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A Guide to Implementing **Systems-Based Approaches to Climate Resilient Infrastructure**

Infrastructure Canada (INFC) and
the BC Ministry of Transportation
and Infrastructure (BC MoTI)

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Contents

List of Worksheets

1 Introduction

This guidebook is intended to be used by climate practitioners; infrastructure planners, engineers and architects; government agencies of all levels; and private organizations to enhance and standardize systems-based approaches (SBA) to climate resilient infrastructure. It aims to:

- Provide readers with an introduction to SBAs,
- Demonstrate how SBAs can be used to **support climate-resilient planning and assessments** in practice, with worksheets that show how tools and techniques can be applied, and
- **Incorporate climate resilience into the business case process** used to support investment decisions.

Need for this Guidance

Policymakers are often required to develop solutions for systemic problems – those which affect systems that involve many interconnected components. Even in the simplest systems, individual components can interact with each other in unpredictable ways; in more complex systems it can prove increasingly challenging to directly link one specific cause to a corresponding effect, or to determine the exact consequences of an earlier policy change.

This is especially true when it comes to infrastructure systems affected by climate change. For example:

- Small variances in the input parameters used by a climate model can have a significant effect on that model's output, particularly when examined over time.
- Failure of one infrastructure asset during a climate event could have cascading effects throughout other interrelated assets. For example, the washout of a main highway during a flooding event may cause overuse of the secondary highway and bridges not intended for the high volumes or excessive loads diverted to it. This could shorten the lifecycle of these interrelated assets or cause them to fail entirely, cutting entire communities off from necessary goods and services.
- Various seemingly unrelated factors occurring concurrently during a climate event may exacerbate the impacts of the event. For example, a forest fire in previous years may not, at first, seem related to flooding in the area. However, with fewer trees able to take up and store water during times of heavy rainfall, much of the precipitation will not be absorbed by the soil and can increase chances of flooding in these areas.
- The frequency and manner of maintaining a critical piece of infrastructure can influence its vulnerability to future climate risks. For example, if cleaning highway culverts lack maintenance, the capacity of the culvert can be compromised by build-up of debris and sediment, which makes the culvert more vulnerable to washing-out the highway in an extreme precipitation event.

Building climate change resilience in an effective and sustainable way requires a whole-of-society effort via a SBA. Systems can be defined as a cluster of various structural and non-structural elements that are connected and organized to achieve specific objectives – they are multi-level, multi-actor, and complex. SBAs look beyond individual assets to consider the interrelationship between the elements and among the clusters, which involves physical systems, such as upstream hydrology, and human systems. A SBA would frame adaptation solutions to account for interdependencies, interconnectivity, as well as cascading impacts through strong and coordinated governance, inclusive planning processes, and flexible pathways that seek to anticipate adverse consequences. In the context of resilient infrastructure, SBAs ensure that solutions account for the spectrum of social, economic, environmental, political, and historical factors that contribute to individual and community vulnerability and consider the multiple scales in which infrastructure systems may cut across, from jurisdictions to ecosystems to watersheds, and beyond, including transboundary.

SBAs also encourage users to think systemically about the problems they are trying to solve. This guidance offers a formalized framework that users can introduce or use to modify their existing processes to incorporate SBAs.

1.1 Introduction to Systems-Based Approaches

Infrastructure in our built and natural environment is complex. To better understand the workings of any complex system, it is often helpful to break it down into simpler parts. For example, the human body is a complex organism, so when defining a problem, it can prove beneficial to consider the body as the combination of separate, simpler systems (the respiratory system, the digestive system, the circulatory system, the nervous system, etc.). A doctor specialising in a particular field of medicine may then isolate one system in order to make a diagnosis; however, any resulting treatment plan must be tailored to take into account the health and wellbeing of the individual as a whole.

Systems thinking provides a framework that helps users identify the interconnections within and between individual system components, with a goal of simplifying complex systems into models that are more easily understood, or those which provide a more holistic view of the wider system.

> A systems-based approach can be used to highlight complexities within one or more subsystem by mapping how changes to one system can result in impacts felt elsewhere (interdependencies), or by showing how an external event can cascade throughout a system and other connected systems.

Using Systems-Based Approaches to support Climate Resilience Planning and Assessment

A SBA can be applied to identify ways to make infrastructure more resilient to a changing climate. This guidebook describes (and links to) some of the more commonly used systems-based tools and techniques.

The successful application of a SBA to climate resilience requires input from a group of experts and community members: to develop a system map; and to provide insight, test theories, and validate assumptions. Depending on the project details, this group may include technical specialists, those with knowledge of historic events affecting the local community, individuals with subject matter expertise, or people with the practical, hands-on experience of operating and maintaining a system and its assets.

This approach - which first requires the group to form a consensus around the purpose - helps to ensure that the scope of the work and the topics being investigated accurately reflect the issue at hand, and that any interdependencies between the affected systems are fully understood and factored into the resultant recommendations and corresponding action plan.

Incorporating Climate Resilience into Business Case decisions

Implementing climate adaptation and risk mitigation options requires funding. Obtaining it often requires a detailed business case, as there typically exist competing priorities (beyond increased resilience) for investment.

A business case process allows alternative options to be directly compared against various criteria (including cost and resilience) and forms an essential part of many decision-making processes. This guidance provides worked examples to demonstrate how a SBA and climate risk assessments (CRAs) can be incorporated into the BC MoTI's business case process.

1.2 Background

The Government of Canada published the first National Adaptation Strategy (NAS) in June 2023, following two years of engagement with provincial, territorial, and municipal governments; First Nations, Inuit, and Métis Nation representatives; key experts and stakeholders; and people from across Canada. The Strategy is framed around five key priority areas (or systems) that make up the backbone of our society, including the Infrastructure System with the following transformational goal:

Beyond climate resilience planning and assessment, SBAs can also be leveraged for disaster management. The paper **Systems Approach to Management of Disasters – A Missed Opportunity**? explores how knowledge and systems science can be deployed to improve disaster management in the face of rapid climate destabilization, and the potential to deploy SBAs for effective disaster management that are based on simulation, optimization, and multi-objective analyses. The paper claims the institutional context means the Canadian approach for disaster management is "decentralized, fragmented and subject to incremental lawmaking. This makes it difficult to address serious disaster management decisions in a comprehensive, holistic (systematic) fashion", and goes on to discuss how systems approaches can be leveraged to improve disaster management, recognizing that disasters often result from failures within one or more of the following three major systems:

- The physical environment
- The social and demographic characteristics of the communities that experience them
- Buildings, roads, bridges, and other components of the constructed environment.

The paper includes several case studies to show how SBAs have been used in disaster preparedness and modelling and concludes with recommendations on how these can contribute towards creating a national disaster management strategy.

> "By 2050, all infrastructure systems in Canada are climate resilient and undergo continuous adaptation to adjust for future impacts, to deliver reliable, equitable, and sustainable services to all of society".

The Infrastructure System also includes advice that encourages SBAs to infrastructure. The Infrastructure System was informed by an expert Advisory Table that highlighted the importance to expand beyond traditional asset-focused management to consider interdependencies and impacts that cross systems, sectors and jurisdictions. The proposed five medium-term objectives from the Resilient Natural and Built Infrastructure Advisory Table, which informed the final advice in the NAS, cover the following themes:

THEME	OBJECTIVE: BY 2030...
Technical	Technical standards have been raised for easier adoption and climate change resilience is skillfully embedded in all decisions to locate, plan, design, manage, adapt, operate, and maintain infrastructure systems across their lifecycle
Financial	A robust investment framework is in place to purposefully guide the allocation of sufficient public and private funds towards low-carbon climate-resilient infrastructure, maximizing the long-term benefits of infrastructure investments
Policy and Legal	All levels of government utilize a coherent and integrated, community-informed policy and regulatory framework to drive resilience in public and private infrastructure decision-making
Socio-Economic	Climate-resilient infrastructure systems support the health and well-being in communities most-at-risk and secure economies, with a particular emphasis on prioritizing benefits and eliminating funding gaps for marginalized populations and those in high-risk areas
Governance and Institutional	There are clear and coordinated responsibilities within and between jurisdictions, including with Indigenous communities, to effectively and cooperatively implement climate adaptation best practices and solutions that account for the unique needs and context across the country

Building upon the NAS, the Government of Canada, as well as provincial, territorial, and local governments, and Indigenous communities, are advancing systems-based work to accelerate climate change adaptation, recognizing a need to better understand best practices in planning, designing, and implementing solutions, with a focus on current priorities regarding the long-term recovery, rebuild, and enhanced climate adaptation and response measures following the impacts of severe weather events. Lessons learned from these post-disaster situations could be applicable to other contexts and levels of systems, from community to national-level, and help inform what a SBA looks like for resilient infrastructure across Canada.

1.3 Using the Guidebook

This guidebook makes recommendations of SBAs to climate resilient infrastructure that are scalable and flexible, providing users with the skills and tools necessary to include systems thinking when developing their climate resilience plans.

The document explains the concept of systems thinking with theory and examples and provides users with a practical understanding of how SBAs can be deployed to support CRAs and inform climate resilience planning.

Within this guidance:

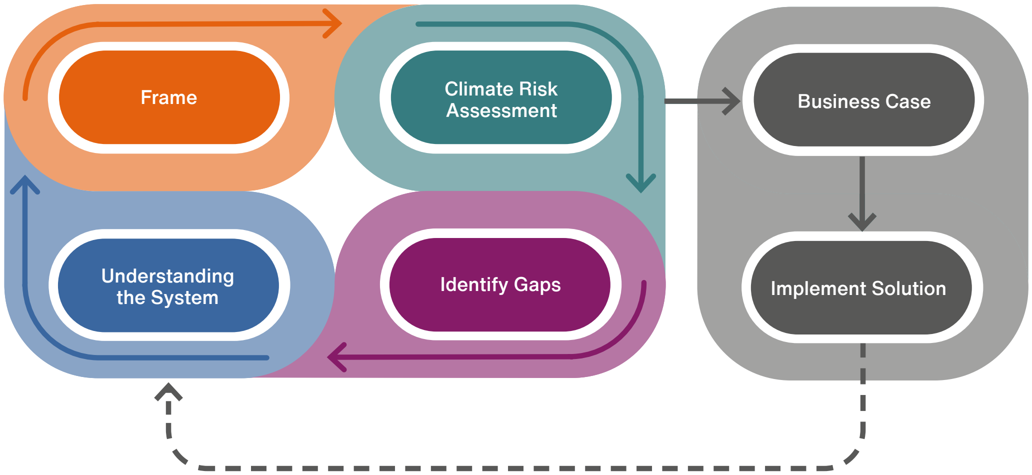
- Key concepts are defined, using terminology in a consistent way to ensure readers develop a robust understanding of the core principles and methods.
- An existing, completed CRA (conducted on behalf of the Kasabonika Lake First Nation community) is used as an example to showcase how the guidance can be applied to a real-world scenario and how SBAs enhance traditional approaches for CRAs.
- Blank worksheets are provided for users to apply the techniques and methods described in this guidance to their own projects.
- Links are provided to additional resources, supporting literature, and other sources of useful information.
- At the end of each chapter, a completion check-in is provided for users to confirm they have completed they key steps in the process.

Icons are used to highlight key pieces of information:

ICON	KEY	DEFINITION
	Theory	Used to introduce and explain the key concepts which underpin this guidance.
	Action	Highlights a critical step in the process where an action is required.
	Worksheet	Provided to support users in applying the techniques and methods described in this guidance to their own projects.
	Consult	Used to indicate when discussions with stakeholders and subject matter experts often prove beneficial.
	Resource	Links to useful resources which complement the material in this guidebook.
	Illustrative Example	Examples used to illustrate specific concepts.

Guidebook Overview

The material provided in this guidebook is structured around a circular process with a branch, as shown in the diagram below. Each topic is covered in detail within a separate chapter of the guidebook.



Note: The "Implement Solution" step is beyond the scope of the guidebook but will be briefly mentioned in the concluding chapter. In practice, implemented solutions could be re-evaluated using the steps in the guidebook for monitoring, evaluation, reporting, and continuous improvement.

The process shown can start at either the **Understanding the System** or **Climate Risk Assessment** steps. As this guidebook is aimed at users less familiar with systems thinking, the process begins in Chapter 3: Understanding the System. Users with an existing **Climate Risk Assessment (CRA)** can start with Chapter 5, and follow the same process shown above, using systems thinking to identify gaps and refine their understanding to enhance their original results.

Chapter 3: Understanding the System describes how SBAs can be used to develop a deeper understanding of the system in question, which is critical to ensuring the right participants are involved.

Chapter 4: Framing the Results describes how the step of Understanding the Systems can be framed in a way that enables it to be used as part of a CRA.

Chapter 5: Performing a Climate Risk Assessment provides users with guidance on integrating the output of the previous steps, developed using systems thinking tools and techniques, into a CRA process that leverages existing CRA tools and processes.

Once a CRA is completed, the results can serve to identify additional linkages between individual system elements or highlight gaps in the collective understanding of the system. **Chapter 6: Identifying Gaps** addresses linkages between elements in a system by providing techniques that can reveal additional risks or vulnerabilities, capturing any missing items to be included in a subsequent CRA.

The BC MoTI Business Case process, which contains a Multi Criteria Assessment (MCA) and a Multiple Account Evaluation (MAE), is used to show how SBA can be incorporated into an existing decision-making process.

By this stage in the process, any list of potential climate risk mitigation measures will require a decision on which measures to prioritise. Although developing ways to monetize the costs and benefits of each specific risk mitigation measure lies outside of the scope for this guidebook, **Chapter 7: Business Case** describes how elements of the CRA can be incorporated into a Business Case evaluation process, using quantified costs and monetised benefits that allow for easier comparisons between options, a key consideration when making investment decisions.

This guidebook provides users with examples to show how SBAs can be used to improve climate resilience, while also recognizing there is no 'right or wrong' way to apply the methods described.

1.4 Glossary of Key Terms

TERM	DEFINITION
Adaptive Capacity	The ability of the system or element to adjust to potential damage, take advantage of opportunities, or respond to consequences
Climate Parameter	A broad category of measurable climate conditions, such as temperature or precipitation
Climate Hazard	A type of event with ability to impact one of the climate parameters, such as extreme heat or drought
Climate Hazard Indicator	A quantifiable climate threshold, determined by the expected impact on an infrastructure system or component, such as temperature exceeding a set threshold
Element	The physical and functional dimensions of the system that will be assessed. Depending on the granularity of the assessment, an element could be a very specific component of an asset (mechanical system, walls, roofs of a building) or a type of infrastructure asset (roads, storm sewer systems, emergency-service buildings, schools)
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected
Hazard	Something with the potential to cause harm under the right circumstances
Infrastructure	System of facilities, equipment, and activities needed for the operation of an organization or society. In the context of this guidebook, infrastructure includes both built as well as natural assets
Interdependency	When two or more components are reliant on each other
Resilience	The capacity of social, infrastructure, economic and ecological systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in the case of ecosystems while also maintaining the capacity for adaptation, learning and transformation
Risk	Effect of uncertainty on objectives. This guidebook quantifies risk as the product of exposure, vulnerability, and the likelihood of a hazard occurring
Sensitivity	The degree to which a system or element is affected when exposed to a hazard
System	A collection of many parts which function synergistically together as a whole
Systems Map	A visual tool that shows the connections and dependencies between the individual components of a system
Systems Thinking	The practice of understanding how systems create the patterns and events seen around us
Variable	Components in a systems map that increase or decrease and affect another component in the system
Vulnerability	The propensity to be adversely affected. Encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt, and can be individual or compound: • Individual Vulnerabilities arise from the direct interaction of the element with the climate hazard, and do not take into account the interdependencies between elements • Compound Vulnerabilities arise from the interdependencies between elements and cascading effects associated with the failure of one element impacting another element

1.5 Acronyms and Abbreviations

ACRONYM	DEFINITION
ALR	Agricultural Land Reserve
BARC	Building Adaptive and Resilient Communities
BC MoTI	British Columbia Ministry of Transportation and Infrastructure
BOT	Behaviour Over Time
CDD	Cooling Degree Days
CRA	Climate Risk Assessment
CREAT	Climate Resilience Evaluation and Awareness Tool
CRI	Climate Risk Institute
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FN	First Nations
FSB	Financial Stability Board
GIS	Geographic Information System
HAZUS	A risk modeling methodology used to identify areas exposed to natural hazards, and estimate the physical, economic, and social impacts of events such as earthquakes and floods.
HLSG	High Level Screening Guidance
HRVA	Hazard, Risk and Vulnerability Analysis
HVAC	Heating, Ventilation, and Air Conditioning
ICLEI	International Council for Local Environmental Initiatives, aka Local Governments for Sustainability: a global network of more than 2500 local and regional governments committed to sustainable urban development
ICLR	Institute of Catastrophic Loss Reduction
INFC	Infrastructure Canada
IPCC	Intergovernmental Panel on Climate Change
IRT	Infrastructure Resilience Toolkit
ISO	International Organization for Standardization
KLFN	Kasabonika Lake First Nation
MAE	Multiple Accounts Evaluation
MTO	Ministry of Transportation, Ontario
NRCAN	Natural Resources Canada
OECD	Organisation for Economic Cooperation and Development
OFNTSC	Ontario First Nations Technical Services Corporation
PIEVC	Public Infrastructure Engineering Vulnerability Committee
RCP	Representative Concentration Pathway (a climate projection scenario)
SBA	Systems Based Approach
SSP	Shared Socioeconomic Pathway (a climate projection scenario)
TBL	Triple Bottom Line: an accounting framework with three parts: social, environmental (or ecological) and economic
TCFD	Task Force on Climate-related Financial Disclosures

How Systems Thinking Differs from Other Types of Thinking

LINEAR THINKING is the simplest type of thinking. It involves making a single link between a cause and an effect to identify a solution to every problem, with a one-to-one relationship. For example: A problem (this house is too cold) can be linked to a cause (the furnace is not lit) and a corresponding effect (the temperature has decreased) in order to identify a solution (I should light the furnace).

While linear thinking can provide a method of quickly identifying solutions, it is not usually appropriate for complex systems which feature many interconnected components. This is due to the potential for unintended consequences to emerge if a solution is designed that only addresses one part of a larger problem. In the above example, the problem of a cold house may have other causes; it would be sensible to ensure all of the external doors and windows are closed before adjusting the thermostat and increasing fuel consumption.

EVENT-ORIENTED THINKING models the world as a series of events: where an event is something that either has happened, or is going to happen. One event follows another – if X happens, then Y will be the result. Example: if you eat less, you will lose weight as a result.

Event-oriented thinking is logical, which can make it easier to understand and apply, but like linear thinking, it is not good at handling complex problems or systems, or events that can have multiple causes. In the above example, it is not just the amount of food consumed that affects a person's weight, but the nutritional value of the food eaten, the age and metabolism of the person eating it, the amount of exercise they perform, etc.

LATERAL THINKING was deliberately developed as a way to counteract the brain's natural preferences to apply the more logical linear or event-oriented thinking approaches. Lateral thinking involves the use of creative techniques to generate new or innovative ideas, or to find novel solutions to problems, beyond those that are already familiar.

One key trait of lateral thinking methods is that initially, all contributions are welcomed, and no ideas are rejected. This helps to maintain a positive environment that encourages 'blue sky' thinking amongst participants and contributors, but a consequence of the less-structured approach is that time and effort can be spent pursuing ideas and solutions which are either not practical, or which are not relevant to the objective in question.

CRITICAL THINKING requires a deeper level of reflection, where facts and data can be objectively analysed to eliminate any bias involved in reaching a decision. It features a systemic approach to solving a problem, and often includes analysis or reasoning to demonstrate that each assumption is supported by sufficient evidence. Critical thinking requires a solid understanding of the issues being addressed, in order to identify logical connections between different items, or to challenge the current understanding. One major challenge to applying critical thinking is finding individuals with sufficient understanding of the (usually complex) problem, who are not wedded to the existing ways of working or reliant on outdated concepts, and who are able to identify and propose workable solutions to the problem.

SYSTEMS THINKING is the study and analysis of a system: where a 'system' is defined simply as a group of interconnected parts that work together toward a common purpose or function. Successful systems thinking requires an understanding of the different components of that system, the interconnections between them, as well as the overall purpose or function of a system, in order to describe how the system works, and to identify possible improvements in the function of that system, as well as mitigate any risks that could prevent the system from working as intended.

By focusing on the connection and relationship between a system's parts, rather than on the parts in isolation, systems thinking can help us view the world in a different way, and develop novel solutions to address hypothetical future conditions. For example, combining data sets to reveal previously unseen patterns in behaviour, or considering the longer-term consequences of taking a particular course of action with a wide group of stakeholders in the form of 'what if?' scenario modelling, are examples of how systems thinking helps us to both understand what exists today, as well as design better systems in future.

Content for this section was adapted from: Thinking in Systems: A Primer (2008), by Donella H. Meadows. Diana Wright (ed.)., The Systems Bible by John Gall (2002), The Fifth Discipline by Peter Senge (2006) and The Art of Thinking in Systems by Steven Schuster (2021)

2 Getting Started

Before starting, it is important to decide whether a SBA is appropriate for the project at hand. There may be situations where the additional effort and resources required to apply a SBA are not justified, and it is therefore important that users of this guidebook have a clear understanding of the objectives of their project. Outlining the objectives of the project also informs assembly of an appropriate project team to deliver it.

Purpose: The purpose of this chapter is to describe the steps needed to determine whether adopting a SBA is appropriate, and if so, to lay the groundwork to set up a project that incorporates systems thinking.

Intended outcomes: By the end of this chapter, users will be able to:

- Understand when a SBA would be required.
- Articulate the purpose and objectives of the assessment.
- Make an initial estimate of the resources needed to implement the project.

2.1 Understand the Purpose and Objectives

Before proceeding through this guidebook, the project team should have a well-defined scope and objectives. This step helps to ensure the objectives of the overall assessment are aligned with the wider project outcomes. In some cases, a SBA may not be well-suited for the project at hand, including very small or isolated infrastructure projects with limited budgets.

Some examples where a systems-based climate-resilient infrastructure assessment may be required:

- To identify vulnerabilities in existing complex infrastructure systems.
- To evaluate the resilience of new infrastructure designs considering the interdependencies of components.
- To develop strategies for adapting to future risks that take into account the interdependencies of infrastructure.

2.2 Assess the Project

The project team should assess the scope and scale of the project. A SBA is most effective when dealing with complex and interconnected systems, where multiple components and factors interact with each other. Projects involving simpler systems or those with minimal interactions are unlikely to warrant the level of complexity that a full, systems-based analysis requires, and other tools may be more appropriate.

Examples of the type of projects likely to benefit from a SBA:

PROJECT SCOPE	BENEFITS OF USING A SYSTEMS-BASED APPROACH
Projects that deal with multiple climate hazards or other large-scale emergencies	SBAs can help to effectively coordinate efforts across multiple departments, organizations, and agencies, and to efficiently deploy resources.
Projects that address environmental sustainability	SBAs help identify the complex relationships between different ecological systems and the human or socio-economic activities that impact them, resulting in more effective strategies for mitigating the impacts of climate change and other environmental threats.
Projects involving changing circumstances or where the situation is complex	SBAs enable interrelated factors to be considered, and their future compounding effects to be estimated using models that are based on predicted values.

Resilience to climate change is not only measured by the ability of an asset to withstand a specific hazard, but by whether the infrastructure as a whole is able to recover and adapt in a way that maintains (or improves) service levels. As SBAs help to identify and visualise the interdependencies between different components of a system, they are valuable for projects which involve an assessment of the impacts of climate change.

2.3 Assemble the Core Team

As with many projects, a successful outcome relies on integrating contributions from individuals who are not part of the core team leading the assessment. Climate resilience is best achieved through a collaborative process: where the insight brought by subject matter experts (SMEs) on specific topics is captured, and their knowledge and expertise are applied using a comprehensive understanding of the underlying project scope. This results in a shared understanding of the problem, approach, findings, and recommendations. Collaboration across departments and agencies is also an important part of the process.

To ensure that the process described in this guidance is implemented effectively, the responsibilities outlined in the table below may be assigned to members of the core project team. Any requirements for SMEs and other specialists to provide input to the project will vary according to the project scope. Opportunities for SMEs to contribute are noted at relevant places throughout this guidance.

CORE TEAM MEMBER	RESPONSIBILITIES
Project Manager (PM)	Typically, the PM works for the organization doing the assessment, and is responsible for starting the project, managing its execution and logistics, and for coordinating work between different disciplines.
Facilitator	A specialist in applying the process. This person facilitates workshops and develops supporting materials; leads the analysis and subsequent discussions; and coordinates the development of final reporting materials. This individual can be internal or external, but there should only be one.
Organization Champion(s)	A “specialist(s)” in the organization, with extensive historical knowledge of the asset(s) under study; able to speak in broad terms to most aspects of the organization's assets and operations, and identify sources for missing information.

A kick-off meeting between core team members can be used to agree on the project scope, define individual roles and responsibilities, and identify any need for additional participants

How much effort will it take to complete this guidebook?

The amount of effort and time that it will take to complete all the chapters will vary greatly depending on the complexity of the project, number of SMEs and stakeholders involved, availability of past studies and data (such as a completed CRA) as well as experience of the core team. In the case of a simple assessment where a CRA exists, it is likely that developing and analysing the system could take at least two days workshopping with a minimal number of participants; with more participants more time is needed to have sufficient time for all participants to contribute.

More days for workshopping may be necessary if a CRA does not previously exist. Preparations for a CRA would depend on the need for a high-level assessment with minimal subject matter experts, or a detailed assessment with multiple disciplines and in-depth analysis. Several hours of effort could also be expected to gather climate data at a high level, and into the hundreds of person-hours if an extensive and more robust climate profile is necessary.

CHAPTER 2 CHECK-IN

Has the core project team:

- [ ] Identified the purpose and objectives of the assessment?
- [ ] Identified the team members?
  - Project manager
  - Process facilitator
  - Organization champion(s)
- [ ] Set up a kick-off meeting?

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

Kasabonika Lake First Nation (KLFN) is a remote community, which is home to around a thousand people and is located ~580 km north of Thunder Bay, Ontario. For most of the year, access and egress is only possible via aircraft, using a 1,100m gravel airstrip operated and maintained by the Ontario Ministry of Transportation (MTO); although each winter a temporary ice road is constructed which allows for the movement of heavier items, such as construction materials.

The location is extremely vulnerable to the impacts of climate change. Rising temperatures cause shorter ice road seasons, and coupled with higher precipitation levels, increase the risk of springtime flooding, while hotter, drier summers increase the likelihood of forest fires.

A climate change risk assessment was carried out for this community using the First Nations Infrastructure Resilience Toolkit (FN-IRT). This assessment identifies infrastructure vulnerabilities, and provides recommendations for adaptation strategies to mitigate risks.

The CRA conducted for KLFN will be cited throughout this guidance as an application example, and used to highlight key features of a SBA and illustrate how they can be applied in practice.

3 Understanding the System

This chapter introduces the main aspects of systems thinking, defines the key terms, and outlines the benefits.

Often, the best way to begin understanding a system is to visualise it. A systems map is a visual tool that shows the connections and dependencies between the individual components of a system, provides a common framework and shared understanding of how the system works, and encourages the identification of patterns or gaps where changes (i.e., adaptations to climate change) could be introduced.

Infrastructure assets and systems depend on each other, often with critical connections between them which may be overlooked if not mapped. Professionals responsible for these systems may consider that the infrastructure will continue to provide the required service as long as it is maintained in a state of good repair. However, one aspect of resilience that can easily be overlooked are the impacts on the infrastructure from other components of the system that support it - interdependencies. This chapter includes tools that are helpful in building the skill set required to create a systems map, show the interdependencies between components, and identify the critical variables of a system.

Sections 3.1 through 3.4 are designed to equip guidebook users with the necessary knowledge and skill sets related to systems thinking in the context of resilience assessments, while Section 3.5 is designed as a practical walk-through for applying the concepts. Section 3.1 provides the background and foundation for systems thinking; Section 3.2 helps users identify and select the right tool; Section 3.3 introduces the concept of interdependencies; and Section 3.4 teaches users how to develop causal loop diagrams. Section 3.5 shows how the knowledge developed during earlier sections can be used to create a systems map.

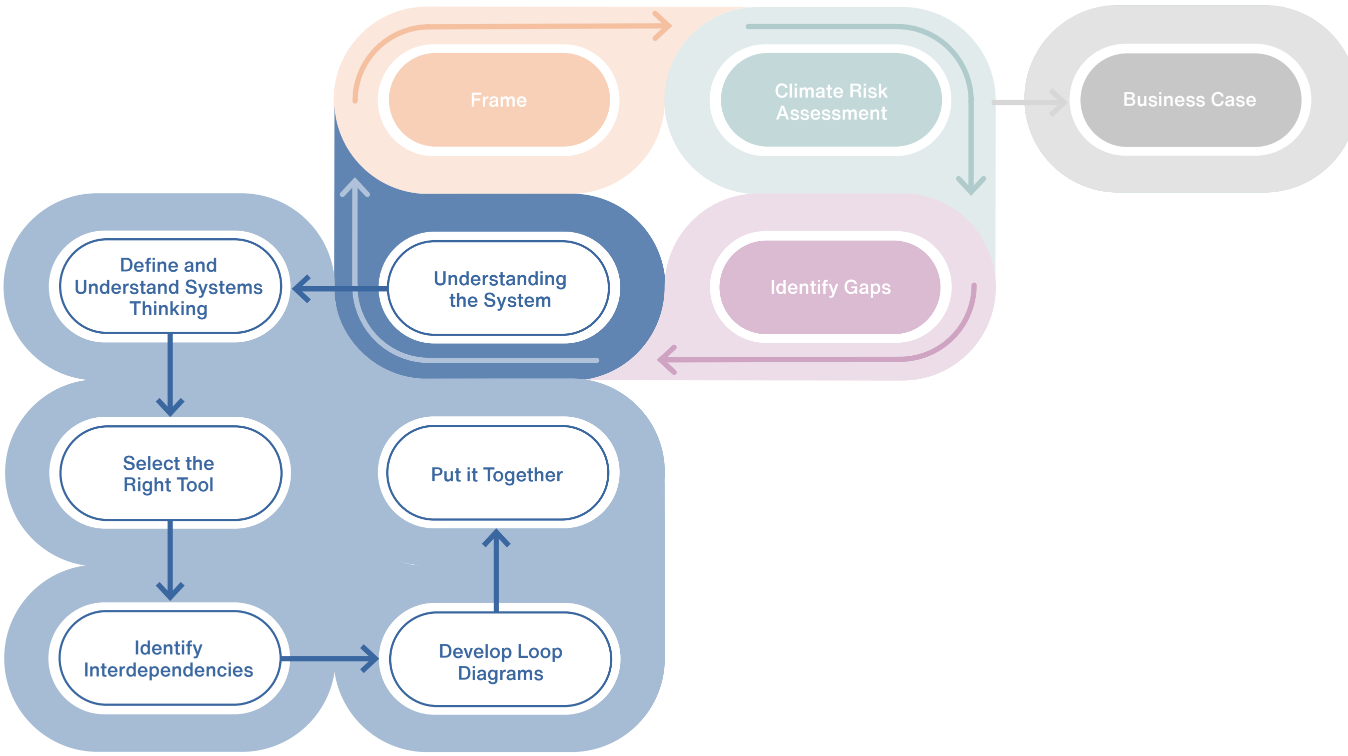
PURPOSE: The purpose of this chapter is to introduce users to the principles of systems thinking, including the terminology used, and provide examples of tools and techniques used to apply those principles in practice.

INTENDED OUTCOMES: By the end of this chapter, users will

- Understand the key aspects of systems thinking and its application.
- Be able to select an appropriate systems-thinking tool, based on the scope of the project.
- Know how to apply systems thinking to identify interdependencies and critical vulnerabilities in the system under analysis.
- Be able to create a systems map, showing causal loops.

RECOMMENDED SUPPLEMENTARY TEAM MEMBERS:

- Systems thinking advisor
- Subject matter experts, as revealed throughout the process



3.1 Define and Understand Systems Thinking

What is a System?

In simple terms, a **system** is a collection of many parts which function together as a whole. To understand how the system works requires an examination of not only the individual components which make up the system, but also how those components interact with each other.

For example, a building can be thought of as a system. Buildings are made up of many components, or **variables**. Some components - such as the walls, the windows, or the wiring - are common to most building types; others - such as ambulance bays or operating theatres - would only appear in the specific case of a hospital building.

For the building to function as a hospital, the components must be connected in the right way. Hospitals are designed to allow sick patients to arrive by ambulance and receive prompt diagnosis. Doctors and nurses then interact with patients to provide care. If the doctors and nurses had no interaction with the patients, the hospital would not function properly. Patient monitors and other devices can help medical staff provide care, but must remain connected to a power supply to work properly.

Many self-regulating systems can also be found in nature. Take the climate and weather in a forest ecosystem for example, including temperature, precipitation, and sunlight, which all significantly influence the forest ecosystem. The climate and weather affect plant growth, animal behaviour, and the overall distribution and composition of species in the forest. Ecosystem processes, such as transpiration from plants and evaporation from soil surfaces, can in turn influence local weather patterns. Changes in climate and natural disasters can impact the forest structure, species composition, and the ecosystem dynamics. All of the species, cycles, and components are heavily reliant upon one another for the forest ecosystem to function in harmony.

Understanding the connections between each component in these systems, and the interdependencies that make up the system, is an important aspect of systems thinking. Identifying which connections are important and how they are vulnerable is a primary objective of the SBA process.

Systems Thinking

Systems thinking helps us understand how systems create patterns and events. By using systems thinking to draw connections and identify dependencies between individual variables, it is possible to gain a better understanding of the influence that each part of a system has on other parts of the system, and on the system as a whole.

Some traditional methods of analysis, such as linear- or event-oriented thinking (Refer to Page 9), often focus on breaking down a problem into smaller pieces that are easier to understand. Systems thinking on the other hand concentrates on the bigger picture, allowing practitioners to simultaneously consider multiple causes and effects, including circular impacts, as well as identify potential solutions to problems that may have been beyond the original scope.

Benefits of Systems Thinking

Fosters collaboration: By engaging individuals from multiple departments and agencies who possess specialist knowledge or can challenge existing assumptions, collaboration can be fostered, leading to a more comprehensive understanding of the system and its limitations.

Provides a visual language: Another benefit of systems thinking is to provide a strong visual language for problem solving. This is achieved by utilizing tools with a strong visual component, which provide a clear way to picture the variables involved and their relationships. By visualizing the entire system, it becomes easier to analyze and identify patterns that drive events. This insight into cause and effect helps to make more accurate predictions when preparing for future events and selecting appropriate levels of resilience to address vulnerabilities.

Using system thinking tools that help to visualize the relationships between components can also provide a useful communications tool to share the results of a resiliency assessment with a wider audience. In the Netherlands, the National Climate Adaptation Strategy[iv] is publicly available at https://nas-adaptatietool.nl and allows users to display the impacts of four climate trends across nine industry sectors.

Increases system resilience: Practitioners are required to define the relationship between different infrastructure assets in many CRAs. Systems thinking provides a systematic approach to define and map the interrelationships between variables in the system. By using a SBA to develop CRAs, practitioners can methodically identify the interrelationships between assets and account for the impacts of hazards on the assets. This understanding of vulnerabilities helps to prioritize necessary adaptations to climate change, ultimately increasing system resilience.

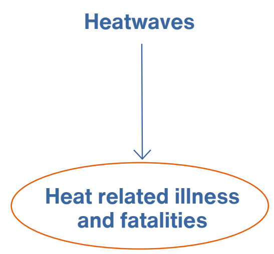
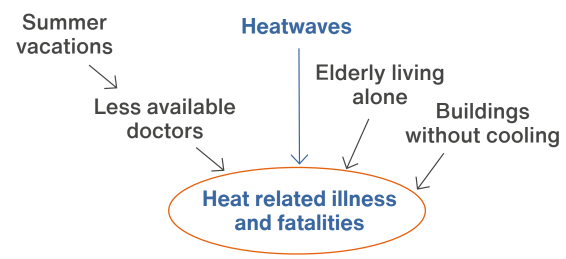
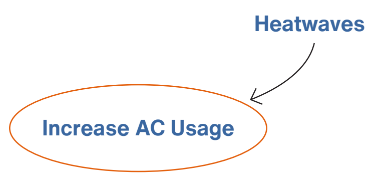
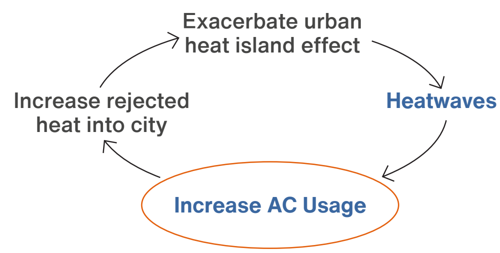
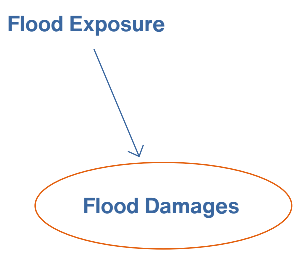
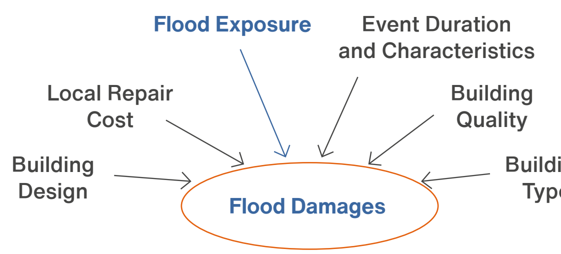
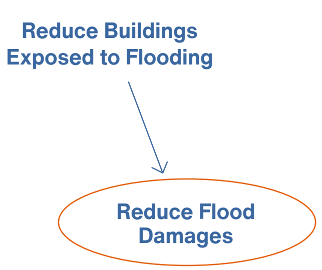
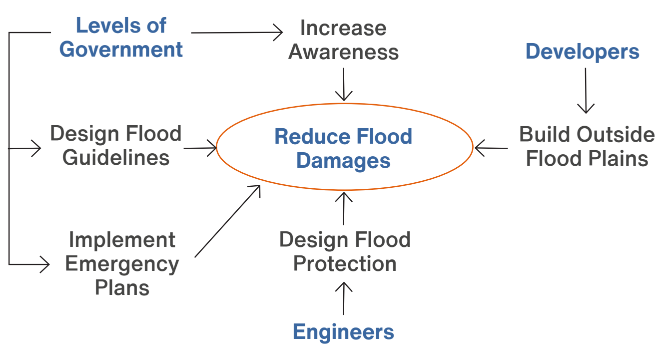
Uncovers hidden variables: By mapping out a system using systems thinking, hidden variables and connections that were not initially apparent can be uncovered. The importance of including these concealed variables in our approach to thinking about problems is recognized as essential by systems thinking practitioners. This inclusion allows their effects to be understood, and their consequences to be mapped out, leading to a more comprehensive understanding of the system.

Improves problem-solving strategies: The application of systems thinking principles and tools can improve problem-solving strategies, especially in the pursuit of climate-resilient infrastructure and complex problem-solving. As more practitioners become familiar with this abstract way of thinking, it can become a useful tool for them to address challenges that require a systemic approach.

The "*Plan National D'Adaptation au Changement Climatique*[v]" presents the French National Adaptation Plan for Climate Change; setting out the actions deemed necessary to achieve carbon neutrality and limit the rise in average global temperatures to no more than 2°C, while avoiding contradictions between the various adaptation and environmental protection actions affecting different sectors.

The action plan was developed using a SBA that considered how the implementation of a particular climate adaption measure or action in one area might affect or impact another part of the system. This resulted in a national plan that not only considers the potential effect of climate change in one region or on one type of physical infrastructure, but also takes into account the wider impacts to the economy, to the environment, or to the community as a whole.

The table below highlights the key differences between traditional thinking and systems thinking, with examples.[iii]

TRADITIONAL THINKING	SYSTEM THINKING
Looks at one cause and effect	Looks at multiple (or cascading) causes and multiple effects
	
Looks at impacts in one direction (e.g., downstream impacts)	Looks at circular impacts
	
Breaks a system down into different segments for ease of understanding	Seeks to understand the fundamental cause or causes of the problem, and find additional consequences and interventions
	
Focuses primarily on the problem and solution	Works with and around people involved in the problem and solution
	

3.2 Select the Right Tool

People experience the world through personal mental models - how information is gathered and processed is shaped by our beliefs and perspectives. Over time our patterns of thinking become habitual, and automatic thought processes can obstruct our ability to learn and communicate. This can lead to bias, a situation where some details are heavily scrutinised, while others are ignored.

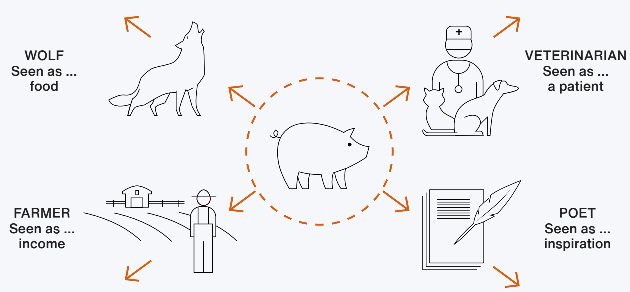
When practicing systems thinking, it is important to think outside the box, and not restrict ideas to a narrow focus. One way to increase the breadth of thinking is to invite others to participate in the process, particularly those with specialist knowledge or those able to provide a different perspective. Working with other stakeholders, especially community representatives, to develop a shared vision of the system can provide richer insight into its problems, and potential solutions.

Existing tools to apply SBAs to problem solving range from highly conceptual approaches - useful for those with little or no experience in systems thinking; to more detailed approaches - aimed at experienced practitioners. It is important that users select a tool that is both appropriate for their level of understanding of systems thinking, and suitable for the problem being addressed. Less experienced practitioners with less complex problems may want to choose the brainstorming and goal-setting tools. Those with more complex and critical problems to solve and more experienced practitioners, or those who have support with systems thinking may move beyond the brainstorming and goal-setting tools to the dynamic thinking tools. They may even want to explore structural thinking tools, though this document will not be exploring structural thinking tools in any depth.

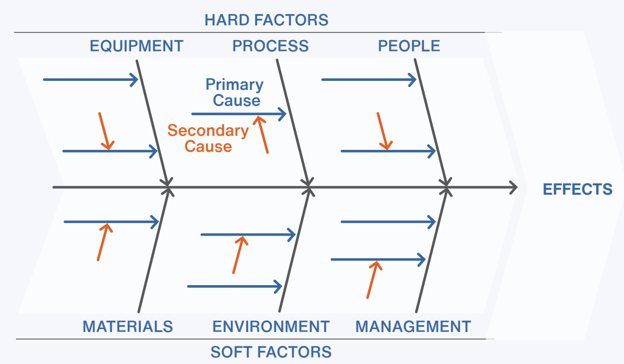
There are many different tools that can be used to support systems thinking. Some examples are provided below; additional resources can be found online.[vi]

Brainstorming and Goal-setting Tools are designed to bring stakeholders together and identify key issues, while reaching a shared understanding of the problem, and encourage thinking beyond one initial point of view. Examples include:

- **Pig model:** Used to assist stakeholders understand the diversity of opinions of other affected parties. The pig model encourages others to see how others might view the problem at hand and can help reach a shared understanding of the problem, but does not explore the relationships between variables. For more information on how to use the pig model, refer to the UK Guidance on introductory systems thinking toolkit for civil servants.

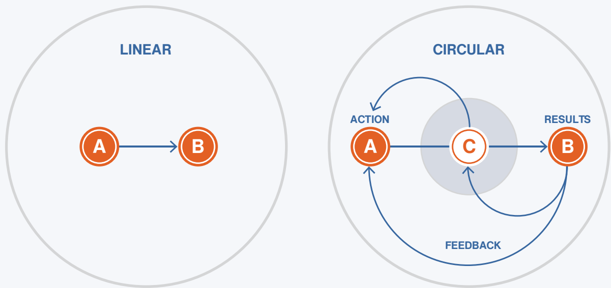


- **Fishbone or Double-Q diagram:** A brainstorming tool used for capturing thoughts in a structured manner, resulting in a cause-and-effect diagram. Named Double-Q because it includes both quantitative (hard) and qualitative (soft) factors, the diagram begins with one horizontal arrow pointing to the issue being addressed, with the hard factors branching off the top and the soft factors branching off the bottom. Each of these in turn have sub factors, so the diagram ends up looking like a fish bone.[viii]

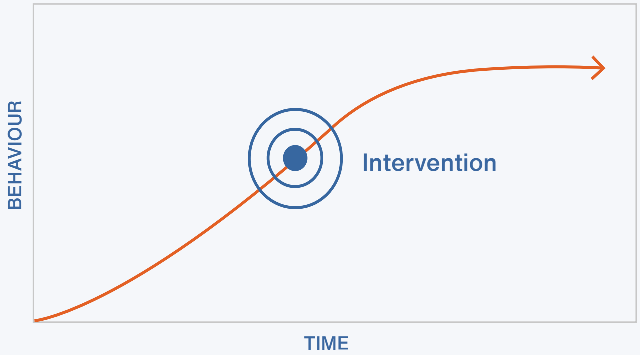


Dynamic Thinking Tools are designed to explore the system and problem more fully; and form an essential part of systems thinking which is explored further in this guidance. Dynamic tools are an essential part of systems thinking because they look at the circular, dynamic relationship of cause and effect, and challenge the user to think broadly about the behaviour of their system and how it can change over time. Examples include:

- **Systems-as-cause thinking:** Humans are naturally accustomed to thinking linearly, where A only influences B (as shown on the left).Circular thinking (as shown on the right) involves multiple factors, and consideration of the influence of each part of a circular loop, in which A has an effect on B, which causes B to have an effect on C, with the loop closed with the effect that C has on A.



- **Behaviour-over-time (BOT) graphs** help to visualize how a variable of interest - the behaviour - changes over time. Plotting key interventions on the graph can show the consequences of taking actions at a certain time.



- **Causal loop diagrams** are used to provide a visual representation of dynamic relationships. They typically focus on the relationships between a small number of variables representing one part of a systems map. Causal loop diagrams are covered in more detail in Section 3.4: Develop Causal Loop Diagrams

- **Systems maps** are created by linking multiple causal loop diagrams together to create a complete map of the system, and are often most effective when created through collaboration. Systems mapping is covered in Section 3.5: Putting it Together – Creating a Systems Map.

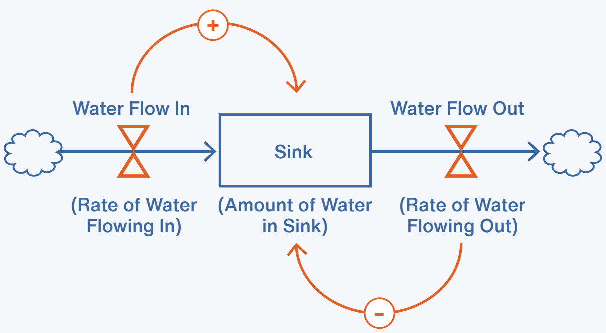
- **Systems archetypes** show common combinations of variables and their relationships to one another. They allow users to fit real-world examples to appropriate archetypes in order to identify possible solutions that could be applied to their problem at the most effective time and place. Examples which demonstrate how archetypes can be applied to solve systemic problems can be found online at The Systems Thinker or in Thinking in Systems: A Primer

- **Boundary matrix:** Beyond a certain size, systems can become complex and difficult to manage. Setting realistic boundaries for the system is key to establishing a manageable system to work within. Guidance on how to set appropriate boundaries is also covered in Section 3.5: Putting it Together – Creating a Systems Map.

Structural Thinking Tools are used to quantify the effects of different variables, or look at the interaction of multiple behaviours over time. They include:

- **Graphical function diagrams** which are similar to behaviour-over-time graphs, but take into account multiple variables and events rather than one. Instead of displaying the behaviour of one variable over time, these diagrams generally involve plotting the interaction of multiple variables, the function of one, as the other one changes.

- **Stock and flow diagrams** are enhanced causal loop diagrams which differentiate between stocks: variables that accumulate within the system (drawn as squares), and flows: variables that flow through the system (indicated by hourglass shapes). Edges, or boundaries of the system are symbolized by clouds. A classic example is the amount of water filling up a sink. Water can accumulate in the sink, so it is a stock. The rate of water flowing into or out of the sink is variable, so these are flows. Stock and flow diagrams enable the study of causal loop diagrams in a quantitative way.



Effective tools for a systems-based approach to climate risk assessments:

- Incorporate insight from external parties or subject matter experts
- Reflect the level of complexity of the problem
- Reflect relevant variables or components of the system
- Identify the connections between the variables or components of the system
- Enable the user to create boundaries

Gaining an understanding of the interactions between variables is an essential part of the process required to identify vulnerabilities. Thereafter, solutions to mitigate vulnerabilities can be established, prioritized, and implemented. Organizations with existing systems-thinking tools in place that meet the above criteria are encouraged to use those tools, supplemented by the tools provided in this guidebook as needed. Within this guidebook, worksheets are provided that encourage users to create their own causal loop diagrams, use causal loop diagrams to develop a systems map, and identify and plot the dependencies and interdependencies between variables.

3.3 Identify Interdependencies

Natural disasters, such as the pacific northwest flooding in 2021 that affected BC and surrounding areas, can help us gain an understanding of the interactions between variables in an infrastructure system and why it is crucial to identify them. Flooding events can have a wide range of interconnected effects on infrastructure and the cascading effects on the systems they impact. For example, in addition to the roads and surrounding infrastructure, a flood in Merritt, BC, had lasting impacts on:

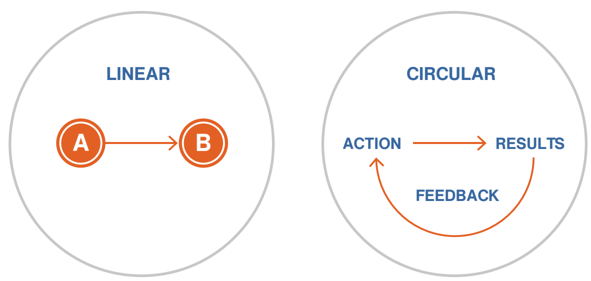
- Economic systems, by damaging businesses, agricultural lands, and industrial areas, as well as disruption of supply chains and reduced productivity.
- Environmental systems, through contamination of water, soil erosion, and destruction of habitat via the release of pollutants and contaminants into rivers, lakes, and aquifers.
- Social systems, which can be disrupted due to displacement of residents, damage to homes, and loss of personal belongings. Less obvious consequences can also arise, such as psychological and emotional distress caused by experiencing a flood. The health care system, education, and emergency response systems may also be overwhelmed or compromised.
- Communication and information systems, particularly if the affected infrastructure supports telecommunication infrastructure like phone poles, fibre optic cables, or communication towers.

Understanding the interdependencies between these systems and their interactions with the impacted infrastructure system is essential for comprehensive vulnerability assessments, risk management, and the creation of effective strategies to mitigate future impacts of flooding and promote resilience in multiple systems.

Application of Causal Loop Diagrams: Basic Feedback Loops

As previously mentioned, humans are naturally accustomed to thinking linearly, in which an action leads directly to a result. Systems thinking requires us to think in circles. The feedback loop shown on the right is an example of circular thinking – where an action leads to a result and provides feedback on the initial action.

Feedback loops can either be reinforcing; or balancing.

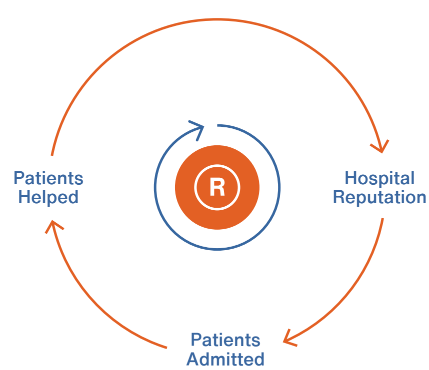


Reinforcing feedback occurs when an action in the system amplifies the original change, pushing it in the same direction. Reinforcing feedback helps a growing system to continue to grow, and will make a declining system continue to decline.

Using a hospital as an example: If the hospital provides a good service that helps patients, those patients will tell others about their positive experience, improving the reputation of the hospital. Hospitals with a good reputation attract more patients, meaning admissions will increase over time.

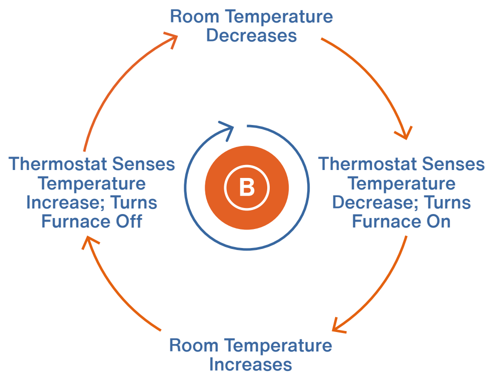
Alternatively, if fewer patients are helped, the reputation of the hospital may decline, which in turn will result in admissions falling, causing fewer patients being helped.

Both situations can be described using the same reinforcing loop; in one case there will be growth, and in the other case, decline.



Balancing feedback occurs when an action in the system opposes the original change, pushing back in an attempt to balance it out. Balancing feedback helps to keep systems in equilibrium – the initial change in one direction is countered by feedback in the opposite direction.

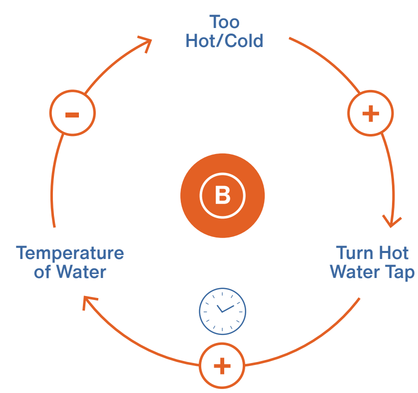
A common example is a household thermostat: If the temperature falls below a certain level, the system responds by turning on the furnace. Once the room has warmed up, the system turns the furnace off again. This cycle repeats over time as the system attempts to maintain a constant temperature.



Introducing time delays. In large, complex systems, making a change to one aspect of the system can affect many other parts. Sometimes, where the original cause and the eventual effect are separated by multiple steps, changes can take a long time to ripple through a system. This can increase the amount of time taken for feedback to be received.

For example, when a tap located a long distance from the hot water tank is first turned on, it can take some time for the warm water to arrive. When the water does start to flow, the initial temperature may not be suitable, and the user may need to turn the tap to adjust the ratio of hot and cold water, then wait for the adjustments to flow through the system, before deciding whether more adjustments are needed.

Feedback loops involving time delays (indicated by the clock in the associated diagram) are common in environmental systems.



3.4 Develop Causal Loop Diagrams

This section introduces causal loop diagrams, and describes the process used to generate them. Causal loop diagrams are a helpful tool used to visually represent and communicate the interactions between components of a system, and will be the building blocks of the systems map.

Feedback loops that capture one part of a system can be used to indicate the circumstances that caused a particular outcome, help to predict the downstream effects of a change before it is implemented, or highlight system components which are critical or important.

If systems mapping provides the visual language necessary to describe complex, interdependent issues, causal loop diagrams can be thought of as individual sentences. By linking the individual sentences together, it becomes possible to tell the story of a system using a coherent and visual narrative.

Three steps are important when creating systems maps using causal loop diagrams:

1. Naming the variables
2. Linking the variables
3. Labelling the feedback loops

STEP 1: NAME THE VARIABLES

Variables are the components of the system that can change (i.e., increase or decrease) and affect something else in the system. Selecting and properly naming the variables is important, as it can influence the scope of the assessment. The same language and terminology should be used consistently throughout the systems map, with variables selected that are measurable (quantitative or qualitative).

Guidelines for Creating Variable Names

GUIDELINE	EXAMPLE	RATIONALE
Use nouns when choosing variable names.	Use 'Fees', rather than 'Fee Increase'.	Avoid verbs because the action will be indicated with the arrow that links the variables.
Use terms that are measurable.	Use 'Happiness', rather than 'State of Mind'	'Happiness' is a variable that can be quantified and can increase or decrease over time. 'State of mind' is also variable, but has many facets, making it harder to quantify, and more difficult to assess or measure changes.
Be specific.	Use 'Availability of Air Conditioning' or 'Demand for Air Conditioning', rather than simply 'Air Conditioning'	Helps to keep focus on the aspect of the variable that is most important.
Use the positive sense of the word.	Use 'Inflation' rather than 'Deflation'	Maintains consistency throughout the systems map, and prevents duplication. Positive change is usually easier to visualize.

Worksheet 3.1 – Causal Loop Diagrams – Brainstorming Variables

Worksheet 3.1 provides a framework that can be used to brainstorm variables of the system.

When identifying and naming variables, it can be helpful to use categories as a prompt. In this guidebook, five categories – Physical, Social, Economic, Environmental and Institutional/Governance – are proposed as a starting point[1]. At this stage, capturing a wide range of ideas is encouraged – initial suggestions can be refined later.

The table below shows how **Worksheet 3.1** might be populated, using an example of a hospital building. This list of categories provides an initial starting point for brainstorming variables that can continue to be expanded or refined as necessary.

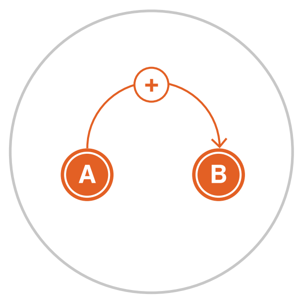
[1] These five categories were adapted from the five dimensions of a social-ecological system described in: Assessing and Monitoring Climate Resilience: From Theoretical Considerations to Practically Applicable Tools - a Discussion Paper

CATEGORIES					
Physical	**Social**	**Economic**	**Environmental**	**Institutional/ Governance**	**Other**
Number of patient Beds	Patients admitted	Staff productivity	Air quality	Government funding	Quality of food
Number of Windows	Number of Doctors	Hours worked	Outdoor temperature		Patient satisfaction
Electricity Use	Number of Nurses		Indoor temperature		Hospital reputation
Number of light switches	Staff burnout		Extreme heat days		
Condition of Drywall	Patients helped		Extreme cold days		
Air conditioning availability					
Air conditioning use					

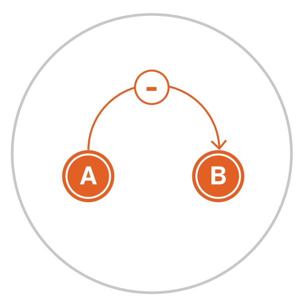
STEP 2: LINK THE VARIABLES

Once an initial set of variables has been identified and named, connections can be made between them using arrows. The direction of the arrow runs from cause to effect, and connections are labelled as follows.

- **a.** A '+' shows instances where a change in variable A causes a change in variable B in the same direction. (i.e., if A increases, B also increases; if A decreases, B also decreases),



- **b.** A '-' shows instances where a change in variable A causes a change in variable B in the opposite direction. (i.e. if A increases, B decreases; if A decreases, B increases).



Worksheet 3.2 – Causal Loop Diagrams – Linking the Variables

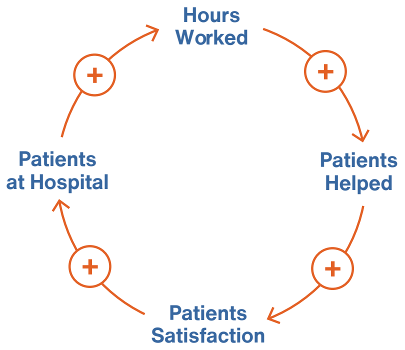
Worksheet 3.2 includes blank templates which can be populated with variables and then used to link them together, or move them around. Many online tools can also be used for this exercise, some links are provided below.

Links to helpful tools for systems mapping

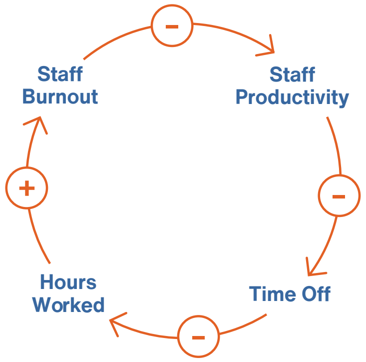
Miro | Mural | Loopy | Kumu

Example: Linking the Variables
Using the hospital as an example, it is possible to identify a causal loop, as shown below:

This example assumes that if number of hours worked by staff increases or decreases, it will mean that the number of patients they help will increase or decrease respectively, which in turn will also increase or decrease the patient satisfaction levels. If patient satisfaction increases, patients will tell other people about the positive experience they had and more people will come to that hospital, increasing the number of patients. The '+' labels indicate that the changes are in the same direction. This means that if the number of hours worked by staff decreases, the number of patients helped would decrease, causing a drop in patient satisfaction levels and patients that come to the hospital. This is again shown using the '+' labels, because the changes are also in the same direction.



Another causal loop diagram can be generated based off the variable "Hours Worked". This example assumes that if the number of hours worked continues to increase, it will eventually lead to an increase in staff burnout. In turn, this will cause a reduction in staff productivity, leading to an increase in time off, which results in fewer hours worked. The '+' labels indicate changes in the same direction (though not necessarily an increase), the '-' labels show changes in the opposite direction (although not necessarily a decrease).



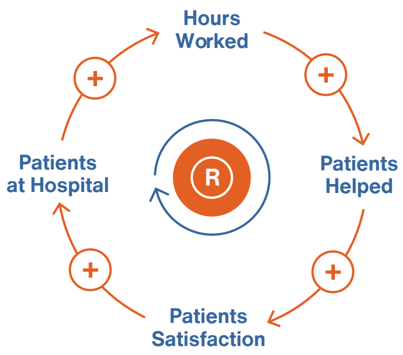
STEP 3: LABEL THE FEEDBACK LOOPS

Once variables have been linked together to create a loop, the final step is to determine whether it is a reinforcing (R) or balancing (B) loop, and label it accordingly:

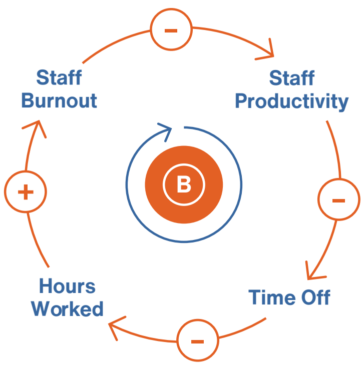
- A **Reinforcing Loop** compounds change in one direction with even more change in that direction, leading to either continual growth or continual decline.
- A **Balancing Loop** counters change in one direction with change in the opposite direction to keep the system in equilibrium

Using the examples from the previous section:

- In the first diagram, each variable compounds change in the same direction, indicating a reinforcing loop that is labelled with the letter 'R'.



- In the second diagram, some variables compound change in the same direction, other variables counter that change. By following the loop around, it shows that the behaviour ultimately corrects itself when staff takes time off to work fewer hours, meaning this is a balancing loop, that is labelled with the letter 'B'.

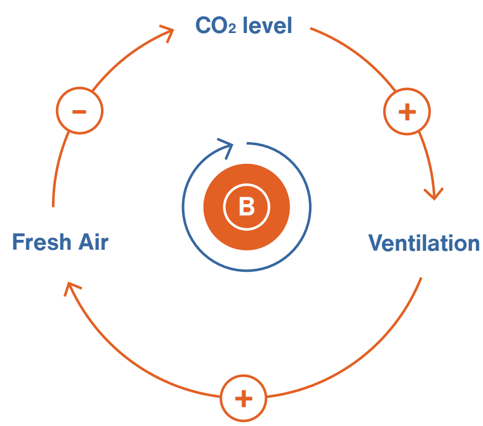


The aforementioned examples show balancing and reinforcing loops where people are involved. The following examples show how they can be applied to buildings.

Consider a building's indoor air quality control system. It monitors the CO_2 levels inside the building. There is a set limit (i.e. threshold) for what is considered healthy. In this scenario, we have a balancing loop that involves the CO_2 levels and the ventilation system:

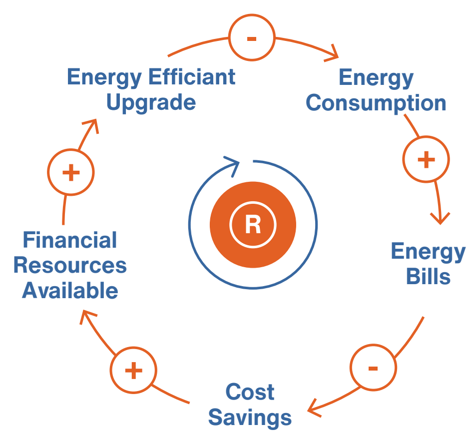
- CO_2 level: The building's indoor air quality is monitored, specifically focusing on CO_2 levels. There is a specific CO_2 level that is considered safe for people inside the building; this is the threshold after which CO_2 levels are unsafe. If the CO_2 levels go beyond the safe limit/threshold, it means there is an issue with the air quality and an alert is set off.
- Ventilation: When a problem is detected, the ventilation system is activated and automatically increases the amount of fresh air coming in and the air from inside being pushed out. This improves the air circulation and reduces the CO_2 levels inside.
- Fresh air: As the ventilation system does its job, more fresh air is brought in, and the CO_2 levels start going down.

Circulation/maintenance (redoing the loop): Once the CO_2 levels are back within the safe range, the ventilation system goes back to its regular settings, to maintain balance and make sure the indoor environment remains healthy. The CO_2 levels are constantly checked and if any deviations continue, the ventilation system adjusts itself to maintain the desired air quality. This demonstrates a simple balancing loop where the ventilation systems responds to elevated CO_2 levels by increasing fresh air intake.



We may also consider a reinforcing loop scenario where a building owner or operator implements energy-efficient upgrades, leading to reduced energy consumption and lower bills and further investments:

- **Energy-efficient upgrades:** The building replaces traditional lighting fixtures with energy-efficient LED lights.
- **Reduced energy consumption**: The energy-efficient lighting reduces the building's energy consumption for lighting purposes.
- **Lower energy bills:** The reduced energy consumption translates into lower energy bills for the building owner.
- **Cost savings:** The building owner realizes cost savings due to the lower electricity bills.
- **Financial resources:** The cost savings provide additional financial resources for further energy-saving investments.



At this point the building owner may invest those financial resources back into additional energy-saving measures, such as installing occupancy sensors, upgrading HVAC systems, or increasing insulation to realize even lower energy bills.

Tip for labelling loops with multiple components

- If a loop has an even number of negative arrows, the overall loop is a reinforcing loop.
- If a loop has an odd number of negative arrows, it is a balancing loop.

This is because the two negative arrows cancel each other out and they have the same overall effect as one positive link.

Worksheet 3.3 – Causal Loop Diagrams - Classifying Loops

Worksheet 3.3 includes blank causal loops that can be populated and used to practice classifying and labelling loops.

3.5 Putting it Together - Creating a Systems Map

Sections 3.1-3.4 were designed to equip guidebook users with the necessary knowledge and skill sets related to systems thinking in the context of resilience assessments. The steps in Section 3.5 are presented as a practical walk-through for applying those concepts and shows how the knowledge developed in earlier sections can be used to create a systems map.

This section describes the 8 steps involved in creating a systems map:

1. Identify and Engage Stakeholders
2. Create a Preliminary Climate Profile
3. List the Variables
4. Define the Boundaries
5. Determine the Starting Point
6. Make the Connections
7. Edit and Organize the Map
8. Analyse the Map to Identify the Critical Variables

Step 1: Identify and Engage Key Stakeholders

Any causal loop diagram or systems maps can only represent the knowledge and opinion of those involved in creating it. Identifying suitable stakeholders and rights holders and gaining their knowledge is important. Such groups may include: community representatives, community organizations, local business leaders, Indigenous knowledge holders, and local government officials.

Stakeholder workshops are useful exercises when developing systems maps, as they:

- Help participants share an understanding of the concepts and tools of systems thinking, and apply the concepts and tools to the problem at hand.
- Define an agreed set of boundaries which limit the scope of the task, used to keep discussions relevant to the chosen audience.
- Allow multiple perspectives to be considered, which help to generate creative and effective solutions.

Effective Stakeholder Engagement

The following tips provide guidelines for effective stakeholder engagement:

- Consult with the Project Manager and Organization Champion to identify people and groups that may be impacted by the project, and identify their interests, expectations, and concerns. This will help you tailor the engagement approach to meet their needs.
- Develop a plan that encompasses the objectives and the expected engagement outcomes. For example, is the plan to inform the public of the project or collaborate with the public throughout the process?
- Listen and be open-minded, as this will help incorporate multiple perspectives into the SBA.
- Be sure to tailor the approach to suit the stakeholders and make it accessible for those in attendance.
- Maintain the relationships that have been created to make it easy to move from thinking as a team to designing and building as a team.

Involving community representatives as stakeholders can help build trust and understanding between community members and decisions makers, and lead to more effective and sustainable solutions.

STEP 2: CREATE A HIGH-LEVEL PRELIMINARY CLIMATE PROFILE

To maintain a focus on climate resilient infrastructure, the systems map should be considered in the context of selected climate hazards. This helps to centre problem-solving energies on only the climate hazards that are relevant to their location and problem. For example, sea level rise may not be a consideration for an inland community, in the way that a coastal community may be affected.

- If a CRA already exists for the system under assessment, it may be possible to reuse the climate profile from the CRA.
- If there is no existing CRA, a high-level preliminary climate profile can be developed using open-source tools such as Climate Atlas of Canada or Climatedata.ca. Alternatively, use **Worksheet 3.4** to generate one.

Worksheet 3.4 – High-level Climate Profile

At this stage, the intent is to create a high-level climate profile to set the context in which the systems map will be built. Guidance to complete a more detailed analysis of climate data is provided later in Section 5.3: Define climate parameters and collect data.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

The following example shows a high-level climate profile filled out for KLFN using Table 2 from Worksheet 3.4 and data obtained from Climate Atlas of Canada since no local experts were available to help fill in Table 1. In exercising an abundance of caution, the High Carbon climate future scenario (RCP 8.5), seen below, was used to fill the table. This exercise helps set the context for the systems map.

RCP 8.5: High Carbon climate future
GHG emissions continue to increase at current rates

Variable	Period	1976-2005	2021-2050			2051-2080		
		Mean	Low	Mean	High	Low	Mean	High
Precipitation (mm)	annual	555	489	597	716	510	628	759
Precipitation (mm)	spring	94	61	102	149	67	111	163
Precipitation (mm)	summer	213	150	221	302	149	221	301
Precipitation (mm)	fall	168	126	182	248	131	191	266
Precipitation (mm)	winter	80	62	91	124	73	105	148
Mean Temperature (°C)	annual	-2	-1.2	0.4	2	0.9	2.8	4.9
Mean Temperature (°C)	spring	-3.6	-5.3	-2	1.3	-3.2	0.1	3.7
Mean Temperature (°C)	summer	14.6	14.7	16.6	18.5	16.5	18.8	21
Mean Temperature (°C)	fall	1	1.3	3.6	5.5	3.6	5.9	7.9
Mean Temperature (°C)	winter	-20.4	-20.8	-17.2	-13.4	-17.4	-13.8	-10.1
Tropical Nights	annual	0	0	2	5	1	7	19
Very Hot Days (+30°C)	annual	2	0	6	14	2	15	30
Very Cold Days (-30°C)	annual	34	5	18	32	0	6	16
Date of Last Spring Frost	annual	June 2	May 11	May 25	June 9	May 4	May 18	June 1
Date of First Fall Frost	annual	Sep. 24	Sep. 20	Oct. 8	Oct. 27	Sep. 29	Oct. 16	Nov. 6
Frost-Free Season (days)	annual	110	111	132	154	125	148	170

Worksheet 3.4 Table 2

CLIMATE PARAMETER	CLIMATE HAZARD	CHANGE IN HAZARD FROM PRESENT	NOTES
Precipitation	Amount of rainfall	Higher	
Temperature	Very Hot Days	More	Currently no tropical nights
	Very Cold Days	Fewer	
	Frost Free Season	Longer	Shorter ice-road season
Sea Level Rise	Sea Level Rise	Higher	
Wind	Wind speeds		Insufficient data to indicate changes
Other	Freezing rain	Neutral	Insufficient data to indicate changes

[2] https://climateatlas.ca/find-local-data

STEP 3: LIST THE VARIABLES

Develop an initial list of variables through collaboration with relevant stakeholders. At this point, list as many as the group can come up with in the time available. The intent is to be broad and include as many relevant variables as possible that the stakeholders in the workshop can think of. The workshop facilitator should help manage the conversation to keep it on track. Any variables that are not relevant will be eliminated in later steps.

Depending on the scale of the project and the number of stakeholders, a collaboration tool which allows multiple participants to simultaneously edit a systems map, add variables, move system elements, draw and label connections – may be helpful.

[Refer to Worksheet 3.1 – Causal Loop Diagrams - Brainstorming Variables for a reminder]

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

The example below shows an extensive list of variables that were initially generated during a stakeholder workshop using Kasabonika Lake First Nation as a working example. Some of the variables may not be appropriate for the particular location, (e.g., transit demand), showing the importance of having knowledgeable stakeholders in the room. Conversely, there are several valid variables that were not considered in the publicly available KLFN CRA[ii], which shows the added value of using systems thinking to complement or enhance a CRA.

Physical

- Water treatment plant reliability
- Food supply
- Road Access
- Airport Utilization
- Airport demand
- Drinking water availability
- winter road functionality
- State of hospitals
- State of schools
- State of community / cultural centres
- Number of power stations
- Reliability of power stations
- Capacity drainage system
- Airport functionality
- Transit demand
- Number of Transportation Modes
- Number of External Road connections
- Adequacy of drainage systems
- Functionality of community hall
- Availability of electricity
- State of network systems
- Condition of flood protection systems

Social

- Transit demand
- Population density
- Proportion of seniors
- Future population growth
- Proportion of youth
- Access to healthcare system
- Access to educational services
- Preservation of cultural heritage
- Access to community / cultural centres
- Access to communications networks
- Food cost
- Drinking water availability
- Availability of mental health services
- Food Supply
- Availability of telehealth
- Quality of services provided by cultural centres

Institutional / Governance

- Federal Government leadership support
- Provincial government support
- Quality of relationship between community and government
- Trust in government
- Capacity of local council to meet needs
- Functionality of band office

Economic

- Food security
- Funding for infrastructure quantity
- Funding for disaster relief quantity
- Insurance costs
- Private vehicle ownership
- Food availability
- Cost of electricity
- Inflation

Environmental

- Frequency of extreme heat days
- Length of ice road season
- Frequency of extreme cold days
- Frequency of forest fires
- Frequency droughts
- Freezing rain

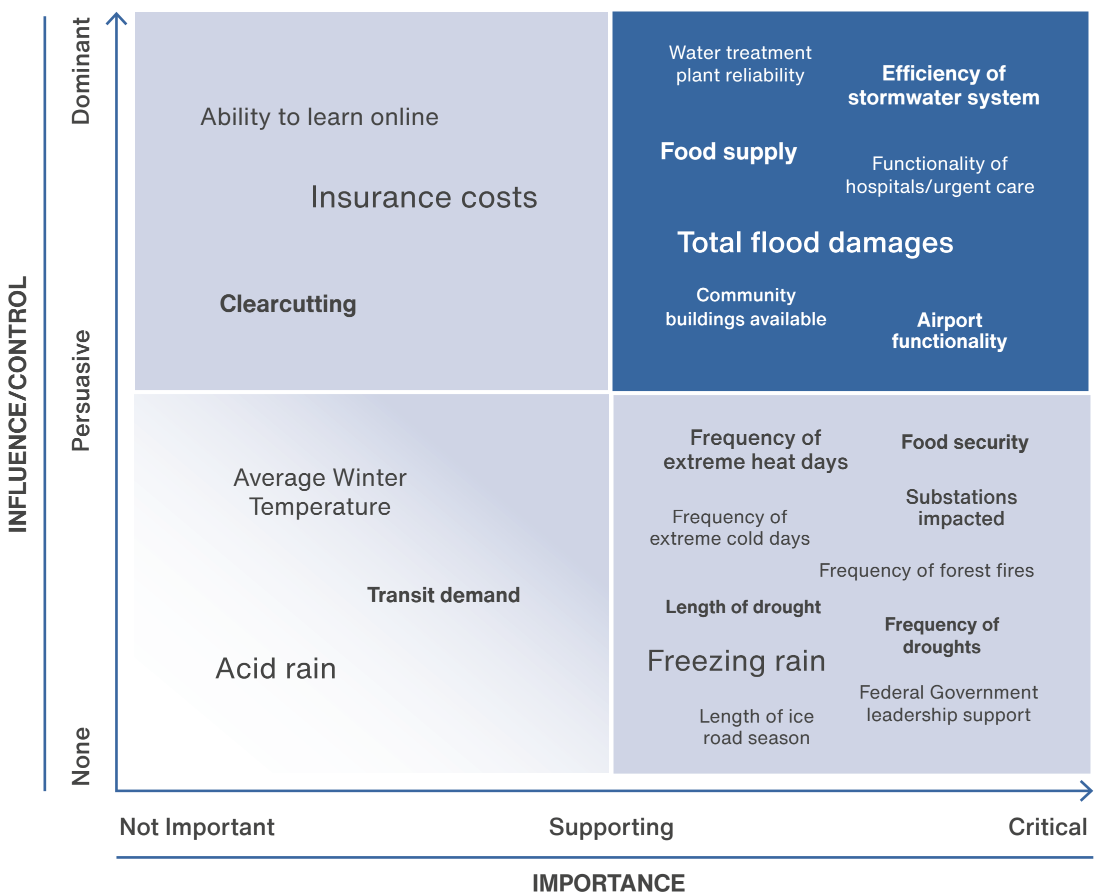
STEP 4: DEFINE BOUNDARIES

Defining the scope and setting boundaries is critical in systems thinking to manage the problem and identify solutions.

If the system is too large, breaking it into smaller pieces can help to focus attention on the most important features, or on the variables it is possible to influence or control. Establishing clear boundaries that define the scope of the assessment is important: if the boundary is too narrow, it may exclude components that influence the system; if the boundary is too wide, it may shift the focus from the actual problem.

Worksheet 3.5 – Boundaries Matrix

To determine the boundaries of the system, plot each variable onto the Boundaries Matrix. The y-axis shows the level of control or influence; the x-axis shows its relative importance. Individual viewpoints can be combined with assessments by other stakeholders to develop a collective view. Variables in the top-right quadrant represent those determined to be both important and where there is a degree of control, and typically form the starting point when plotting a systems map.



STEP 5: SELECT A STARTING POINT

With complex systems, it is not always obvious where to start when creating a systems map. The boundary matrix can help identify potential starting points, by highlighting the variables that are both (i) important and (ii) under your control or influence.

Since all variables are part of the same system, the resulting systems map should connect all variables. It therefore does not matter which variable is chosen to start with.

STEP 6: MAKE CONNECTIONS

Starting with the first variable, add new variables to the systems map that either directly influence it, or are influenced by it. Draw the connections between variables based on their relationship, using the following rule.

- If the two variables change in the same direction, mark the arrow with a “+”.
- If the two variables change in the opposite direction, mark the arrow with a “-“.

Refer to Step 2: Creating Links and Worksheet 3.2 – Causal Loop Diagrams – Linking Variables for a reminder

Working with stakeholders, continue adding content until all the important connections are mapped. The systems map will continue to grow and change over time: some original variables may be adjusted as additional connections are made; more variables may be added; others may be excluded completely.

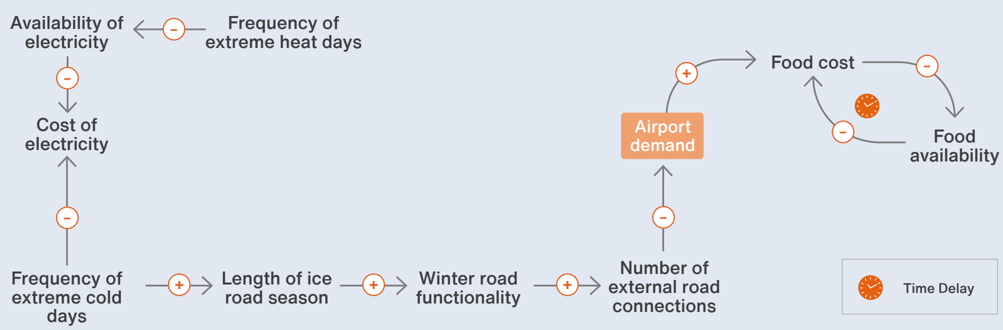
APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

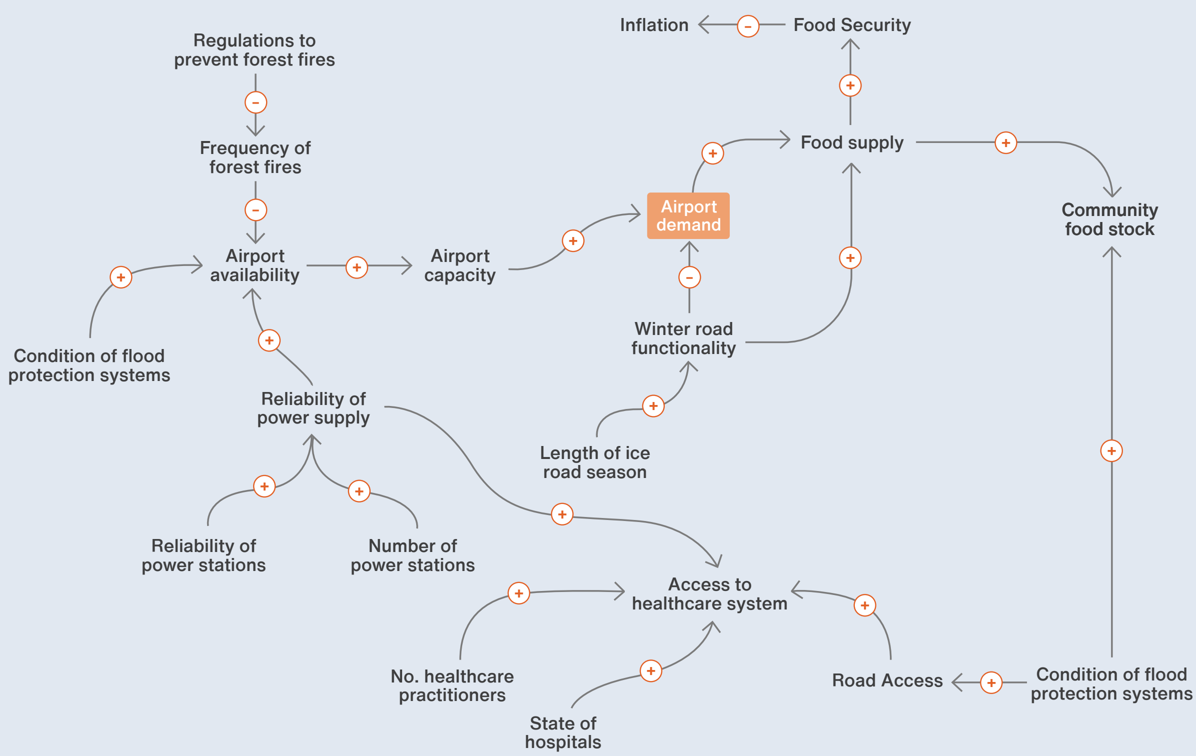
System maps for KLFN were generated during brainstorming exercises, where participants agreed to use “Airport Functionality” as the starting point due to the community’s reliance on that transport hub, making that variable both critically important, and something that could be controlled through appropriate investment and decision making.

In the example, "Airport Functionality" was connected to “Airport Demand”, given the anticipated impact on food supply. Since these two variables move in the same direction (increasing functionality leads to increased demand), the arrow connecting them is marked with a “+”.

Alternatively, demand for the airport is affected by the presence, or absence, of a winter road. As the variable “Number of External Road Connections” increases, it causes a decrease in “Airport demand”, and vice versa. The arrow connecting these variables is marked with a “-“ to reflect this.

The examples below show two partial systems maps for KLFN.



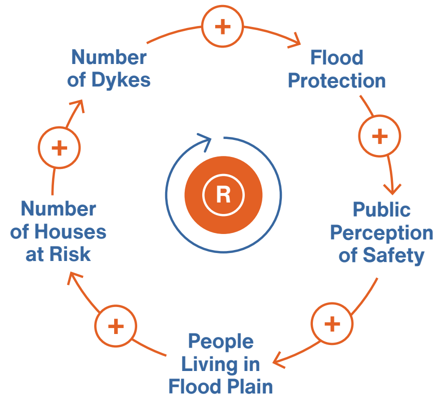


STEP 7: EDIT AND ORGANIZE

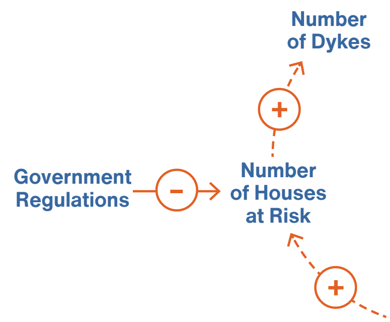
As more connections are made and the map grows, some variable names may need to be added, moved, or renamed for clarity. Important variables should be retained, and their connections maintained.

Organising the map helps to identify loops which can be labelled as either balancing (B) or reinforcing (R), and used to determine parts of a system where an intervention may be needed – for example to balance a reinforcing loop.

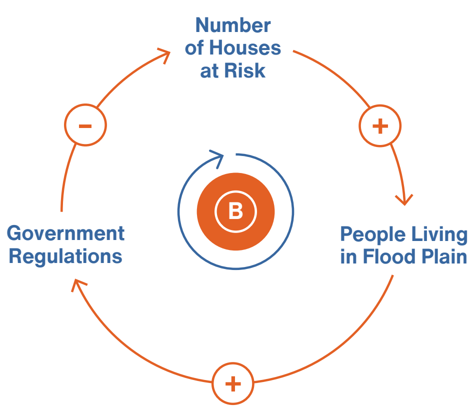
In the example shown here which looks at flood defences, a reinforcing loop indicates that increasing the number of dykes to provide more structural flood protection will increase public perception of safety, causing more people to live on a flood plain, increasing the number of houses at risk. A mitigation assumed to provide more protection actually puts more structures and people at risk, particularly in the event that the dyke fails.

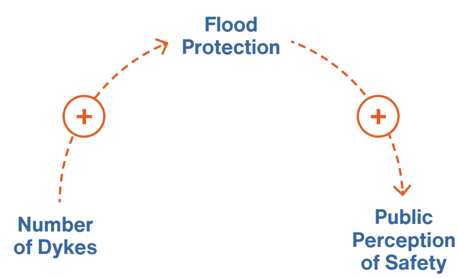


One potential balancing intervention involves the introduction of measures that decrease the number of houses at risk of flooding – such as government regulations preventing houses being built in the floodplain. Other potential interventions may exist for the scenarios documented on the systems map. The intention at this point is not to find all of the possible solutions, but to examine the downstream effects of the existing actions so that they are not overlooked. This is, however, a good time to begin documenting potential ideas for recommendations or solutions to return to when looking for alternative interventions in Section 5.6: Risk Calculation and Adaptation Strategies.



In this instance, the government regulations prevent people from building in the floodplain, so their perception of safety is no longer directly linked to how many people can build there. What is most closely related to the number of houses, and therefore people at risk, is the amount of government regulations in place. Note that this is only one piece of a systems map, and there are other factors not taken into account here.

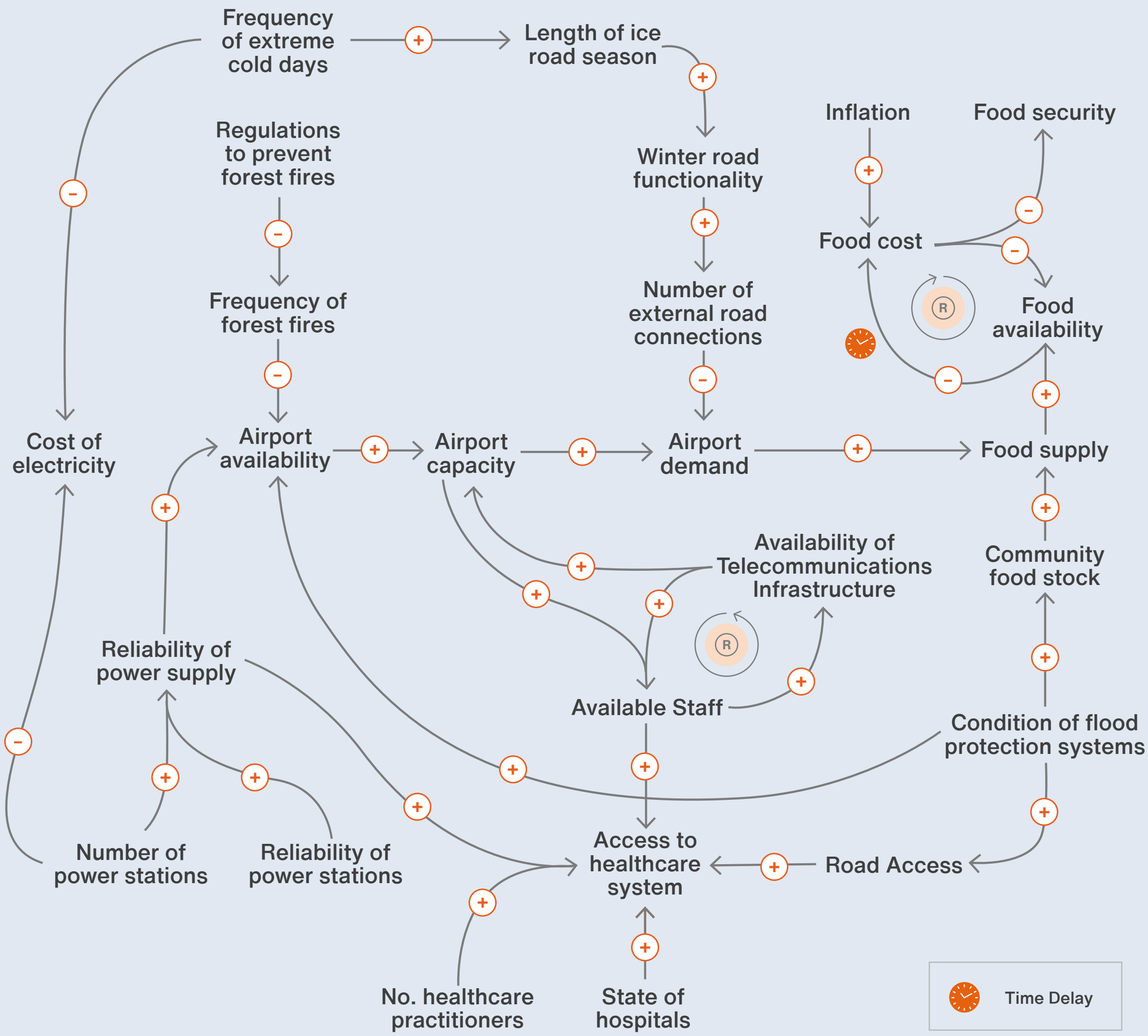




Stakeholders can continue to add and modify content until the systems map is sufficiently detailed. At this stage, variables and loops can be repositioned so that elements can be grouped logically (in the same category) and physically (together on the page). This step can help when translating the systems map into a climate risk framework (see Chapter 4: Framing the Results).

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

Note this map is only a sample of certain variables identified in the process, and not necessarily a complete map of the entire KLFN community.



STEP 8 - IDENTIFY THE CRITICAL VARIABLES

Once the systems map is created, with links drawn between related variables, it is ready to be analysed to determine whether the map has reached a level of completeness to move to the next stage.

This stage may require further input from the stakeholders or subject matter experts involved in creating the map, and can also involve a review of whether the original boundaries remain appropriate.

Carry out an analysis of the systems map to identify the critical variables. These include those with a high number of interdependencies (indicated by multiple connections to other variables).

For each critical variable, establish whether:

- the connections go outward, indicating an **influential variable**.
- the connections go inward, indicating a **vulnerable variable**.
- the connections go in both directions, **indicating a central or bridging variable**.

If there are variables where many arrows converge, it may indicate a problem caused by a limitation or bottleneck. Increasing resilience at that point can help to improve resilience across the entire system.

Identification of the critical variables is a key step when determining vulnerability drivers - see Chapter 4: Framing the Results.

Worksheet 3.6 – Critical Variables

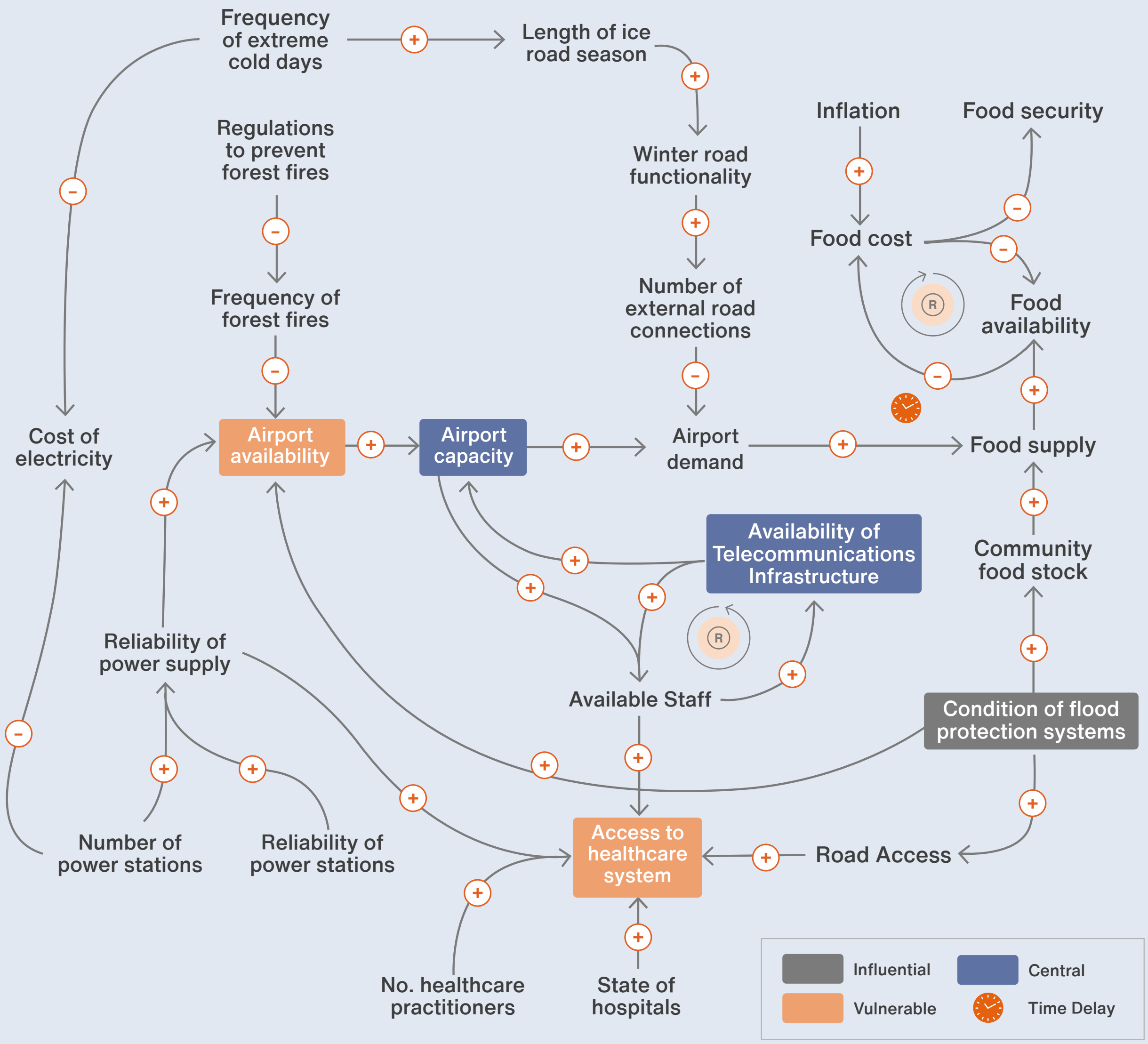
Worksheet 3.6 can be used to identify and track critical variables.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

Examples of critical variables - taken from the KLFN systems map are:

- “Condition of flood protection systems” has a number of connections flowing out, indicating that it has a large influence on other variables in our system – it is an **influential** variable.
- “Access to healthcare system” and “Airport availability” have a number of connections flowing into them, indicating that they may be **vulnerable** variables, affected by others,
- “Airport capacity” and “Availability of Telecommunications Infrastructure” are both variables that have many connections flowing in and out, potentially indicating that they are **central**, or important bridging variables in our system.

Note this is not an exhaustive list and other critical variables could be identified in the map.



CHAPTER 3 CHECK-IN

Has the core project team:

- [ ] Selected a tool for completing a system thinking exercise?
- [ ] Created a climate profile of the area under assessment?
- [ ] Defined the boundaries of the system?
- [ ] Identified the variables within the system?
- [ ] Identified and characterized the interdependencies within the variables?
- [ ] Created a visual representation of the system?

If using causal loop diagrams, the core project team should also answer if they have:

- [ ] Developed causal loops?
- [ ] Classified loops as balancing or reinforcing?
- [ ] Created a system map?

4 Framing the Results

The detailed understanding of the system developed during previous chapters must now be framed in a way that allows the results to be used as part of a climate risk assessment (CRA). This chapter demonstrates how systems-based analysis is compatible with the CRA methodologies described in ISO 31000 and the ISO 1409x series.

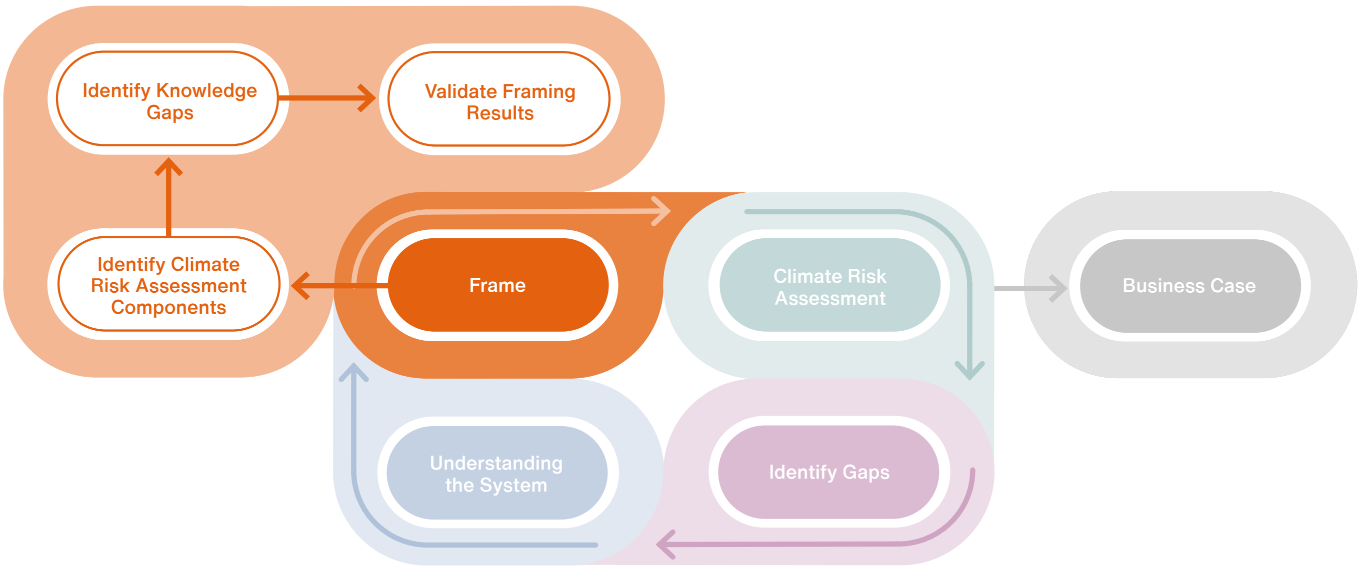
PURPOSE: The purpose of this chapter is to frame the results of the systems-mapping activity into a format that can be used in a CRA.

INTENDED OUTCOMES: By the end of this chapters, users will be able to:

- Identify variables that relate to potential climate hazards.
- Document variables with potential to influence the vulnerability of other events.
- Group together infrastructure variables with similar properties to simplify analysis.
- Identify and bridge gaps in knowledge or expertise.

RECOMMENDED SUPPLEMENTARY TEAM MEMBERS:

- Subject matter experts identified in Chapter 4.2



4.1 Identify Relevant Climate Risk Assessment Components

A CRA utilises three components, which combine to provide an understanding of how the different variables relate to each other. The three components are:

1. Infrastructure Elements
2. Climate Hazards
3. Vulnerability Drivers

In this step, users will review the completed system map to identify and classify the variables into the component categories, so that the inputs of the climate risk assessment can be developed. Additionally, subject matter experts (SMEs) who can speak to the vulnerability of each component of the CRA will be identified.

Worksheet 4.1 – Climate Risk Assessment Components

Worksheet 4.1 contains a template that can be used to identify and categorize variables, and to track the CRA components of the system, in the three categories.

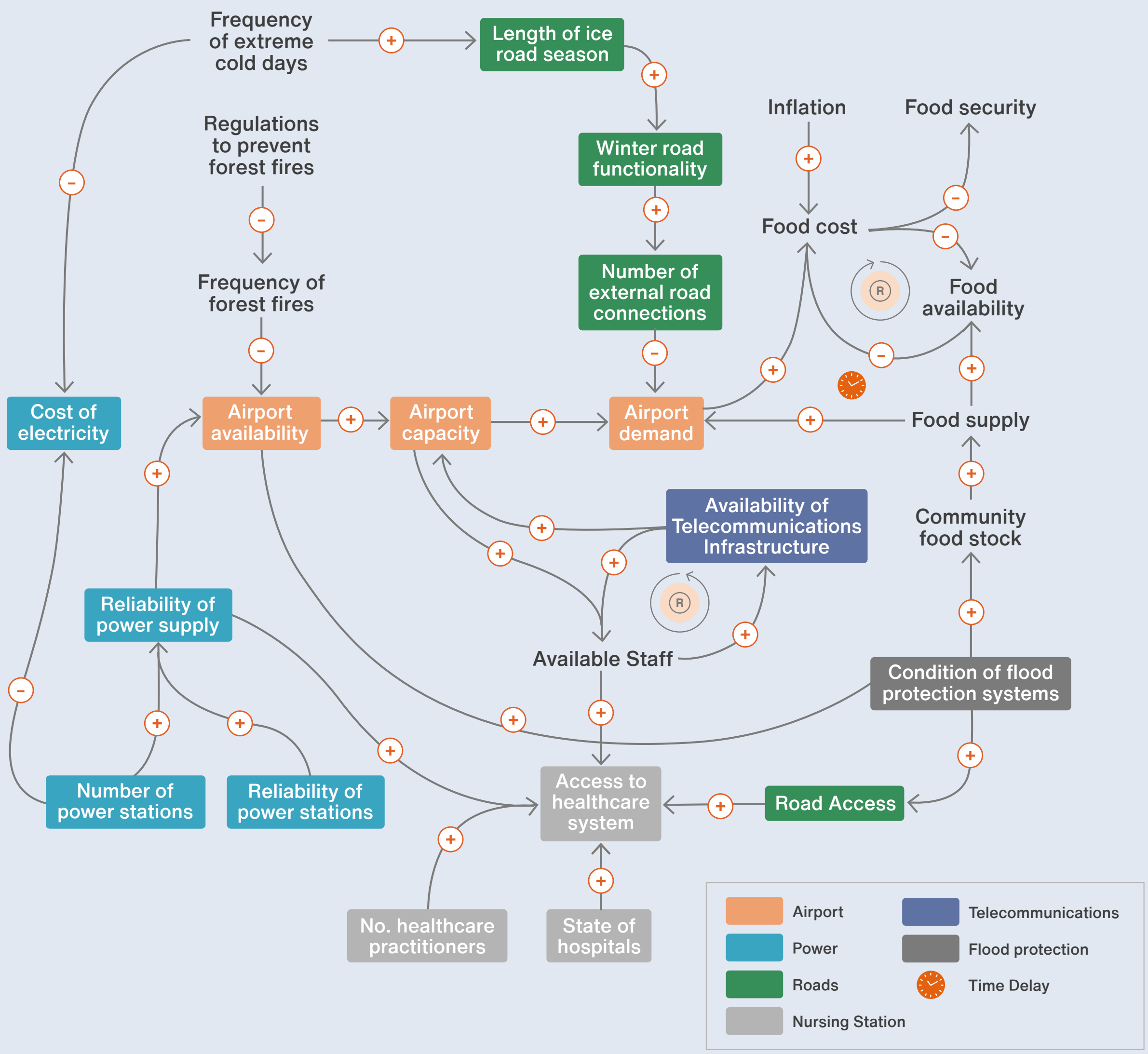
	DEFINITION	EXAMPLES
Infrastructure Elements	• The physical and functional dimensions of the system that will be assessed. • Usually (but not always) physical – they can also relate to how a system operates. • Variables that belong to the same infrastructure element can be grouped together. • Variables categorized into the infrastructure element categories may not all be physical or functional, but the categories themselves will be.	Airports Roads Hospitals Flood defences
Climate Hazards	• Relate to current or potential climate variables. • May be related directly to a climate hazard, or linked to climate mitigation or natural systems.	Precipitation Drought Flooding Wildfires Heat waves
Vulnerability Drivers	• System variables able to make other variables in a system more (or less) susceptible to the influence of other elements, which can affect their vulnerability, with consequential impacts on risk.	Clearcutting influences the vulnerability of a forest to flooding, forest fires, drought, and other variables. Inflation has an influence on the price of goods, such as food, clothing, housing, travel, and other necessary items, making these things more vulnerable.

Notes

- Infrastructure element categories may have multiple variables within them. For example, the Airport category may include "Condition of airport runway" and "Airport functionality".
- A single variable can be part of a single category of infrastructure element, or it may exist in more than one category. For example, "Condition of heating system" could belong to both the "Airport" and "Nursing Station" infrastructure element categories.
- Variables can relate to one or more climate hazards; and climate hazards can map to one or more variables in a systems map. For example, the variable "River level", could map to climate hazards for both drought and flooding.
- Vulnerability drivers are their own catalyst, and should not be grouped together. They can be identified from variables that have many downstream connections, as these indicate the variables more likely to influence others.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

The example below shows a completed example of Worksheet 4.1, populated with variables taken from the KLFN systems map, shown below:



CATEGORY	ELEMENT NAME	VARIABLE NAMES	SUBJECT MATTER EXPERT
Infrastructure Element	Airport	Airport availability; airport capacity; airport demand	Engineering, architecture
	Power	Cost of electricity; Reliability of power supply; Number of power stations; Reliability of power stations	Electrical engineering
	Roads	Length of ice road season; Winter road functionality; Number of external connections	Transportation engineering
	Hospital (Nursing Building)	Access to healthcare system; Number of healthcare practitioners; State of hospitals	Engineering, architecture, healthcare
	Telecommunication	Availability of Telecommunications Infrastructure	Engineering, architecture
	Flood Protection	Condition of flood protection systems;	Civil engineering, hydrology

CATEGORY	CLIMATE HAZARD NAME	VARIABLE NAMES	SUBJECT MATTER EXPERT
Climate Hazards	Wildfires	Regulations to prevent forest fires; Frequency of forest fires	
	Precipitation and Flooding	Condition of flood protection systems	Civil engineering, hydrology
	Extreme Heat / Cold	Frequency of extreme cold days	

CATEGORY	VARIABLE NAMES	SUBJECT MATTER EXPERT
Vulnerability Drivers	Frequency of extreme cold days	
	Regulations to prevent forest fires	
	Cost of electricity	
	Reliability of power supply	Electrical Engineering
	Reliability of power stations	Engineering
	Number of healthcare practitioners	
	Available staff	
	Food cost	
	Inflation	

In the KLFN example, it is revealed that some things may be obvious when planning for resilience, such as the reliability of the power supply, or the condition of the flood protection systems. Other variables may be less obvious, but equally important. In the case of KLFN, one of the underlying problems that many variables were ultimately connected to was the issue of food security and the physical and social wellbeing of the people in the community.

4.2 Identify Knowledge Gaps

Using the list of infrastructure elements, climate hazards, and vulnerability drivers identified in the previous step, determine whether any additional stakeholders or subject matter experts (beyond the core team) are needed to provide specialist input or bring additional knowledge to the assessment process.

Worksheet 4.2 – Identifying Subject Matter Experts

Worksheet 4.2 contains a template which can be used to determine whether additional input is needed.

4.3 Validate Framing Results

Engage the necessary stakeholders and SMEs to validate the proposed list of infrastructure elements, climate hazards, and vulnerability drivers; and confirm the results of the framing exercises. Depending on the project complexity, this step may involve additional workshopping or asynchronous engagement.

This process establishes the systems map that will be used in subsequent steps of the CRA, so gaining a consensus on exactly what is included and excluded from the scope of the assessment is important.

CHAPTER 4 CHECK-IN

Has the core project team:

- [ ] Classified variables into infrastructure elements, climate hazards, or vulnerability drivers?
- [ ] Identified additional subject matter experts who may need to participate in the assessment?
- [ ] Validated the framing results with subject matter experts?

5 Performing a Climate Risk Assessment

A CRA is used to formally document the impact of climate change on a system and provide a quantitative understanding of risk for different infrastructure assets to inform development and prioritization of resilience measures. This chapter shows how systems thinking can be used to enhance a CRA in order to account for the interdependencies between elements.

The purpose of this chapter is not to replicate existing guidance on the application of CRA methodologies, but instead to demonstrate how systems thinking can be integrated into a CRA process compliant with ISO 31000, or the ISO 1409x series. The approach described in Public Infrastructure Engineering Vulnerability Committee High Level Screening Guidance (PIEVC HLSG) is referenced throughout this chapter as one such example of a CRA methodology; others are available.

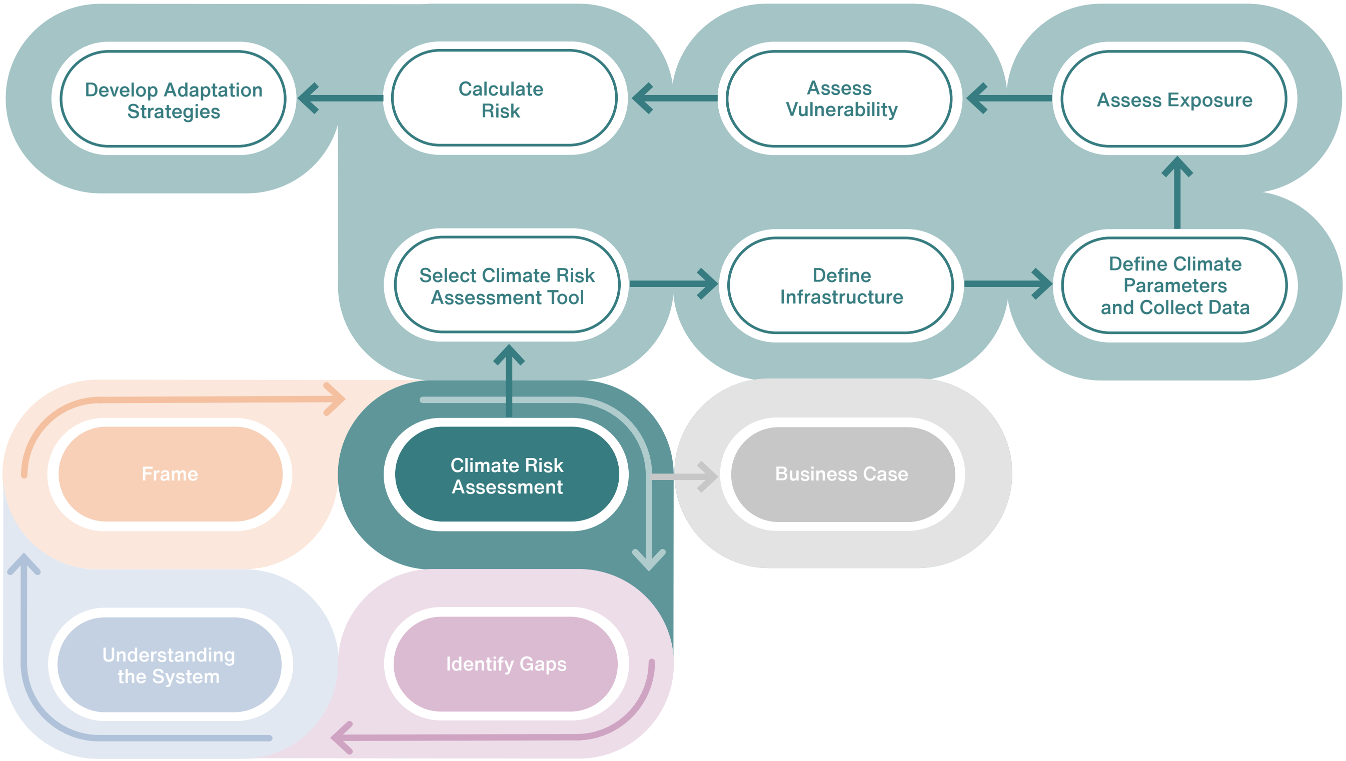
PURPOSE: The purpose of this chapter is to demonstrate how systems thinking can be incorporated into a climate risk assessment, using examples to illustrate key concepts.

INTENDED OUTCOMES: By the end of this chapter, users will be able to:

- Select an appropriate Climate Risk Assessment tool, aligned with ISO 31000 and the ISO 1409x series
- Complete a CRA, accounting for the effects of interdependencies and cascading impacts.
- Create a climate risk profile that can be used to develop adaptation measures.

RECOMMENDED SUPPLEMENTARY TEAM MEMBERS:

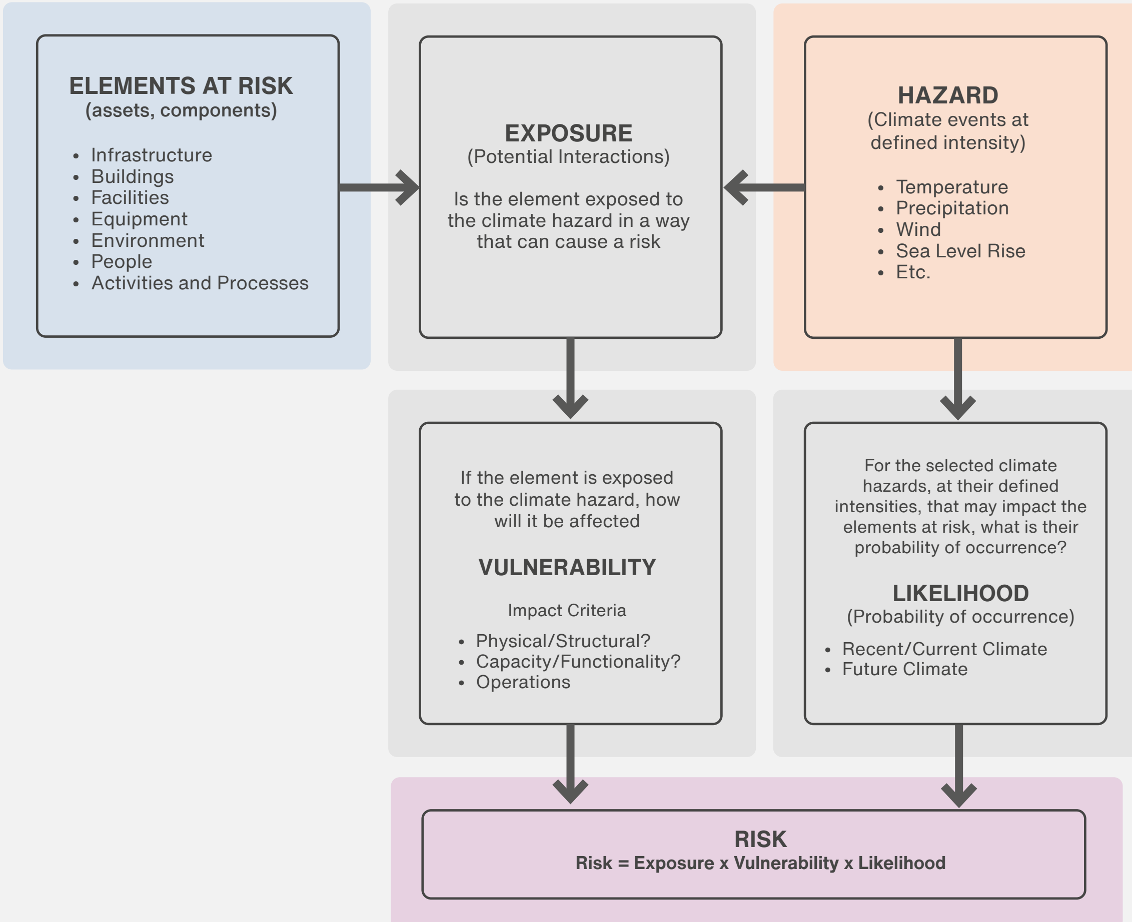
- Climate risk or climate adaptation specialist



5.1 Select a CRA Tool

Use the skill set and experience of the participants in the CRA to select a tool that will deliver the desired outcome.

A majority of existing CRA tools follow the approach outlined in the general CRA framework below. In this framework, Risk is quantified, with the score determined as the product of the Likelihood of a Hazard occurring, multiplied by the Exposure and Vulnerability of a given Element with respect to the Hazard.



General Climate Risk Assessment Framework

To score risks in a consistent way requires a clear definition and understanding of the key terms. In this guidance, the following definitions are used.

Term	Definition
Hazard	Something with the potential to cause harm under the right circumstances
Element	Represents the physical and functional dimensions of the system that will be assessed
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected
Vulnerability	The propensity or predisposition to be adversely affected. This encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt
Risk	The product of exposure, vulnerability, and the likelihood of a hazard occurring

The Canadian Council of Ministers of the Environment (CCME) Guidance on Good Practices in Climate Change Risk Assessment is a useful reference when selecting a tool for the CRA. Factors to consider when selecting a CRA tool include:

- **Complexity of the assessment.** Tools such as PIEVC HLSG are designed for higher level assessments; others such as FEMA HAZUS suit more complex and detailed analysis.
- **Organizational alignment and training needs.** Prior experience and familiarity with using a particular tool is invaluable.
- **Costs.** Some tools are free and open access, others have a cost or are proprietary.

The Organisation for Economic Co-operation and Development (OECD) is an international body that works with governments and policy makers to find solutions to a range of environmental challenges using evidence-based international standards. "Climate-resilient infrastructure"[xi] is a 2018 policy paper aimed at encouraging climate resilience in the development and planning of infrastructure projects, and the inclusion of climate risks in financial decision making; and which contains examples that illustrate the impacts of climate change on different sectors and regions, and links to some of the different tools used by OECD and G20 countries to perform CRAs.

The report includes links to a number of sustainability rating tools to help decision makers assess their options, as well as examples of frameworks that have been developed and used to assess climate risks, and tools to perform cost-benefit analysis; while noting that given the context-specific nature of climate adaptation, the outcomes of any measures used will vary widely between locations.

Some examples of CRA tools are provided in the table below. A link to each tool can be found by clicking on the name of the tool.

Name	Owner(s)	Description
Climate Lens – Climate Resilience Assessment	**Infrastructure Canada**	• Describes federal requirement for funding under various programs. • Resilience assessment must use a methodology that is broadly consistent with ISO 31000 and include both current and future climate. • Assessment must also follow guiding principles of Proportionate Assessment, Systemic Analysis of Risk, Pursuit of Multiple Benefits, and Avoiding Unintended Results.
Guidance on Good Practices in Climate Change Risk Assessment	**Canadian Council of Ministers of the Environment**	• Guidance document for CRA practitioners. • Include six key questions to consider before starting a CRA. • Summarizes six good practices in the form of six existing CRA frameworks being used, alongside with case studies.
Technical Guide Related to the Strategic Assessment Of Climate Change – Assessing Climate Change Resilience	**Environment and Climate Change Canada**	• Technical guidance document for completing CRA assessments on projects. • Presents a five-step framework, aligned with ISO31000. • Includes high level summary of climate change trends in Canada and links to climate information resources.

Name	Owner(s)	Description
Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol	**Institute of Catastrophic Loss Reduction (ICLR), Climate Risk Institute (CRI) and Deutsche Gesellschaft für Internationale Zusammenarbeit (giz)**	• Structured guidance along with worksheets to conduct CRAs, with an optional component to complete engineering analysis. • Includes a module to complete a triple bottom line (TBL) analysis of vulnerability findings and recommendations. • Designed for a multidisciplinary process involving interdisciplinary collaboration and professional judgement.
PIEVC High Level Screening Guide (HLSG)		• Streamlined version of the PIEVC Protocol, removing the TBL analysis.
PIEVC Large Portfolio Assessment Manual: A Guide for Prioritizing a Large Portfolio based on Climate Vulnerability (BETA release)		• This manual provides guidance on the ways infrastructure owners may use vulnerability and risk assessment to inform setting priorities and managing the climate resilience of a large portfolio of assets.
PIEVC Green Protocol: Integrating Ecosystem-based Adaptation into Infrastructure Climate Risk Assessments (BETA release)		• Outlines a process to assess infrastructure component responses to climate change impacts, while considering the broader social and environmental systems
First Nations Infrastructure Resilience Toolkit (FN-IRT)	**Ontario First Nations Technical Services Corporation (OFNTSC)**	• Toolkit designed for First Nation (FN) communities to assess the vulnerability of their infrastructure to extreme weather. • Climate Risk Assessment module of this toolkit is also known as the FN-PIEVC, a variant of the PIEVC Protocol designed for FN communities.
Federal Contaminated Sites Action Plan (FCSAP)	**Environment and Climate Change Canada**	• Guidance document to provide a framework for integrating climate change adaptation into the exiting 10 step process of the FCSAP Decision Making Framework • This allows practitioners completing contaminated sites assessment evaluations to integrate climate considerations into their workflow
Building Adaptive & Resilient Communities (BARC)	**ICLEI**	• Program focused on resilience and adaptation, designed for municipal governments. • Offers a comprehensive way to respond to the impacts of climate change, develop and implement an adaptation plan. • Available for a fee based on municipality size
Hazard, Risk And Vulnerability Analysis (HRVA) For Local Authorities And First Nations	**Emergency Management BC**	• Online tool for Local Authorities and First Nations to conduct an HRVA. • Includes accompanying guidebooks and worksheets. • Multi hazard, and allows for the development of a risk profile as well as identify risk reduction strategies.
Climate Resilience Guidelines for B.C. Health Facility Planning and Design	**GreenCare**	• Guideline for health authorities and consultant teams providing a process for identifying and reducing climate risks in planning and design of healthcare facilities. • Includes considerations to account for compounding hazards as well as cascading effects. • Includes guidance on how to integrate into a Business Case process to support investment in the selected option.

Name	Owner(s)	Description
Hazus MH	**US Federal Emergency Management Agency (FEMA)**	• GIS based toolkit for estimating risk from earthquakes, floods, tsunamis, and hurricanes. • Quantify and map risk information such as physical damage to infrastructure, economic loss, social impact, and evaluate cost effectiveness of mitigation strategies. • Requires GIS based hazard data (for example flood inundation maps).
CanFlood	**National Resources Canada (NRCAN)**	• GIS based toolkit for floods. • Quantify and map risk information such as physical damage to infrastructure, economic loss, social impact, and evaluate cost effectiveness of mitigation strategies. • Requires GIS based hazard data.
Task Force on Climate-Related Financial Disclosures (TCFD)	**Financial Stability Board (FSB)**	• Framework to guide organizations on the types of information they should disclose to support investors, lenders, and insurance underwriters in appropriately assessing and pricing a specific set of risks related to climate change. • Organizations must report on governance, strategy, risk management, metrics and targets as it relates to climate change. • Disclosures include physical as well as transition risks
Vulnerability Assessment Scoring Tool (VAST)	**US Department of Transportation**	• Excel based tool designed for determining vulnerability scores for transportation assets, including rail, ports and waterways, airports and heliports, oil and gas pipelines, bridges, and roads and highways. • Tool considers characteristics of transportation assets as indicators of exposure, sensitivity, or adaptive capacity, and collects information on these indicators to estimate a vulnerability score. • Designed to work for 11 predetermined climate stressors
Climate Resilience Evaluation and Awareness Tool (CREAT) Risk Assessment Application for Water Utilities	**US Environmental Protection Agency**	• Web based tool for completing climate resilience evaluations for water utilities. • Tool designed around 5 modules, which allows for identifying consequences of climate impacts and developing and evaluating adaptation plans. • Integrates with other EPA tools such as Vulnerability Self-Assessment Tool (VSAT).

Next steps after selecting a tool

The purpose of this guidebook is not to recreate well-established tools for completing CRAs, but rather provide a framework that integrates SBAs into existing CRA tools. The following sections provide a step-by-step guidance on the typical steps that a CRA would follow to illustrate where SBAs fit in. The most critical step for integrating SBAs into the CRA process is within the vulnerability assessment (Section 5.5). Users that are very familiar with CRAs may opt to skip the following sections and go straight into Section 5.5.

5.2 Define Infrastructure

This stage defines the scope and boundaries of the CRA, and identifies the information needed to complete the CRA.

Note on Objectives and Boundaries

The purpose of the CRA is to understand how climate impacts the system, taking into account interactions within the system. However, the CRA may be focused on a subset of components as opposed to the entire system, and thus its objectives may differ from those of the overall assessment (see Chapter 2.1). Because objectives may differ, the physical boundaries of the CRA may also differ from the boundaries of the systems map.

To illustrate this using the example from the Kasabonika Lake First Nation study:

1. The overall assessment considered impacts on the entire community, including external factors (such as inflation) with the potential to impact vulnerability across several areas.
2. The CRA example described in the following sections will focus on a single element in the system – the Airport – and uses this as a starting point to define the boundaries and objectives, expanding the scope to include other elements with potential to impact airport operations.

Define the boundaries and objectives of the CRA, finalize the list of elements and participants, and establish the timeframe for the assessment.

Objectives. When defining an objective, it is important to establish whether any specific information is required. For example, there may be specific needs related to:

- Details needed to support funding applications (e.g., as part of an Infrastructure Canada (INFC) Climate Lens submission)
- Environmental impact assessments
- Criteria for financial disclosures of climate-related risks (as per the Task Force on Climate-related Financial Disclosures)

An objective should be succinct, realistic, and actionable. For example, "The climate risk assessment for the proposed water treatment plant expansion is to be completed by 2024 and align with Infrastructure Canada's Climate Lens Guidance."

Articulating the scope of the CRA, helps to determine the elements at risk, and the corresponding level of detail needed to conduct the assessment, which influences the scope and level of effort of the CRA, as shown in the figure below.

DEFINING THE ELEMENT AT RISK

- Scope of the CRA
  - Individual assets (e.g., building)
  - System of assets (e.g., water supply system from source to tap)
  - Collection of systems (e.g., roads, bridges and drainage; water and wastewater systems)
  - Portfolio of assets (e.g., all buildings owned by agency)
  - All assets within a region (e.g., a municipality)

Expanding the Boundary

Boundaries. Since this chapter of the guidebook is focused on assessing the impacts that climate hazards have on the assets under study, it is necessary to redraw the boundaries from Chapter 3: Understanding the System based on the CRA objectives. This will allow users to extract relevant climate hazard data and finalize the list of elements under study.

Finalize list of Elements

The elements of the CRA are now finalized, by taking the list of elements identified in Chapter 4: Framing the Results and considering whether the current level of detail is appropriate, or whether an element needs to be further broken down into constituent parts for a full assessment. This process depends on the objectives and boundaries determined in the previous step.

For example, different components of an Heating Ventilation and Air Conditioning (HVAC) system may respond in a different way to specific climate hazards. Accordingly, a choice can be made to split the element into two parts to allow the potential impacts on the heating and cooling functions to be considered separately.

Elements can include:

- **Asset/Components:** Physical components of infrastructure assets
- **Activities/Operations:** Operational activities performed by an organization that maintain the functionality of assets to provide services
- **Personnel/Community:** Staff and others involved in the assets, components, activities and operations may be at risk due to exposure to climate hazards. May be divided by functions (for example, those working at heights or staff responsible for vegetation control)

The table below provides examples of elements that might be used in a CRA, covering the categories of buildings, roads, and solid waste management. The final list of elements to be included in the CRA should be tailored based on the assets being assessed, and to meet the scope and boundaries of the assessment. The Uniformat system for components classification and site elements can be a useful resource for finalizing the list of elements for buildings.

Example: Building			
Grounds	Landscaping	**Interior**	Ceilings
	Fences/Gates/Railings		Partitions (walls, doors)
	Retaining walls		Stairs
	Pedestrian surfaces		Signage
	Vehicular surfaces (access) and parking		Storage
	Play areas		Finishes
Exterior	Access (steps, ramps, platforms)	**Mechanical**	Heating / Cooling (equipment, distribution, controls, fuel supply)
	Painting and finishes		Ventilation (fans, ducts)
	Openings (doors, windows, skylights)		Plumbing (internal)
			Conveyance
	Exterior mounted equipment (lights, security cameras, antennae, signage)		Fire system (pump, standpipe, hose cabinets, extinguishers)
Substructure	Foundations	**Electrical**	Distribution (services, panels, wiring)
	Basement		Lighting (interior, emergency)
Shell	Superstructure		Emergency power (generator – internal or external)
	Exterior enclosure (envelope)		Communications
	Roofing		Alarm systems
	Surface	**Other Elements**	As required depending on the type of building considered in the risks assessment
Activities/ Operations	Process loads	**Personnel**	Building staff
	Maintenance		Residents

Example: Roads, Streets and Bridges

Roads/Street	Driving surface	**Bridge**	Deck
	Base		Curbs
	Shoulders		Railings
	Curb and gutter		Drainage
	Sidewalks		Lighting and signage
	Lighting		Pedestrian walks
	Traffic signals		Expansion joints
	Signage		Superstructure
Drainage	Culverts (< 3.0m diameter)		Foundations
	Culverts (> 3.0m diameter)		Abutments
			Piers
			Bearings
			Approach barriers
			Channel + Erosion Protection

Example: Solid Waste Management

Landfill site	Soil covering	**Recycling and composting facilities**	
	Compaction equipment		Building (see Building components)
	Fencing		Access road
	Access road		Composting area
Incinerator	Incinerator		Hazardous waste depot
	Controls		Drop-off areas
	Fuel tank		
	Ash disposal		

Finalize list of Participants

Once the elements to be included in the CRA are finalized, the participant list can be agreed upon. The core team plus the list of participants from Chapter 4.2 can be used as a starting point, then reviewed and refined accordingly.

The owner and/or operator of an asset usually have the most detailed information and knowledge of the asset's performance, their input is critical to ensuring there is a common understanding impacts of climate change on the performance of that asset.

For a CRA, subject matter knowledge from a climate scientist or specialist is often beneficial.

The involvement of other participants and subject matter experts will depend on the scope of the CRA. There may be a benefit in including representation from the following areas:

- Planning
- Engineering
- Operations
- Maintenance
- Risk management
- Environment
- Others as required

Define the timescales of the CRA

The time horizon selected for the risk assessment is used to both assess the likelihood of a particular climate hazard occurring within the specified time period, and to assess whether the vulnerabilities identified in the assessment are likely to change over time.

The timescales for the assessment should be based on the typical service life of the elements included in the study, established as a function of the service life of individual assets or components.

Typically, a baseline or reference period is selected, defined as a 30-year period in the past (for example, the years from 1981-2010). Future time horizons are then defined typically as 30-year blocks that occur after that baseline, for example, the years 2011-2040 (2020s); 2041-2070 (2050s); and 2071-2100 (2080s).

Worksheet 5.1: Contains a template that can be used to summarize the assessment objectives, boundaries, timescales and elements.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation (KLFN), Worksheet 5.1 can be used as follows. Note that this is based on assumptions for illustrative purposes and not the drivers of the publicly available study that was completed.

Objectives

The following table can be used to record the key considerations to determine the objectives of the assessment

Consideration	Response
Is the CRA required for a funding application (e.g., as part of an INFC Climate Lens submission)?	NO
Is the CRA part of the development a community climate change adaptation plan?	YES
If responded Yes to the previous question, provide further details	Assessment results are meant to inform community wide adaptation strategies.
Is the CRA required under an environmental impacts assessment?	NO
Is the CRA performed to assess the adequacy of design criteria for infrastructure that will have a long service life during which climate changes are expected?	NO
Will the CRA results be used in financial disclosures of climate-related risks (as per the TCFD)?	NO
Please use this space to list any other considerations that should be accounted for in the assessment	• Use traditional knowledge • Consult with elders, band council, and community leaders • Complete within next year

Using the information in the table above, sample objectives could be defined as follows

The CRA will be completed by 2024
The CRA will include all physical assets within the boundaries of the community
The CRA will include consultation with elders, band council, and other community leaders
The CRA will incorporate traditional ecological knowledge wherever possible

Boundaries

For the CRA, the physical boundaries of the site are defined as shown in the figure below.

Elements

Building on the elements list identified in the Frame step, a final list of elements and required SMEs can be completed. The example below shows how this can be done for select infrastructure assets, which is not inclusive of the entire asset base of KLFN.

Element	Lifecycle	Required SME
HOSPITAL (NURSING BUILDING)		
Building structure	70 years	Structural engineer
Electrical system	Varies	Electrical engineer
Mechanical system	25 years	Mechanical engineer
Building envelope	25 – 35 years	Envelope consultant/Civil engineer
Medical equipment	Varies	Healthcare professional
Site services	50 years	Civil engineer
Medical staff	(N/A)	Healthcare professional

Element	Lifecycle	Required SME
AIRPORT		
Building Structure	70 years	Structural Engineer
Electrical System	Varies	Electrical Engineer
Mechanical system	25 years	Mechanical engineer
Building envelope	25 – 35 years	Envelope Consultant/Civil Engineer
Site services	50 years	Civil Engineer
Runways and taxiways	50 years	Civil Engineer
Communications equipment	30 years	Telecommunications Engineer
Radar and weather equipment	25 years	Electrical Engineer
Airport staff	(N/A)	Operations staff
Airport Flight Operations	(N/A)	Operations staff
ROADS		
Culverts	50 years	Civil Engineer
Road surface	15 years	Civil Engineer
Utilities	50 years	Civil Engineer

Timescale

Time horizon	Years included	Justification for selection
Baseline	1981-2010	Commonly used baseline for CRAs
2020s	2011-2040	Some components have a short lifespan and are expected to be renewed in the next 15-20 years
2050s	2041-2070	To address elements with expected renewals within the next 25 – 30 years such as building systems
2080s	2071-2100	To plan for long term investments

5.3 Define Climate Parameters and Collect Data

Creating a Detailed Climate Profile

Typically, a comprehensive CRA requires a more detailed climate profile than the version used to develop the initial systems map (see Chapter 3: Understanding the System). For the CRA, a climate profile that takes account of the specific infrastructure and other elements of the study scope is needed.

Creating this detailed climate profile involves selecting an appropriate Representative Concentration Pathway (RCP)/Shared Socioeconomic Pathway (SSP) climate scenario, with representative climate parameters, hazards, and hazard indicators. The choice of climate scenario depends on the selection of assets and elements being assessed, the risk tolerance of the asset owner, and on the availability of relevant climate data.

The final results of a CRA will be influenced by climate change projections that the core project team uses. Climate projections are extracted from climate models which are generated for alternative scenarios based on projected greenhouse gas emissions (for further detail see the box below). From a conservative risk management perspective, standard practice for CRAs is to select the worst-case scenario, which corresponds to RCP8.5 or SSP5-8.5.

Instances when other scenarios may be justified include the use of a lower emissions scenario, such as RCP4.5, to project a reduced rate of change in the annual freeze-thaw cycles over the analysis period.

Based on the assessment objectives, select the appropriate RCP/SSP scenario to be used to extract climate change projections.

Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSP)

Global Climate Model (GCM) results are influenced by the projected change in global greenhouse gas (GHG) emissions. Various future trajectories of GHG emissions and associated concentrations are possible depending on socio-economic choices and the global mitigation efforts in the coming years.

AR5 and RCPs

The Intergovernmental Panel on Climate Change (IPCC)'s Coupled Model Intercomparison Project Phase 5 (CMIP5) completed during the Fifth Assessment Report (AR5) developed a set of GCMs based on Representative Concentration Pathways (RCPs). Four RCPs were developed to represent various trajectories with varying degrees of atmospheric GHG concentrations. RCPs were explicitly designed for the climate modelling community, however, the underlying socio-economic characteristics used to define RCPs were not standardized.

AR6 and SSPs

In the Coupled Model Intercomparison Project Phase 6 (CMIP6) completed during the Sixth Assessment Report (AR6), the IPCC now uses Shared Socioeconomic Pathways (SSP) to develop a set of GCMs. SSPs further refine the RCPs by defining how societal choices can lead to changes in emissions and atmospheric GHG concentrations.

Select the climate parameters

Climate parameters represent climate conditions that either impact (in the current climate) or could impact (in the future climate) the performance of an asset/component or activity. Within these climate conditions, specific type of climate events, or hazards, can be identified.

As the impact on performance also depends on both the intensity and frequency of a climate event, it will be necessary to define multiple indicators for the climate hazards used in the assessment.

Based on the above, the following key terms are used consistently throughout this guidebook.

Term	Definition	Examples
Climate Parameter	A broad category of measurable climate conditions	Temperature, Precipitation, Sea level rise, Wind speed
Climate Hazard	A specific type of event within the climate parameter category	Extreme heat, Cooling degree-days, Rainfall intensity
Climate Hazard Indicator	Quantifiable climate thresholds determined by their expected impact the elements (infrastructure asset or component, or activity) of the system assessed	Number of days with T_{max} >35°C; Precipitation > 100mm in 24hrs; Freezing Rain > 30 mm in 12hrs

The selection of climate hazard indicators often requires input from subject matter experts able to advise on the thresholds to include in the assessment. Some examples of common climate hazard indicators, and the corresponding climate hazards and parameters are provided below.

Climate Parameter	Climate Hazard	Climate Hazard Indicator	Comments on Selection (If available, include examples with dates and details of events that have occurred and caused damages or disruptions that support selection of parameters and hazards)
Temperature	Extreme heat	Number of days with T_{max} >35°C	• May impact sensitive electronic equipment, particularly if located in metal enclosures. • Impacts on the productivity of outdoor staff (health and safety policy requires breaks/ hydration during episodes of extreme heat)
		Number of days with T_{max} >40°C	• Although the area has not yet experienced this extreme high temperature, projections in future climate indicate these will occur. • Similar impacts as for T_{max} >35°C • Potential for accelerated damage to components if material sensitive to extreme heat. • Impacts on capacity of A/C systems and indoor air quality • Potential damage to asphalt concrete surfaces if mix design is for lower temperatures (e.g., asphalt temperature may be +20°C or more higher than ambient temperature
	Seasonal variation Cooling degree-days (CDD)	Double the cooling degree days from reference period accompanied with earlier (spring) and later (autumn) CDD's	• Service life impacts on cooling equipment that has to operate at maximum capacity for longer periods of time • Increased demand on HVAC systems and in some cases, requiring the addition of A/C systems in buildings that do not have them. • Loss of functionality of indoor environment due to inadequate cooling • Increase operational requirements to balance HVAC systems during shoulder seasons due to fluctuations between heating and cooling needs.
Precipitation	Short duration / high intensity (SD/HI) rainfall	Number of events per year with > 50 mm rain in < 6 hr hours	• The capacity of the stormwater management system in the area where the assets are located (built to older standards) has been established at 50 mm/6 hrs. Exceedance of this rainfall has caused local flooding in the past. • Flooding from past events of this type of SD/HI have caused street flooding requiring closure of sections, and basement property damages.

Depending on the scope of the assessment, it may be more effective to select the climate parameters and hazard indicators as part of a facilitated workshop which includes a climate specialist.

Extract climate data

Historical and projected climate data for all the time horizons can be extracted after finalizing the list of climate parameters, hazards and hazard indicators. The specifics of climate data extraction is beyond the scope of this guide. Typically, this will involve using various sources of data such as online portals as well as scientific literature. A climate scientist or specialist is a key subject matter expert for this process.

Extract historic and projected data for all climate hazard indicators.

Establish Likelihood Scores

Using the historical and projected data extracted in the previous step, a value that represents the future probability of occurrence can be assigned to each climate hazard indicator. This value is typically expressed as a score, often on a 1-5 scale.

The thresholds and definitions used to assign a particular likelihood score depend on the CRA tool being applied. The examples provided below demonstrate two alternative approaches:

- the Infrastructure Canada (INFC) scale is **absolute**, with scores based on the anticipated frequency of occurrence in specified time periods,
- the PIEVC middle baseline approach is **relative**, using the anticipated change in frequency compared to current conditions to determine the score.

Each tool is accompanied by guidelines on how to calculate likelihood scores, and those guidelines should be followed in each case.

Select an appropriate scale to use when assigning a likelihood score to each of the climate hazards included in the assessment.

INFC Climate Lens General Guidance[xii] – Climate Change Resilience Assessment Likelihood Score Scale

Probability Range / Type of Event	1 Very Low	2 Low	3 Moderate	4 High	5 Very High
Event(s)	Not likely to occur in period	Likely to occur once between 30 and 50 years	Likely to occur once between 10 and 30 years	Likely to occur at least once a decade	Likely to occur once or more annually
On-going / Cumulative Occurrence	Not likely to become critical / beneficial in period	Likely to become critical / beneficial in 30-50 years	Likely to become critical / beneficial in 10-30 years	Likely to become critical / beneficial in a decade	Will become critical / beneficial within several years

PIEVC HLSG Middle Baseline Approach for Likelihood Score

Score	Relative Frequency	Relative Change
5	Likely to occur **more frequently or intensely** than current climate	Increase of 50 - 100%
4		Increase of 10 - 50%
3	Likely to occur **about as frequently or intensely** as in the current climate	Change of +/- 10%
2	Likely to occur **less frequently or intensely** than current climate	Reduction of 10 - 50%
1		Reduction of 50 - 100%

The "middle baseline" likelihood scoring method is reproduced with permission from the PIEVC Program. Source: PIEVC Program. 2022. PIEVC© Family of Resources, High Level Screening Guide. Toronto/Ottawa: Institute for Catastrophic Loss Reduction/Climate Risk Institute.

Worksheet 5.2 – Contains a template that can be used to summarize the climate hazards, their projected changes, and the corresponding likelihood scores.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation (KLFN), Worksheet 5.2 can be used as follows. The data was extracted from the publicly available report [i]

Note: only select climate hazards are shown in this application example for illustrative purposes. A full climate profile is likely to include more parameters, hazards, and hazard indicators.

Climate Parameter	Climate Hazard	Climate Hazard Indicator and Threshold	Rationale for selection - Include references to past events if available.
Temperature	Extreme heat	Number of days with T_{max} > 30°C	Affects building occupant comfort
		Number of days with T_{max} > 35°C	Increases risk of heat strokes or heat related illness
	Extreme cold	Number of days with T_{min}<-30°C	Increases energy for heating, can result in hypothermia
Precipitation	Freezing rain	10 mm of ice accumulation	Can result in damages to powerlines and outside equipment

For this example, the PIEVC HSLG's Middle Baseline Approach for Likelihood Score was selected

Score	Description
1	Likely to occur **less frequently or intensely** than current climate Reduction of 50 - 100%
2	Likely to occur **less frequently or intensel**y than current climate Reduction of 10 - 50%
3	Likely to occur **about as frequently or intensely** as in the current climate Change of +/- 10%
4	Likely to occur **about as frequently or intensely** as in the current climate Increase of 10 - 50%
5	Likely to occur **about as frequently or intensely** as in the current climate Increase of 50 - 100%

The extracted and analyzed climate data could then be summarized in a table as follows. For this example only mean values are shown. The data was extracted from the publicly available KLFN CRA report[i]

Climate Parameter	Climate Hazard	Climate Hazard Indicator and Threshold	Unit	Baseline	Change from Baseline Under [RCP8.5] (%) Median			Projected Value Under [RCP8.5] (units) Median			Likelihood Scores			
					2020s	2050s	2080s	2020s	2050s	2080s	Baseline	2020s	2050s	2080s
Temperature	Extreme heat	Number of days with T_{max} > 30°C	Days/ year	1.6	131	469	1219	3.7	9.1	21.1	3	5	5	5
		Number of days with T_{max} > 35°C	Days/ year	0.2	0	450	2600	0.2	1.1	5.4	3	3	5	5
	Extreme cold	Number of days with T_{min} <-30°C	Days/ year	32.5	-33	-71	-93	21.8	9.4	2.2	3	2	1	1
Precipitation	Freezing rain	10 mm of ice accumulation	Data for this parameter was not available in the report, however likelihood scores for future climate were reported and used here for illustrative purposes.								3	4	5	5

5.4 Assess the Exposure

Once the climate data collection is completed, an assessment of the impacts of climate on the final list of elements that form part of the system can begin. This begins with the identification of all elements exposed to each climate hazard.

The Intergovernmental Panel on Climate Change (IPCC) Working Group II defines **exposure** as:

> "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected."

For the purposes of a CRA, exposure is assessed using a binary scale.

- **Yes** - If an element exposed to a climate hazard is likely to result in a material impact, then further assessment is needed to determine the extent of that impact.
- **No** - If an element exposed to a climate hazard is unlikely to result in a material impact, no detailed assessment is needed at this stage. If necessary, the element-hazard pair can be re-assessed later.

If in doubt, adopt a prudent approach and assume there is exposure.

Typically, depending on the scope of the assessment, the exposure and subsequent vulnerability assessment is conducted or validated in a workshop setting allowing for discussion and interactions between participants.

Exposure example:

For a building exposed to a climate hazard of **Extreme Precipitation**:

- The exterior components of a building, such as the roof and walls, would experience a material impact caused by precipitation, and are therefore **exposed**
- The interior components of the building, such as fixtures and furnishings, would not experience a material impact due to precipitation (assuming the envelope is in good condition and does not leak), and are therefore **not exposed.**

Worksheet 5.3 – Contains a template that can be used to record the exposure assessment

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation (KLFN), Worksheet 5.3 can be used as follows, for the elements described in the earlier step.

Element	Climate Hazards		
	Extreme heat	Extreme cold	Freezing rain
Hospital (Nursing Building)			
Building Structure	NO	NO	NO
Electrical System	YES	YES	YES
Mechanical system	YES	YES	YES
Building envelope	YES	YES	YES
Medical equipment	NO	NO	NO
Site services	YES	YES	YES
Medical staff	YES	YES	NO
Airport			
Building Structure	NO	NO	NO
Electrical System	YES	YES	YES
Mechanical system	YES	YES	YES
Building envelope	YES	YES	YES
Site services	YES	YES	YES
Runways and taxiways	YES	YES	YES
Communications equipment	NO	NO	YES
Radar and weather equipment	NO	NO	YES
Airport staff	YES	YES	YES
Airport Flight Operations	NO	NO	YES
Roads			
Culverts	NO	NO	NO
Road surface	YES	NO	YES
Utilities	NO	YES	YES
Total Exposed (YES)	**12**	**12**	**14**
Total Not Exposed (NO)	**7**	**7**	**5**

5.5 Assess the Vulnerability

Once the elements that are exposed to each climate hazard have been identified, the vulnerability of the exposed elements can be determined.

The IPCC Working Group II defines **Vulnerability** as:

> "The propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."

This definition introduces two key properties often referenced in risk and resilience assessments:

- **Sensitivity:** the degree to which a system or element is affected when exposed to a hazard.
- **Adaptive Capacity:** the ability of the system or element to adjust to potential damage, take advantage of opportunities, or respond to consequences.

Enhancing vulnerability assessments with systems thinking

CRAs which focus only on assessing the vulnerability of elements due to direct interaction with hazards often do not take into account the **dependencies between elements**.

Systems thinking allows us to account for these interdependencies in a systematic, transparent, and consistent manner.

To complete a vulnerability assessment leveraging systems thinking, two different types of vulnerabilities are assessed: **individual** and **compound,** as further defined in the example below.

Individual Vulnerabilities

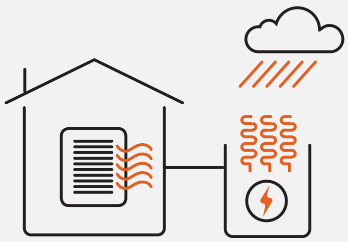
Description: Arise from the direct interaction of the element with the climate hazard. They do not take into account the interdependencies between elements.

Example: A roof deteriorating due to increased rain would be an individual vulnerability of the roofing system to rain.

Compound Vulnerabilities

Description: Arise from the interdependencies between elements and cascading effects associated with the failure of one element impacting another element.

Example: The air conditioning of a building requires power to operate. If the power grid has an individual vulnerability to rain, the air conditioning may have a compound vulnerability to rain due to power loss during a rain event.



Worksheet 5.4 – Contains a template to record the vulnerability assessment. Note that certain tools (such as the PIEVC HLSG) already contain worksheets or spreadsheets that can be used for this step; but which may require modifications to accommodate the compound vulnerabilities assessment.

Individual Vulnerabilities

Many CRA tools include bespoke mechanisms which can be used to assess and score individual vulnerabilities, together with guidance to describe how the process should be followed.

Typically, this step involves defining the scoring thresholds used to quantify vulnerability, based on the impacts that the climate hazard has on the element. The scoring scales often draw from impacts that include the following types:

Impact Type	Notes
Physical	Used to define the impacts on the structural integrity of the asset or component – measured by fractures, excessive or permanent deformations, loss of supporting elements, etc. Can be applied to “people” assets to capture the impact of extreme weather events on workers’ health and safety.
Service life	Considers the gradual degradation of materials due to progressive changes in climate events’ intensity or frequency which may result in reduced service lives of assets or components. Can be applied to assets and components of assets.
Functional	Relates to the loss of capacity or function of an asset or component to meet demand at its design capacity, or inadequate design capacity to meet current or future climate loads. Can be applied to assets and components.
Operational	Used to measure changes in operational activities such as inspections, clearing debris after storms, use of deicing products, or energy use; or to assess the impact on worker productivity, or which result in maintenance delays and backlogs. Can be applied to assets, activities, and people.

Considerations when developing a vulnerability scale include:

- The scale used when scoring vulnerability should be selected based on the impact criteria, and reflect the risk tolerance of the organisation.
- Once the scale is selected, the vulnerability assessment can be completed by individuals with sufficient knowledge of the design and operations of the assets, components and activities.
- When assigning a score, it is important to document the justification for that score. The same factors which influence scoring may also inform potential adaptation strategies.

The table below demonstrates the use of a five-point scale to assess vulnerability, with examples drawn from each of the four types of impact used to indicate the relative consequences. Note that the actual definitions will vary by organization – for example a service interruption of 6 hours may only represent a minor inconvenience in one industry, but indicate a major disaster in another.

Rating and Description	Physical Impacts	Operational Impacts	Service Life Impacts	Impacts on Functionality/ Productivity
1 Insignificant	No structural damage	Fixed with regular maintenance	Slight loss of service life due to climate hazard	Less than 10% loss of capacity
		Full access to asset or component	Expected service life reduction < 5%	Service interruption less than 1 hour
	Health and Safety (H&S) employees: No injuries or first aid requirements (minor accident) with no consequences for the person affected			
2 Minor	Minor structural damage	May require inspection	Minor loss of service life	Loss of capacity > 10% and < 20%
	Less than 10% components damaged	Corrected with current O&M staff and within budget	Expected service life reduction > 5% and < 10%	Service interruption > 1 hr and < 6 hrs
	H&S employees: Slight injury (any minor injury other than a disabling injury that may require medical treatment by a health professional (ambulance, nurse, doctor). The consequences do not exceed the initial day of the event.			Employees: Loss of productivity > 10% and < 30%
3 Moderate	Moderate damage	Requires additional inspections	Moderate loss of service life	Loss of capacity > 20% and < 30%
	Between 10% and 25% of components damaged	Repairs require external service/parts	Expected service life reduction >10% and < 20%	Service interruption > 6 hrs and < 12 hrs
		Additional O&M budget required but can be accommodated within organization		Repairs may require temporary closure of other components/assets
	H&S Employees: Injury resulting in temporary disability (>1 day), absence from work and/ or temporary functional limitation may take a few days to get back to work with restricted functions. Reversible health effects ex: fracture.			Employees: Loss of productivity > 30% and < 50%

Rating and Description	Physical Impacts	Operational Impacts	Service Life Impacts	Impacts on Functionality/ Productivity
4 Major	Major damage	Requires inspections by external expert team and equipment	Major loss of service life	Loss of capacity > 30% and < 40%
	Between 25% and 50% of components damaged	Requires external assistance to repair	Expected service life reduction >20% and < 40%	Service interruption > 12 hrs and < 24 hrs
		Requires additional budget – need to access external funding		Repairs may require temporary closure of other components/ assets
				Alternative service delivery or relocation of service required
	H&S Employees: Major injuries with hospitalization requiring a prolonged absence from work. Irreversible damage to health by severe disability without loss of life. E.g. head trauma or paraplegia.			Employees: Loss of productivity > 50% and < 75%
5 Catastrophic	Catastrophic damage	Complete loss of access to assets	Significant loss of service life	Loss of capacity > 40%
	More than 50% of components damaged	Specialised external help required	Expected service life reduction > 40%	Service interruption of > 24 hrs
	Full replacement of asset required	Emergency funding needed		Potential injuries or loss of life if service not restored
	Impacts on other assets			Requires relocation of people and service
				Declaration of state of emergency
	H&S Employees: 1 or more deaths			Employees: Loss of productivity > 75%

An example of an individual vulnerability assessment for select elements of a hypothetical residential building is shown below. The score scale is 1-5, and accompanying rationale are shown in each cell.

Element	Climate Hazards	
	Extreme heat (Days with T max > 31°C)	**Extreme precipitation (Maximum rain intensity)**
Building envelope	**Score = 2:** increased heat will increase heat flow through components of the envelope (cladding, windows, doors). In the short term this results in increased thermal gains in the building. In the long term, this will impact durability	**Score = 3:** increased precipitation increases risk of leaks which could cause significant damages
Heating system	**Not exposed**	**Score = 1:** outdoor components (exhaust vent) minimally impacted by rain
Cooling system (lobby only spaces)	**Score = 3:** increased heat will exceed the design capacity of the AC system, which is critical for cooling common spaces as they provide the only refuge for occupants during a heat event	**Score = 1:** outdoor components (condenser) minimally impacted by rain
Building occupants	**Score = 5:** increased heat can result in heat illness or death, as building does not have cooling in units, and occupants have mobility issues	**Not exposed**
Electrical Grid	**Score = 3**: Grid has had brownouts in past heat events, resulting in prolonged periods without power	**Score = 3:** Grid has had several brownouts/blackouts during heavy precipitation events, resulting in prolonged periods without power

Compound Vulnerabilities

For compound vulnerabilities, the objective is to quantify, in a systematic, transparent, and reproduceable manner, the combined impact that the individual vulnerabilities of one element have on another one based on their interdependencies.

Systematically accounting for compound vulnerabilities is a relatively novel concept in CRA and is a key example of how systems thinking can be leveraged into the CRA process.

A five-step mechanism for calculating the **compound vulnerability score** is provided below. **Worksheet 5.4** contains tools that can be used to calculate a compound vulnerability score. Alternative approaches can also be used, provided they meet the following criteria.

A compound vulnerability score assessment should:

- Leverage engagement from qualified SMEs.
- Be transparent and well documented.
- Be internally consistent, such that if two or more elements share a critical dependency, their score with dependencies must be consistent.
- Account for the magnitude of the relationship between elements.
- Prevent the “endless” propagation of a high-risk score throughout the entire system map.

Calculating the compound variable score is a five step process:

1.	Identify the vulnerable elements
2.	Determine the connected elements
3.	Rate the individual dependencies
4.	Tabulate the dependencies
5.	Calculate the compound vulnerability scores

STEP 1: IDENTIFY THE VULNERABLE ELEMENTS

Shortlist the elements to focus on those with the highest individual vulnerability scores. Identifying these elements, and the elements they are directly connected to, provides a solid starting point to locate the most critical elements within a system, since compound vulnerabilities are driven by relationships between elements.

Using systems maps to understand compound vulnerabilities

Systems maps use variables, not elements, as their building blocks. Variables are converted to elements during the ‘frame’ step.

To simplify the assessment of compound vulnerabilities, it can sometimes be helpful to redraw portions of the original system map, replacing variables with elements that more clearly represent the relationship.

Remember that one element can map to multiple variables, and vice versa.

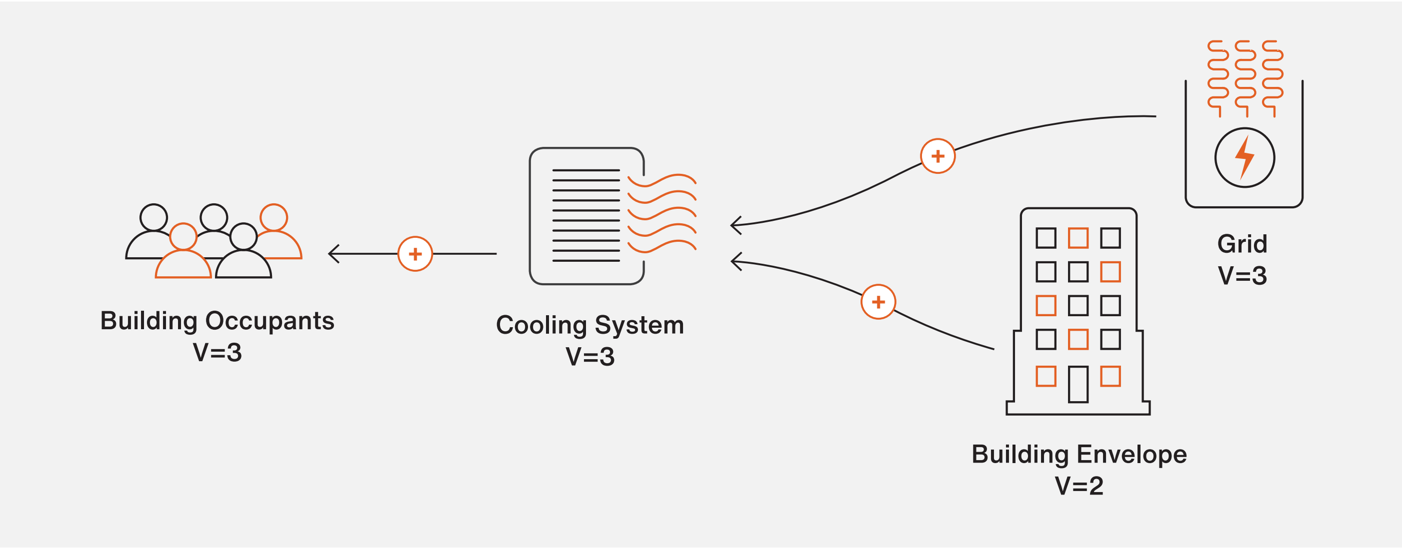
STEP 2: DETERMINE THE CONNECTED ELEMENTS

For each shortlisted element, use the system map to identify additional connected elements which are also vulnerable to the climate hazard.

Focusing on the elements of the system map connected to each shortlisted element, or redrawing a portion of the systems map centered on a key area for greater clarity, can help to identify previously unseen connections.

The diagram below shows one portion of a systems map, highlighting the cooling system as an element that is vulnerable to extreme heat, and also showing other connected elements (building occupants, building envelope, grid); together with their respective individual vulnerability scores, given by (V=n).

Individual Vulnerabilities of Elements Connected to Cooling System
Climate Hazard: Extreme Heat



STEP 3: RATE THE INDIVIDUAL DEPENDENCIES

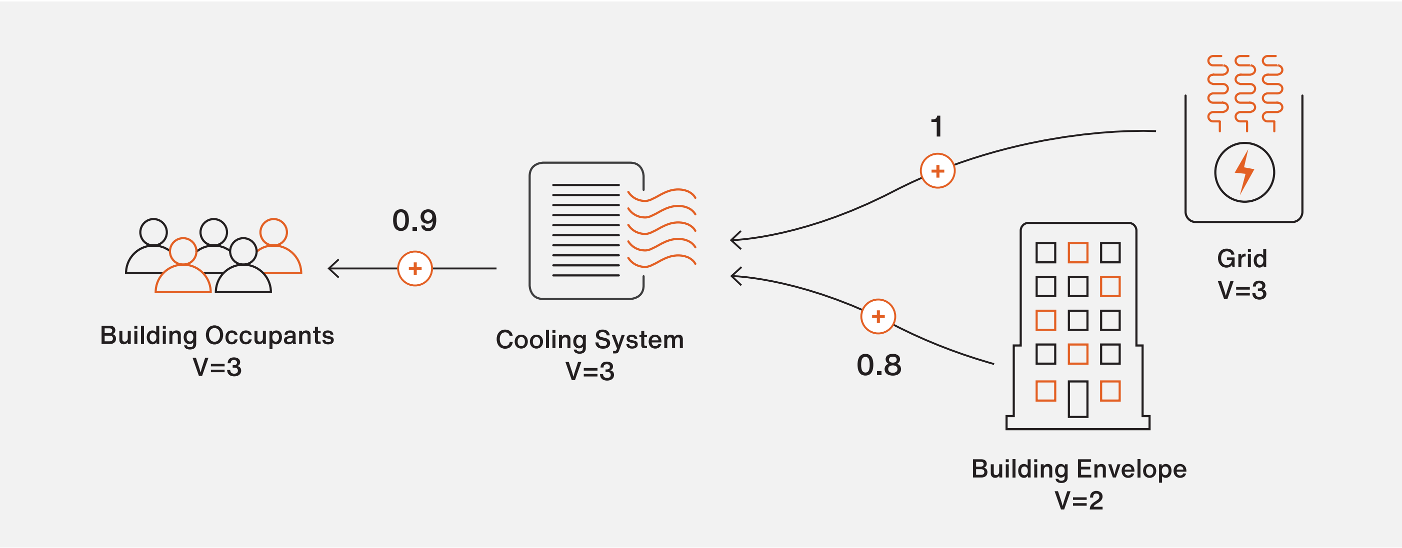
For all relationships and connections identified, assess the relative strength of each relationship by assigning a score to each connection. To do this, a scale from 0 to 1 can be used. In this scale a higher value represents a stronger relationship (or a greater dependency), and vice versa. Users can use this scale as a continuous one (being able to select any value between 0 or 1) or establish set thresholds, such as:

- 0.1: very weak relationship/dependency
- 0.25: weak relationship/dependency
- 0.5: average relationship/dependency
- 0.75: very strong relationship/dependency
- 1: critical relationship/dependency

This assessment should be done by the members of the team most familiar with the elements whose dependencies are being assessed.

The example below now includes a score to show the relative strengths of the relationship, next to the arrows that represent each relationship in the systems map. In this example, a critical relationship (air conditioning cannot operate without power) received a score of 1, whereas a weaker relationship (the condition of the building envelope influences the AC performance but is not essential for its functioning) received a score of 0.8.

Individual Vulnerabilities of Elements Connected to Cooling System
Climate Hazard: Extreme Heat



STEP 4: TABULATE THE DEPENDENCIES

Using the results of the previous step, create a table and populate it with each element-hazard pair and the upstream elements they connect to. This is needed to collate the full set of elements to be included in the compound vulnerability assessment. To prevent double counting, only the upstream vulnerabilities are assessed for each element.

Continuing the building example, the grid and building envelope are elements that are upstream of the cooling system, so the individual vulnerabilities of those elements will be included in the cooling system's compound vulnerability calculation. The building occupants are downstream of the cooling system, so their individual vulnerability is not included in the cooling system compound vulnerability (it will be calculated when examining the building occupants, compound vulnerability). A table summarizing the upstream dependencies for this example would therefore look as follows.

Element	Climate Hazard	Upstream Element
Cooling System	Extreme Heat	Grid
		Building Envelope
Building Occupants	Extreme Heat	Cooling System

STEP 5: CALCULATE THE COMPOUND VULNERABILITY SCORES

For each entry in the table, record the individual vulnerability scores and the relationship magnitude determined in Step 3, and use the values to calculate the impact on compound vulnerability for each upstream element, as follows.

Impact on compound vulnerability = Individual vulnerability * (1/5) * relationship magnitude

Note: The 1/5 factor is used to normalise the results, and assumes that the vulnerability scores are based on a 1-5 scale. If a different scale is used, the factor should be scaled accordingly. (e.g. for scores based on a 1-7 scale, a scaling factor of 1/7 should be used)

Where there is more than one upstream element, the above process is repeated to calculate the impact on compound vulnerability for each upstream element. These values are then added together to generate the total impact on compound vulnerability score, as shown in the example below.

Continuing with the building example, looking at the cooling system, the compound vulnerability score would be calculated as follows.

Element: Cooling System
Climate Hazard: Extreme Heat

Upstream elements	Individual vulnerability	Relationship magnitude	Impact on compound vulnerability
Grid	3	1	(3*1/5*1) = 0.6
Envelope	2	0.8	(2*1/5*0.8) = 0.32
Total	-	-	**0.6+0.32 = 0.92**

To determine the overall vulnerability score, the impact on compound vulnerability score calculated in this step must be added to the initial individual vulnerability score of the element.

For this example, the individual vulnerability score of the cooling system (3) is combined with the impact on compound vulnerability score (0.92) to give a **compound vulnerability score of 3.92.**[3]

[3] The maximum permitted compound score should be capped at the maximum value of the individual vulnerability scale (e.g. if vulnerability is scored using a 1-5 scale, the maximum compound vulnerability score should not exceed 5.0).

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation (KLFN), Worksheet 5.4 can be used as follows to complete the vulnerability assessment.

The vulnerability scale from the original publicly available report [ii] can be used for this step, as described in the following table.

Score	Structural	Functional	Operational
1	No impact	Asset functions normally	No loss of service (LOS)
2	Minor impact, can be corrected through normal maintenance	Minor impact	<10% customers affected by some LOS
3	Larger impact, may require outside resources repairs	Service not available in parts of the community	30-50% customers affected / possible LOS May require external funding for repairs
4	Loss of asset component or several critical components	Requires community-based response action/plan	Requires alternative service delivery 50-80% costumers affected by some LOS
5	Total loss of asset Impacts multiple assets/ components	May require declaration of state of emergency	Will require significant additional funding Will impact public health and safety Widespread impact on community (>80% of community impacted)

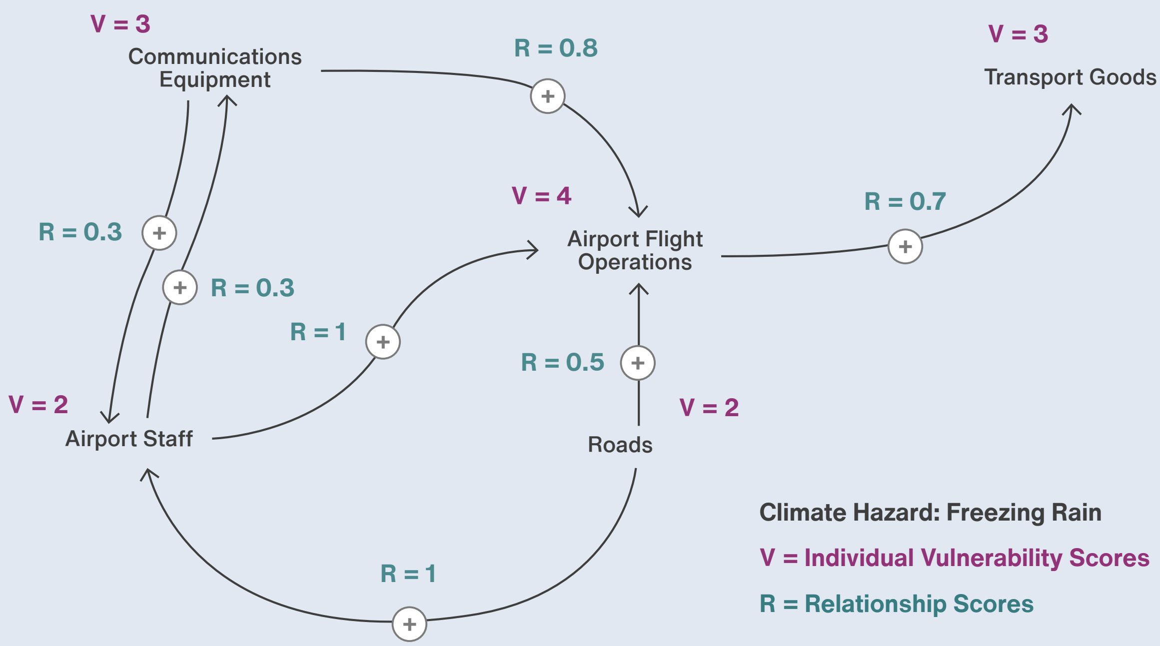
The individual vulnerability assessment can then be completed and validated in a workshop setting. The following table summarizes sample results from this assessment for a subset of the elements only. Greyed out cell represents an element-hazard interaction that received an exposure of "NO".

Element		Climate Hazards		
		Extreme heat	Extreme Cold	Freezing rain
Building Envelope	**Score**	2	1	3
	Comments	Increased heat flow through envelope and rate of deterioration of materials	Increased heat loss and energy consumption, increased risk of condensation in cavities	Increase rate of deterioration due to ice accretion. Risk of falling ice.
Mechanical System	**Score**	3	1	2
	Comments	Increased temperatures may exceed design capacity of HVAC	Extreme cold could damage outdoor units of HVAC	Ice accumulation could damage outdoor units of HVAC
Airport Staff	**Score**	3	2	2
	Comments	Heat waves increase risk of heat stroke / illnesses	Extreme cold increases risk of hypothermia or frostbite	Ice accumulation can result in slippery surfaces and result in injury
Airport Flight Operations	**Score**		2	4
	Comments		Extreme cold with precipitation can result in ice formation in wings of planes	Ice formation in airplane wings can result in accidents

After completing the above for all elements, the compound vulnerability assessment can be completed. For this case, **assume 4 is determined to be the threshold for identifying high individual vulnerabilities. Based on this, Airport Flight Operations** will be the only element that is explored further.

A simplified system map for this element can be redrawn to bring back the related elements based on the results from Chapter 3: Understanding the System and Chapter 4: Framing the Results. The diagram has also been labelled to include the following for ease of visualization:

- Individual vulnerability scores (from the individual vulnerability assessment, note that for this example some individual vulnerability scores where not shown in the earlier table)
- Relationship score, labelled in each of the connecting lines, which would be assigned.



With the above information, the compound vulnerabilities can then be calculated as follows

Element: Airport flight operations Climate Hazard: Freezing Rain			
Upstream elements	**Individual vulnerability**	**Relationship magnitude**	**Impact on compound vulnerability**
Communications equipment	3	0.8	0.48
Airport staff	2	1	0.4
Roads	2	0.5	0.2
Total	-		**1.08**

The **compound vulnerability** score for the Airport Operations is therefore 4 + 1.08 = 5.08, but since the score is 1 to 5, it will be capped at **5**.

5.6 Calculate Risk

The risk is calculated for each element-climate hazard interaction using the formula:

Risk = Likelihood x Vulnerability

The calculation can be completed for each time period in the assessment, and also for both the individual and compound vulnerabilities. The risks calculated using the 1-5 likelihood and vulnerability scales can then be shown in a "risk matrix" as shown below from the INFC Climate Lens Guidance.

Vulnerability		Likelihood 1	Likelihood 2	Likelihood 3	Likelihood 4	Likelihood 5
	5	5: Moderate Risk	10: High Risk	15: High Risk	20: Extreme Risk	25: Extreme Risk
	4	4: Low Risk	8: Moderate Risk	12: High Risk	16: High Risk	20: Extreme Risk
	3	3: Low Risk	6: Low Risk	9: Moderate Risk	12: High Risk	15: High Risk
	2	2: Negligible Risk	4: Low Risk	6: Low Risk	8: Moderate Risk	10: Moderate Risk
	1	1: Negligible Risk	2: Negligible Risk	3: Low Risk	4: Low Risk	5: Low Risk

For the example of the cooling system (page 75), and assuming the climate hazard of extreme heat has a **likelihood score of 3**, the overall risk score with individual and compound vulnerabilities are as follows:

Element: Cooling system
Climate Hazard: Extreme Heat

Risk with Individual vulnerability	Risk with Compound vulnerability
3x3 = 9 (moderate risk)	3x4 = 12 (high risk)

These results further illustrate how accounting for interdependencies escalated the risk from moderate to medium. By systematically documenting what drives individual and compound vulnerabilities, adaptation strategies can then be developed.

5.7 Develop Adaptation Strategies

Once all risk scores are calculated and risk justifications documented, adaptation strategies can be developed to mitigate the risks. Developing adaptation strategies is a complex task and may or may not be included in the scope of a CRA. Detailed guidance on how to develop adaptation strategies is outside the scope of this guidebook.

If adaptation strategies are developed, they can be summarized alongside the risks in a risk register to identify and prioritize the strategies based on risk levels. Strategies can also then be categorized by type, for example:

- **Physical Interventions.** Strategies whose primary function is to either reduce vulnerability to climate hazards (such as installing physical barriers) or retrofit the infrastructure to increase its resilience (such as adding cooling capacity to HVAC systems).
- **Planning/Policy.** The development of risk mitigation policies and contingency plans for extreme events, mandating resilience requirements in specifications and contracts for future developments, and liaising with other agencies.
- **Operating and Maintenance Procedures.** This category is focused on recommendations for reducing the risks through changes in operating and maintenance procedures.
- **Capacity development.** Capacity building strategies may be precursors to other types of strategies by providing leaders and staff with the resources they need to carry out solutions, or educational and outreach strategies that build community awareness of how to prepare for and respond to hazards.
- **Additional investigation.** These strategies are reserved for situations where a potential risk was identified but more detailed technical analysis beyond the scope of a high-level assessment (such as structural calculations) is required to validate the risk and determine a solution.

In 2021, the World Bank, together with the Global Facility for Disaster Reduction and Recovery, published "A Catalogue of Nature-based Solutions for Urban Resilience"[xiii] as a resource for those aiming to shape urban resilience with nature.

To help determine the suitability of nature based solutions within an urban landscape, and their effectiveness for climate resilience, they recommend using a systems-based approach to assess the risks, costs and benefits of that solution across all of the affected local typologies (e.g. urban forest, river floodplain, green corridor), before implementing any change. The report contains several real-world examples, covering three different spatial scales (river basin, city, neighbourhood).

The process to develop adaptation strategies can be enhanced through SBAs. Guidebook users can bring back the system map and analyse it in the context of the results from the CRA. Through this process, solutions can be reviewed in the context of the interconnectedness of the variables within the system. For example, if an element has a high risk due to compound vulnerabilities (such as culverts through roads vulnerable to extreme precipitation events compounded by the effects of deforested terrain), adaptation strategies that address the upstream elements generating the high vulnerability can be evaluated (such as addressing deforestation).

Worksheet 5.5 contains a template that can be used to summarize risk assessment results, and to record potential adaptation measures in a risk register.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation (KLFN), Worksheet 5.5 can be used to summarize the risk scores as follows. These were calculated using the likelihood and vulnerability scores summarized in the previous examples. In this example, compound vulnerabilities were only calculated for Airport Flight Operations, and as such, only this element has risk scores for compound vulnerabilities.

Element	Climate Hazard	Risk Scores [Individual Vulnerabilities]			Risk Scores [Compound Vulnerabilities]		
		2020s	2050s	2080s	2020s	2050s	2080s
Building Envelope	Extreme heat	10	10	10			
	Extreme cold	2	1	1			
	Freezing rain	15	15	15			
Mechanical System	Extreme heat	15	15	15			
	Extreme cold	2	1	1			
	Freezing rain	10	10	10			
Airport Staff	Extreme heat	15	15	15			
	Extreme cold	4	2	2			
	Freezing rain	15	15	15			
Airport Flight Operations	Extreme heat						
	Extreme cold	4	2	2			
	Freezing rain	16	20	20	20	25	25

The risk scores then support the development and prioritization of adaptation strategies. Understanding compound effects becomes important in this step. For example, for airport flight operations, the inclusion of compound effect changed the risk profile in the 2020s from high to extreme. With this information, adaptation strategies can be developed to not only address the direct vulnerabilities but also the compound ones.

CHAPTER 5 CHECK-IN

Has the core project team:

- [ ] Selected a CRA tool?
- [ ] Defined the objectives, timescales, and boundaries of the CRA?
- [ ] Finalized the list of elements of the CRA?
- [ ] Finalized the list of participants for the CRA?
- [ ] Defined the climate parameters and collected the data?
- [ ] Assigned likelihood scores to the climate parameters?
- [ ] Completed an exposure assessment?
- [ ] Completed a vulnerability assessment for:
  - Individual vulnerabilities?
  - Compound vulnerabilities?
- [ ] Calculated risk scores and created a risk profile?
- [ ] Developed adaptation strategies?

6 Identifying Gaps

After a CRA is conducted, it is important to test the assumptions made, and establish whether there are any gaps in understanding the system, or gaps in opportunities for resilience.

This chapter closes the loop, taking the outputs from a completed CRA, and circling back to assess whether they support the original understanding of the system. Identifying gaps in understanding or anomalies in the results can help to detect additional risks or vulnerabilities.

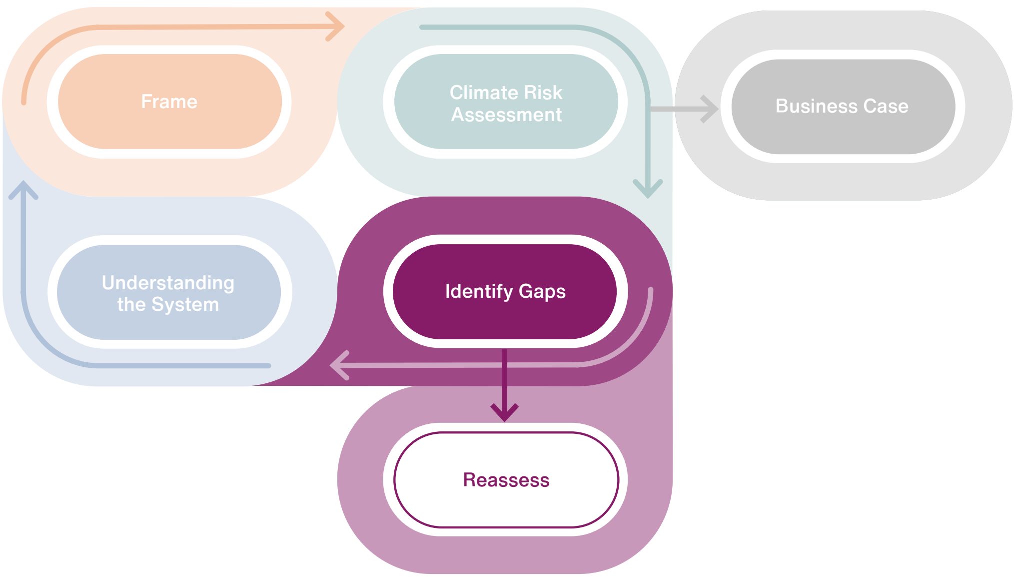
PURPOSE: The purpose of this chapter is to encourage users to return to their original systems map, with the aim of identifying any gaps in the CRA process that warrant further investigation or analysis.

INTENDED OUTCOMES: By the end of this chapter, users will have:

- A comprehensive set of variables vulnerable to climate hazards, including variables with only indirect exposure to climate hazards.

RECOMMENDED SUPPLEMENTARY TEAM MEMBERS:

- Additional subject matter experts or stakeholders, as identified in previous steps



6.1 Reassess

The exposure of each element to a climate hazard was originally assessed during the CRA process– (see Section 5.4: Assess the Exposure). A lack of direct exposure may have caused some assets to be eliminated, but their relationships and connections with other elements can increase their vulnerability. By reviewing the systems map, missing connections or elements can be identified, and included in subsequent CRAs.

It is also important to recall that there is inherent bias in both the systems map and the CRA because of the people involved in creating them. Take a moment to examine the results of the CRA and the systems map and compare them to the inputs and organizational goals and objectives. Do they align?

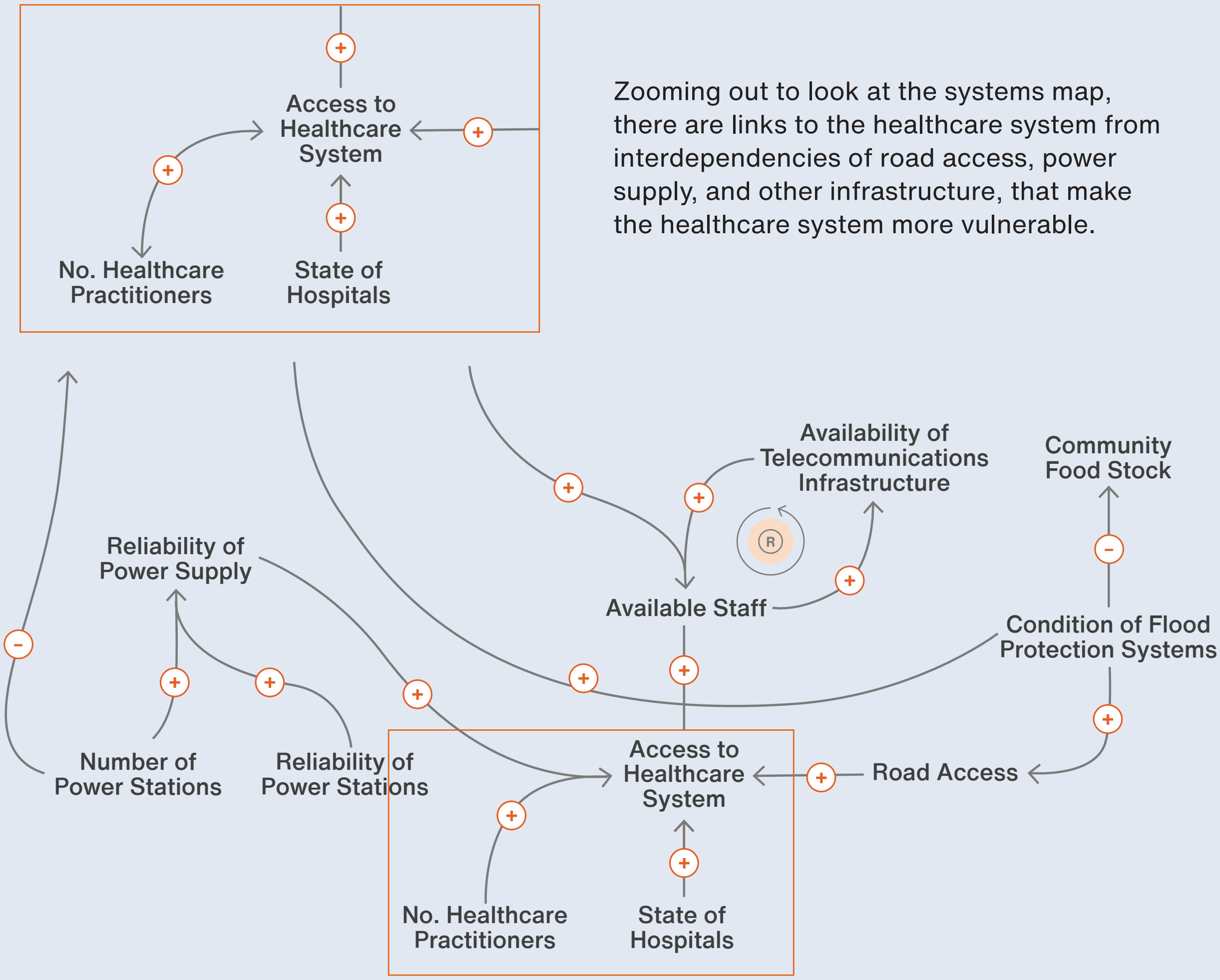
For example, suppose the goal of an organization was to perform a systems-based CRA for a stretch of coastal highway. In this step, the core project team reassesses the process and systems map and realizes that there were many land use changes from a nearby ski resort which have an impact on the highway and were left unexamined. This would be an appropriate time to bring in additional or returning subject matter experts to balance out both the systems map and the CRA if the core project team believes that certain variables or elements have not received enough attention.

Remember that there is a valuable systems map showing important interdependencies. The systems map should remain a living document to be revisited at any time.

By revisiting the links and elements and variables and identifying potential vulnerabilities due to cascading effects, gaps due to oversight or omission in the original CRA process may emerge. SBAs can then be applied to reassess these gaps, with the results fed back into the CRA, and used to develop adaptation solutions that take vulnerabilities into account.

APPLICATION EXAMPLE: KASABONIKA LAKE FIRST NATION

In the case of Kasabonika Lake First Nation, on first assessment, access to the healthcare system was not directly exposed to climate hazards; the healthcare system is protected from wildfires, flooding, and freezing rain.



Zooming out to look at the systems map, there are links to the healthcare system from interdependencies of road access, power supply, and other infrastructure, that make the healthcare system more vulnerable.

The healthcare system is reliant on the power supply, roads, staff, and flood protection. This shows the importance of looking at the elements in the context of a system, as opposed to in isolation.

CHAPTER 6 CHECK-IN

Has the core project team:

- ☐ Reassessed the exposure assessment using the systems map?
- ☐ Identified any gaps that require further analysis?

7 Business Case

This chapter describes how the information gathered throughout the assessment, including the initial adaptation strategies identified, can be integrated into a Business Case process that informs investment prioritization.

The approach described in this chapter was modelled on the Business Case process used by the BC Ministry of Transportation and Infrastructure (MoTI). This approach can be applied as is, with minor changes to align with the guidebook user organization, or alternative approaches may be selected based on the knowledge and experience of the core project team.

The guidance described in this chapter is used to inform a Business Case process, for example when several adaptation strategies are developed as part of an option selection and investment prioritization process.[4] If the intention is to proceed directly to implement adaptation strategies without requiring a business case, guidebook users may not need to complete this section.

PURPOSE: The purpose of this chapter is to demonstrate how the findings of the CRA can be integrated into a Business Case.

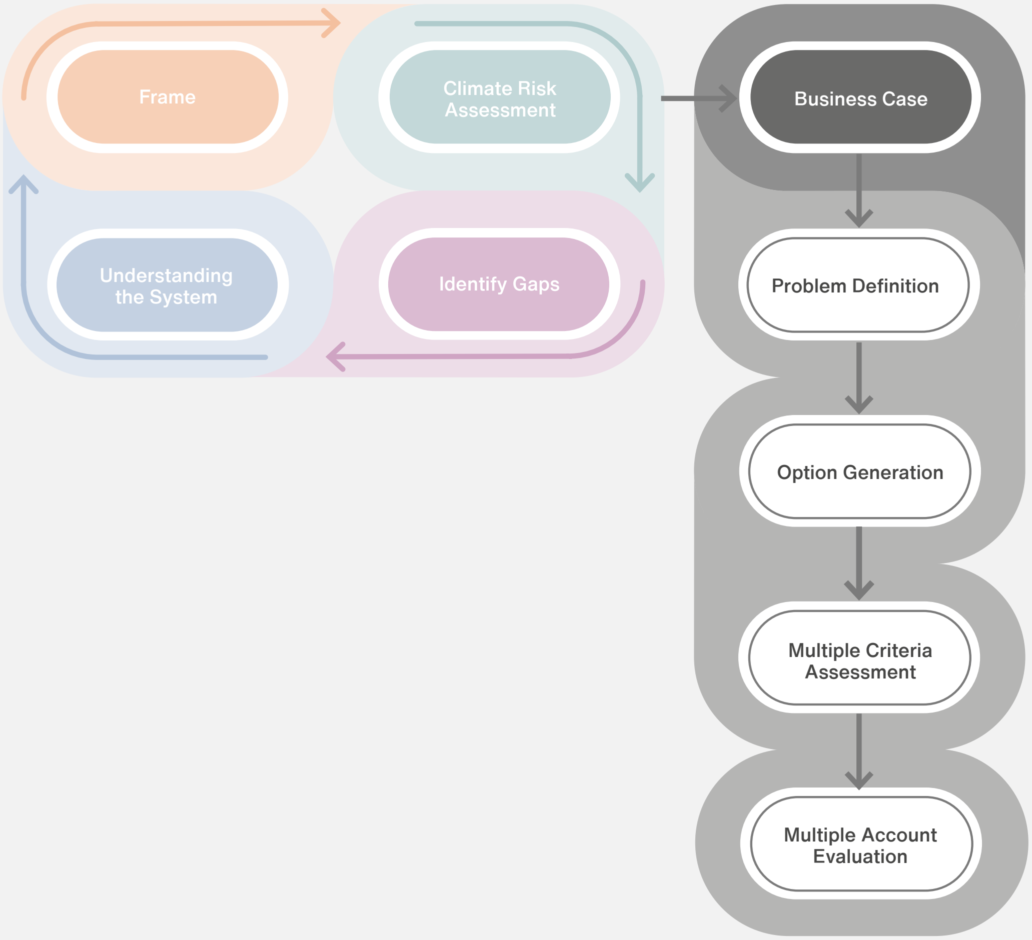
INTENDED OUTCOMES: By the end of this chapter, users will:

- Understand how to summarize the key findings from a CRA, using a format that can be shared with others involved in developing a Business Case.
- Know how to define resilience goals and develop alternative options.
- Be able to apply resilience considerations:
  - during the multiple criteria assessment (MCA), used to shortlist options, and
  - in the multiple account evaluation (MAE), used to select the final option.

OPTIONAL SUPPLEMENTARY TEAM MEMBERS:

- Business Case specialist

[4] The development of various adaptation strategies can also result in the development of "adaptation pathways". For additional info on this concept, refer to this example from British Columbia and this one from the UK.



Business Cases at BC MoTI

One of the main goals of a Business Case is to provide a strong foundation for a rational and defensible project development and implementation process. BC MoTI uses business cases to support decision-making and project prioritization throughout the project development life cycle, as well as to help the integration of community land-use planning and development impacts to transportation corridors and networks.

At BC MoTI, business cases are applied to both expansion projects (e.g. highway widening) as well as new projects (e.g. replacing aging infrastructure) funded by the MoTI's Transportation Investment Plan. Business cases address all stages of planning, design, property acquisition, and construction; with consideration given to the benefits of increasing highway capacity and improving mobility, safety, accessibility, and reliability.

Typically, a business case contains two main components: a **recommendation** (supported by an implementation plan); with a **justification** for that recommendation.

The recommendation, applicable to projects at the planning stage or design stage, should include specific information describing:

- the asset(s) to be built,
- the location of the project,
- the anticipated project cost,
- the source of the project funding, and
- for multi-year projects, how and when the project will be implemented.

The Business Case should include:

- **Problem Identification:** a statement identifying the problem(s) being addressed,
- **Option Generation:** the list of potential options under consideration to address the identified problems,
- **Multiple Criteria Assessment:** a multi-disciplinary process to screen the generated options into the most feasible options that will be analyzed with a more detailed Multiple Accounts Evaluation Framework
- **Multiple Accounts Evaluation:** a comprehensive evaluation of each of the shortlisted options to select the preferred option, and
- **Risk and Implementation:** a supporting risk assessment and implementation strategy for the preferred option (note this was excluded from previous flowchart diagrams as it is outside of the scope of this guidebook).

BC MoTI's Guidelines for Preparing Business Cases: Overview, updated in 2015, includes advice on the steps required in the preparation of business case, covering:

- Identification of potential options to address the identified problems, including multi-modal opportunities;
- Identification of the preferred option based on a Multiple Accounts Evaluation (MAE) Framework;
- Identification and quantification of risks; and
- Federal Funding Applications (e.g., Building Canada Fund, Federal Disaster Financial Assistance Arrangements (FDFAA).

This guidebook includes guidance on how to integrate resilience into the problem identification, option generation, multiple criteria assessment, and multiple accounts evaluation steps of the Business Case process. Additionally, as of the development of this guidebook, BC MoTI was planning to launch a project that will rebuild and modernize the existing MAE process; by delivering a multi-modal, integrated Multiple Account Evaluation toolkit.

7.1 Problem Definition

The Business Case begins by defining the problem to be addressed by the proposed infrastructure investment. Every other chapter in this guidebook has so far been focused on achieving climate change resilience. However, when prioritizing investment decisions, resilience is only one of many competing priorities. For example, when evaluating investment for a highway corridor, typical considerations would include:

- Mobility
- Safety
- Reliability
- Infrastructure Conditions
- Constraints

Similar additional considerations could be drawn for any proposed infrastructure investment.

Subject matter experts may be called upon to provide input on the problem definition from the perspective of their discipline. This guide focuses on climate resilience considerations only, and follows a two-step process.

Step 1: Prioritise high risk elements that are critical and material to the project.

Using the outcomes of the CRA (refer to Chapter 5: Performing a Climate Risk Assessment), develop a list of the element-hazard interactions considered to be **critical and material** for the Business Case being developed.

- This step may require additional consultation with the subject matter experts who participated in the CRA.
- Use the risk tolerance of the organization conducting the assessment to determine the risk scoring thresholds to define what critical and material means.

Step 2: Summarise the elements and vulnerability description.

Summarize the key element-hazard interactions shortlisted during the CRA into a tabular format, and provide this information to the team completing the Business Case. When assembling this summary, use separate tables to record individual and compound vulnerabilities.[5] The asset owner and organization completing the assessment has the ability to influence individual vulnerabilities. When third parties influence the vulnerability of the asset (as identified through the assessment of compound vulnerabilities), the analysis provides the opportunity for discussions with those third parties to reduce the impacts on the element at risk.

For example, a CRA on a coastal road reveals an individual vulnerability of a bridge washing out, and the road agency has control over the bridge design. However, a compound vulnerability might involve the land uses at an adjacent ski resort for which the road agency has no control. This information could be valuable for engaging the third party responsible for the ski resort, but depending on the scope of the project it may not be actionable in the development of a business case to consider alternative road options.

Avoid double counting compound vulnerabilities

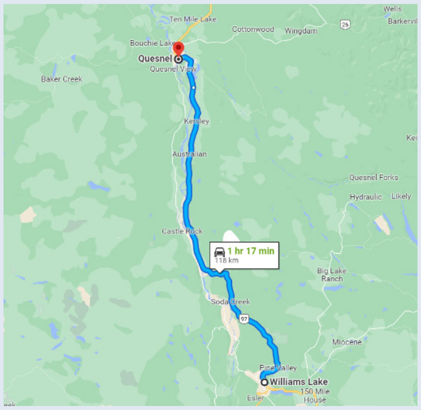
When identifying compound variables (see Section 5.5: Vulnerability Assessment), only the upstream variables of each element are included in the assessment, to prevent double counting.

The same approach should be applied when summarizing compound vulnerabilities: only report those that arise from "upstream" elements, to prevent double counting.

Worksheet 7.1: Contains a template that can be used to summarize the elements and vulnerability descriptions.

[5] In this guidebook, only individual vulnerabilities are used past Step 1 for simplicity purposes. Compound vulnerabilities could also be carried through the next steps following a similar approach.

APPLICATION EXAMPLE:
WILLIAMS LAKE TO QUESNEL HIGHWAY CORRIDOR



As this section is modelled after the BC MoTI existing Business Case process, a different application example is used instead of the Kasabonika Lake First Nation. The example is a theoretical highway corridor being evaluated between Williams Lake and Quesnel, BC.

This example assumes a resilience assessment was completed and the critical and material element-hazard interactions shortlisted based on their risk scores. The results are summarized in a tabular format below.

Element	Hazard	Individual Vulnerability Description	Adaptation Strategies	Collaborating Agencies, if applicable
Critical Individual Vulnerabilities				
Structure over stream	Precipitation	Risk of washout during heavy precipitation event	• Retrofit bridge • Realign highway	• Structural engineering • Transportation engineering
Hillsides	Precipitation	Risk of landslide during heavy precipitation event	• Stabilize soil • Realign highway	• Geotechnical Engineering
Critical Compound Vulnerabilities				
Structure over stream	Precipitation	Land use policies increase flow in river and increase vulnerability of bridge to washout during rain event	• Change land uses to increase permeability	• Planning
Hillsides	Precipitation, Forest fires	Forest fires can increase soil instability and lead to landslide	• Forest fire management plan	• Emergency Services
Transported Goods	Precipitation	If bridge or hillside fail, there may be issues with supply	• Retrofit bridge • Stabilize Soil • Realign Highway • Develop plan in case of closure event, include stakeholder engagement	• Structural engineering • Transportation engineering • Emergency services
Emergency Services	Precipitation	If bridge or hillside fail, there may be issues with emergency services supply	• Retrofit bridge • Stabilize Soil • Realign Highway • Develop plan in case of closure event, include stakeholder engagement	

7.2 Option Generation

Once the problem is defined, options are developed to address it. These options should address the vulnerabilities identified in the CRA and incorporate the adaptation strategies previously developed wherever possible. Option generation requires inputs from a design team that is comprised of experts from appropriate disciplines.

The methods used to generate options to address issues will naturally vary according to the scope and nature of the problem and will draw heavily on the contributions of the project team. For consistency, when generating options, the design professionals involved should:

1. Develop a common guiding principle regarding Climate Adaptation and Resilience
2. Consider how each option affects the results of the CRA, and describe how to:
   - account for the vulnerabilities in the Problem Definition stage, and
   - integrate the Adaptation Strategies developed in the CRA.

Tips for Option Generation

Typically, the option generation process is led by the design team. Users should consider organizing a brief workshop to present the results of the CRA as well as the systems map and walk the design team through the main findings. This will allow the design team to better understand the vulnerabilities with respect to climate change, as well as how interdependencies are driving compound vulnerabilities.

APPLICATION EXAMPLE: WILLIAMS LAKE TO QUESNEL HIGHWAY CORRIDOR

Continuing with the Williams Lake to Quesnel highway alignment the option generation stage would require the designers to generate a guiding principle, such as the following, to be included in their analysis:

Climate resilience guiding principle: Maximize climate resilience

Designers would also be required to comment how the options are incorporating the findings of the CRA. For this example, assume two highway options named L400 and L500 are generated. Assuming that both options still have vulnerable hillsides, but L400 does not cross over any streams and L500 crosses a different stream than the existing highway, the description of each option might then include language as follows:

- **Option L400**: This option will not include any river crossings so risk for structure over stream is eliminated. Soil stabilization to be included in scope to mitigate risk for hillsides.
- **Option L500**: This option will cross over a different stream than existing alignment, further analysis required. Soil stabilization to be included in scope to mitigate risk for hillsides.

In this example, the language only addresses the individual vulnerabilities for the Structure over streams and Hillsides items. If deemed appropriate, designers can expand and include a discussion on compound vulnerabilities (i.e., Land Use and Forest Fire influences).

7.3 Multiple Criteria Assessment

The Multiple Criteria Assessment (MCA) process takes the options generated in the previous step, and qualitatively evaluates each option against the problem definition, for multiple criteria (such as Constructability, Mobility, Safety, etc.). A new criterion called Climate Resilience is proposed to be introduced in this step to incorporate resilience.

The MCA process is often best achieved through facilitated workshop(s) that include subject matter experts involved in the design of the options, as well as those involved in the CRA who can speak to the vulnerabilities.

When assessing each option against the criteria of climate resilience, the initial focus should include any hazard-element interactions determined to have critical vulnerabilities during the problem definition stage. These are the interactions assessed to be **critical and material**. Failure of a critical interaction has potential to cascade through a system, and the resilience of each option depends on the resilience of each critical element.

The outputs from the CRA can be documented in a table, such as the one provided in **Worksheet 7.2**. In this table, the elements and hazards associated with each critical vulnerability (individual or compound) is recorded, together with a description of how well (or poorly) each option addresses that vulnerability. Cells can then be color coded to indicate the effectiveness of each option at mitigating the risk.

In the example below, green cells show where the risk is mitigated, orange cells highlight where further investigation is needed, and red cells show where the option does not address the risk, but maintains the risk.

Critical Vulnerabilities (Individual or Compound)		Option 1	Option 2
Element	Hazard		
Element 1	Hazard 1	Risk Mitigated - Description	Risk Mitigated - Description
Element 2	Hazard 2	Additional Investigation Required - Description	Risk Mitigation - Description
Element 3	Hazard 3	High Risk Maintained Investigation Required - Description	Additional Investigation Required - Description

Many infrastructure agencies have their own methodologies to score or categorize infrastructure and distinguish between mitigation or maintenance options. The table provided in **Worksheet 7.2** is one such option, however, the method of evaluation may be adapted to suit the organization and existing evaluation mechanisms.

Once all options are assessed against each vulnerability, an overall score for Climate Resilience for each option is assigned by the review team, using a five-point scale that reflects how well each option addresses the overall criteria of vulnerability (higher score meaning the option addresses the specific criteria better). In the example shown above, Option 2 mitigates more of the critical vulnerabilities than Option 1. For this reason, Option 2 is assigned a higher score of 4 for Climate Resilience, while Option 1 is assigned a lower score of 3.

As the name suggests, a Multiple Criteria Assessment considers the scores assigned to each option against multiple criteria. In the example shown below, the two options are assessed against four criteria: mobility, safety, constructability, and climate resilience (which score was calculated earlier). The actual list of criteria will depend on the project scope.

Consideration	Option 1	Option 2
Mobility	1	2
Safety	3	2
Constructability	2	5
Climate resilience	**3**	**4**

Note: Methods to determine scores for considerations other than climate resilience are beyond the scope of this guidebook.

Worksheet 7.2 Contains a template to record the climate resilience score of each option, based on the critical and material element-hazard interactions.

Art or Science?

Assigning an overall score for climate resilience can seem to be more of an art than science. The matrix interacting the options with the critical vulnerabilities will provide a useful “10,000 ft” level view of the resilience of each option but translating that into a single score will require professional judgment. It is important that this assignment is done in a **transparent and consistent** manner so the rationale for selecting the final score is well documented. A workshop to complete this assessment, with a dedicated note taker to document the critical discussions, is a useful tool for this step

APPLICATION EXAMPLE: WILLIAMS LAKE TO QUESNEL CORRIDOR

Continuing with the Williams Lake to Quesnel highway, each option is evaluated against the critical and material element-hazard interactions. The cells were color coded as follows: green – risk mitigated, orange – additional investigation is required, red – risk is maintained.

Critical Individual Vulnerabilities (worksheet 7.1)		Do nothing	Option L400	Option L500
Element	Hazard			
Structure over stream	Precipitation	Impact description: High risk maintained	Impact description: Risk avoided - no stream crossing	Impact description: Potential new risk with new stream – further assessment required
Hillsides	Precipitation	Impact description: High risk maintained	Impact description: Risk mitigated with soil stabilization	Impact description: Risk mitigated with soil stabilization

Using these results, it is clear that Option L400 achieves the best climate resilience, followed by L500, and then the Do-nothing approach. The team completing the Business Case could then assign a global score for climate resilience based on these results and their professional opinion.

7.4 Multiple Account Evaluation

A Multiple Account Evaluation (MAE) uses the results of the MCA and applies a framework to further evaluate each option against preset criteria. The criteria used by each organization may vary; as an example, the MAE process applied by BC MoTI uses the following five indicators (or accounts) as part of the evaluation:

Account	Rationale for inclusion in the MAE process
Financial	Used to account for the present value of capital costs, maintenance, and salvage values over the planned horizon of the project (typically 25 years).
Customer Service	Used to account for the direct benefits to road users, expressed in dollar terms as savings (or extra cost) attributed to travel time, expected collisions, and vehicle operating costs.
Social / Community	Used to account for the external effects on communities, such as noise, community displacement, and community severance; and to account for the impact on specific groups (e.g., Gender-Based Analysis Plus identifies the different groups of women, men, and non-binary people that may be impacted by the project) to ensure consistency with community plans.
Environmental	Used to account for impacts to the natural environment, which can include fish and fish habitat, wildlife habitat, recreation, First Nations impacts, archaeological impacts, and ALR.
Economic Development	Used to account for the economic impacts of a project on the local and Provincial economy in terms of GDP and employment. These impacts can be direct, indirect, or induced; and BC MoTI has developed an input-output model which is applicable to most highway projects.

- The evaluation of the financial and customer service accounts can be quantified (or monetized) using a benefit/cost analysis to compare the benefits and costs of each improvement option with a baseline scenario.
- The social / community, environmental, and economic development accounts are measured in a qualitative way; with the outputs informing the selection of the preferred option.

Each benefit/cost analysis is supported by a sensitivity analysis, which measures the elasticities of the benefit/cost model with respect to variations of key parameters of the project such as discount rate, cost escalation, and traffic growth.

Integrating Resilience into Multiple Account Evaluations

The MAE framework does not include explicit consideration of climate resilience; although resilience can affect the accounts described above. For example, the finance account can be affected by any costs due to the impacts of climate change, and both the customer service and social / community accounts can be affected if climate change impacts service provision.

This guide describes one approach to incorporate climate change as part of the financial account,[6] although organisations may prefer to use an existing methodology for consistency. Monetizing resilience is a complex topic, and a detailed discussion is beyond the scope of this guidebook. For more information, refer to the Costing Climate Change Impacts to Public Infrastructure Project completed by the Financial Accountability Office of Ontario.

[6] The financial account was selected for simplicity purposes. As noted previously, the impacts of climate change, including financial impacts, could span multiple accounts. Where to allocate the costs of climate change calculated with the provisions in this guidebook will depend on the specifics of each project.

The approach outlined below can be tailored to account for damage to infrastructure associated with increases in the environmental loads imposed on them. An example is a bridge washout due to increased precipitation. Some impacts of climate change, such as casualties due to heatwaves, are more challenging to monetize.

Step 1. Establish failure thresholds. Determine the climate thresholds that indicate failure. Ideally, tie these thresholds to specific climate hazard indicators, to enable further analysis.

Step 2. Calculate the probability that the failure thresholds are exceeded. The climate specialist supporting the CRA analysis assesses the likelihood that the failure thresholds are exceeded, during each future time horizon.

Step 3. Calculate the probability of failure. Use a Markov chain[7] to calculate the probability of failure of each element, in any given year. To be conservative, assume that the element will fail if the threshold is exceeded.

The World Bank has assessed that the cost of building additional resilience into systems is typically equivalent to 3% of the total investment but can lead to significantly fewer disruptions and outages. In some countries, they estimate $4 is returned for every dollar invested. In "Lifelines: The Resilient Infrastructure Opportunity",[xiv] they assess the cost of infrastructure disruptions, and the economic benefits of investing in resilient infrastructure. The report lays out ways to invest capital dollars more wisely that can be applied in any country.

Alternatively, if no thresholds can be identified in Step 1 and 2 (due to the nature of the failure mechanism or lack of availability of climate data), probabilities of failure from other relevant studies conducted at nearby locations may be used for this step.

The formula used to calculate the probability of failure in year n is given by the following equation[8] :

$$k_n = p_n * q_{n-1}$$

Where

k_n = Probability of failure in year n
p_n = Annual probability of failure (or exceeding threshold) in year n
q_n = Probability of element surviving to year n

For example, in year 1, $q_1 = 1 - p_1$; and $k_1 = p_1$
In year 2, $q_2 = q_1 * (1 - p_2)$; and $k_2 = p_2 * q_1$

[7] A Markov chain is a stochastic model describing a sequence of possible events in which the probability of each event depends on the state from the previous event. In this case, the probability of the asset experiencing failure in any given year is dependent on whether the asset failed or not in previous year.
[8] The proposed equation showed in this example is based on a Markov Chain.

For example, assume that the probability of failure for an asset in any given year within the next 10 years (p_n) is 5%. Then, the calculations would be as follows:

<u>**Year 1**</u>

k_1 = 0.05 = 5%
q_1 = 0.95 = 95%

<u>**Year 2**</u>

k_2 = (0.05)*(0.95) = 0.0475 = 4.75%
q_2 = (0.95)*(1-0.05) = 0.9025 = 90.25%

<u>**Year 3**</u>

k_3 = (0.05)*(0.9025) = 0.0451 = 4.51%
q_2 = (0.9025)*(1-0.05) = 0.8574 = 85.74%

Step 4. Calculate Expected Value of Costs. To determine the expected value, multiply the probability of an event occurring by the costs associated with that event; and then add together the expected values for all events to establish the total expected value.

Worksheet 7.3: Contains a template which can be populated with the information needed to complete the MAE.

The expected value (EV) costs can then be used to inform the benefit costs analysis of the MAE process.

APPLICATION EXAMPLE: WILLIAMS LAKE TO QUESNEL HIGHWAY CORRIDOR

Continuing with the Williams Lake to Quesnel alignment example, the MAE for any of the shortlisted options would be completed as follows.

Step 1: Establish failure thresholds
For each critical individual vulnerabilities, SMEs establish failure thresholds

Critical Individual Vulnerabilities (worksheet 7.1)		Hazard indicator Failure threshold	Notes
Element	Hazard		
Structure over stream	**Precipitation**	300 mm	Events exceeding 300 mm in 24 hrs will result in stream flows sufficient to wash out bridge
Hillsides	**Precipitation**	50 mm	Events with daily precipitation above 50 mm may result in landslide which will cut off access to highway

Step 2: Calculate probability of exceeding thresholds
For each hazard indicator, climate specialists establish probability of exceedance.

Event	Probability of occurring (2020s)	Probability of occurring (2050s)	Probability of occurring (2080s)
24 hr Precipitation > 300 mm	3%	5%	8%
Daily precipitation > 50 mm	2%	3%	5%

Step 3: Calculation of probability of failure
Assuming the elements will fail if the threshold is exceeded, the probability of failure can be calculated as follows. In this example, the probabilities were extracted from the climate data used in the CRA. This data is based on 30-year time horizons, and it was assumed that the probability within each 30-year time horizon is constant.

Element: Structure over stream
Hazard: Precipitation
Hazard indicator and threshold: 24 hr rain above 300 mm

Time Horizon	Year	Year Number (n)	Annual probability of failure (p)	Probability of survival to year n (q)	Probability of failure in year n (k)
	2023	1	3.00%	97.00%	3.00%
	2024	2	3.00%	94.09%	2.91%
	2025	3	3.00%	91.27%	2.82%
	2026	4	3.00%	88.53%	2.74%
	2027	5	3.00%	85.87%	2.66%
	2028	6	3.00%	83.30%	2.58%
	2029	7	3.00%	80.80%	2.50%
	2030	8	3.00%	78.37%	2.42%
	2031	9	3.00%	76.02%	2.35%
2020s	2031	10	3.00%	73.74%	2.28%
	2032	11	3.00%	71.53%	2.21%
	2033	12	3.00%	69.38%	2.15%
	2034	13	3.00%	67.30%	2.08%
	2035	14	3.00%	65.28%	2.02%
	2036	15	3.00%	63.33%	1.96%
	2037	16	3.00%	61.43%	1.90%
	2038	17	3.00%	59.58%	1.84%
	2039	18	3.00%	57.80%	1.79%
	2040	19	3.00%	56.06%	1.73%
	2041	20	5.00%	53.26%	2.80%
	2042	21	5.00%	50.60%	2.66%
	2043	22	5.00%	48.07%	2.53%
	2044	23	5.00%	45.66%	2.40%
	2045	24	5.00%	43.38%	2.28%
2050s	2046	25	5.00%	41.21%	2.17%
	2047	26	5.00%	39.15%	2.06%
	2048	27	5.00%	37.19%	1.96%
	2049	28	5.00%	35.33%	1.86%
	2050	29	5.00%	33.57%	1.77%
	2051	30	5.00%	31.89%	1.68%

Step 4: Calculate Expected Value.

The expected value (EV) for costs in current dollars for any given year can then be calculated as follows:

EV Costs = [k * cost of failure in year n] + [(1-k) * cost of non-failure in year n] + [q * cost of adaptation strategies in year n]

For example, assume for the Structure over stream:

- cost of failure (in any given year) = $10,000,000
- cost of retrofit (assume in year 10) = $2,000,000
- annual maintenance cost of retrofitted bridge $50,000

Then, for year 10 the EV Costs_{10} (Expected Value in Year 10 dollars) is calculated as follows:

EV Costs_{10} = [2.28% * 10,000,000] + [(1-2.28%) * (50,000)] + [73.74% * 2,000,000] = $1,751,660

The EV costs can then be discounted into net present value and incorporated into the benefit costs analysis of the MAE process.

Note that in this example, the calculation relates to the **cost of not implementing any adaptation / resiliency measures**. A similar calculation could be completed to estimate the benefits of implementing a given adaptation / resilience measure to use that information in the MAE process.

The earlier table can be then updated with the EV calculations as follows (only first 10 years shown)

Year	Year Number (n)	Annual Probability of Failure (p)	Probability of Survival to Year n (q)	Probability of Failure in Year n (k)	Cost of Failure	Cost of Retrofit (year 10)	Maintenance Cost	Expected Value
2023	1	3.00%	97.00%	3.00%	$10,000,000		$50,000	$348,500
2024	2	3.00%	94.09%	2.91%	$10,000,000		$50,000	$339,545
2025	3	3.00%	91.27%	2.82%	$10,000,000		$50,000	$330,590
2026	4	3.00%	88.53%	2.74%	$10,000,000		$50,000	$322,630
2027	5	3.00%	85.87%	2.66%	$10,000,000		$50,000	$314,670
2028	6	3.00%	83.30%	2.58%	$10,000,000		$50,000	$306,710
2029	7	3.00%	80.80%	2.50%	$10,000,000		$50,000	$298,750
2030	8	3.00%	78.37%	2.42%	$10,000,000		$50,000	$290,790
2031	9	3.00%	76.02%	2.35%	$10,000,000		$50,000	$283,825
2031	10	3.00%	73.74%	2.28%	$10,000,000	$2,000,000	$50,000	$1,751,660

CHAPTER 7 CHECK-IN

Has the core project team:

- [ ] Summarized the outputs of the CRA to inform the problem definition?
- [ ] Provided input into the option generation?
- [ ] Accounted for resilience criteria in the Multiple Criteria Assessment?
- [ ] Integrated resilience in the Multiple Account Evaluation?

8 Conclusion

This guidebook presented a four-stage process to enhance and standardize SBAs to climate-resilient infrastructure, as well as a framework to integrate resilience into a standardized business case process. Most of the contents of this guidebook are therefore focused on resilience planning, where risks are identified, and adaptation strategies developed.

To achieve resilience, it is necessary to go beyond planning and into implementation and monitoring of the developed strategies. Doing so will require additional consultation, design work, and stakeholder engagement. While the details for these stages are outside of the scope of this guidebook, the principles of systems thinking can still be applied through implementation and monitoring:

- **Implementation:** The understanding of the system can be leveraged as a design aid through the detailed development of options and used as a tool when engaging stakeholders.
- **Monitoring:** The results from the planning stage can be updated post-implementation to serve as a monitoring tool to identify any necessary changes.

Through continuous iterations, improvements can be frequently integrated and the resilience of the system can be progressively increased.

Acknowledgements

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References

[i] Simonovic, S. P. (2015, December 17). Systems approach to management of disasters – a missed opportunity?: Published in Idrim Journal. IDRiM Journal. Retrieved March 21, 2023, from https://www.idrimjournal.com/article/11677-systems-approach-to-management-of-disasters-a-missed-opportunity

[ii] Penno, W. L. E. (2020). (rep.). (K. Pingree-Shippee & G. Félio, Eds.) Climate Change Impacts on Kasabonika Lake First Nation Infrastructure. North Bay, ON: Stantec Consulting Ltd. https://pievc.ca/wp-content/uploads/2021/03/Stantec-Kasabonika-Lake-First-Nation-March-2020.pdf

[iii] Various resources
Government of United Kingdom. (2023). Introduction to systems thinking for civil servants. GOV.UK. Retrieved March 21, 2023, from https://www.gov.uk/government/publications/systems-thinking-for-civil-servants/introduction

Kim, D. H. (2016, April 1). Systems thinking tools: A user's reference guide. The Systems Thinker. Retrieved March 21, 2023, from https://thesystemsthinker.com/systems-thinking-tools-a-users-reference-guide/

The Systems Thinker (2018). Leverage Networks Inc. https://thesystemsthinker.com/

Thinking in Systems: A Primer (2008), by Donella H. Meadows. Diana Wright (ed.). Chelsea Green Publishing: White River Junction, Vermont.

Thinking in Systems: Strategies for Problem Solving, Planning and Critical Thinking (2018), by Alex J. Golding. Newstone: Bolton, ON.

[iv] Klimaatadaptatie. (n.d.). Retrieved March 21, 2023, from https://klimaatadaptatienederland.nl/

[v] Ministere de la Transition Ecologique et Solidaire. (2018). (rep.). Le Plan National d'Adaptation au Changement Climatique, from https://www.ecologie.gouv.fr/sites/default/files/2018.12.20_PNACC2.pdf

[vi] For more tools and information on how to use them, access the following resources:

Government of United Kingdom. (2023). An introductory systems thinking toolkit for civil servants. GOV.UK. (2023). Retrieved March 21, 2023, from https://www.gov.uk/government/publications/systems-thinking-for-civil-servants/toolkit

Systems Thinking Tools: A User's Reference Guide (2000), by Daniel H. Kim. Pegasus Communications: Waltham, MA. Available online at: https://thesystemsthinker.com/systems-thinking-tools-a-users-reference-guide/

Mian, J., & Carluccio, S. (2020). (rep.). System Mapping for UK Infrastructure Systems Decision Making. ARUP. from https://nic.org.uk/app/uploads/Systems-mapping-for-UK-infrastructure-systems-decision-making.pdf

Thinking in Systems: A Primer (2008), by Donella H. Meadows. Diana Wright (ed.). Chelsea Green Publishing: White River Junction, Vermont.

[vii] Government of United Kingdom. (2023). An introductory systems thinking toolkit for civil servants. GOV.UK. (2023). Retrieved March 21, 2023, from https://www.gov.uk/government/publications/systems-thinking-for-civil-servants/toolkit

[viii] Originally introduced in A Guide to Quality Control (1976) by Dr. Kaoru Ishikawa, Tokyo: Asian Productivity Organization: New York, NY.

[ix] The Systems Thinker: A Pocket Guide to Using the Archetypes (2018), Daniel Kim and Colleen Lannon. from https://thesystemsthinker.com/a-pocket-guide-to-using-the-archetypes/

[x] Thinking in Systems: A Primer (2008), by Donella H. Meadows. Diana Wright (ed.). Chelsea Green Publishing: White River Junction, Vermont.

[xi] OECD Environment Policy Paper. (2018). (rep.). Climate-Resilient Infrastructure (Vol. 14). from https://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

[xii] Infrastructure Canada. (2019, October 31). Climate Lens - General Guidance. Infrastructure Canada. Retrieved March 21, 2023, from https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html

[xiii] World Bank. (2021). A Catalogue of Nature-Based Solutions for Urban Resilience. © World Bank, Washington, DC. https://openknowledge.worldbank.org/entities/publication/c33e226c-2fbb-5e11-8c21-7b711ecbc725 License: CC BY 3.0 IGO.

[xiv] Hallegatte, Stephane; Rentschler, Jun; Rozenberg, Julie. (2019). Lifelines: The Resilient Infrastructure Opportunity: The Resilient Infrastructure Opportunity; Pour des infrastructures plus résilientes; Tomando acción hacia una infraestructura más resiliente. Sustainable Infrastructure;. © Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/c3a753a6-2310-501b-a37e-5dcab3e96a0b License: CC BY 3.0 IGO.

Worksheets

WORKSHEET

3.1 Causal Loop Diagrams – Brainstorming Variables

Purpose:

The purpose of this worksheet is to provide a framework that can be used to brainstorm variables within your system to create your systems map.

Objectives:

- Understand the importance of selecting and naming variables when systems mapping
- Create an initial list of variables as part of a systems map

Guidelines:

- Variables are components of a system that can change (increase or decrease) over time with potential to affect other parts of the system.
- When selecting variables to include as part of a systems map, aim to use consistent language throughout.
  - Use the positive sense of the word (e.g., profit, growth, increase) rather than the negative (loss, reduction, decrease) for consistency, and to prevent duplication.
  - It may help to use categories to group variables by theme or topic, as shown in the table provided. The categories shown, which may be referred to as the pillars of resilience or categories of infrastructure relevant for resilience, are commonly used in resilience planning and are suggestions as prompts to get started but are not a requirement. It may be just as effective to use categories tailored to a specific project or organization, or a blank sheet of paper.
- Good variables to select are those which are measurable, whether quantitative or qualitative.
  - Remember that things that are changeable are not always things that are measurable. For example, your state of mind is something that can change over time, but which is hard to measure. Using a variable like “Happiness” expressed as a number that can increase or decrease over time is a better variable to use.
- Where possible, avoid using verbs when naming variables. The action aspect is indicated by the arrow used to connect different variables. For example, instead of ‘increase in price’, simply use ‘cost’ or ‘fee’.

Note: we use ‘variables’ at this stage in the process rather than ‘infrastructure elements’ to ensure that we are comprehensive in developing our systems understanding. As we will demonstrate in later steps of the guidebook, we will follow a process to translate ‘variables’ to ‘infrastructure elements’ for use in a climate risk assessment.

Individually or as a group-workshopping exercise, brainstorm variables for your system and list them in the relevant categories below or develop categories that are more appropriate for your needs.

CATEGORIES					
Physical	Social	Economic	Environmental	Institutional/ Governance	Other
Number of Patient Beds	Patients Admitted	Staff Productivity	Air Quality	Government Funding	Patient Satisfaction

WORKSHEET

3.2 Causal Loop Diagrams – Linking Variables

Purpose:

Provide demonstrations and practice on how to connect different variables using causal loop diagrams, which will be the building blocks of your systems map. Demonstrate how to connect different variables

Objectives:

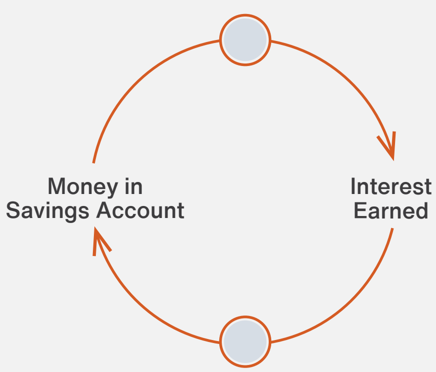
- Understand the purpose of linking variables that affect each other
- Understand the naming conventions used to label the links
- Be able to populate a blank causal loop diagram

Guidelines – Part 1: Practicing with Causal Loop Diagrams

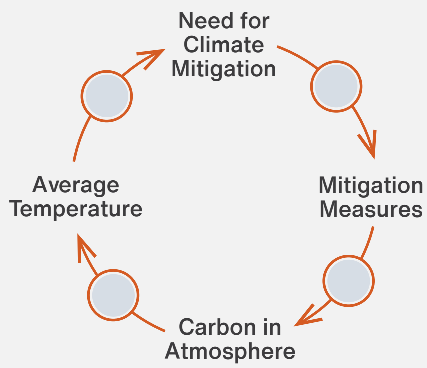
Examples of variables are provided below.

For **Examples A** and **B**, the arrows linking the variables have been provided. Place a “+” in the blue circle on the arrow if the first variable causes the second to move in the same direction, and a “-“ if it causes the second to move in the opposite direction. Correct responses can be found on the following page.

Example A



Example B

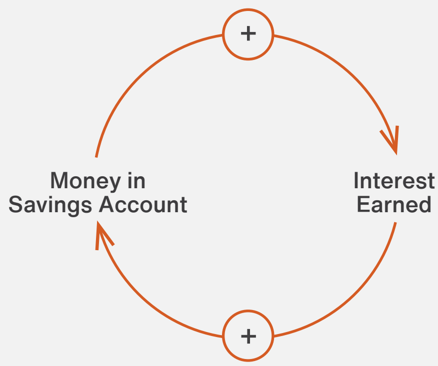


For **Example C**, the arrows have not yet been placed. Place the arrows in the blue circle indicating which variable is influencing which other variable, and label it with a “+” if the two move in the same direction, and a “-“ if the two variables move in the opposite direction.

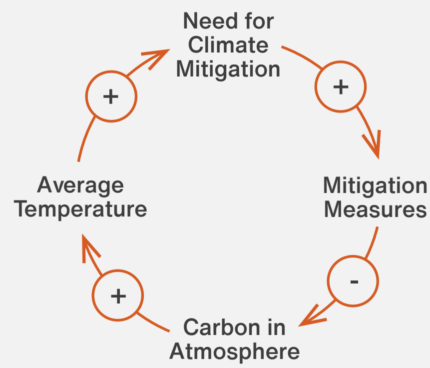
Example C

Part 1 Responses

Example A



Example B

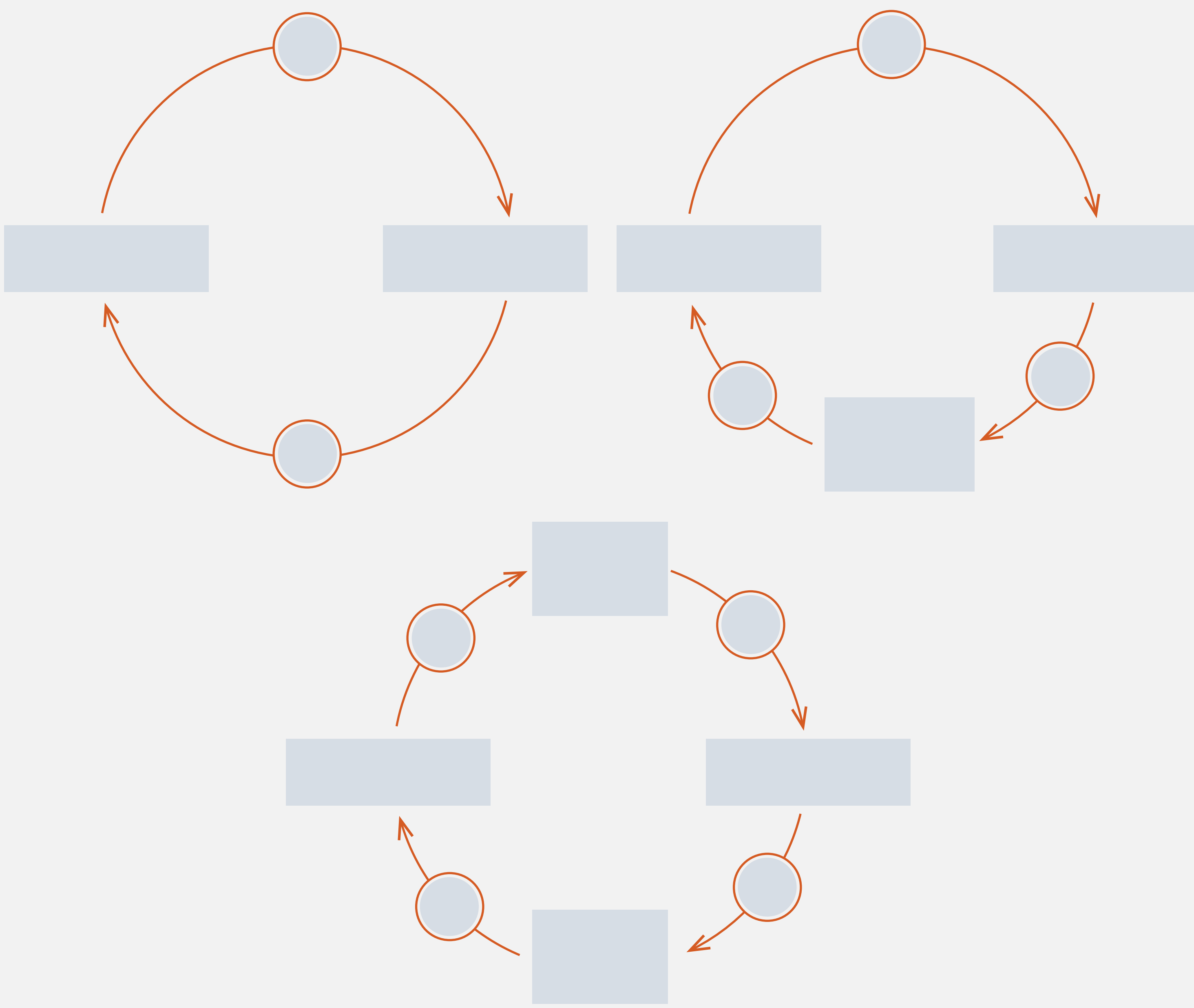


Example C

Guidelines – Part 2: Creating Causal Loop Diagrams for Your System

Use this section to practice building and labelling your own causal loops. Some templates have been provided below, but you may use your own space to create other forms or for additional space.

- Start by filling in the variables in the wider boxes. You may want to pull variables from your table in Worksheet 3.1.
- Walk through how one would change along with another, and place a "+" or "-" as appropriate (see previous page) in the small boxes connecting the variables.
- Ensure that the direction of change works for both an increase and decrease in all variables.



Causal Loop Diagrams – Classifying Loops

Purpose:

This worksheet is intended to provide practice and blank templates for users to classify feedback loops as balancing or reinforcing, which can help provide insights when developing interventions

Objectives:

- Classify feedback loops as balancing (B) or reinforcing (R)

Guidelines

Examples of simple causal loops are provided below. Classify the loops as balancing (B) if change in one direction is counteracted with a change in the opposite direction. Classify the loops as reinforcing (R) loops if they produce compound change in one direction with even more change in that direction.

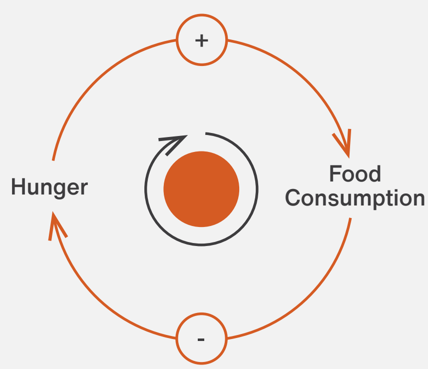
Tip for labelling loops

Sometimes there are multiple elements and links in a loop. If a loop has an even number of negative arrows, the overall loop is a reinforcing loop. If a loop has an odd number of negative arrows, it's a balancing loop. This is because the two negative arrows cancel each other out and they have the same overall effect as a positive link.

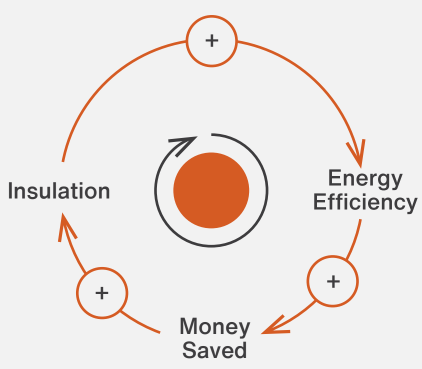
Part 1: Practice labeling feedback loops

For Examples A and B, decide if the feedback loop is a balancing loop or a reinforcing loop. If it is a balancing loop, label the orange circle in the middle with a B, if it is a reinforcing loop, label the orange circle in the middle with an R. Correct responses can be found on the bottom of the page. [i]

Example A



Example B



1 Example A is a balancing loop and should be labelled with a 'B'. Example B is a reinforcing loop and should be labelled with an 'R'.

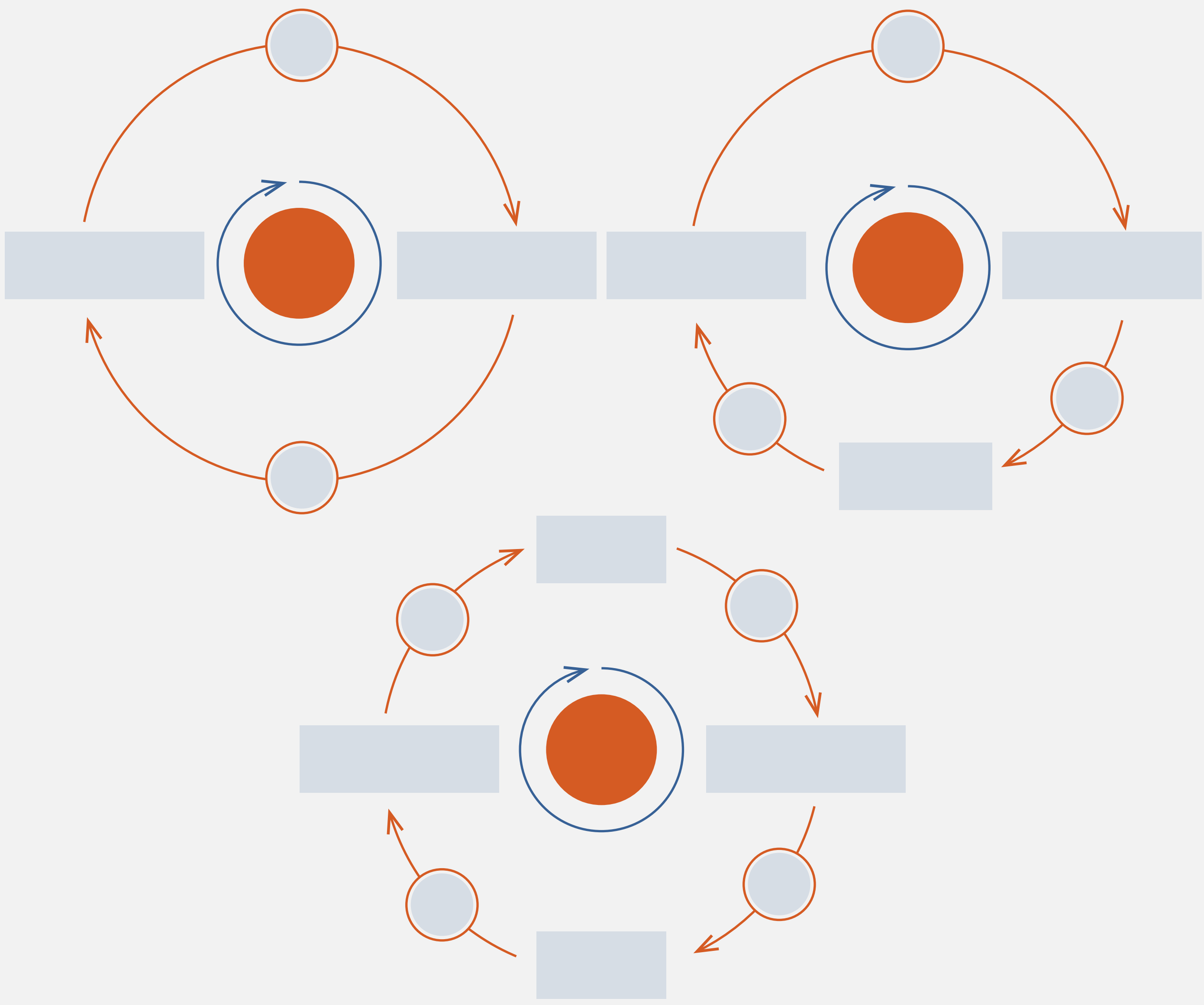
Part 2: Building and labeling feedback loops

Use this section to practice building and classifying your own causal loops. Some templates have been provided below.

- Start by filling in the variables in the wider boxes.
- Walk through how one would change along with another, and place a “+” or “-“ as appropriate in the small boxes connecting the variables.
- Ensure that the change works for both an increase and decrease in all variables.

Note: you may pull over your causal loop diagrams from Worksheet 3.2 to complete the three bullets above, and then proceed with the next step.

- Classify the loop as balancing (B) or reinforcing (R) according to the type of change produced as you go around the loop.



WORKSHEET

3.4 High-level Climate Profile

Purpose

Provide users with guidance on how to create a high-level climate profile that can inform the systems map and be enhanced in later stages of the climate risk assessment.

Objectives

- Have a climatic context within which to create the systems map
- Create a climate profile and resources to create one

Guidance

The climate profile should be filled in by someone who has an understanding of the project area and has the ability to answer general questions about the climate.

Begin by listing past climate disasters. These will give users an idea of some of the climate hazards that the area will be at risk from. For example, recent and historical heat waves could be noted.

These climate disasters and hazards could then be classified under their corresponding climate elements:

- Temperature
- Precipitation
- Wind
- Sea Level Rise
- Other

Begin by filling in as much of Table 1 as possible based on historical climate events that are known to affect the area. Then move to Table 2.

Table 1 – Past Climate Events

Past Climate Event	Climate Parameter	Climate Hazard	Year	Notes, including any summary information on damages experienced
Example: Heat dome	Temperature	2021	2021	
Flooding due to heavy rainfall	Precipitation	Flooding	2012	Major Flooding

If limited data is available, users can access websites such as Climate Atlas of Canada (https://climateatlas.ca/find-local-data) entering the location to get additional information to fill in the Table 2.

Table 2

Climate Parameter	Climate Hazard	Change in Hazard from Present	Notes
Example: Temperature	Frost-free season	Shorter	Shorter ice-road season

WORKSHEET

3.5 Boundary Matrix Worksheet

Purpose:

The purpose of the boundary matrix is threefold: it helps the project team decide as a whole what is most important and what they have control over giving them a chance to create a shared vision; it allows them set boundaries for what they will include in their systems map; and it gives the team a reference point for where to start building their systems map.

Guidance

This boundary matrix can be used to formulate the context of any system. Using your list of variables from Worksheet 3.1, place variables in the boundaries matrix on the next page. You may find it useful to establish standard classifications for Influence and Importance that make sense for your project before filling out the matrix.

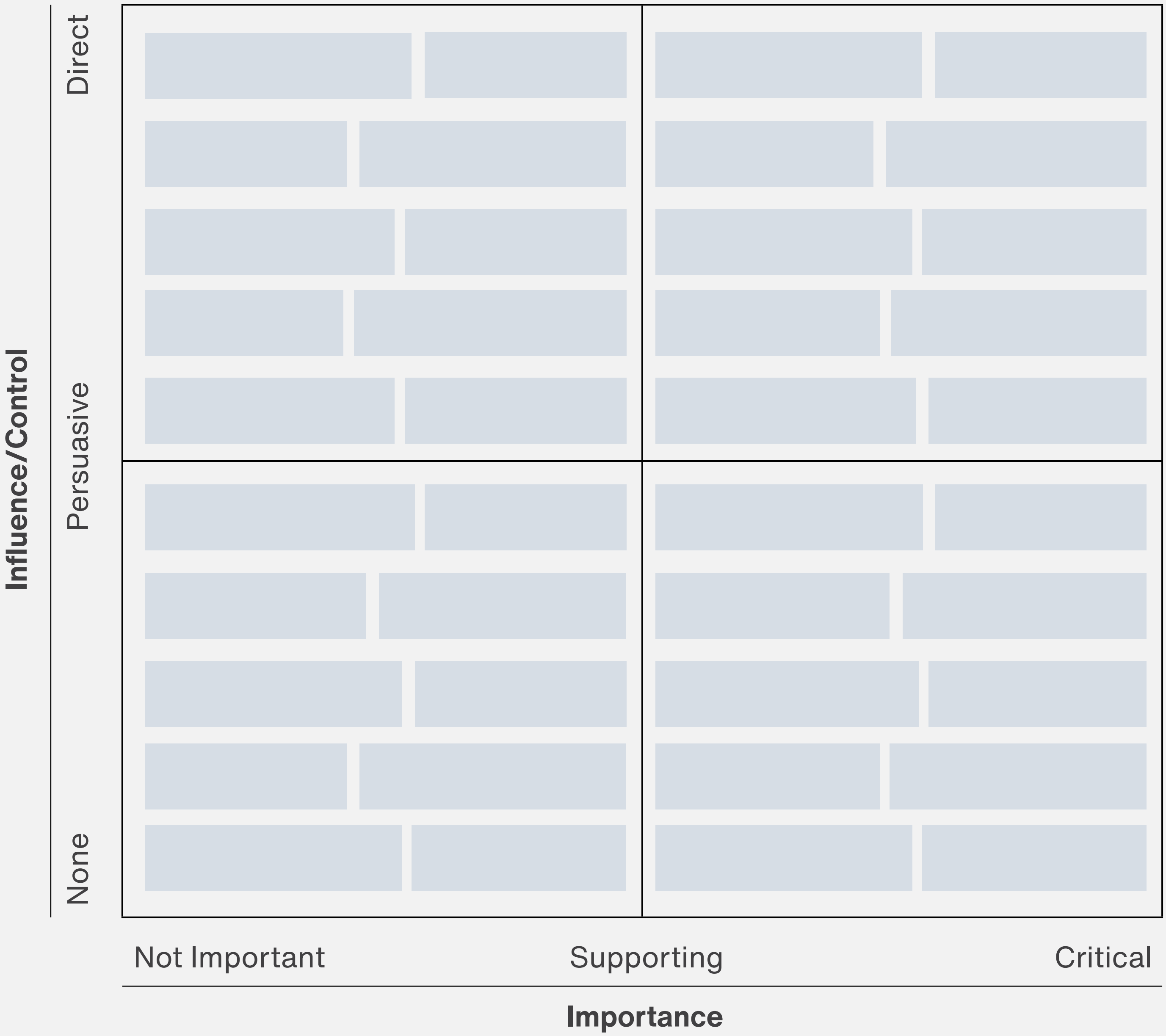
The y-axis corresponds to the level of influence the project team has over that variable, while the x-axis corresponds to how important that variable is to the project team.

Reflect on your boundary matrix

After filling out the matrix, it may be helpful to discuss the following questions:

- For variables that are important and you have control over, what are the biggest challenges that you are currently facing (may or may not be directly related to climate resilience)?
- For variables that are important that you do not control, what other stakeholders would you need to engage to make changes (Depending on the circumstances, it may make sense to engage these other stakeholders during some portion of this process)?
- For variables that are not important, but you have control over, are there any opportunities to make connections to other variables that are more important so that you can make changes?

After completing the boundary matrix, users should then begin mapping their system with a variable in the top right quadrant – something that is important and that they have control over. Starting with variables in the top right quadrant is not required but is recommended to focus attention.


Influence/Control
Direct
Persuasive
None
Not Important
Supporting
Critical
Importance

WORKSHEET

3.6 Critical Variable Worksheet

Purpose

Help users identify and track critical variables from their systems map to provide a reference for use during the climate risk assessment.

Objectives

- Determine variables that have a high number of interdependencies.
- Establish whether those variables are influential, vulnerable, or central

Guidance

Looking at the systems map, visually determine which variables have a high number of connections to other variables.

- If there are multiple connections going outward, this may indicate an influencing variable
- If there are multiple connections going into the variable, this may indicate the variable is vulnerable
- If there are multiple connection going both to and from the variable, this may indicate the variable plays a central, or bridging role in the system

List the variables in the table below, along with the number of inbound and outbound connections to help determine the type of critical variable.

Variable Name	No. Incoming Connections	No. Outgoing Connections	Type of Variable (Influential, Vulnerable, Central/Bridging)
Access to Health Care Workers	4	1	Vulnerable
Condition of flood protection system	3	0	Influential

WORKSHEET

4.1 Climate Risk Assessment Components

Purpose

Help users identify, categorize, and track risk assessment components from the systems map

Objectives

- Separate each type of component needed for the climate risk assessment into various components into one of the tables below.
- Identify a subject matter expert, if applicable.
- Track variables that may drive consequences and make other variables more vulnerable further along into the process

Guidance – Infrastructure Elements

Refer to the systems map and look for variables that represent the physical and functional dimensions of the system. These may be physical but could also be operational or social components of the infrastructure element category.

An example of variables that may be included in the Roads infrastructure element category is included on the top line of the table below.

Category: Infrastructure Elements

Element Name	Variable Names	Subject Matter Expert (If applicable)
Example: Roads	Access to roads; Condition of asphalt; Road access in and out of community; Maintenance workers available	Transportation Engineering

Guidance – Climate Hazards

Refer to the systems map and look for variables that represent climate hazards in your system. Variables in the map may be related to one or more climate hazard; and the climate hazards may be mapped to one or more variables in the system map.

An example of variables that may be included in the Precipitation and Floods climate hazard category is included on the top line of the table below.

Category: Climate Hazards

Climate Hazard Name	Variable Names	Subject Matter Expert (If applicable)
Example: Precipitation and Floods	River Level; Severity of raverine flooding; Length of rainfall; Severity of rainfall	

Guidance – Vulnerability Drivers

Refer to the systems map and look for variables in the system that influence the vulnerability of other variables or elements, and the consequences of any risks arising as a result. These variables are not grouped into categories in this step because they are able to drive consequences on their own. They may have already been categorized into a previous category, but they will be listed and tracked in the table below.

Some examples of vulnerability drivers are: clearcutting; inflation; and permafrost melt.

Category: Vulnerability Drivers

Vulnerability Driver Name	Subject Matter Expert (If applicable)
Example: Inflation	N/A

WORKSHEET

4.2 Identifying Subject Matter Experts

Purpose

To help users identify additional Subject Matter Experts (SMEs)

Objectives

- To identify and track missing SMEs that may be needed to bring additional knowledge to the table

Guidance

Refer to Worksheet 3.1 to help fill in the categories of infrastructure elements and climate hazards for your systems. If these categories can be broken down into subcategories, this will be helpful for subsequent steps. List the title of the SMEs in the space provided. The first table is intended for SMEs of infrastructure elements. The table on the following page is for climate hazard SMEs.

Infrastructure Element	Required SME
Category Example: Building	Title of SME who can assess vulnerability
Subcategory Example: Mechanical System	
Element Name Example: Outdoor Cooling Unit	Example: Mechanical Engineer
Subcategory	
Category	
Subcategory	
Subcategory	

Climate Hazard	Required SME
Category Example: Drought	Title of SME who can assess vulnerability
Subcategory Example: Drought	
Element Name Example: Reservoirs	Example: Civil Engineer
Subcategory	
Category	
Subcategory	
Subcategory	
Category	
Subcategory	
Subcategory	

WORKSHEET

5.1 Assessment Objectives, Boundaries, Timescales and Elements Definition

Purpose

Help users identify the following components necessary to begin the climate risk assessment.

- **Objectives.** Determines what the intended outcomes from the assessment are, which shape the scope of work and level of effort.
- **Boundaries.** Determines what elements are included or excluded from the assessment.
- **Timescale**. Selects the historical and future time horizons to be included.
- **Elements.** Final list of infrastructure elements (asset components, activities, personnel) to be included in the assessment.
- **Workshop participants.** Subject matter experts who can assess vulnerability of the elements.

Objectives

The following table can be used to record the key considerations to determine the objectives of the assessment

Consideration	Response
Is the CRA required for a funding application (e.g., as part of an INFC Climate Lens submission)?	(●) YES ( ) NO
If responded Yes to the previous question, provide further details	
Is the CRA part of the development a community climate change adaptation plan?	( ) YES (●) NO
If responded Yes to the previous question, provide further details	
Is the CRA required under an environmental impacts assessment?	(●) YES ( ) NO
If responded Yes to the previous question, provide further details	
Is the CRA performed to assess the adequacy of design criteria for infrastructure (existing or planned) that will have a long service life during which climate changes are expected?	(●) YES ( ) NO
If responded Yes to the previous question, provide further details	

Consideration	Response
Will the CRA results be used in financial disclosures of climate-related risks (as per the Task-Force on Climate related Financial Disclosures)?	YES NO
If responded Yes to the previous question, provide further details	
Please use this space to list any other considerations that should be accounted for in the assessment	

Using the information in the table above, describe below the Objectives that the CRA intends to complete, preferably in the form of sentences such as “The assessment shall align with Infrastructure Canada’s Climate Lens guidance”.

Boundaries

In the following space, insert a plan view of the area under assessment and highlight the area(s) included in the study. Depending on the scale, consider labelling the infrastructure assets (i.e. hospital building, elementary school, pumping station) for clarity.

Elements and Subject Matter experts

The assessment timescale and required subject matter experts (SMEs) will depend on the final list of elements under study. Use following template to record the final list of elements, associated lifecycle and required SMEs to assess vulnerability. The breakdown of categories and subcategories will depend on the scope of the study and level of detail required.

This template can be circulated for feedback with the CRA team when finalizing the list of elements, and SMEs may wish to add more elements or break down some rows further.

Element	Lifecycle	Required SME
Category Example: Building		
Subcategory Example: Mechanical System		
Element Name Example: Outdoor Cooling Unit	Typical lifespan in years (i.e. 25 years)	Title of SME who can assess vulnerability (i.e. Mechanical Engineer)
Subcategory		
Category		
Subcategory		

Assessment Timescale

Based on the information on the element's lifecycle, identify in the table below the time horizons that will be used for the assessment. Typically, 30 year periods are used for each time horizon.

Time horizon	Years included	Justification for selection
Baseline	(i.e 1981-2010)	
Future Horizon 1 (i.e. 2050s)	(i.e. 2041-2070)	
Future Horizon 2 (i.e. 2080s)	(i.e. 2071-2100)	

WORKSHEET

5.2 Climate Hazards Summary

Purpose

Summarize the climate hazards, expected projections, and likelihood scores.

Use the table below to summarize the climate parameters, hazards and indicators used in the study. An example is provided in the top rows.

Climate Parameter	Climate Hazard	Climate Hazard Indicator and Threshold	Rationale for selection, Include references to past events if available.
Temperature	Extreme Heat	Number of days with Tmax >31°C	Prolonged heat with little overnight cooling results in increased risk of thermal stress
		Number of days with Tmax > 30°C and Tmin >20°C	Prolonged heat with little overnight cooling results in increased risks of thermal stress

Use the table below to summarize the climate parameters likelihood score scale selected for this project.

Score	Description
1	
2	
3	
4	
5	

Use the table below to summarize the climate data and likelihood scores for all the climate hazard indicators.

Climate Parameter	Climate Hazard	Climate Hazard Indicator & Threshold	Unit	Baseline	Change from Baseline under [Climate Scenario] (%) Median (90th, 10th percentile)			Projected Value– under [Climate Scenario] Median (90th, 10th percentile)			Likelihood Scores			
						[Time Horizon 2]	[Time Horizon 3]	[Time Horizon 1]	[Time Horizon 2]	[Time Horizon 3]	Baseline	[Time Horizon 1]	[Time Horizon 2]	[Time Horizon 3]
Temperature	Extreme Heat	Number of days with Tmax >31°C	days/ year	3.4	132.8 [38.5, 193.8]	355.9 [257.2, 481.5]	778.2 473.9, 1031.2]	7.9 [4.7, 10.0]	15.5 [12.1, 19.8]	29.5 [19.5, 38.5]	3	5	5	5
		Number of days with Tmax >31°C and Tmin >20°	days/ year	1.4	163.6 [53.9, 284.5]	592.8 [452.8, 872.4]	1306.8 903.8, 2033.0]	3.7 [2.2, 5.4]	9.7 [7.7, 13.6]	19.7 [14.1, 29.9]	3	5	5	5

WORKSHEET

5.3 Exposure Summary

Purpose

Summarize the exposure assessment to climate hazards for each element.

Use the table below to record the exposure assessment, with the following on a binary scale:

- **Yes** - If an element exposed to a climate hazard is likely to result in a material impact, then further assessment is needed to determine the extent of that impact.
- **No** - If an element exposed to a climate hazard is unlikely to result in a material impact, no detailed assessment is needed at this stage. If necessary, the element-hazard pair can be re-assessed later.

Element	Climate Hazards			
	(i.e. Extreme Heat)	Hazard 1	Harzard 2	Hazard 3
Category Example: Building				
Subcategory Example: (Mechanical System)				
Element Name (Example: Outdoor Cooling Unit)	[YES/NO]			
Subcategory				
Category				
Subcategory				
Total Exposed (Yes)				
Total Not Exposed (No)				

WORKSHEET

5.4 Vulnerability Assessment

Purpose

Guide users through the completion of an individual and compound vulnerability assessment.
Use the table below to summarize the individual vulnerability score scale selected for this project. Columns can be added or subtracted as needed based on the impact criteria used to define the scale.

Score	[Criteria 1]	[Criteria 2]	[Criteria 3]
1	[Descriptions]		
2			
3			
4			
5			

Individual Vulnerabilities

Use the following table to record individual vulnerabilities with respect to each climate hazard.

Element		Climate Hazards			
		(i.e. Extreme Heat)	[Hazard 1]	[Hazard 2]	[Hazard 3]
Category Example: Building					
Subcategory Example: (Mechanical System)					
Element Name (Example: Outdoor Cooling Unit)	**Score**	(i.e. 3)			
	Comments	(i.e unit performance affected by extreme heat)			
	Score				
	Comments				
Subcategory					
	Score				
	Comments				
	Score				
	Comments				
Category					
Subcategory					
	Score				
	Comments				
	Score				
	Comments				
	Score				
	Comments				

Compound Vulnerabilities

In the table below, define a threshold value for individual vulnerability to be considered "high vulnerability" and thus carried forward to the compound vulnerability assessment. The threshold can be different based on the criteria selected for impact scoring.

Threshold	[Criteria 1]	[Criteria 2]	[Criteria 3]
[value]	[Descriptions]		

Use the table below to list the elements whose individual vulnerability exceeds the thresholds noted in the earlier table and document the associated hazard driving the vulnerability.

Element	Vulnerability Score	Climate Hazard

In the following space, draw the portion of the system map that relates to each of the elements noted in the earlier table and label them with their individual vulnerability score. Also label the relationships with the relationship magnitude (0-1) score.

For each element shortlisted in the earlier table, use the following table to calculate the impact on compound vulnerability scores, based on the individual vulnerability of the upstream elements.

Element: Climate			
Upstream elements	**Individual vulnerability**	**Relationship magnitude**	**Impact on compound vulnerability**
Total			

WORKSHEET

5.5 Risk Assessment and Adaptation Strategies

Purpose

Document the risk scores and selected adaptation strategies developed by the CRA team

Use the following table to document the risk scores and adaptation strategies developed in the CRA process.

Element	Climate Hazard	Risk Scores [Individual Vulnerabilities]			Risk Scores [Compound Vulnerabilities]			Adaptation Strategies			
		[Time Horizon 1]	[Time Horizon 2]	[Time Horizon 3]	[Time Horizon 1]	[Time Horizon 2]	[Time Horizon 3]	[Category 1]	[Category 2]	[Category 3]	[Category 4]

WORKSHEET

7.1 Business Case Problem Definition

Purpose

Help users summarize the results of the CRA into a framework that can be used to define the problem of a Business Case.

Use the tables below to summarize the critical and material element-hazard interactions, both for individual and compound vulnerabilities, with the information from the CRA.

Critical Individual Vulnerabilities

Element	Hazard	Individual Vulnerability Description	Adaptation Strategies	Collaborating Agencies, if applicable

Critical Compound Vulnerabilities

Element	Hazard	Individual Vulnerability Description	Adaptation Strategies	Collaborating Agencies, if applicable

WORKSHEET

7.2 Multicriteria Assessment Resilience Analysis

Purpose

Help users evaluate the resilience of each option to generate a single score that can be fed into the MCA

Use the following table to interact the critical and material elements with the various options. In each cell, document the impact of each option on vulnerability. The cells can be color coded, for example: green – risk mitigated, orange – additional investigation is required, red – risk is maintained.

Critical Individual Vulnerabilities (worksheet 7.1)		Option 1	Option 2	Option 3	Option 4
Element	Hazard				
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:
		Impact description:	Impact description:	Impact description:	Impact description:

WORKSHEET

7.3 Multiple Account Evaluation (MAE)

Purpose

Help users integrate resilience considerations into the MAE process

Step 1: Establish failure thresholds

Use the following table to document failure threshold for each critical vulnerability.

Critical Individual Vulnerabilities (worksheet 7.1)		Hazard Indicator Failure threshold	Notes
Element	Hazard		

Step 2: Calculate probability of exceeding thresholds

Use the following table to document probability of exceeding thresholds.

Event	Probability of occurring [Time Horizon 1]	Probability of occurring [Time Horizon 2]	Probability of occurring [Time Horizon 3]

Step 3: Calculate probability of failure

Use the following table to calculate the probability of failure in any given year

Element: ______________________

Hazard: ______________________

Hazard indicator and threshold: ______________________

Year	p Annual probability of failure	q Probability of element surviving to year n	k Probability of failure in year n