the ten CI sectors and may also include representatives from the NCSF, LFDs, provinces and territories, and the international CI community to discuss topics related to CI resilience.

THE FEDERAL, PROVINCIAL AND TERRITORIAL CRITICAL INFRASTRUCTURE WORKING GROUP

The Federal, Provincial and Territorial Critical Infrastructure Working Group (FPT CI WG) is the primary

Figure 2: Wastewater treatment plants provide critical water infrastructure (Photo: Public Safety Canada).

mechanism for federal, provincial and territorial government collaboration on current and emerging issues facing CI sectors, including recent COVID-19 response efforts. Membership is open to all governments for participation if it meets their needs and as their resources permit. The FPT CI WG is co-chaired by a representative from Public Safety Canada and a provincial/territorial representative determined by group consensus. The co-chairs report to the Federal-Provincial-Territorial Senior Officials Responsible for Emergency Management (SOREM) on CI matters. Public Safety Canada serves as the secretariat for the FPT CI WG by organizing meetings, as identified by the co-chairs, and is responsible for preparing and distributing material.[22]

THE LEAD FEDERAL DEPARTMENTS CRITICAL INFRASTRUCTURE NETWORK (LFD CI NETWORK)

The Lead Federal Departments Critical Infrastructure Network (LFD CI Network) is a group of officials from departments leading each of the ten CI sectors, as follows:

- Energy and Utilities (Natural Resources Canada)
- Finance (Department of Finance Canada)
- Food (Agriculture and Agri-Food Canada)
- Health (Public Health Agency of Canada
- Information and Communication Technology (Innovation, Science and Economic Development Canada)

- Manufacturing (Department of National Defense)
- Manufacturing (Innovation, Science and Economic Development Canada)
- Transportation (Transport Canada)
- Government/Safety/Water (Public Safety Canada)

Through network meetings between government departments that are industry leads, the group works to strengthen their collective ability to identify and address disruptions to Canada's CI and share information with their networks of CI stakeholders.

SECTOR NETWORKS

The Strategy and first Action Plan (2010–2013) established sector networks: "national sector-specific standing fora for each of the ten CI sectors to address sectoral and regional issues, and enable information sharing on CI."[23] The sector networks reflect a partnership model that enable governments and CI sectors to undertake a range of activities (e.g., risk assessments, plans to address risks, exercises) unique to each sector. The Strategy provided a framework for the functions of the sector networks, including:

- Promotion of timely information sharing.
- Identification of issues of national, regional or sectoral concern.
- Use of subject-matter expertise from CI sectors to provide guidance on current and future challenges.
- Development of tools and best practices for strengthening the resilience of CI across the full spectrum of prevention, mitigation, preparedness, response and recovery.[24]

Working with CI partners, each LFD has facilitated the development of sector networks to meet the needs of their stakeholders.[25] Sub-sector networks have also been established to reflect the diversity of a particular sector where appropriate. Participation in these networks is voluntary. The sector networks are composed of CI owners and operators as well as national associations from CI sectors and relevant federal, provincial and territorial departments and agencies.[26]

CI GATEWAY

Public Safety Canada also engages CI partners and stakeholders through the CI Gateway—a practical online tool for facilitating information sharing across the ten CI sectors. It hosts information products such as risk management documents, best practices, lessons learned, meeting materials, standards, and event calendars to enhance situational awareness. Membership is granted to stakeholders belonging to a CI sector network and to relevant government partners. There is ongoing work to renew and modernize the GI Gateway in the coming years.[27]

CROSS-CUTTING ISSUES

SUPPLY CHAIN MANAGEMENT AND IMPACTS TO CI

Canada relies on national and international supply chains, which means that the goods and services that CI requires, from fertilizer to pharmaceuticals, can come from anywhere in the world. As a result, Canada's critical functions can be impacted by both domestic and international disruptions. A trade dispute, international conflict (e.g., 2022's Russian invasion of Ukraine), a transportation issue (e.g., 2020's Canadian National Railway blockade, 2022's blockages by the "Freedom Convoy") or other disruption in another country could impact the ability for Canada's CI to acquire important supplies.[28] Increasingly, malicious actors are leveraging supply chain vulnerabilities to conduct cyber-attacks. For example, a 2020 cyber-attack led to thousands of organizations, from the information and communications technology sector to government, downloading malware through IT management software supplied by SolarWinds. At the time of writing, the Canadian Security Establishment's (CSE) Centre for Cyber Security is warning CI organizations and suppliers to bolster their awareness and protection against Russian state-sponsored cyber threads amid the invasion of Ukraine.[29]

RANSOMWARE ATTACKS DURING COVID-19

One of the most significant threats to Canada's CI during the COVID-19 pandemic has been ransomware cyber-attacks. Ransomware attacks are those where criminals hold data or computer systems hostage in exchange for payment. CSE's Centre for Cyber Security predicted that as the pandemic continues, attacks directed against Canada will continue to target large enterprises and CI owners and operations Canadian CI is also at risk of the type of ransomware attack that recently shut down the Colonial pipeline in the US for multiple days. Health-sector organizations have also become popular ransomware targets during the COVID-19 pandemic, due to the importance of keeping health services available and reliable with zero downtime or disruption. At such a critical time, network downtime can have life-threatening consequences for patients, while increasing the likelihood that victims of such attacks will pay the ransom.[30]

THE NATIONAL STRATEGY FOR CRITICAL INFRASTRUCTURE RENEWAL

DRIVERS OF CHANGE IN CANADA'S CI ENVIRONMENT

The risk landscape facing the Canadian CI community is a complex one, characterized by a range of uncertainties and evolving threats and pressures, including environmental and climate change impacts, security (e.g., cyber, national, physical, economic, health, and foreign interference), aging CI, and economic recovery. The global pandemic health crisis has identified the need for greater focus by CI stakeholders on organizational preparedness, business continuity and management of risks posed by globally distributed supply chains that support critical infrastructure operations.[31]

Several key drivers of change were identified as part the Strategy examination: digitalization of systems and processes, environmental risks, security threats, and economic prosperity. These drivers are adding to the pressures and demands to which CI must adapt.

DIGITALIZATION OF SYSTEMS AND PROCESSES

The digitalization of systems and processes, and the ability to control CI operations remotely, continues to present new cyber security challenges. The increased use of digital systems to operate physical infrastructure has improved overall connectivity, communications, and service delivery to Canadians. However, the use of internet-enabled systems increases the likelihood and scale of both intentional and unintentional disruptions. Malicious actors continue to find new ways to

THE EXTENDED NATIONAL CROSS SECTOR FORUM (E-NCSF) ON COVID-19

In March 2020, at the onset of the pandemic, NCSF meetings were expanded to include hundreds of new participants across all ten CI sectors and began to be delivered in a virtual format. This new forum was rebranded as the Extended National Cross Sector Forum (E-NCSF) on COVID-19 in order to differentiate its activities from the "core" NCSF. The CI community used this outlet as events continued to unfold in the pandemic, to review the current status of the COVID-19 virus in Canada, update CI stakeholders on federal planning activities, and share areas of priority for CI industry owners and operators. E-NCSF meetings have included updates from the Public Health Agency of Canada, Public Safety Canada and the Government Operations Centre on various topics including supply chain and liquidity issues, personal protective equipment (PPE), testing and vaccination, guidance, and more. Representatives from each of the ten CI sectors also provide updates share common challenges and impacts to their respective sectors and supply chains during E-NCSF roundtable discussions. On average, 120–150 stakeholders attended E-NCSF meetings.

use cyber-attacks to disrupt CI and exploit Canadians.[32]

ENVIRONMENTAL AND CLIMATE CHANGE RISKS

Canada's climate is changing. The effects of global warming are apparent in many parts of the country and are anticipated to increase in the future. These shifts are significantly affecting Canada's natural environment, built infrastructure, economy, and the health of Canadians. Extreme weather events, such as floods and fires in Western Canada, continue to threaten the ability of CI to deliver services.[33]

SECURITY THREATS

Terrorism, extremism, organized criminals, and hostile state actors all pose threats to Canada's national security and CI. Foreign actors, with the support of state-level resources, are developing advanced capabilities to target CI and other public-private sector institutions, increasingly leveraging cyber systems to conduct espionage, steal intellectual property, and disrupt operations. Security concerns related to the rise of global supply chains, which CI depends on for products and services continues to pose significant concern. Supply chains are world-wide, making it difficult to identify single points of failure and rendering them vulnerable to accidental and international disruption.[34]

ECONOMIC PROSPERITY

Dependable CI drives economic growth by creating jobs, improving productivity and enabling business confidence, which fosters innovation and investment in CI. Continued investment requires customers, taxpayers and a thriving economy to fund investments, whether privately or publicly owned.[35] However, as record deficits have added to government debt at a time when aging infrastructure requires servicing, the full impact of the pandemic is yet to be seen. While recovering from the impacts of the pandemic, Canada will have to address inequitable access to infrastructure in order to allow all Canadians to prosper.

The challenge of securing and maintaining Canada's critical assets and systems in a complex and fast-changing risk landscape will require coordinated approaches between the public sector, private sector, and citizens, which in turn will foster ingenuity, promote adaptability, and ensure collaboration.[36] The National Strategy for CI renewal provides an opportunity to help bring CI communities together and equip them with a common framework for identifying and managing risks and for coordinating decision-making activities to meet collective resilience goals.

CONSULTATION

The purpose of the consultation process, as part of the Strategy renewal, is to solicit input, advice, and ideas to renew the Strategy and Canada's overall approach to CI resilience. Consultation will focus on six key areas of inquiry.

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1. FUNDAMENTAL CONCEPTS AND DEFINITIONS

Assessing the criticality of CI is not easy because criticality can be dynamic; it changes depending on the current context and situation. For example, during the COVID-19 pandemic, the federal, provincial and territorial governments published lists of essential services. These lists helped determine which businesses could remain open and access reserves of personal protective equipment (PPE), but they were not exhaustive. Criticality affects risk management, planning and preparedness efforts and helps governments respond more effectively during event state. In steady state, the concept of criticality is helpful for governments in determining supports, such as risk assessments provided at no cost to the business, and minimum standards of resilience. It could be argued that a range of key CI-related concepts and definitions are either dated, not widely agreed upon, or could be improved.[37]

2. CROSS-SECTOR INTERDEPENDENCIES AND DIGITALIZATION

CI sectors are highly interdependent, which means that sectors rely on one another to deliver the goods and services that Canadians need. The resilience of a CI sector is therefore determined not only by its own efforts to secure its operations but by the resilience of the many integrated systems that it relies on within other CI sectors. The interdependency of CI sectors means that a failure in one sector can have a domino effect on other sectors. Additionally, the growing connection of CI to the internet not only causes greater cyber security challenges but adds to the dependence of CI on the information and communications technology sector.[38] CI relies heavily on the information and communications technology sector to communicate, conduct business and connect with other sectors. An information and communications technology disruption, caused by a natural disaster, a cyber-attack, or an accident, could have far-reaching consequences (Figure 3).

Figure 3: Satellite ground systems provide critical information and communication infrastructure (Photo: Public Safety Canada).

Digitalization will continue to create greater interdependencies that will require greater coordination of risk management practices across CI sectors, as an attack on a physical-cyber system could result in a catastrophic failure in an area we previously considered unrelated to CI. The digital and interconnected nature of CI complicates interdependency analysis in such a way that will not easily be addressed by one model. A way to address this issue could be to develop new types of responses to protect CI systems and mitigate risk to ensure their resilience.[39]

3. CI SECTOR CONFIGURATION AND COLLABORATION

It can be argued that Canada's ten designated CI sectors and engagement mechanisms are in need of a review because the current sectors do not represent the full range of Canada's vital assets and systems. Exclusions of these businesses and systems from the ten CI sectors means that experts in these areas are not represented in current CI engagement forums.[40] For example, current engagement mechanisms do not include key CI representatives, like Indigenous leadership or municipal governments. Indigenous and municipal governments own and provide CI, for example, in the water sector. As previously discussed, the interdependency of CI sectors presents significant risks that can only be better understood through collaboration. A possible solution could be the reconfiguration of CI sector networks into networks grouped by function, could help to identify interdependencies and related risks, as well as facilitate cross-sector information sharing.[41]

4. CROSS-SECTOR COORDINATION, GOVERNANCE AND COMPLIANCE

Although CI is the common factor that connects many initiatives, priorities and approaches to CI and resilience often vary across various initiatives, CI sectors and regions. Although the current Strategy was developed to be the coordinating link between various domains (i.e., emergency management, national security, cyber security), other initiatives and strategies often have stronger governance, authorities, incentives and compliance mechanisms to address specific risks within a particular domain.[42] Several cross-sector CI fora exist; however, these engagement mechanisms do not have cross-sector authorities or compliance measures.

A way to address these issues could be to develop a clear framework that supports results and accountability to help ensure that a focused direction exists, that objectives are achieved for public and private sector investments, and that efforts to enhance the security and resilience of CI are measurable. Canada currently does not have a national results-based framework in place that effectively measures the collaborative, non-regulatory efforts to achieve CI objectives (as set out in the Strategy) and supporting action plans.[43]

A way to address these issues could be to develop a clear framework that supports results and accountability to help ensure that a focused direction exists, that objectives are achieved for public and private sector investments, and that efforts to enhance the security and resilience of CI are measurable. Canada currently does not have a national results-based framework in place that effectively measures the collaborative, non-regulatory efforts to achieve CI objectives (as set out in the Strategy) and supporting action plans.

5. ROLES, RESPONSIBILITIES AND SUPPORT TO CI OWNERS AND OPERATORS

Service delivery models and support available to CI owners and operators differ across Canada as well as at regional and municipal levels. The roles and responsibilities are not clearly understood across CI partners and stakeholders. Although different delivery models across regions might be needed to address the specific situation, the cluttered organizational landscape makes it difficult to advance common CI priorities and resilience goals and creates conflicting advice for CI owners and operators.[44]

6. ACADEMIC RESEARCH AND EXPERTISE TO SUPPORT RISK MANAGEMENT

Through research and expertise, academia and the scientific community play an important role in supporting various CI initiatives in an ad hoc manner. However, experts from federal, provincial and territorial emergency management, municipalities, Indigenous organizations, academia, policy think tanks and subject matter experts in cyber security, physical infrastructure, digital infrastructure, climate change, economic security, and business continuity are not regularly engaged through formal engagement mechanisms like the NCSF. To address this issue, building stronger and more formalized partnerships in the future with academia and think tanks that study issues related to CI security and resilience, infrastructure protection and digital technology could provide valuable advice to Canada's CI leadership.[45]

NEXT STEPS

The consultation process to support the renewal of the National Strategy will be launched in Spring 2022 and will seek input from a broad range of CI stakeholders, including from governments, industry, academia, and Indigenous communities.

RESOURCES

1. The *National Strategy for Critical Infrastructure* (to be read in conjunction with *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*) sets out Canada's approach to strengthening the resilience of critical infrastructure:

Public Safety Canada. *National Strategy for Critical Infrastructure*. Canada: Her Majesty the Queen in Right of Canada, 2009. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/srtg-crtcl-nfrstrctr/srtg-crtcl-nfrstrctr-eng.pdf

2. To continue advancing the objectives of the Strategy until the renewed national approach to critical infrastructure resilience, Public Safety Canada has created the Action Plan (2021–2023):

Public Safety Canada. *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*. Canada: Her Majesty the Queen in Right of Canada, 2021. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2021-ctn-pln-crtcl-nfrstrctr/2021-ctn-pln-crtcl-nfrstrctr-en.pdf

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Photo: Neighbour Lab

2.2 SOCIAL INFRASTRUCTURE AND COMMUNITY RESILIENCE

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

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2.2 SOCIAL INFRASTRUCTURE AND COMMUNITY RESILIENCE

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ABOUT SOCIAL INFRASTRUCTURE

OVERVIEW

In the wake of disasters, survivors emphasize the importance of community-based support systems, including neighbours, grassroots groups, organizations, and businesses that mobilize and deliver aid in response to the failure of basic services. These community-based assets make up networks of social infrastructure (SI) and include programs and services, physical facilities and spaces, and people—informal networks, deep relationships, knowledge, and resourcefulness that support and enable social interaction and hold social purposes.[i,1]

Networks of SI play a fundamental role in strengthening social fabric and community resilience by fostering social connections, improving equity, reducing disaster risk and vulnerability, and facilitating collective action and essential services through crises, emergency response, and recovery. SI takes a relational approach to community-building and is "predicated on practices, policies and social covenants that increase individual agency and dignity; collective resilience; and human-centred networks."[2] Still, SI is often considered to be an optional investment in government budget and capital planning cycles, rather than essential. Yet investments in SI are an underutilized mechanism for risk reduction and resilience building, despite delivering "hard-hitting, tangible impacts ensuring that all members of society can fulfil their basic needs, realize their potential, and experience a deep sense of belonging and well-being."[3]

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[i] *SI has also been defined as social services that serve people across lifespans, or address lifelong needs, and include physical spaces, buildings and facilities as an element (Davern et al, 2017). Sociologist Eric Klinenberg drew attention to the concept of SI among academic and mainstream audiences with his 2018 book* Palaces for the People: How SI Can Help Fight Inequality, Polarization, and the Decline of Civic Life. *He describes SI as "the physical places and organizations that shape the way people interact" (Klinenberg, 2018, p. 5), and argues that physical conditions and places are important for building social connectedness and social capital.*

Often, SI is equated with non-profit and charitable organizations, though this is not always the case. In the broadest sense of the concept, SI spaces may be owned or administered by public, non-profit, or faith-based entities, as most are, but they may even be social enterprises or commercial establishments, or even simply informal associations. Community centres, libraries, schools, healthcare centres, and parks all fall under the category of SI, yet they are typically owned and operated by government agencies. Businesses such as coffee shops, bookstores, salons and barbershops can also fall under this category, despite being for-profit, if people use them as a space for socializing. They all have a common function of bringing people together.

This article will largely focus on SI in the form of public and non-profit organizations (or social infrastructure organizations, SIOs) and their facilities because their primary purpose is to enable social connections and deliver services at the local level, and they rely in large part on public financial support, donations, and philanthropic grants, which creates particular funding challenges. The sheer number and variety of SIOs is staggering, and their decentralized locations offer unique opportunities for place-based planning. In BC, there are over 29,000 non-profit organizations that employ 86,000 people and contribute $6.7 billion to BC's economy.[4] There is also a growing discussion and collaborations around social purpose real estate (SPRE), referring to real estate or property that hosts facilities and/or open outdoor space used for social purposes. In 2009, a group of funders, investors and government bodies in BC formed the SPRE Collaborative to mitigate the effects of the real estate affordability crisis on non-profit and social enterprise organizations. SIOs compete primarily in the commercial real estate market to find land and property, and sharply increasing real estate prices, property tax values, and redevelopment pressures create significant challenges for these organizations.

ALIGNMENT WITH THE SENDAI FRAMEWORK

As of 2022, the Government of Canada, Government of British Columbia, and several municipalities (including the City of Vancouver) have adopted the *Sendai Framework for Disaster Risk Reduction 2015–2030* to guide their disaster risk reduction activities. The Sendai Framework emphasizes the criticality of civil society in disaster risk reduction and outlines an all-of-society approach under guiding principle "d."[ii] Guiding principles "f" and "i"[iii,iv] recognize the importance of understanding the local and specific characteristics of disaster risks and empowering local authorities and communities to reduce risks. Engagement and partnerships must be inclusive, accessible, and empower all people—particularly those disproportionately impacted by disasters—to participate in risk reduction efforts. SI plays a critical role in shaping civil society and in the "all-of-society" approach by elevating the needs and rights of those disproportionately impacted by disasters in risk reduction efforts. Additionally, Priority 1 of the Sendai Framework (Understanding Risk), directs governments to develop policies and practices for disaster risk management based on all dimensions of vulnerability (including socioeconomic vulnerability).

ALIGNMENT WITH INTERNATIONAL, NATIONAL, AND REGIONAL FRAMEWORKS

UN SUSTAINABLE DEVELOPMENT GOALS

Nearly all of the Sustainable Development Goals are relevant to the type of work performed by SIOs, including but not limited to the eradication of poverty, inequity,

[ii] *Principle "d" in the Sendai Framework: "Disaster risk reduction requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non-discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest. A gender, age, disability and cultural perspective should be integrated in all policies and practices, and women and youth leadership should be promoted. In this context, special attention should be paid to the improvement of organized voluntary work of citizens."*

[iii] *Principle "f" in the Sendai Framework: "While the enabling, guiding and coordinating role of national and federal State Governments remain essential, it is necessary to empower local authorities and local communities to reduce disaster risk, including through resources, incentives and decision-making responsibilities, as appropriate."*

[iv] *Principle "i" in the Sendai Framework: "While the drivers of disaster risk may be local, national, regional or global in scope, disaster risks have local and specific characteristics that must be understood for the determination of measures to reduce disaster risk."*

food insecurity, and improvement of health and wellbeing, sustainability, and climate action. Most if not all of these goals are addressed by various SIOs. Moreover, goals 9 and 11 have more direct implications for the physical spaces through which SIOs operate. Goal 9 calls for governments to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation," again demonstrating a focus on "traditional infrastructure" like transportation networks, power, and more. Yet, goal 11 recommends that governments "make cities and human settlements inclusive, safe, resilient and sustainable." While this section primarily describes the built environment of communities, including public transportation and public spaces, it also articulates the critical role of civil society and non-governmental organizations.

Increasingly, institutions and networks are recommending the integration of sustainable development goals and the Sendai Framework to holistically address risk and resilience in all of its dimensions and bolster the role of civil society or SIOs. Concurrently, "governments are beginning to recognize the value of social infrastructure—both from a pragmatic economic investment standpoint reducing health care, incarceration and demographic-ageing expenditure, and as a way of promoting a peaceful and democratic society amid increasing civil unrest."[5] Still, there is a need for a more direct focus on the physical spaces and facilities of SI because SIOs struggle to access adequate investment for this purpose.

Smaller, locally based SIOs that have [deep-rooted] relationships in community are often left out of formal response and recovery efforts.

NATIONAL POLICY AND INVESTMENT

In the Government of Canada's *Investing in Canada* plan, SI was a key funding stream (including "investments in Indigenous communities, early learning and childcare, affordable housing, home care, and cultural and recreational infrastructure").[6] The federal government also launched the Canada Community Revitalization Fund (CCRF), a two-year, $500-million national infrastructure program providing project funding to community infrastructure projects.[7] While these funding streams are an encouraging trend, the sector has been chronically underfunded for decades, leaving major lag time in these investments' ability to producing measurable results in the strength and vitality of the sector. In addition to inadequate day-to-day funding, there is also a lack of appropriate funding and resourcing for SIOs within the disaster risk reduction sector. Funding streams to address long-term and operational funding for organizations is inadequate in the face of the expenses accrued by SIOs during disaster response and recovery. At present, only a small handful of grants are offered by philanthropic agencies and local governments to support SIOs to participate in disaster risk reduction, emergency management, and climate adaptation.

PROVINCIAL EMERGENCY MANAGEMENT POLICY AND INVESTMENT

SI is not currently a focus of existing provincial emergency management legislation. BC's *Emergency Program Act* (EPA), passed in 1993, provides the legislative framework for the management of disasters and emergencies in BC. The Province is currently updating the legislation (EPA Modernization)[8] and the proposed changes consider the role of volunteers, non-governmental organizations, and service providers. Existing agreements exist between large non-profit organizations like the Red Cross and Salvation Army. While these organizations play a crucial role in response and recovery, they typically mobilize and establish themselves within disaster-impacted communities at the onset of an emergency but are not necessarily grounded in these communities to provide regular services prior to the event. As a result, they seldom have deep-rooted relationships with local communities. Smaller, locally based SIOs that have these relationships in community are often left out of formal response and recovery efforts. Trust and relationships are critical both in reaching disaster-affected community members quickly in critical moments and addressing the needs of communities who are left out of formal response and recovery planning. While legislation plays a directive function that cannot be applied to an independent sector like SI, formal acknowledgement of the importance of place-based and embedded SIOs and their facilities could serve to promote engagement between disaster management professionals and the SI sector.

SOCIAL INFRASTRUCTURE IN DISASTER RISK REDUCTION

SOCIAL RESILIENCE AND SOCIAL VULNERABILITY

A core benefit of SI is that it plays a crucial role in risk reduction at the local level by decreasing individual and community vulnerabilities and building collective capacities and actions. Largely, technocratic approaches to Emergency Management, Disaster Risk Reduction, and Climate Adaptation focus on addressing physical exposure to hazards and physical vulnerabilities. Social vulnerability is often left out of formal Disaster Risk Reduction programs, projects, and policies, even though vulnerability underpins disaster impacts.

SI builds community resilience strengthening social capital and social cohesion, and it supports more inclusive and sustainable economic development—which is important for minimizing a community's vulnerabilities to the negative impacts of a disaster and strengthening capacities for recovery and reconstruction.[v,9,10] Local leaders and professionals increasingly appreciate the role of spaces along with social capital networks in community resilience. In reviewing the research literature on community resilience, "there has been little coordinated effort to address the complex interactions between physical, social, and economic infrastructure that enable community resilience. Instead, most studies have focused on a single hazard (often earthquakes) or specific infrastructure (e.g., health care facilities)."[11] Practitioners should focus on the ways that communities build social cohesion and address ongoing social and economic stresses in order to minimize vulnerabilities to the impacts of disasters.[12]

SIOs play a crucial role in fostering the conditions that support resilience. In many cases, SIOs form to fill gaps in government services and assist people who are systemically excluded from formal government supports. While a majority of SIOs provide direct services, they also act as advocates and conveners between government and equity-denied communities, leading to direct improvements and access to governmental services. This role of SI in addressing root causes of vulnerability and advocating for the rights and wellbeing of equity-denied and systemically marginalized communities is irreplaceable. To reduce risk and build resilience, practitioners must connect directly to work that is reducing socioeconomic vulnerability and ultimately advancing justice. SIOs are an important partner in this work. The disaster and emergency management field does not leverage the full potential of SI to contribute to more holistic and comprehensive risk assessments and risk management.

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UNDERSTANDING AND ASSESSING RISK

Historically, risk assessments have been conducted primarily by state-defined experts and professionals, with little community involvement, and are presented as relatively objective truth. Defining and assessing risk is a process that is laden with emotion, bias, and value judgement, regardless of whether the

[v] SI allows people to come together and interact, and this is important for building social connectedness and social capital. Klinenberg (2018) draws on many other scholars to describe this connection to social capital. Latham and Layton (2019) outline the relevant literature on public space, social interactions, and SI. Aldrich and Meyer make the case for the importance of social capital networks for communities in disaster response and recovery.

NEIGHBOURHOOD HOUSES, SOCIAL CONNECTION AND COMMUNITY BUILDING

Figure 1: Neighbours attend a Resilience Walk during Emergency Preparedness Week in 2019, starting at the Mount Pleasant Neighbourhood House (Photo: Neighbour Lab).

Neighbourhood houses (NHs) focus on building community, are place-based and open to anyone, and offer many programs, services, and activities for a range of target groups (children, youth, seniors, adults, newcomers, and more). In their multi-year survey and research of NHs in Metro Vancouver, Lauer and Yan found that NHs contribute to two key aspects of community building in a neighbourhood: the development and maintenance of relationships and friendships, and the development of social capacity, which they define as the "ability to work with others to achieve shared goals." While NHs organize activities in schools, libraries, community centres and parks, their own facilities are crucial to enable their community-building role (Figure 1). NHs are found in Canada, the United Kingdom, the United States, Australia, and other places, but they are each unique as they serve the needs of local communities.

person conducting the assessment is a formal expert or a member of the public.[13] Those who define risk also determine the focus of risk reduction actions.[14] As an example, extreme heat response has historically focused on outdoor interventions like spray parks, or indoor interventions like centralized and public cooling centres. These interventions are critical but leave out socially isolated seniors and people with complex health conditions who may not be able to leave their homes to reach this supportive infrastructure. Involving SIOs in risk assessments early on allows them to inform practitioners about the specific needs of the community they serve and to guide disaster management practitioners in coming up with interventions that will best serve those who are the most vulnerable.

In addition, SI sometimes plays a direct role in reducing social vulnerabilities. Social vulnerability is a core component of hazard, risk, and vulnerability assessments, but it is often misunderstood and distilled into reductionist individual characteristics. Many practitioners in emergency management, disaster risk reduction and climate adaptation use social vulnerability indices as the primary mechanism for understanding social vulnerability. Many such indices build on the pioneering work of Susan Cutter and colleagues, who developed place-based, local-level models for measuring social vulnerability and community resilience.[15] Within these indices, which are typically based on census data, characteristics like age, gender, economic status, education, and more are used as proxies for social vulnerability so that they can be used comparatively across communities. However, indicators used in these indices do not accentuate the underlying systems at the root of social vulnerability.

Social vulnerability, at its core, is determined by systems of power—who holds power and resources, and who does not. People who face systemic oppression, exclusion, and marginalization receive labels of vulnerability based on demographic characteristics. Yet demographic characteristics are not an inherent vulnerability (e.g., being a racialized person is not a vulnerability—being a racialized person and living in a racist society is the vulnerability.)

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Another challenge with commonly used social vulnerability methodologies is that they do not illustrate whether people have access or proximity to community assets in their neighbourhood (organizations and facilities for social services and activities) that they can turn to for information, basic needs, and collective action during emergencies. Moreover, to date, most social vulnerability indices have not captured bonding, bridging, and linking social capital—which support adaptive capacity.[16] Reducing disaster risk and building resilience is contingent on policies, programs, and processes that address the root causes of vulnerability, not just response solutions for individual characteristics. Disasters are not just about hazards; they are, at their core, historical and political processes, and practitioners must work with communities to understand socioeconomic conditions and historical drivers of risk in order to identify the best measures to reduce risk. Tools and methodologies for capturing social vulnerability need to become more nuanced to capture not only root causes of vulnerability, but also reflect adaptive capacities so that risk reduction investments can build on strengths and address gaps.

Through the EPA Modernization, local governments are facing an increasing responsibility to conduct hazard, risk, and vulnerability assessments to inform risk reduction efforts. In recent years, federal funding was made available for local government disaster mitigation and climate adaptation efforts, including the National Disaster Mitigation Program, Municipalities for Climate Innovation Program, Disaster Mitigation and Adaptation Fund, First Nation Adapt Program, and the Community Emergency Preparedness Fund. As the obligations, responsibilities, and support for local authorities increases related to climate and disaster risk management and mitigation, they will rely on SI for effective and equitable assessment, planning, and action. This must be acknowledged and reflected in policies, legislation, and resource distribution. Governments are required by law to conduct hazard, risk, and vulnerability assessments (HRVA). Under the existing *Emergency Program Act* there is no direction to develop HRVA using participatory approaches that engage diverse stakeholders, resulting in inconsistent standards, quality, and approaches to assessing risks. At the time of writing this article, the HRVA design and process is under evaluation by Emergency Management BC; the findings and new directions could be included in the EPA Modernization.

This coincides with historical processes in which "climate adaptation and hazard mitigation take a technocratic approach, one that privileges quantitative data above people, and argues for colour-blind risk reduction."[17] Such an approach sidelines equity-denied communities in the shaping of risk narratives and the development of solutions. Communities bear the brunt of risks, despite not having created these risks themselves. SIOs can host and mediate participatory discussions about risk and the co-creation of risk reduction actions that meet the needs of communities.

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Few SIOs have seen or participated in risk assessments for their own geographic areas, or developed continuity plans and long-term resilience strategies. There is increasing focus on the role of volunteer networks and social missions or community-based organizations during emergency response and disaster recovery,[18] and guides and toolkits are available for such organizations to conduct risk assessments and emergency planning and training.[19] However, there is little research on how many social-purpose organizations have completed risk assessments or undertaken resilience planning,[20] or the kinds of plans and measures these organizations adopt and their motivations for them.[21]

While there are no surveys to gather data on this topic from the SI sector in BC, this is a common challenge for organizations in the social sector in many places. They often struggle with short-term project cycle funding, securing core operational or long-term funding, and limited and overburdened staff capacity for current service needs. This makes it challenging for

RESILIENT NEIGHBOURHOODS PROGRAM IN VANCOUVER

In 2017, the City of Vancouver launched the Resilient Neighbourhoods Program, aimed at transforming the way the City and communities collectively build resilience to a range of shocks and stresses. This program focused less strictly on emergencies and emphasized that social networks and relationships matter just as much, if not more, than emergency kits. Ultimately, community resilience is "based on collaborative problem-solving, and built at the speed of trust." This pilot was run in conjunction with the development of the Resilient Vancouver Strategy. From 2017 through 2019, City staff partnered with four (SIOs) in four neighbourhoods that each received a $50,000 grant to participate.

Each partner was encouraged to identify the shocks (acute events) and stresses (chronic challenges) that were of greatest concern to their communities. These ranged from social isolation, the opioid poisoning epidemic, earthquake risk, and racism. Over the course of the pilot, SIOs, community members, and City staff held engagement events, conducted social and physical asset mapping (Figure 2), completed resilience evaluations and conversational hazard, risk, and vulnerability assessments to ground actions in relevant potential disruptions. The pilot culminated in the development of neighbourhood resilience action plans to address both shocks and stresses. From the beginning of the pilot, SPO partners raised the critical need to incorporate anti-racism and equity work, poverty reduction, food security, and social connection into emergency planning efforts. These partners innately understood that addressing disaster risk and resilience required addressing the underlying conditions that result in disproportionate and compounding impacts to communities. Moreover, these SIOs were already working to address these stresses in their day-to-day programming and had deep, trust-based relationships with equity-denied community members (those impacted by power and resource imbalances). While this program paused through the first two years of the COVID-19 pandemic, staff are re-launching the program in 2022 with lessons from the pandemic and 2021 heat dome event incorporated into a revised model.

Figure 2: Community leaders share ideas and identify neighbourhood assets in the Downtown Eastside during the Resilient Neighbourhoods Program Asset Mapping Workshop at 312 Main in 2019 (Photo: City of Vancouver).

them to devote staff and resources to general long-term planning or risk, emergency, and continuity planning. During the COVID-19 pandemic, these challenges were reflected and emphasized in *Imagine Canada*'s advocacy in response to the federal government's approach to emergency aid packages and inadequacies based on the needs of the non-profit and social sector. It included the ability to sustain facilities and operations in its call for a Sector Resilience Grant Program to provide core operating support of the full sector.[22]

ENHANCING PREPAREDNESS, RESPONSE, AND RECOVERY

EMERGENCY RESPONSE

When disasters strike, SIOs and informal groups are often the first to activate to meet community needs well before government agencies have time to mobilize formal response plans. SIOs collect and distribute supplies, mobilize volunteers, offer spaces for people to gather, and more.[23] SIOs, and the staff and volunteers who run them, have unique knowledge, skills, and trusting relationships with community members which allow them to identify and address needs via adaptable and tailored supports, particularly for equity-denied communities and those who are considered to be socially vulnerable.[24] SIOs often addresses major gaps and inequities in existing governmental response frameworks. These organizations are key partners in delivering services in an equitable, timely, and culturally appropriate way.[25]

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Governments, on the other hand, have formal roles to play in emergency response, but often lack key relationships, or even basic awareness of the location and needs of vulnerable community members. Government response plans and services are often generic and inflexible, meaning they rarely meet the needs of large percentages of the population. In particular, they often fail to meet the needs of those most vulnerable. Standardized programs and support offered by government agencies in many cases do not work for equity-denied groups because they are laden with rigid bureaucratic procedures that slow down or exclude access to services, even further traumatizing disaster victims.[26] Indeed, the "need to stick to consistent procedures can serve to mask unjust actions and excuse the failure to put human rights of survivors first and foremost."[27] SIOs, on the other hand, work in hyper-local and relational ways, making them much more responsive to emerging needs during a disaster.

DISASTER RECOVERY

SIOs also play an important role in long-term disaster recovery by supporting the psychological health of survivors. SI enables people to participate in physical and psychosocial recovery. Community spaces and facilities will always be needed to host support services and community-building activities.[28] People will need places to work together to rebuild the social and economic fabric of society.[29] Still, while disasters strengthen social ties in some cases, they can also sever social networks, particularly when residents are displaced on a large scale. The loss of community ties and social cohesion is traumatizing and can be described as a secondary disaster.[30] Disasters are inherently traumatic experiences, and SI often supports and even facilitates the collective processing of trauma and healing. SIOs are also subject to displacement, but not to the same extent as individuals, which allows these organizations to do what they do best: bring together community members to connect, share, heal, celebrate, and offer ongoing services that meet basic needs.

COVID-19 RESPONSE AND COMMUNITY RESILIENCE

At onset of the COVID-19 pandemic, City of Vancouver staff gathered to begin assessing potential impacts not only of the virus itself, but of some of the unintended consequences of government restrictions. Initial direction for physical distancing triggered widespread closures of businesses, organizations, and community spaces. The closure of these spaces brought forth a secondary disaster, one in which the loss of free meal programs, public washrooms, and other amenities had devastating consequences for equity-denied communities and people already experiencing poverty, loneliness, limited mobility, and reliance on social services. Organizations that kept their facilities open were inundated and overextended.

Figure 3: Residents enjoy a Pop Up Plaza during the summer of 2020 (Photo: City of Vancouver).

To address these gaps, City staff formed a Community Resilience Branch in the Emergency Operations Centre and worked closely with SIOs to identify impacts and needs and also collaborate on solutions and build capacity to meet surging demand. SI played a critical role in delivering services like grocery hampers to low-income residents, preparing and delivering culturally appropriate meals to seniors, setting up outdoor gathering spaces like parklets, increasing access to sanitation and hygiene facilities, staging emergency shelters, providing storage space for personal protective equipment, and disseminating important messaging about health orders and guidance to people without regular or direct access to the internet (Figure 3). None of these actions would have been possible without the knowledge, relationships, and resourcefulness of SIOs.

Another key role of SIOs in the context of recovery is advocacy. Disasters expose and exacerbate our deepest pre-existing inequities, as impacts are not equally distributed among populations and communities. Government-led disaster recovery programs and policies are designed "to compensate for measurable monetary losses, with no real consideration of need, resulting in . . . the perpetuation of existing inequalities."[31] SIOs are closer to community, both geographically and relationally by way of offering front-line services that require face-to-face interactions. They have experience navigating government and philanthropic grants, and often have relationships with government staff or elected officials. This allows them to use their positional power to advocate for unmet needs in communities. At the same time, SIOs are often subject to the same disaster impacts as the communities they serve. According to the Vantage Point *Unraveling* report on the impact of COVID-19 on non-profits across BC eight months into the pandemic, of the organizations that serve specific populations, those that serve racialized people (61%) and adults (60%) were most likely to be concerned about having to shut down.[32] Recovery support for communities and SI must address these inequities.

POLICIES IN THE MUNICIPAL CONTEXT

To date, at the local level, only two municipalities in Metro Vancouver have recent policies or strategies that focus directly on SI.

The City of Richmond's *Building Our*

Future: A Social Development Strategy for Richmond[33] includes a strategic direction to "strengthen Richmond's SI," and the city has a Non-Profit Organization (NPO) Replacement and Accommodation Policy. Under this policy, if NPOs are displaced through development, they receive support for a temporary location or replacement space and moving costs, and they have the first right of refusal to return as a tenant in the new development. If the NPO tenant declines to return to the new development, the space is reserved for another NPO acceptable to the City of Richmond.

The City of Vancouver has two strategies that directly link resilience and SI. In 2019, the City of Vancouver approved *Resilient Vancouver*,[34] includes several objectives and actions specifically designed to reframe and transform the role of SI in disaster risk and resilience. These objectives include: "Cultivating community connections, stewardship, and pride through actions like participatory budgeting processes" (1.1); "Empowering communities to support each other during crises and recover from disasters through actions like scaling the Resilient Neighbourhoods Program and training community centre staff to support disaster preparedness" (1.2); and "Strengthening social and cultural assets and services through actions like evaluating the resilience of food assets and meal programs" (1.4). These actions signify a shift away from traditional, individualistic approaches of personal preparedness towards a more collective, socially collaborative approach.

More recently, the City of Vancouver approved its first strategy dedicated exclusively to SI. The city council approved *Spaces to Thrive: Vancouver SI Strategy Policy Framework* in December 2021. *Spaces to Thrive* takes a human rights–based approach that emphasizes addressing the needs of those most disproportionately impacted by shocks and stresses. Directions within the strategy cover a broad range of supportive policies, including: building partnerships and capacity; addressing persistent facility deficits (quality, quantity, and location); prioritizing reconciliation, equity, and resilience in supply; investing in operational funding for the health and vitality of the sector; and optimizing the SI ecosystem to improve resilience and adapt to pressures from climate change and disasters.[35]

Government agencies can improve resilience outcomes for communities by funding and supporting comprehensive packages for SI that recognize the importance of the operational costs, staff, facilities, and physical assets that make services, programs, and social connections possible.

OPPORTUNITY

RECOMMENDATIONS

Many meaningful actions can be taken to support SI in its role contributing to community resilience and disaster risk reduction. These are presented under two key ideas, one that supports and strengthens the ongoing work of SI in communities and another that specifically identifies opportunities to integrate SI into the work of disaster risk reduction.

FUNDING FOR STABILITY, LONG-RANGE PLANNING, AND ADAPTATION

Government agencies can improve resilience outcomes for communities by funding and supporting comprehensive packages for SI that recognize the importance of the operational costs, staff, facilities, and physical assets that make services, programs, and social connections possible.

Core funding and operational grants: Many organizations have called for changes to existing philanthropic models that largely offer project-based or innovation funding. Organizations require longer-term operational grants to maintain their core programs and services and conduct long-term planning. Many SIOs are continually creating new programs to qualify for grants, while struggling to fund their existing and impactful work. An ongoing lack of operational funding prevents organizations from planning for long-term administrative costs and creates instability in programming, staffing, and even facility maintenance.

Contingency funds and flexible funding during emergencies: A dominant misrepresentation of overhead costs as excessive and unnecessary for social purpose organizations contributes to the problem of insufficient operational funding and a lack of contingency funds for these organizations. Availability of operational funding and contingency funds would allow organizations to adequately pay staff, resource ongoing programming appropriately, and proactively plan and respond to emergencies. During the pandemic, many government and philanthropic funders notified SIOs quickly that their funding would be flexible. This allowed organizations to keep their staff and adapt their programs and service delivery methods during the pandemic emergency. This lesson should inform standard approaches for flexible funding through emergencies in the future.

Capital funds and real estate tenure: In cities in BC and across Canada, sharply increasing real estate prices, property tax values, and redevelopment pressures are creating insecurity and displacement pressures for organizations owning or renting properties for social purposes. The pandemic compounded these pressures. The SPRE Collaborative's 2021 survey of the BC social purpose sector found that lack of affordable space, suitable space, and declining tenure and long-term security in terms of ownership and leasing of space are the biggest challenges the sector faces, and these challenges directly affect the quality or extent of programs and services offered.[36] Mechanisms are needed to help these organizations stay close to the people they serve.

Capital funds for resilience and adaptation: At a practical level, SI spaces are a collective investment in resilient and protective facilities and services for communities. A significant number of residential buildings in BC are not designed beyond life-safety code for earthquakes, are built in flood plains, have limited air filtration for pollutants and wildfire smoke, and are not designed for thermal safety in heat waves. As climate change increases the frequency and severity of extreme weather (like the heat dome of 2021) and BC faces persistent and significant earthquake risk, investments in SIOs offers a temporary stop-gap. SIOs need capital funding to upgrade and replace aging facilities and construct flexible-use spaces that can accommodate emergency response activities like shelters or mass feeding.

SI AS KEY PARTNER IN DISASTER RISK REDUCTION

Support for the SI sector should receive serious consideration in the modernization of BC's EPA legislation and should be considered in the renewal of Canada's *National Strategy for Critical Infrastructure* (2021–2023).[37] There should be more connections among the disaster risk and emergency management fields, the social sector, and communities. Communities and municipalities rely heavily on SIOs during disasters, and local authorities should be encouraged to seek out partnerships with SIOs in advance of disasters. There should also be clear pathways of government funding and compensation for SIOs that take on response and recovery roles.

Liability considerations for the role of SI during emergencies: Current documents on the BC EPA modernization process include consideration of civil liability protection for registered and convergent volunteers during emergencies. This could include protection from undue liability for service providers using their facilities for emergency response activities, even those that do not have a mission to engage in emergency response but that step in to fill a need in their neighborhood.

Insurance and financial backstops: SI owners and operators need accessible and reasonably affordable insurance products and services, and regulations to ensure that they do not encounter excessive cost increases, exclusions, or complete denial of insurance coverage or renewal during emergencies and disasters, as many have during the pandemic.

Incorporating SI into hazard, risk, and vulnerability assessment (HRVA) processes and comprehensive recovery plans: SIOs must be included as partners in shaping HRVAs. They are essential for developing comprehensive and relevant hazard, risk, vulnerability, and capability assessments and in supporting participatory processes that involve civil society and diverse communities. This requires a fundamental shift in what type of knowledge we elevate, and a willingness to see non-traditional and non-technical knowledge as valuable expertise. It also requires appropriate resources for SIOs to have the capacity to participate in these processes.

Communication, coordination, and collaboration in emergencies: Emergency situations involve rapidly changing conditions, logistics, required provisions, and available supports, so SIOs need to receive information and resources in a timely manner as they decide how to adapt their services and support residents. Emergencies also necessitate quick and flexible collaboration, and, often, staff of local government and philanthropic grant-making institutions will play an informal coordinating role to help SIOs and community leaders connect with each other, share resources, or identify gaps in services that need to be filled. For a lasting and supportive relationship between local authorities and SIOs, it is necessary for local authorities to ensure clear and effective support for SI across all municipal departments during emergencies. For example, though social policy departments tend to have the most direct engagement and relationships with community partners, SIOs and smaller community groups may need permits for new or temporary facilities or activities, or may need to use municipal-owned property. For this, they must deal with building permit departments that may have a different understanding of how or whether the local government should support community groups.

Governance and decision-making mechanisms for local SI networks are also important. A general lack of coordination, formal roles, and decision-making frameworks to allocate resources and aid in disasters abounds, but should be established to ensure that key emergency response services such as food provision are provided without interruption, and that appropriate facilities are kept available for use, whether by their normal operators or other operators that can step in during emergency contexts.

THE CHALLENGE

Practitioners in the fields of disaster risk reduction and resilience increasingly recognize that preventing, responding to, and recovering from disasters is not only predicated on our physical environment, but equally contingent on the strength, flexibility, and equity of our social and economic systems. To address disaster risk in all its complexity and dimensions, we need to see the social dimensions of disasters as equally valid and equally ripe for risk reduction action. The stresses that erode community resilience on a continual basis are just as critical to address as the shocks that cause acute disruptions. The challenge often seems to be that practitioners do not quite know how to do this—but social infrastructure can help. Involving social infrastructure in comprehensive disaster risk reduction efforts is a crucial step in achieving a whole-of-society approach, extending both the breadth of potential disaster risk reduction actions and the depth of these actions. Building relationships and investing in these social-purpose places opens up new knowledge, new potential plans, and new interventions to ensure that community needs are centred in immediate and long-term disaster risk reduction work.

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2. An introduction to the concept of social infrastructure and cases and evidence of how SIOs and their physical spaces strengthen social connections in communities, reduce vulnerability to disasters, and play a role during emergencies:

Klinenberg, Eric. *Palaces for the People: How SI Can Help Fight Inequality, Polarization, and the Decline of Civic Life*. New York: Penguin Random House, 2018.

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Photo: Lizz Koebel-Davidson

2.3 RISK AND RESILIENCE APPROACHES IN ELECTRICAL INFRASTRUCTURE

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.3 RISK AND RESILIENCE APPROACHES IN ELECTRICAL INFRASTRUCTURE

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ABOUT ELECTRICAL INFRASTRUCTURE AND UTILITIES

OVERVIEW

The generation, transmission, and distribution of electricity within BC is under the jurisdiction of the Ministry of Energy, Mines and Low Carbon Innovation. The electrical system extends beyond the provincial boundaries and is part of a larger power grid known as the Western Interconnection. BC's utilities collaborate with reliability bodies, including North American Electric Reliability Corporation (NERC), Western Electricity Coordinating Council (WECC), and Western Interstate Energy Board.

Utilities are regulated by the British Columbia Utilities Commission (BCUC) under the *Utilities Commission Act*. BCUC's mandate is to balance the interest of the consumer and the utility companies.

In BC, there are two major utilities supplying electricity: British Columbia Hydro Power and Authority (BC Hydro) and FortisBC Inc. There are also five BC municipalities that have their own utilities: City of Nelson, City of New Westminster, City of Grand Forks, City of Penticton, and District of Summerland. These municipal utilities sell electricity directly to their customers. FortisBC is a Canadian-owned, BC-based company servicing customers in the Southern Interior region. BC Hydro is a provincial Crown corporation, owned by the government and the people of BC. BC Hydro services 95% of the province's population. The Lieutenant-Governor in Council appoints the board of directors for BC Hydro and they are responsible for overseeing BC Hydro's affairs. The day-to-day management is delegated to BC Hydro's president and CEO.

BC has some of the cleanest grid-supplied electricity through generating power from hydroelectric dams. Electricity will continue to play a critical role in helping the BC Government move towards its commitment of reducing greenhouse gas emissions to 40% from 2007 levels by 2030. As a result, grid resilience and secure supply of electricity will be important to the functioning of society.

This article is a high-level overview of hazards, threats, vulnerabilities, and risks from a generic electrical utility perspective, but in order to clarify the concepts it uses examples from BC Hydro, which is the main utility in BC. Since the electricity in BC is largely generated by hydroelectric power, the electrical grid is dependent on understanding the trends in climate and hydrology at the generation level. The bulk electrical system is responsible for bringing electricity to the end-use customer. The end user not only includes residential, commercial, and industrial customers, but also neighbouring utilities to the east and south who are part of the Western Interconnection.

In today's world, where modern technologies are integrated with legacy technologies and where there is more and more reliance on remote monitoring and control, a secure telecommunication system becomes one of the important elements for a utility and the operation of its power electrical system; the power electrical system relies on a robust and secure telecommunication system designed to ensure continuity of its operation.

In the event of any catastrophic incidents, the electrical system will be a vital resource for minimizing the cascading impacts of a disaster and will be critical for providing support for emergency services, aiding in recovery, and rebuilding the province.

ALIGNMENT WITH THE SENDAI FRAMEWORK

The resilience of the utility system is directly related to (18) Target (d) of the Sendai Framework for Disaster Risk Reduction and is critical for achieving Targets (a), (b), (c), and (g).

In the Sendai Framework, item 18 (d) states: "Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030."[1]

IMPACT OF PAST HAZARD THREATS ON ELECTRICAL INFRASTRUCTURE

Electrical outages occur all year round and the causes include motor vehicle accidents, animal and tree contacts, obstructions in the wires, equipment failure, sabotage, theft, and extreme weather events. During outages, electrical service is restored by both field work and system control work. Electrical utilities have some contingencies built into the system design to ensure that as many customers are restored as quickly as possible, thus minimizing outage duration and overall disruption to customers and businesses.

Residential, commercial, and industrial customers are largely serviced by the distribution infrastructure. Distribution infrastructure includes the poles and wires that are along the highway, streets, and, in some cases, along the hillsides. These poles and wires are known as the overhead system. The overhead system is the most susceptible to weather-related hazards. Other distribution infrastructure is in underground facilities and not visible, or is placed on the sea floor. Underground infrastructure can be damaged by flooding, landslides, ground shaking, liquefaction caused by ground shaking (from an earthquake), or even improper construction methods.

Larger than the distribution system is the transmission system, which can also be damaged during storm events. If the transmission system is affected, the impact is greater since the transmission system feeds the distribution system and several very large industrial customers. To restore power to the most customers as soon as possible, alternate circuits may need to be used (where such a contingency in the system exists) and large customers could be asked to reduce their consumption or areas will need to remain out of service, resulting in a reduction of supply service.

Every year, electrical utilities prepare for winter storm season, which usually occurs from fall to spring. Wildfire season starts March 1, overlapping the winter storm season. The primary hazards resulting in outages are from windstorms, severe rain events, ice storms, and wildfires. Other hazards affecting the electrical system include avalanches, tsunamis, severe temperatures, drought, landslides, extreme inflow events, floods, and earthquakes. The demand created by high temperatures is also a factor affecting electrical service. BC's climate risk assessments evaluated the likelihood of 15 climate risk events that could occur. The greatest risks identified were wildfire, water shortage, heat wave, ocean acidification, glacier loss, river flooding, and coastal storm surge.[2]

ICE STORMS

In December 2017, Fraser Valley East had two ice storms that resulted in outages to more than 162,000

Figure 1: Ice buildup on electrical infrastructure (Photo: BC Hydro).

customers. The ice storm made conditions dangerous—icy roads, poor visibility, and fallen trees. Crews had to repair and replace equipment in the substations from the ice buildup (Figure 1).

WILDFIRES

Every year during the summer months, electrical utilities prepare to address damage from wildfires and need to assess wildfire risk when working in dry areas. Everyone in BC is required to follow the *Wildfire Act* and *Wildfire Regulation*. The legislation specifies responsibilities and obligations on fire use, wildfire prevention, wildfire control, and rehabilitation. BC Hydro and BC Wildfire Service have agreements in place where BC Hydro is exempt from regulation 6 (3) (a) *High risk activities within 300 m of forest land or grass land* if the restoration work is deemed as a "trouble call," on the condition that fire suppression equipment and a fire watcher is maintained. Trouble calls, most of which are reported outages, are identified, assessed, and dispatched for repairs by BC Hydro's Restoration Centre. The Fire Risk Management Team develops, maintains, and implements fire safety standards and resources to ensure those working in wildfire risk areas are working safely.

From 2008 to 2016, BC had an average of 1,700 wildfires each year affecting roughly 165,000 hectares of land.[3] However, beginning on July 7, 2017, BC experienced one of its worse wildfires: 1.2 million hectares were on fire and more than 65,000 people needed to leave their homes.[4] The winter preceding the 2017 wildfire season was wet and cold. In early May of 2017, Southern BC was dealing with flood conditions in Kelowna, Cache Creek, and Salmon Arm. The wet spring resulted in fertile growth throughout the province, but with no rain in June, the new growth became dry and fuel for a wildfire. The trend is that wildfires are increasing each year in numbers and severity. The following year in 2018 saw 1.35 million hectares affected by wildfires. In 2021, a provincial state of emergency was declared. The Village of Lytton burned, destroying the town. Even a large community like the City of Vernon was put on evacuation alert.

WINDSTORMS

In December 2018, the BC's South Coast (BC Hydro territory) experienced one of its worst windstorms. There were several factors that contributed to this large outage. The windstorm came after several heavy rain events; some areas experienced more than 400 mm of rainfall. As a result of over a week's worth of heavy rain, the soil in some areas was completely saturated, exposing roots and making tress with shallow roots more vulnerable. The wind also came from an atypical direction, and wind speed ranged from 85 km/h to as high as 144 km/h. Over 750,000 customers were without power (400,000 customers in the Lower Mainland and Fraser Valley and 350,000 on Vancouver Island and Gulf Islands). BC Hydro mobilized over 900 field workers, including those from other parts of the province and contractor crews from other provinces. Within 24 hours, power was restored to over 550,000 customers. The windstorm resulted in significant equipment damage (Figure 2) as well as vegetation destruction.[5]

HEAT

In late June 2021, BC experienced extreme record-breaking temperatures. Although there were only localized outages, BC Hydro confirmed a new summer peak load of over 8,300 MW. BC Hydro is a winter-peaking utility, and the new record summer peak identified that the need for cooling (requiring electricity to run cooling appliances) may change the utility's load profile.

On July 8, 2021, BC Hydro detected a bulge and oil leak in one of its submarine cables. It was suspected that the cause of the damage was due to the extreme heat. The cause remains under investigation.[6] Heat, with increased cooling loads, on overhead circuits, will result in the wires sagging. The sag can result in two circuits inadvertently touching, causing outages or power surges. The sag can also result in reducing the safe distance between people and equipment.

Repairing damage in the heat is a concern for crews; the work needs to be completed safely for both the public and the worker.

Figure 2: Fallen trees and poles during 2018 windstorm (Photos: BC Hydro).

Figure 3: Electrical infrastructure in the Sumas Prairie during November 2021 flood (Photo: Lizz Koebel-Davidson).

FLOODS

In November 2021, strong winds and heavy rainfall came in the form of an atmospheric river, caused floods and mudslides, resulting in outages to over 219,000 customers in parts of the Lower Mainland, Vancouver Island and Interior. Access to dam sites and damaged areas was at times difficult or not possible due to flooding (Figure 3).

Heavy rain also affects the reservoir levels and increased inflows in the local rivers. BC Hydro's Emergency Operations Centres engaged provincial and local agencies to provide regular updates on current and forecasted reservoir levels and dam outflows. In the storm of November 2021, flood alerts were made to Wahleach (near Hope), Alouette (near Maple Ridge), and Daisy Lake – Cheakamus (near Squamish) reservoirs.

With the increase in temperature and precipitation from climate change, there will be an increase in riverine flooding due to the higher flows.

These higher flows put transmission river crossings at risk from the damage caused to tower foundations by changing currents and debris. The lower Fraser River and the Skeena River have been impacted by the flows from spring freshets. During the 2011 freshet, BC Hydro spent $25 million repairing transmission infrastructure.

UNDERSTANDING AND REDUCING RISK

All outage events, including planned outages, are documented and tracked. The information tracked includes asset damage and extent of the outage. This information, along with scheduled maintenance inspections, is used to identify the performance of the circuits and provide reliability statistics. Maintenance inspections include overview inspections, detailed inspections, climbing or bucket inspections, vegetation patrols, infrared scanning, switch inspections, test-and-treat inspections, ground corrosion inspections, access inspections, and ad hoc inspections. The asset management aligns with ISO 55001, an industry asset management specification where the goal is to maximize the value of the physical asset over the entire life cycle of the equipment. The risk and performance of the asset are measured by looking at safety, reliability, revenue, cost, and environmental and social performance. Utilities use asset management processes, methodology and tools to ensure the system performs optimally.

EMERGENCY PLANNING PRACTICE AND CAPABILITIES (RESPONSE, PREPAREDNESS, SHORT-TERM RECOVERY)

Electrical infrastructure is a critical resource during emergencies. To ensure the safety of the public and workers, the system must be safeguarded with risk-prioritized security solutions, and operations must be prepared with well-practiced emergency response plans to support reliable and resilient infrastructure.

BC Hydro's Emergency Management Program is based on emergency response best practices such as CSA-Z1600 and meets the requirements of the provincial *Emergency Program Act* and the *Water Users' Communities Act*.[7] The program follows the resilience cycle (Figure 4) and is part of a safety framework that aligns safety processes, programs, and responsibilities of the company.

A dedicated Emergency Management Team supports, integrates, and delivers the Emergency Management Program. The team supports the development of emergency plans that identify risks and outline actions. These plans are validated through drills and exercises and improved with regular plan reviews and after-incident reviews. The team works with all business units throughout the organization, sharing learnings between groups as needed.

During larger emergency events, an Emergency Operation Centre (EOC) is activated to support response and recovery. An EOC is a central command and control facility for carrying out emergency management and ensuring continuity of operation. BC Hydro's EOC is scalable and flexible to adjust to the needs of the emergency. The role of the EOC

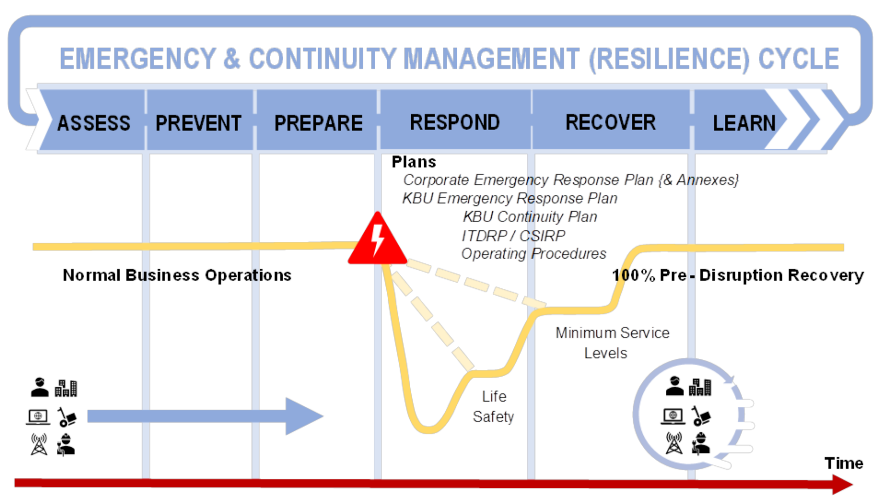

Figure 4: Emergency management resilience cycle (Graphic: BC Hydro).

Table 1: Organizations and industries involved in electrical infrastructure

Organization	Type of Organization	Legal Mandate	Role
Attorney General	Provincial government	Emergency Program Management Regulation	Coordinates government response to specific hazard event of power outage
BC Hydro	Provincial Crown corporation	Clean Energy Act	Restores electrical facilities; interrupts hydro service when threat to life or property is posed; operates and monitors its own dams safely
British Columbia Utilities Commission (BCUC)	Provincial regulator	Utilities Commission Act	Adopts reliability standards
North American Electric Reliability Corporation	Not-for-profit international self-regulation authority	US Federal Energy Regulatory Commission and Canadian governmental authorities	Enforces reliability standards
WorkSafe BC	Provincial regulator for occupational health and safety	Workers Compensation Act	Sets emergency response requirements
Canadian Dam Association	Owners, operators, regulators, consultants and suppliers interested in dams and reservoirs	Water Sustainability Act, Dam Safety Regulation	Exchanges ideas and experience in the field of dam safety, public safety, and protection of the environment
Canadian Standards Association	Accredited national standards association	Adopted as national electrical code	Designs the basis and requirements for overhead and underground line designs; National Electrical Code and equipment specifications
Ministry of Energy, Natural Resources Canada	Federal government	Interprovincial governance	Regulates the international movement of energy and energy goods; develops policies in the national interest
Institute of Electrical and Electronic Engineers Standards Association (US)	Accredited international standards association	Internationally recognized standards association	Provides global electrical system standards and equipment standards
International Electrotechnical Commission	Accredited international standards association	Internationally recognized standards association	Provides global electrical system standards and equipment standards

is to provide a strategic oversight from a central location to ensure that communication, reporting, and coordination tasks are streamlined. EOC staff are senior managers and subject matter experts that are scheduled as needed to support effective coordination internally and externally. The EOC's support increases situational awareness through coordination calls and technology, and deliverables include reporting internally and sharing information externally as needed. In addition to internal dam and power system information, the EOC accesses provincial and municipal information to ensure the awareness of risks and supports decisions to be made at the appropriate level in the organization. BC Hydro also has mutual aid agreements and logistics with the third parties, including other utilities and agencies, in the event that a situation overwhelms BC Hydro and external help is needed (Table 1).

LONG-TERM RESILIENCE PLANNING PRACTICE AND CAPABILITIES

Severe storm and heat events have happened every year since 2017 and are expected to increase in frequency due to the changing climate. The Emergency Management Program addresses current incidents, but long-term resilience planning is needed to prevent or better adapt to future events.

BC Hydro identifies climate change as an external risk. The failure to mitigate or adapt to the changing climate will result in damage to the electrical infrastructure and impact the reliability of the electrical system. BC Hydro created a Climate Change Steering Committee consisting of stakeholders across the company to provide oversight and coordination on BC Hydro's climate change adaptation process and ongoing work.[8]

Utility asset management recognizes that long-term resilience planning will rely on other methods beyond robust preventative maintenance programs—such as being ready for increased electrification, expanding existing tools, adding new technologies, incorporating non-wired alternatives, and collaborating with other parties.

MAINTENANCE PROGRAMS

There are tools used by the Asset Management Team that develop knowledge to ensure the resilience of long-term investments. Data is extracted from the preventative maintenance program, including schedules and reports. As part of the condition assessments, the degrees of inspections vary from visuals from the ground to more detailed inspections and infrared testing. Damaged equipment can also be sent for failure analysis and further study.

INCREASED ELECTRIFICATION NEEDS

For long-term resilience, electrical system planners create models from load forecasts as a driver for system reinforcements. The Future Grid Roadmap, currently in development, includes the modification of standards to integrate contemporary climate data. The Emergency Management Program addresses near-term disasters but will also provide learnings for long-term resilience.

> Electrical utilities will need to develop scenarios to acknowledge the range of uncertainty from the new realities of climate change, evolving customer needs (such as transportation), and technology advancement.

Electricity supplies only 20% of BC's energy needs. To meet the BC Government's greenhouse gas emission reduction goals for 2030, the switch from fossil fuels to electricity will be key. The success of long-term resilience planning for the electrical system is a priority for the electrical utilities. The 2021 *Integrated Resource Plan for BC Hydro* (BCH IRP)[9] includes initiatives advanced by the provincial government, such as CleanBC. The BCH IRP identifies and explains how Reconciliation with Indigenous Peoples, climate action, evolving customer needs, changing electricity consumption, and technology advancement are modifying how electrical utilities do business. Electrical utilities will need to develop scenarios to acknowledge the range of uncertainty from the new realities of climate change, evolving customer needs (such as transportation), and technology advancement. In the next five years, BC Hydro will be implementing its *Electrification Plan*[10] to increase low-carbon electrification. The *Electrification Plan* is expected to increase electrical load and decrease greenhouse gas emissions.

EXPANDING EXISTING TOOLS

There are existing tools used for design or operation that can also be used for long-term resilience planning. Designers and engineers use geographic information systems (GIS) to observe or modify the electrical system. To better inform the designer, GIS can include climate data, erosion data, and land stability information. Additional information should be added, such as wildfire fuel loading, spring runoff models, and topology.

NEW TECHNOLOGIES AND NON-WIRED ALTERNATIVES

Newer equipment, such as communicating line monitors, now have data collection and communicating capabilities that are used for fault (disruption to the system) location identification. Communicating line monitors are devices that can detect and report on a fault at the point where they are connected to the system or monitor the system during normal conditions. This information can help improve fault location and average restoration times during trouble instances by narrowing down the location of a fault or helping to predict local system overloads or voltage problems. These automated devices can be utilized to provide information beyond just location and operation for long-term resilience.

To address reliability and resilience, BC Hydro will need to examine and enhance its radial line policy to include non-wired alternatives and new technologies such as increased battery deployment. Radial lines are single-circuit distribution or transmission lines that do not have redundancy—there is no second source of supply. Non-wired alternatives include demand-side management initiatives and customer-sited new technologies.

Technology can assist with long-term resilience. BC Hydro can leverage technologies used in other jurisdictions, such as remote cameras, drones, undergrounding lines, shutting off lines during wildfire risk, and more. But with technology comes cyber security risks; with a strong cyber security system, utilizing some of these smart devices would be beneficial.

EXTERNAL COLLABORATION

BC Hydro has partnered with government, academia, and industry to understand the climate impact to its assets. In 2006, BC Hydro worked with the Province and the University of Victoria to form the Pacific Climate Impacts Consortium (PCIC), which focuses on three main themes: hydrologic impacts, regional climate impacts, and climate analysis and monitoring. The current research agreement with PCIC is for the 2019–2023 period and covers improving hydrological model simulations, investigating new climate models and analysis techniques, improving storm forecasting, and providing training and workshops.[11]

The current research agreement with PCIC is for the 2019–2023 period and covers improving hydrological model simulations, investigating new climate models and analysis techniques, improving storm forecasting, and providing training and workshops.

Utilities are involved with other organizations and communities that can contribute to long-term resilience planning. BC Hydro has a representative in the following working groups and committees: SFU Adapting to Climate Change Program Advisory Committee; Centre for Energy Advancement through Technological Innovation (CEATI) Climate Change Opportunities, Risks and Adaptation Working Group (CCORA); CEATI Transmission Line Design and Extreme Event Mitigation (TODEM), Canadian Standards Association (CSA) Codes and Standards Committee; Canadian Electric Association (CEA Climate Change Adaptation Working Group;

and the Electrical Power Research Institute (EPRI).

Utilities also have strong relationships with all levels of government, which is ideal for collaboration. Communities, especially Indigenous communities, are great partners for smaller microgrids and renewable penetration to ensure remote communities have reliable power.

The distribution infrastructure is typically built adjacent to roads, and being along a road allows for easier access for repairs by the field crews. During emergency events, roads will need to be accessible and drivable; electrical utilities cooperate with the Ministry of Transportation or local municipalities during any catastrophic events.

GAPS

The current best practice uses historical knowledge for weather and geographical information. Modern climate and environmental models should be used and mapped geospatially. Secondary hazards from climate change such as ice accretion, slope stability, and avalanches should be modelled, and these used as part of the preventative maintenance program.

Weather reporting is used to understand how to manage the near-term operations; the current equipment and systems are designed to standards based on historical temperatures. Long-term resilience planning, however, requires understanding more complex weather conditions, such as icing events, and revised thermal ratings based on future extreme conditions.

Using climate data, a vulnerability study should be initiated to understand the condition of the existing infrastructure and how to improve its long-term resilience. The study would identify which areas or regions require strengthening. Addressing the recommendations from the study will require additional resources for field verification, modelling, GIS upgrades, standard revisions, procurement resources, and capital upgrades to the system.

Using climate data, a vulnerability study should be initiated to understand the condition of the existing infrastructure and how to improve its long-term resilience. The study would identify which areas or regions require strengthening.

OPPORTUNITY

RECOMMENDATIONS

The following are recommendations to reduce risk in the sector and to ensure long-term resilience:

- Continue to develop wildfire management and methods to reduce the risk of BC Hydro infrastructure causing wildfires.
- Improve the radial line policy to include changes based on increased electrification and the integration of non-wired alternatives and new technology integration.
- Share information within the utility both in planning and responding to emergencies. Learn best practices from other departments and gather input from each area of expertise.
- Share climate change risks, impacts, adaptation, and mitigation strategies externally with other utilities. Learn from other utilities' best practices and lessons learned. The Emergency Management Team is already a part of a mutual assistance group that collaborates and shares learnings.
- Centralize the risk reduction planning. Hazards and risks do not have municipal or even provincial boundaries.
- Improve local weather and climate data. Continue to improve data collection.
- Streamline changes to allow for increased fuel switching. Work with regulators to make changes easier and beneficial to the end user.

THE CHALLENGE

Utilities are used to being the service provider; this is especially so for a Crown corporation utility. The challenge is to have the utility be the unifying source to solve future problems. If given the latitude to affect change, the utility can be a unifying link between levels of government and government entities, the end user, the community, and emergency responders. The biggest test is the change management—to accept the utility in this role. With many sectors having different rules and regulations, it would be beneficial to streamline the regulations such that there are no barriers to collaboration. The Emergency Management Team already works with 9-1-1 to improve agency-to-agency communication during events, build relationships, appreciate challenges, and identify opportunities. Having a similar type of collaboration with other organizations would be a desired end state.

Given the latitude to affect change, the utility can be a unifying link between levels of government and government entities, the end user, the community, and emergency responders.

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2.4 SEISMIC DESIGN OF BUILDINGS FOR FUNCTIONAL RECOVERY

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.4 SEISMIC DESIGN OF BUILDINGS FOR FUNCTIONAL RECOVERY

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POST-EARTHQUAKE RECOVERY OF BUILDINGS

OVERVIEW

Prompt post-earthquake recovery of buildings is an integral component of a community's seismic resilience. As defined by EERI, "functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality."[1] Functional recovery of buildings enables people to return to their homes and facilitates access to other essential functions such as schools, healthcare, and commerce.[2,3] Nevertheless, past earthquakes have highlighted that building performance is generally inadequate to ensure the seismic resilience of communities. After the Kobe earthquake in 1995, roughly 15,000 households (19% of those impacted) relied on temporary housing three years after the earthquake.[4] After the Northridge earthquake in 1994, 33% of the damaged multi-family housing units, approximately 890 buildings, took more than two years to complete repairs.[5,6] One year after the L'Aquila earthquake in 2009, only 4% of 427 buildings surveyed had completed repairs, 29% had ongoing repairs, and the remaining 67% had not yet started repairs (Figure 1).[7]

While modern seismic design codes intend to ensure life-safety in extreme earthquakes, in recent years, planners and policy makers have directed a concentrated research effort to achieve better-than-code seismic performance. Functional recovery—the performance state of a building wherein it maintains or regains the ability to perform its basic intended use—is gaining significant importance.[8] In the US, the National Institute of Standards and Technology (NIST) and the Federal Emergency Management Agency (FEMA) are developing performance objectives in terms of post-earthquake recovery times.[9,10] FEMA P-2082 has also recommended making functional recovery the primary basis for seismic design by assigning target recovery times (ranging from hours to months) to every new building, depending on the building's risk category.[11] Similarly, SPUR (San Francisco Planning and Urban Research) has identified target post-earthquake recovery times for a resilient San Francisco.[12] Despite these efforts, the efficacy of these resilience-based performance objectives is dependent on the availability of tools to assess the post-earthquake recovery time of buildings.

To expedite post-earthquake recovery, design targets in building codes should extend beyond the life-safety performance objective in extreme earthquake events to include resilience-based performance measures. These design targets and related performance measures should describe: 1) the ability to withstand earthquake loads without degradation or loss of function (i.e., robustness); and 2) the ability to regain functionality within a specified timeframe (i.e., rapidity).[13]

This article provides an overview of existing tools to estimate the post-earthquake recovery time of buildings. While the use of these tools presents a great opportunity, the importance of understanding the modelling assumptions and limitations cannot be overstated. These tools primarily serve to assess different structural and non-structural design options to enable the seismic design of buildings for enhanced performance, and to inform building owners of the expected earthquake performance as related to functional recovery. However, the results should not be regarded as hard truths, but rather as data to support effective decision making.

Figure 1 : In 2019 in L'Aquila, Italy, buildings in the historic centre were still undergoing restoration after the 2009 earthquake (Photo: Daniele Gussago/Shutterstock).

While modern seismic design codes intend to ensure life-safety in extreme earthquakes, in recent years, planners and policy makers have directed a concentrated research effort to achieve better-than-code seismic performance. Functional recovery—the performance state of a building wherein it maintains or regains the ability to perform its basic intended use—is gaining significant importance.

Pathways to the adoption of seismic design guidelines for the functional recovery performance of buildings in British Columbia are also discussed. This includes some commentary on new provisions in the 2020 edition of the National Building Code of Canada[14] related to an enhanced performance objective of "no structural damage" for a subset of all new buildings, for lower-level earthquakes, which is a positive move towards addressing the functional recovery objectives discussed herein.[i]

ALIGNMENT WITH THE SENDAI FRAMEWORK

The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines four priorities for action to prevent new and reduce existing disaster risks: 1) Understanding disaster risk; 2) Strengthening disaster risk governance to manage disaster risk; 3) Investing in disaster reduction for resilience; 4) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction. As previously defined, "functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality." As such, enabling the seismic design of buildings to achieve functional recovery enables people to return to their homes and facilitates access to other essential functions such as schools, healthcare, and commerce in the aftermath of a damaging earthquake. Designing buildings to achieve functional recovery performance enables disaster risk reduction by minimizing losses in lives, livelihoods, and in the economic, physical, social, cultural, and environmental assets of persons, businesses, and communities, resulting in direct alignment with the Sendai Framework for Disaster Risk Reduction.

[i] *For brevity, this article focuses primarily on new building design, as enhancing the seismic performance of existing buildings to achieve functional recovery objectives presents further challenges.*

EXISTING TOOLS TO ASSESS FUNTIONAL RECOVERY

Until recently, no tools were readily available to estimate the time required for a building that experienced damage in an earthquake to achieve a desired recovery state (e.g., functional recovery). Over the past decade, a growing number of frameworks have been developed to assess the anticipated seismic performance of buildings:

- The FEMA P-58 methodology,[15] a seismic performance assessment tool for individual buildings, translated engineering demand parameters (e.g., storey drifts and floor accelerations) obtained from structural analyses into performance metrics such as casualties, economic loss (repair costs), and repair time.
- The Resilience-based Earthquake Design initiative (REDi)[16] advanced the FEMA P-58 methodology by developing a framework to estimate the downtime of individual buildings to a defined recovery state by aggregating the repair time of damaged components, the delay time to start repairs, the effect of utility disruption, and other "impeding" factors.
- Developed more recently, TREADS[17] is a framework to probabilistically model the post-earthquake recovery of buildings and provide quantitative seismic performance measures, expressed in terms of downtime.
- Similarly, the ATC-138-3 project published a preliminary methodology to assess seismic performance in terms of the probable functional recovery time of individual buildings subjected to a damaging earthquake. The ATC methodology maps component-based damage to system-level operations, and system-level performance to tenant and building level re-occupancy and function.
- Both TREADS and ATC-138-3[18] are extensions to the FEMA P-58 methodology that conceptually implement impeding factor delay estimates as defined in REDi.

FEMA P-58

FEMA P-58 proposed a seismic performance assessment methodology for individual buildings based on the performance-based earthquake engineering framework.[19,20] The methodology employs predefined fragility functions to predict damage states in building components from structural response parameters, such as storey drift and floor acceleration. Consequence functions translate these damage states into various performance metrics, such as casualties, repair costs, and repair times. Monte Carlo simulations are used to account for the high degree of uncertainty in the structural response parameters, damage state predictions, and consequence estimates.

While the repair cost estimation procedure employed in the FEMA P-58 methodology is well established, the repair time calculation only estimates the time required to achieve full recovery and does not consider any intermediate recovery states, such as re-occupancy or functional recovery. Two estimates of building repair time are provided: repair time in series (considering repairs in each floor in a building take place sequentially) and repair time in parallel (considering repair in all floors in a building occur simultaneously). The assumed workforce depends only on the building floor area and not on the extent of damage to the building, and the repair sequencing is simplified to consider repairs of only one trade at a time on a floor. While these assumptions do not provide a realistic representation of the building's repair sequencing, the series and parallel repair estimates may serve as lower or upper bounds for the expected repair time to achieve full recovery. More importantly, FEMA P-58 does not account for any possible delays prior to the initiation of repairs, such as contractor mobilization, financing, permitting, or repair design, which can be significant contributors to a building's downtime.[21]

REDi

The REDi guidelines extended the FEMA P-58 methodology and proposed a framework to estimate downtime in individual buildings to a defined recovery state. The developments include an estimate of the impeding factor delays between the occurrence of an earthquake and the start of repairs (e.g., inspection, financing, contractor mobilization, etc.), as well as estimates of utility disruption (e.g., electrical systems, water systems, etc.). The guidelines identify three post-earthquake recovery states: re-occupancy (building is safe enough to occupy), functional recovery (basic building functionality is restored), and full recovery (building is restored to its pre-earthquake condition). To identify the required repairs to achieve the desired recovery state, a repair class is assigned to each component in the building based on its extent of damage.

While the guidelines represent a significant contribution to downtime quantification, there are several limitations, such as conservative re-occupancy criteria, worker allocation, and repair sequencing. The REDi guidelines use the re-occupancy recovery state to determine if a building is safe enough to occupy—if it can be used for shelter. However, the structural and non-structural component recovery criteria suggested to achieve this recovery state seem overly conservative. According to the guidelines, repairs of almost all structural, plumbing, and HVAC components must be completed before a building can be occupied. By contrast, several researchers recommend that sheltering criteria for buildings in a post-disaster setting should consider relaxed habitability standards that allow people to stay in their own homes—even if damaged—after an earthquake, as long as the building does not pose a life-safety risk.[22,23]

To help define the order of repairs to be conducted, the REDi guidelines segregate all non-structural repair activities into groups of repair sequences. The guidelines consider that repair activities begin with the building's structural components and repair progresses only one floor at a time. The non-structural repair commences only after the entire building's structural repairs are complete. In contrast with this assumed approach, after the 1994 Northridge earthquake, contractors often repaired several floors simultaneously and performed elevator and staircase repairs in parallel with structural repairs.[24]

TREADS

TREADS (Tool for Recovery Estimation And Downtime Simulation) is a framework to probabilistically model the post-earthquake recovery of buildings and provide quantitative seismic performance measures, expressed in terms of downtime, that are useful for decision making.

Downtime estimates include the time for mobilizing resources after an earthquake and for conducting necessary repairs. The TREADS framework advances the well-established FEMA P-58 and REDi methodologies by modelling temporal building recovery trajectories to different recovery states. Analogous to safety-based US codes, which specify a threshold for the probability of collapse under a given ground motion shaking intensity (e.g., 10% or less probability of collapse under the risk-targeted maximum considered earthquake), this framework permits evaluating the probability of a building not achieving a target recovery state (e.g., shelter-in-place immediately after the earthquake), or, alternatively, the probability of not achieving a target recovery state (e.g., functional recovery), within a specified time frame.

The framework leverages the damage state predictions and component repair times obtained from the FEMA P-58 analysis to estimate building performance in terms of downtime. This process consists of five sequential steps:

1. Evaluate the extent of damage and identify the post-earthquake usability of the building, considering five distinct recovery states immediately after the earthquake: stability, shelter-in-place, re-occupancy, functional recovery, and full recovery. The shelter-in-place recovery state accounts for relaxed post-earthquake habitability standards, in contrast with the re-occupancy recovery state, which relates to pre-event habitability criteria.
2. Evaluate impeding factor delays—the various factors that may delay or impede the initiation of repair activities. These activities include the time required for building inspection, securing financing, arranging engineering services and designs, obtaining permits, mobilizing a contractor, and performing repairs to stabilize the structure or the building envelope (i.e., mitigation work to minimize aftershock collapse risk and falling debris hazard).
3. Assess the building's repair time to achieve the desired recovery state.
4. Model the building's time to recovery by using the delay time and repair time estimates, providing downtime estimates for each storey in the building. (To account for the various uncertainties within the downtime estimation procedure, the first four steps are performed for thousands of Monte Carlo simulations, resulting in thousands of downtime realizations (plausible outcomes) and recovery trajectories, each having an equal likelihood of occurrence, as illustrated in Figure 2.)
5. Link the downtime estimates to probabilistic performance measures (robustness and rapidity) that support decision making by building owners, engineers, and policy makers.

Each of the recovery states considered by TREADS represents a milestone in a building's overall recovery trajectory. To estimate downtime to achieve each of these recovery states, the framework uses the repair class concept introduced by the REDi guidelines. The damage state of each building component in each realization is tagged with a repair class, which serves to identify the recovery state hindered by the damage extent to

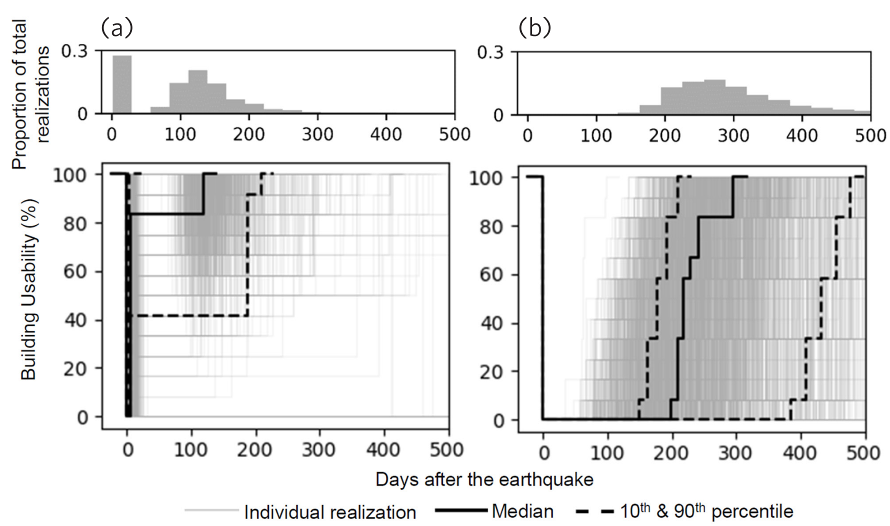

Figure 2: Recovery trajectories to (a) shelter-in-place and (b) functional recovery for 1000 realizations of building performance under ground motion shaking with a return period of 975 years (adapted from Molina Hutt et al, 2022).

the component. The post-earthquake usability is determined by identifying the recovery state achieved by the building immediately after the earthquake, before any recovery activities begin. The building condition when each of the recovery states is achieved and the associated repair class is shown in Table 1. Components that are damaged to a level that hinders achieving the building condition outlined in the table will need to be repaired before the recovery state can be achieved.

To illustrate this concept, consider a reinforced concrete shear wall building. The structure's slender shear walls are characterized by a fragility function with three distinct damage states. Damage state DS1 represents spalling of the cover with vertical cracks greater than 1/16 of an inch, which is tagged with a repair class RC3 and hinders achieving the re-occupancy recovery state. Damage state DS2 represents exposed longitudinal reinforcing and triggers an unsafe placard per the FEMA P-58 methodology, hence is tagged with a repair class RC4 and hinders achieving the shelter-in-place recovery state. Damage state DS3 represents concrete core damage or buckled/fractured reinforcing. Because this is believed to compromise the load carrying capacity of the member, it is linked to a repair class RC5 and hinders achieving the stability recovery state.

Within the proposed assessment framework, all component damage linked to a repair class equal to or greater than that associated with the desired recovery state, as indicated in Table 1, must be repaired before the recovery state in question can be achieved. To achieve functional recovery, for example, all components with repair classes RC2, RC3, RC4, and RC5 need to be repaired. If no[ii,iii] component damage hinders achieving the desired recovery state, the repair time to the recovery state in question is zero (e.g., if the maximum repair class across all structural and non-structural components is RC3, the repair time to shelter-in-place is zero).

Table 1: *Recovery state, building condition, and repair class, in descending order of criticality (adapted from Molina Hutt et al, 2022)*

Recovery State	Building Condition[ii]	Repair Class[iii]
Stability	Significant structural and non-structural damage that does not compromise the building stability	5
Shelter-in-place	Moderate structural and non-structural damage that does not threaten the safety of residents	4
Reoccupancy	Cosmetic structural and moderate non-structural damage	3
Functional recovery	Cosmetic structural and minor non-structural damage	2
Full recovery	No damage, pre-earthquake functionality maintained or restored	1

TREADS[iv] permits calculating the following outputs and resilience-based metrics: 1) the recovery trajectory of the building showing the progress of building restoration, or reconstruction, over time; 2) the robustness, or "the ability [of the building] to withstand a given level of stress or demand without suffering degradation or loss of function;"[25] 3) the rapidity, or "the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption;"[26] and 4) the downtime disaggregation to help prioritize design or retrofit interventions to minimize downtime.

In addition to the recovery trajectories, previously illustrated in Figure 2, sample robustness and rapidity outputs are illustrated in Figure 3. While the terms "robustness" and "rapidity" are frequently used to measure the seismic resilience of communities, within the TREADS framework, the terms measure seismic performance of individual buildings. Figure 3a illustrates the probability of not achieving the shelter-in-place

[ii] *Describes the state of the building when the recovery state is achieved.*

[iii] *Indicates the minimum repair class that hinders achieving the corresponding recovery state.*

[iv] *TREADS is fully compatible with the SimCenter's (the computational modelling and simulation center of the Natural Hazards Engineering Research Infrastructure program) tool for loss assessment, PELICUN, an open-source application that implements the FEMA P-58 methodology. Thanks to this compatibility, a user can perform a complete damage, loss, and downtime assessment within a unified workflow. The TREADS framework coded in Python is available as an open-source application at the following Github repository: https://github.com/carlosmolinahutt/treads. TREADS is also available at the Python Package Index (PyPI) and can be easily installed using pip. See A. Zsarnoczay and P. Kourehpaz P, NHERI-SimCenter/pelicun: pelicun v2.5 (Version v2.5), 2021.*

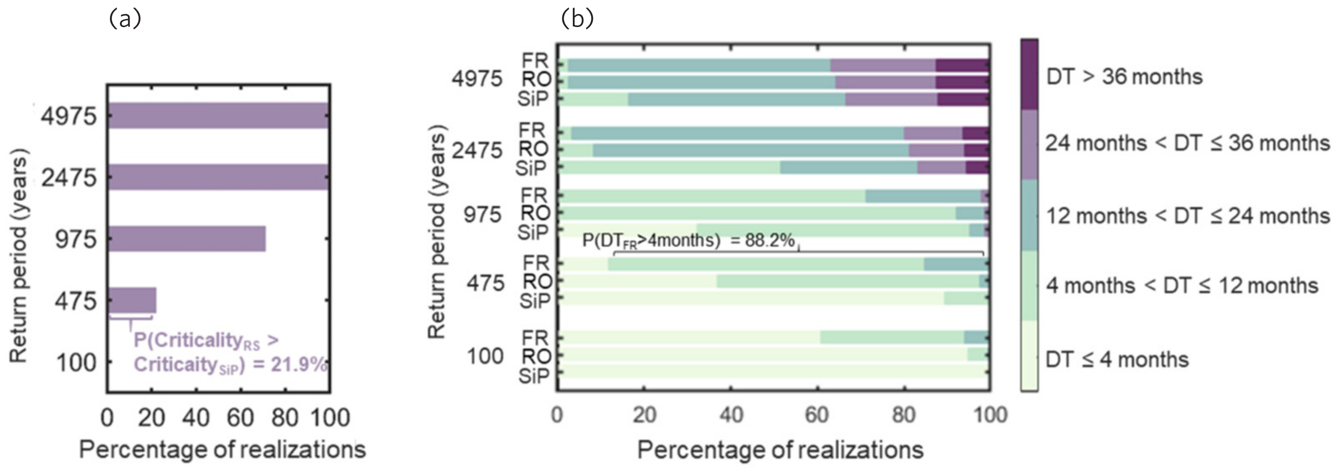

Figure 3: Sample assessment outputs under a range of hazard levels with low to high probabilities of exceedance (high to low return periods) including: (a) Robustness or the probability of not achieving the shelter-in-place recovery state immediately after the earthquake, and (b) Rapidity or the downtime to achieve functional recovery (FR), re-occupancy (RO), and shelter-in-place (SiP) recovery states within specified time frames (adapted from Molina Hutt et al, 2022).

recovery state immediately after the earthquake (ground motions representative of a range of hazard levels with low to high probabilities of exceedance). Figure 3b summarizes the downtime to achieve functional recovery (FR), re-occupancy (RO), and shelter-in-place (SiP) recovery states (also across a range of ground motion shaking intensity levels). If the building design does not conform with the desired performance measures, the framework also provides a disaggregation of downtime that highlights the components that contribute to inadequate performance, thus enabling effective design interventions.

ATC-138-3

As described in the ATC-138-3 Preliminary Report,[27] this methodology[v] for assessing functional recovery time utilizes the architecture of FEMA P-58 to explicitly quantify the loss of building function and the time to restore it. The method defines a new re-occupancy and building function module to the FEMA P-58 process, which maps component-based damage to system-level operations, and system-level performance to tenant and building level re-occupancy and function.

This new logic is implemented as a series of fault trees. In defining recovery time, the framework conceptually adopts the REDi impeding factors and certain aspects of repair scheduling proposed in the REDi guidelines and by Terzic and Yoo in 2016.[28] The recovery states tracked in this methodology are re-occupancy, functional recovery, and full functionality. While the ATC-138-3 definition of functional recovery is consistent with that employed in the TREADS framework, the ATC-138-3 definition of re-occupancy is consistent with TREADS's shelter-in-place, and full functionality in ATC-138-3 corresponds to full recovery as defined in the TREADS framework.

The general approach and logic for assessing building function is illustrated in Figure 4. First, for a building to be functional, the building must be safe to enter and re-occupy. Then, each storey of the building must be accessible, and tenants must be safe from falling and other safety hazards. Finally, tenant units within the building must be able to provide their basic intended functions within the tenant space. As illustrated in Figure 4, in "Stage 1: Building Safety," the building is evaluated for occupant safety hazards that would cause the whole building to be shut down. This check identifies whether damage

[v] The source code associated with the ATC-138-3 methodology is freely available at https://github.com/dcook519/PBEE-Recovery. The computational algorithms have also been implemented by HB-Risk in their SP3 software modules, which are available at www.sp3risk.com.

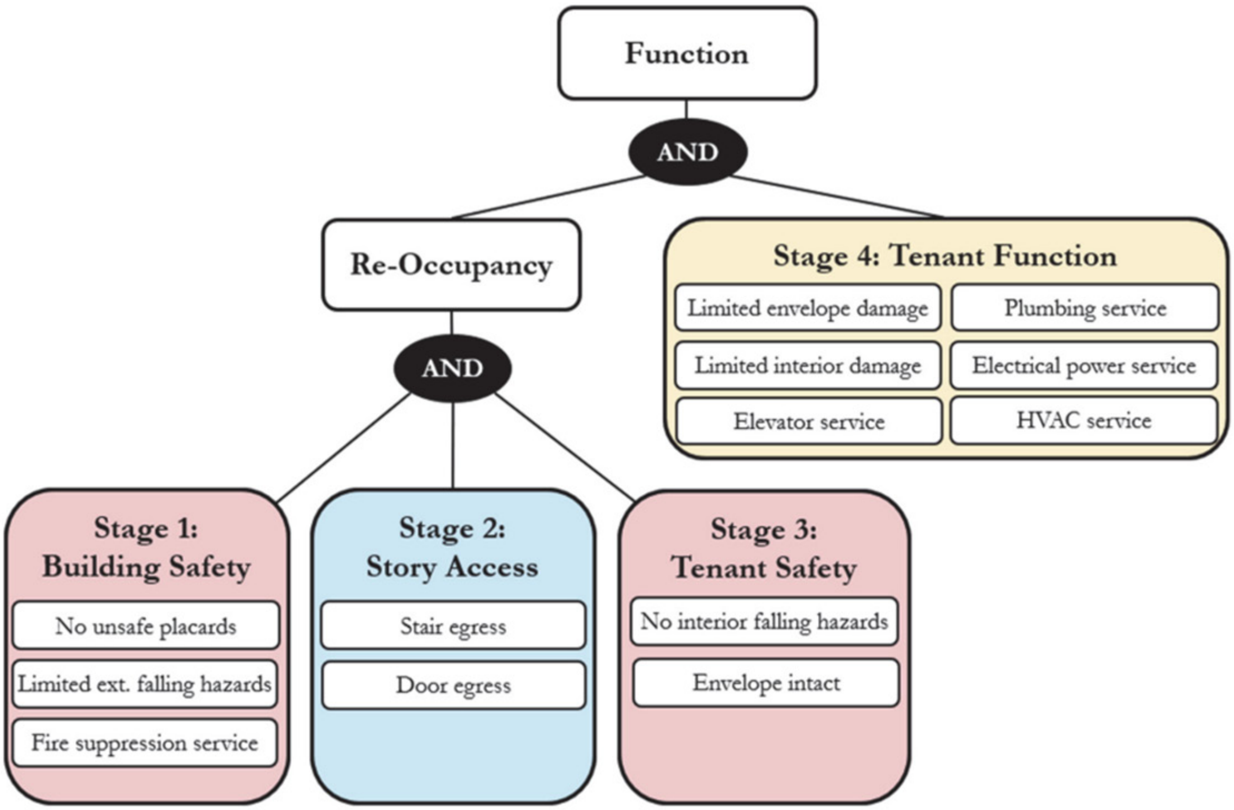

Figure 4: ATC-138-3 logic tree framework for assessing functionality (ATC-138-3, 2021).

exists that can lead the entire building to being classified as unsafe to occupy (e.g., structural safety concerns, external falling hazards). In "Stage 2: Storey Access," each storey is verified for egress and access routes, based on damage to stairways and doors. "Stage 3: Tenant Safety," identifies local safety issues, such as interior falling hazards, in tenant units within the building. Finally, "Stage 4, Tenant Function," checks whether building systems are in a condition such that the tenants can function in the space. Stages 1, 2 and 3 are required for re-occupancy of a particular space. In addition to these, Stage 4 is required for function to be restored.

As outlined in the ATC 183-3 preliminary report, the functional recovery methodology recognizes that building function may imply unique requirements for each tenant within the building, and, therefore, breaks down the building into tenant units and quantifies the functional performance of each tenant-unit individually. Building-level functional performance is quantified as the collection of the functional performance of all tenant units within the building. In each stage, component damage is related to system-level function based on a series of fault trees. These fault trees are used to define the effect that component damage has on the condition or operation of different building systems, based on assumptions as to how the condition or operation of each system affects the re-occupancy or functionality of each tenant unit. In the last stage, the function of each tenant unit is determined based on whether the performance of each system meets, or fails to meet, tenant-specific functional requirements. Figure 5 illustrates a sample fault tree employed to define the performance of the interior system in "Stage 4: Tenant Function." Similar fault trees are employed to assess other building systems, such as HVAC, electrical power, plumbing or elevators.

While the ATC-138-3 preliminary report was recently made publicly

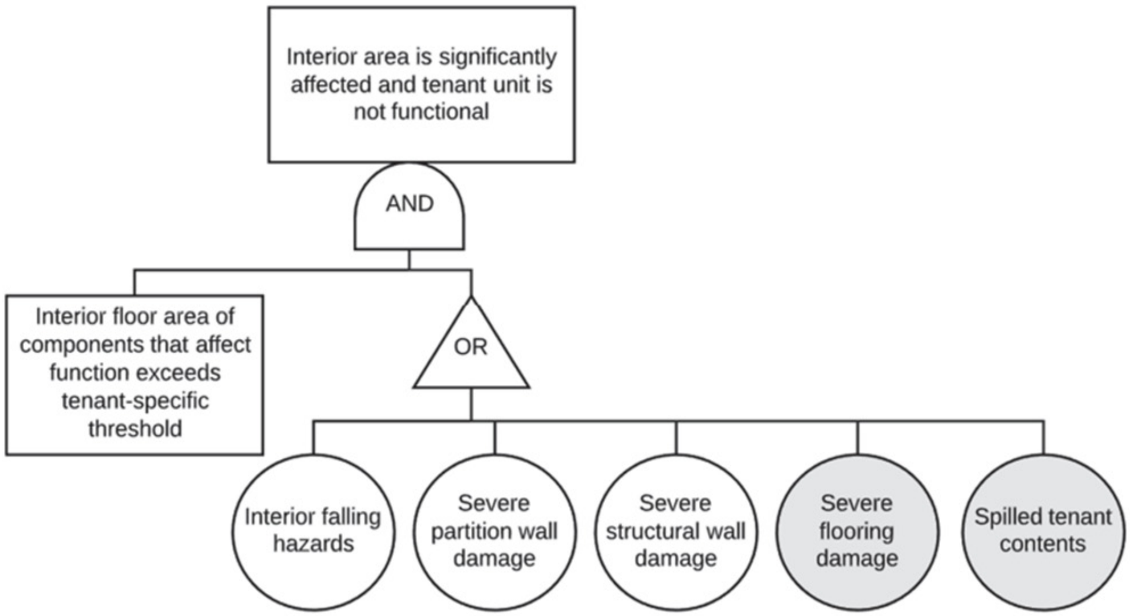

Figure 5: Fault tree defining the performance of the interior system for the Tenant Function stage (Stage 4). Gray events are not currently considered in the framework (ATC-138-3 2021).

available, to date no case studies have been published to demonstrate the implementation of the proposed framework. As new methodologies are developed, there is a clear need for comparative studies that evaluate the functional recovery performance (among other resilience-based metrics) of range of case study buildings leveraging different frameworks to enable moving towards a consensus-based approach.

OPPORTUNITY

PATHWAYS TO IMPLEMENTATION IN BC

The 2015 edition of the National Building Code of Canada,[29] adopted for the most part in the 2018 edition of the BC Building Code and the 2019 Vancouver Building By-law, is an objective-based code with varying earthquake performance objectives according to the importance category of buildings, which are set as a function of intended use and occupancy. For instance, buildings that are essential in the event of a disaster, such as hospitals, are termed "post-disaster buildings" and correspond to the highest importance category. As a result, the seismic design of these buildings includes an importance factor of 1.5. Buildings that are likely to be used as post-earthquake shelter, such as schools, have a high importance category and, in turn, an importance factor of 1.3. By contrast, buildings with a normal importance category have an importance factor of 1. The use of higher importance factors intends to achieve three things: 1) provide reduced damage to the structure; 2) provide reduced damage to elements, non-structural components and equipment (also known as operational and functional building components) and their connections; and 3) minimize residual structural drift by the requirement of reduced peak transient storey drift limits.

The design-level earthquake according to the National Building Code is equivalent to ground motion shaking with a 2% probability of exceedance in 50 years. Despite defining a single design earthquake level, the resulting performance of buildings designed according to this standard could vary widely.[vi]

[vi] *This variation in performance is attributed to the large number of seismic force resisting systems available in the code with different Rd values (ductility-related force modification factors reflecting the capability of a structure to dissipate energy through reversed cyclic inelastic behavior*

The implicit performance objectives of the National Building Code are to: 1) protect the life and safety of building occupants for the code-level earthquake; 2) limit building damage due to low-to-moderate levels of shaking; and 3) increase the chances of post-disaster buildings being functional and occupiable after strong ground shaking.[30] Referring back to the recovery states introduced in Table 1, and considering the range in anticipated seismic performance previously discussed, when subjected to ground motion shaking consistent with the design-level earthquake, buildings with a normal importance category are most likely to achieve stability, high importance category buildings might achieve shelter-in-place, and post-disaster buildings would likely achieve the top range of shelter-in-place nearing the re-occupancy recovery state.

The 2020 edition of the National Building Code[31] introduces additional requirements for post-disaster and high importance category buildings, as well as a subset of buildings with a normal importance category—those with heights above grade greater than 30 metres. These requirements are applicable to structures in areas of moderate to high seismicity, expressed in terms of seismic category in the new edition, and introduce additional design requirements at a lower hazard level (an earthquake more frequent than the design level, with ground motion shaking with a 5%–10% probability of exceedance in 50 years). The additional requirements include ensuring the structure and the connections of operational and functional components (OFCs) behave elastically (no structural damage and undamaged OFC connections), and also includes stricter drift limits that minimize seismic damage to non-structural components at these lower levels of ground shaking. Ultimately, these new requirements reduce the variation in anticipated seismic performance across seismic force resisting systems under the hazard levels considered (because the structure is undamaged) and would implicitly result in seismic performance consistent with the functional recovery state, previously defined in Table 1.

While these new design requirements can bring us closer to achieving desirable recovery states for selected levels of earthquakes, the evolution of codes to further address recovery states will be a slow process as new editions are updated only every five years. Therefore, code efforts should be complemented by the various frameworks presented herein. The availability of these frameworks to estimate downtime to functional recovery (or other recovery states) means that explicit consideration of these performance measures for use in building design is now a possibility. Training of all involved in the building industry on the use of these methodologies, as well as education of and outreach to the general public to enhance their understanding of earthquake risk and recovery-based objectives, is vital to improving how our buildings are designed and constructed.

> The evolution of codes to further address recovery states will be a slow process as new editions are updated only every five years. Therefore, code efforts should be complemented by the various frameworks presented herein.

In BC, there may be unique pathways to the adoption of enhanced seismic design requirements to achieve functional recovery objectives. In contrast with other municipalities in BC, the City of Vancouver via the Vancouver Charter can set its own Building By-law independent from the BC Building Code, and the University of British Columbia has its own Building Regulations that do not need to comply with the BC Building Code. This independence provides an opportunity to raise the bar by enhancing earthquake design and performance requirements and serve as an example for the BC Building Code or the National Building Code of Canada, the latter of which serves as the model code for the provinces and territories. A shift from an

via expected localized damage). For example, a concrete ductile shear wall building with an Rd of 5 will have a different performance compared to a steel concentrically braced frame with an Rd of 2. While all of these systems meet the minimum requirements of the code, they perform in very different ways in terms of their anticipated ductility and damage level.

implicit to a more explicit verification of a building's seismic performance would also align with other current efforts considering a transition from objective-based to performance-based building codes.

While such shifts in our design philosophy may be foreign to some, there already are examples of projects in BC that utilized the tools presented here. For instance, the FEMA P-58 methodology is currently being used in the high-profile St. Paul's Hospital project in Vancouver, where design requirements include specific FEMA P-58 metrics (repair costs, repair times, etc.) for different levels of shaking, introduced as part of a rezoning condition.[32] The outputs of the FEMA P-58 assessment are provided to help the owner understand the expected damage state of building components on a floor-by-floor basis and the potential impacts on building occupancy and functionality. Similarly, the University of British Columbia is utilizing the REDi rating system to provide guidance to project teams in achieving resilience, and UBC has ongoing retrofit projects that aim to achieve a high resilience level of "immediate occupancy" following a major earthquake.[33]

FEMA P-58 AND REZONING ST. PAUL'S HOSPITAL

As part of the City of Vancouver's rezoning process for the new St. Paul's Hospital (Figure 6), a "Resilience Rezoning Condition" was created. This condition required the proponent to perform a climate risk assessment and a seismic assessment to inform facility design and operations with the goal of advancing likely post-disaster building functionality (and patient safety) in response to the impacts of both climate change and seismic events.

Figure 6: Concept of the new St. Paul's Hospital in Vancouver (Illustration: flickr/Province of BC).

The climate assessment followed a hybrid methodology of the PIEVC protocol, Climate Lens, ISO 31000 Risk Management, and the ICLEI BARC tool. FEMA's P-58 standard was used for the seismic assessment—a first for a hospital in Canada.

Outputs of this seismic assessment exceeded the resolution of the BC Building Code by providing proxies for the building's likely functionality (e.g., seismic damage, repair costs and repair times) following a major earthquake. This form of seismic assessment, performed during the design process of new buildings, is a potential strategy to advance high-performance buildings more broadly. The process of assessment provides design teams and developers invaluable information so that they may make performance-based design decisions to meet functionality expectations within, but also possibly above and beyond, the life-safety protection minimum requirement currently in the code.

RECOMMENDATIONS

Table 1: Recommendations

Recommendation	Description of Impact	Priority Level	Capabilities Needed
1. Train all involved in the building industry on the use of these methodologies; educate and engage with the public to enhance their understanding of earthquake risk and recovery-based objectives.	Training enables the delivery of building projects in which the expected seismic performance of buildings expressed in terms of their functional recovery is explicitly verified. Outreach results in direct demand from end-users (building owners and occupants) for buildings with enhanced seismic performance.	Critical	Technical and financial
2. Raise the bar by enhancing earthquake design and performance requirements.	The ability of the City of Vancouver and UBC to set their own bylaws independent of the BC Building Code or the National Building Code of Canada, which serves as the model code for the provinces and territories, provides a unique opportunity to raise the bar by enhancing seismic design and performance requirements.	Critical	Leadership
3. Shift from objective-based to performance-based design.	Shifting from the current implicit verification of a building's seismic performance (i.e., building meets code) to an explicit verification of performance (e.g., the building will take five days to achieve functional recovery after a major earthquake) will enhance our understanding of earthquake risk and will engage end-users (building owners and occupants) in defining the desired seismic performance of buildings.	Recommended	Technical and legislative (reflect in code)

CHALLENGES

Addressing the following three challenges will be necessary to advance the functional recovery of buildings.

1. **Cost:** The cost associated with the design of buildings to achieve enhanced seismic design requirements is a known challenge. But case studies[34] and research[35] suggest that the cost premium is small and there is a benefit to raising the bar if one were to consider costs from a lifecycle perspective as opposed to simply upfront or initial design and construction costs.

2. **Reaching a consensus-based approach:** New frameworks to evaluate downtime and functional recovery performance of buildings are just that—very new; they require a large number of assumptions and are yet to be tested or assessed against empirical data collected after major earthquakes, which allows us to check how our analysis results compare to reality. As a result, it will take time for the engineering community to embrace these new concepts and, more importantly, to reach consensus on how to conduct these assessments to ensure

consistency in our approach. The slow evolution of codes referenced in the article is in part related to this notion of the difficulty in reaching consensus.

3. **Existing buildings:** While adopting these design requirements and procedures for new building design might be challenging, applying these to existing buildings raises an even greater challenge. Existing buildings need only comply with the requirements of the code at the time they were designed and constructed. Updated editions of the building code are not applied retroactively to existing buildings. Therefore, the seismic upgrade of existing buildings could be costly and difficult to implement other than on a voluntary basis.

Training of all involved in the building industry on the use of these methodologies, as well as education of and outreach to the general public to enhance their understanding of earthquake risk and recovery-based objectives, is vital to improving how our buildings are designed and constructed.

RESOURCES

INTERNATIONAL

1. More information on the key frameworks discussed:

FEMA P-58

FEMA. *Seismic performance assessment of buildings FEMA P-58.* Washington, DC: Federal Emergency Management Agency, 2012. https://femap58.atcouncil.org/documents/fema-p-58/24-fema-p-58-volume-1-methodology-second-edition/file.

REDi

Almufti, I. and M. Willford. "REDi™ Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings." San Francisco: Arup, 2013. https://www.redi.arup.com/.

TREADS

Molina Hutt, C., T. Vahanvaty, and P. Kourehpaz. "An analytical framework to assess earthquake induced downtime and model recovery of buildings." *Earthquake Spectra* (2022, in press). https://journals.sagepub.com/doi/full/10.1177/87552930211060856.

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2. White paper on functional recovery:

Earthquake Engineering Research Institute (EERI). "Functional Recovery: A Conceptual Framework with Policy Options." Oakland: EERI, 2019. https://www.eeri.org/images/archived/wp-content/uploads/EERI-Functional-Recovery-Conceptual-Framework-White-Paper-201912.pdf

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[11] FEMA, "NEHRP recommended seismic provisions for new buildings and other structures FEMA P-2082" (Washington, DC: Federal Emergency Management Agency, 2020).

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