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» LARGE PORTFOLIO ASSESSMENT MANUAL «

A Guide for Prioritizing a Large Portfolio based on Climate Vulnerability

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This guide has been prepared based on many years of professional experience using the PIEVC Protocol and other climate and infrastructure vulnerability and risk assessment methods. Writing Team members include:

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We also thank the Institute for Catastrophic Loss Reduction for their ongoing input and guidance on the PIEVC Family of Resources.

What is PIEVC?

In 2005, Engineers Canada established a national committee called the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee development and delivery of a Protocol for the evaluation of risks related to the impacts of climate change on physical infrastructure in Canada. The PIEVC Protocol has been used in over 100 assessments of various types of individual infrastructure, larger infrastructure systems, and infrastructure portfolios.

The PIEVC Program is owned and operated through a partnership consisting of the *Institute for Catastrophic Loss Reduction (ICLR)*, the *Climate Risk Institute (CRI)* and *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*. This manual is one member of the growing family of PIEVC resources to help organizations achieve climate resilience.

Contents

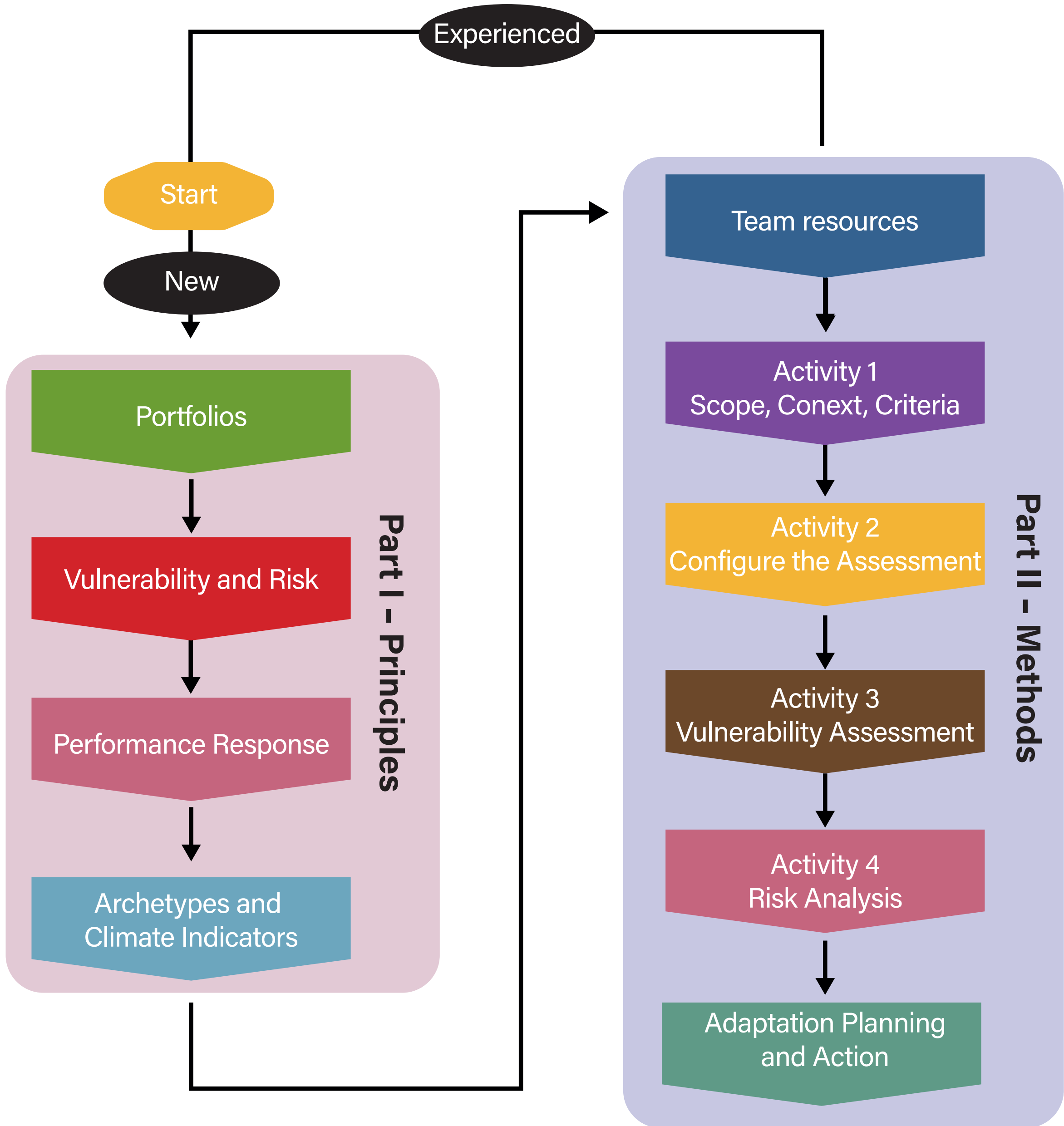
About This Manual

Purpose of this Manual

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.

Document Map

This document is divided into two key pathways.



The first pathway outlines the principles of Portfolio Climate Assessment. This path offers background on vulnerability and risk. Parties who are new to portfolio assessment may find it helpful to review *Principles* before starting work.

The second pathway goes directly into portfolio assessment. Parties experienced in portfolio assessment may follow this path directly to the assessment methods.

A Living Document

Climate change work is in a period of rapid change. This Manual reflects the most recent knowledge about climate resilience work. It summarizes the latest thinking about how users may assess climate risk and develop effective actions.

As this Manual evolves, new knowledge, information and other factors may develop that are not covered in the current document. This manual is a living document. As it develops, the manual will incorporate the latest ideas, concepts, resources, and examples.

Part I – Principles

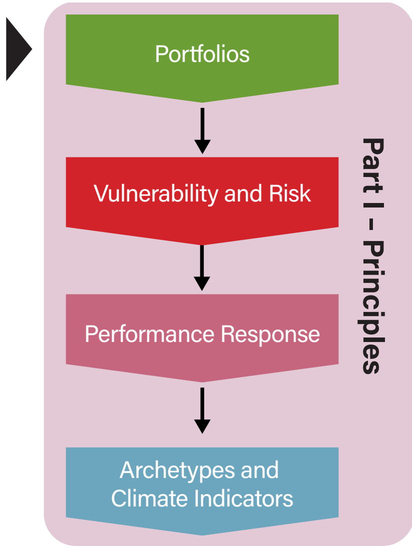
Core concepts that set the foundation for the vulnerability and risk assessment techniques described in **Part II – Methods**

1 Portfolios

1.1 What is a Portfolio?

This manual defines portfolio as a collection of assets that are characterized by different climate vulnerabilities and risks.

It is important to keep in mind that a portfolio is owned, operated, or under the control of an entity. This addresses issues that could confound assessments such as a range of similar assets owned by different entities. Assets must be viewed through a common risk lens, the risk appetite of the single entity that controls the asset.



In conducting a PIEVC Assessment on a portfolio of assets, the user must begin by answering three key questions.

1. Is the system owned or under the operational control of one risk owner?

2. What level of assessment is required to meet the project objective?

3. What type of portfolio is being assessed?

Examples of Portfolios

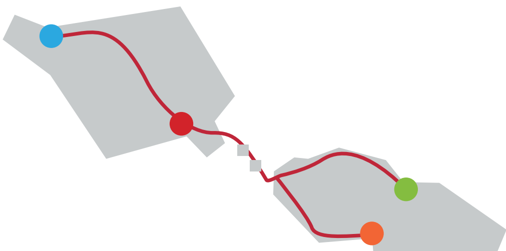
Similar Assets in Many Locations

Example:
All ports owned by one organisation across multiple geographical and climate zones.

One Location with Many Assets

Example:
An organisation with many asset types (roads, waterworks, etc.) in one location.

One Linear System Crossing Multiple Climate Zones



Example:
A single asset that crosses several climatic zones creating a range of different climate considerations. (A highway or pipeline.)

Many Locations with Many Assets

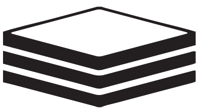
Example:
A territory assessing the asset portfolios of multiple municipalities under its control.

1.2 Portfolios

Portfolio climate resilience management is driven both by the size and the complexity of the portfolio. Complexity increases based on several factors, and will require more refined techniques to address climate resilience issues. Factors that influence complexity include:

1. Number of assets in the portfolio
2. Locations of the assets
3. Number of assets at each location
4. Maintenance at each location
5. History at each location
6. Scale of individual assets
7. Discrete assets or integrated systems
8. Data availability

Small Portfolios



A simple portfolio may comprise a few assets. Prioritizing climate adaptation for a small portfolio is straightforward. Owners may check every asset, or a sample. This work is like a single asset assessment, typically done using the *PIEVC High Level Screening Guide* or the full *PIEVC Protocol*.

As the system gets larger, checking every asset, or choosing samples, is more difficult. If the owner uses the methods for simple portfolios, they may miss important issues, leave critical assets too late, and have no sense of the climate priorities in the system. Effective analysis demands more advanced prioritization techniques.

Moderately Sized Portfolios

For medium sized portfolios, owners may use a variety of standard business decision analysis methods to select representative assets for assessment.

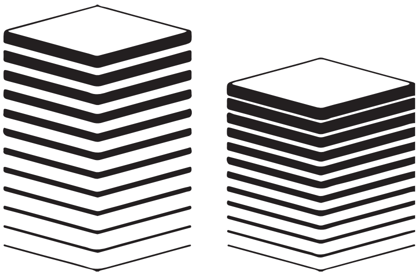
These techniques may include:

- Multi-Factor Analysis based on user-defined criteria
- Statistical sampling of representative assets
- Owner judgement
- Assessing locations that have experienced problems

Owners have had excellent results using these strategies and extending the conclusions to the rest of their system. However, as systems get even larger, these processes may be inadequate. For example, doing a multi-factor analysis of hundreds of items takes a lot of effort. It's difficult to sort out the subtle differences between similar assets. A different method is needed and is outlined in the following sections.

This guide does not discuss the standard management decision aids that organizations have used to address medium sized portfolios. These approaches are user-specific, and well-documented in management literature.

Large Portfolios



When portfolios become very large, standard decision tools fail. Owners must use different methods to prioritize and sort assets for further examination and resilience action. Fortunately, vulnerability and risk analysis can address these issues. These approaches align with *ISO 31010* methods, the *ISO 31000* risk management framework , and the vulnerability and risk analysis described in *ISO 14091*.

This guide focuses on vulnerability analysis for sorting and prioritizing assets in large portfolios for detailed examination and resilience action. Results help owners concentrate on more vulnerable assets. They may use the *PIEVC High Level Screening Guide*, the full *PIEVC Protocol*, or other tools for followup analysis. Or, they may opt to move directly to action, such as sending the issue to engineering to develop mitigation options, depending on their goals.

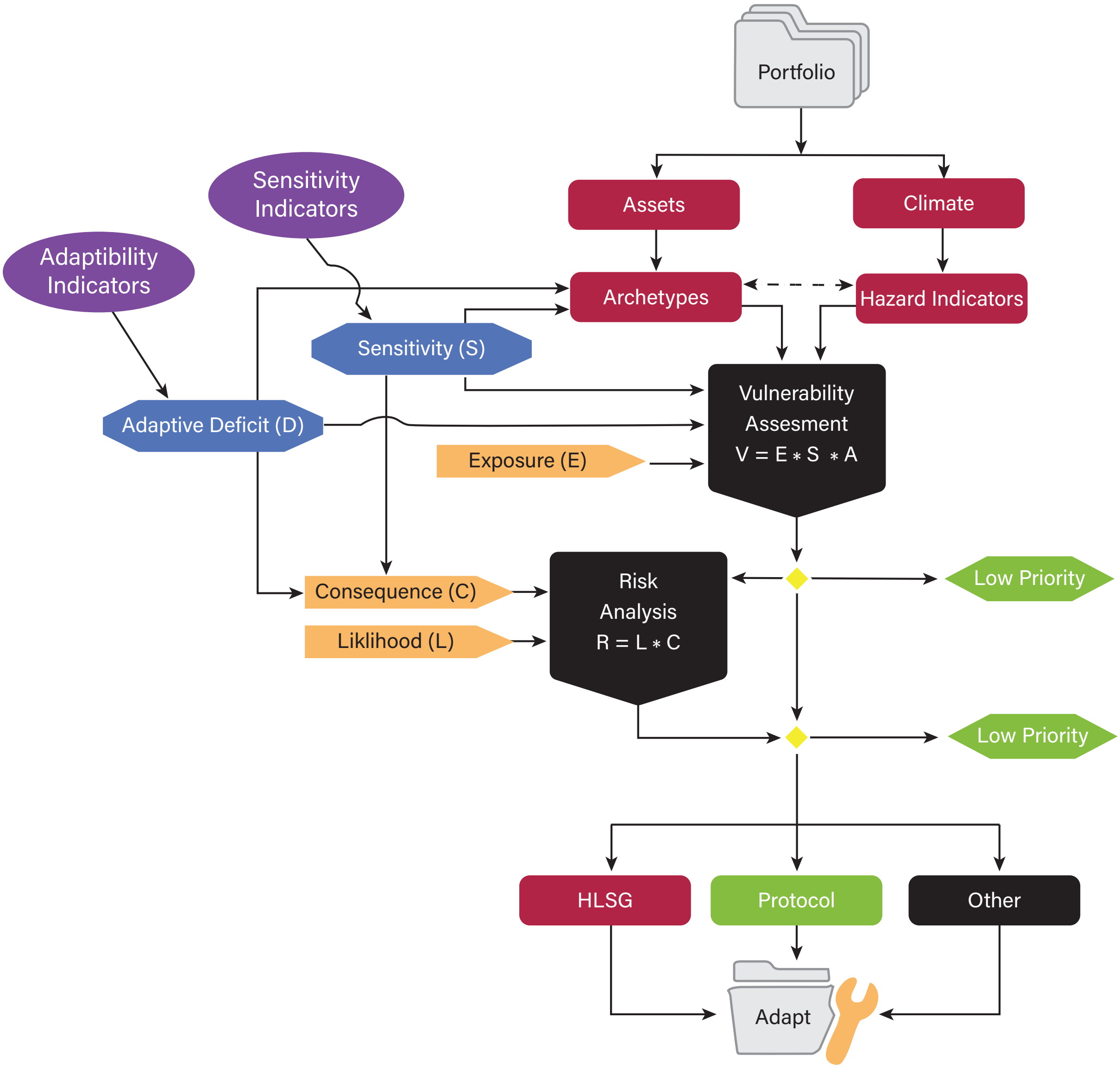
1.3 Prioritizing Portfolio Assets

In this guide, we lay out a way to prioritize assets based on climate change vulnerability.

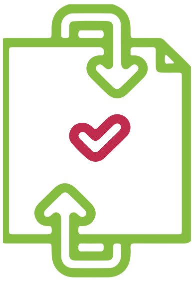
This approach aligns with standard risk identification and classification methods such as *Bowtie and Failure Modes and Effects Analyses*.

The procedure formalizes these methods into an assessment and scoring system based on the use of infrastructure archetypes, an initial exposure analysis, and climate hazard, archetype sensitivity, and adaptive capacity indicators.

The method lends itself to consultation and the use of professional judgment. While the process will be familiar to users of other PIEVC tools, it is done at a much higher level. It allows teams to prioritize assets into categories based on climate vulnerability. From there, they can choose a variety of routes to address issues. This allows them to concentrate on the most vulnerable assets, informing planning and using resources efficiently.



1.4 Objectives of Portfolio Assessment



The objectives of the assessment will dictate its complexity, the time to complete it, the resources, and data required.

The objectives of the assessment should be documented at the beginning of the project. Objectives will be different for different organizations. They should be based on the risk appetite of the project owner.

For large portfolios, assessment objectives may include:

- Identify the assets with the highest vulnerability due to climate change
- Identify common climate risks among common Infrastructure archetypes
- Identify common climate risks among common Infrastructure elements in different climate regions
- Other, based on the portfolio owner's needs, as appropriate.

Infrastructure owners may have a wide range of objectives, over and above those that relate to large portfolio sorting.

Following the portfolio assessment, portfolio managers may wish to do further analysis of individual assets. Selecting the assets for followup work would be based on the priorities established by the portfolio assessment. With large numbers of assets, the portfolio assessment sets the priorities and direction for subsequent analysis.

If the owner is focused on generalized risk profile of a single asset, they may use screening-level risk assessment approaches. The *PIEVC High Level Screening Guide (HLSG)* is one tool that meets these requirements.

The owner may require a thorough grasp of the risk profile of a single asset. Here, they would use more detailed assessments methods like the PIEVC Protocol.

Further detail on selecting appropriate PIEVC tools may be found in the *PIEVC Family of Resources Catalogue*.

A table offering preliminary guidance on selecting the right PIEVC methods is offered in *Annex V*.

What Assessments can do

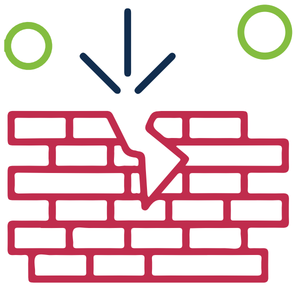
Assessments are very good at spotting and prioritizing vulnerability and risk to changing climate. They itemize which elements of a portfolio are more vulnerable and provide context to decision-makers on where to put their efforts.

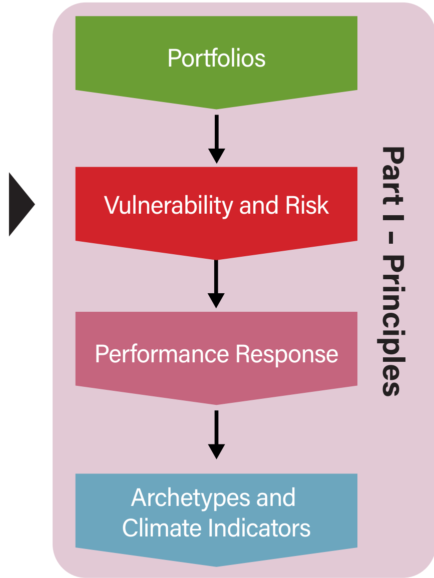
What Assessments cannot do

Usually, assessments do not generate a complete picture of climate adaptation options. They can offer insight on preliminary options and a list of steps that may be examined later. Often, teams do not have the skills or time to work out fulsome options. So, they can describe who and where to go for further climate adaptation work and offer opinions on some plausible options. Final adaptation options call for work by relevant disciplines.

2 Vulnerability and Risk

2.1 Vulnerability





ISO defines vulnerability as the *propensity or predisposition to be adversely affected*. Vulnerability encompasses sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

ISO 14091, which concentrates on climate change risk assessment, provides guidance on vulnerability, as seen through a climate lens.

Climate change impacts take place because a system is exposed to hazards such as drought, flooding, and heat stress. The system's sensitivity and adaptive capacity affect the extent of the impact.

Sensitivity covers factors that could affect the degree to which hazards upset the system. These include factors such as design features, construction of the assets, operations and maintenance histories, and age of the assets. These are the characteristics that make the impact of the climate hazard worse.

Adaptive capacity covers factors that affect the degree to which the system can mitigate the effects of the impact, after it has occurred. This concept deals with more with recovery from event, once it is in progress, and could include emergency response planning, continuity planning, and other similar activities. These are the characteristics that reduce the impact of an event.

Vulnerability is the result of *exposure, sensitivity, and adaptive capacity*. It determines the extent to which an impact may be significant.

2.2 Risk

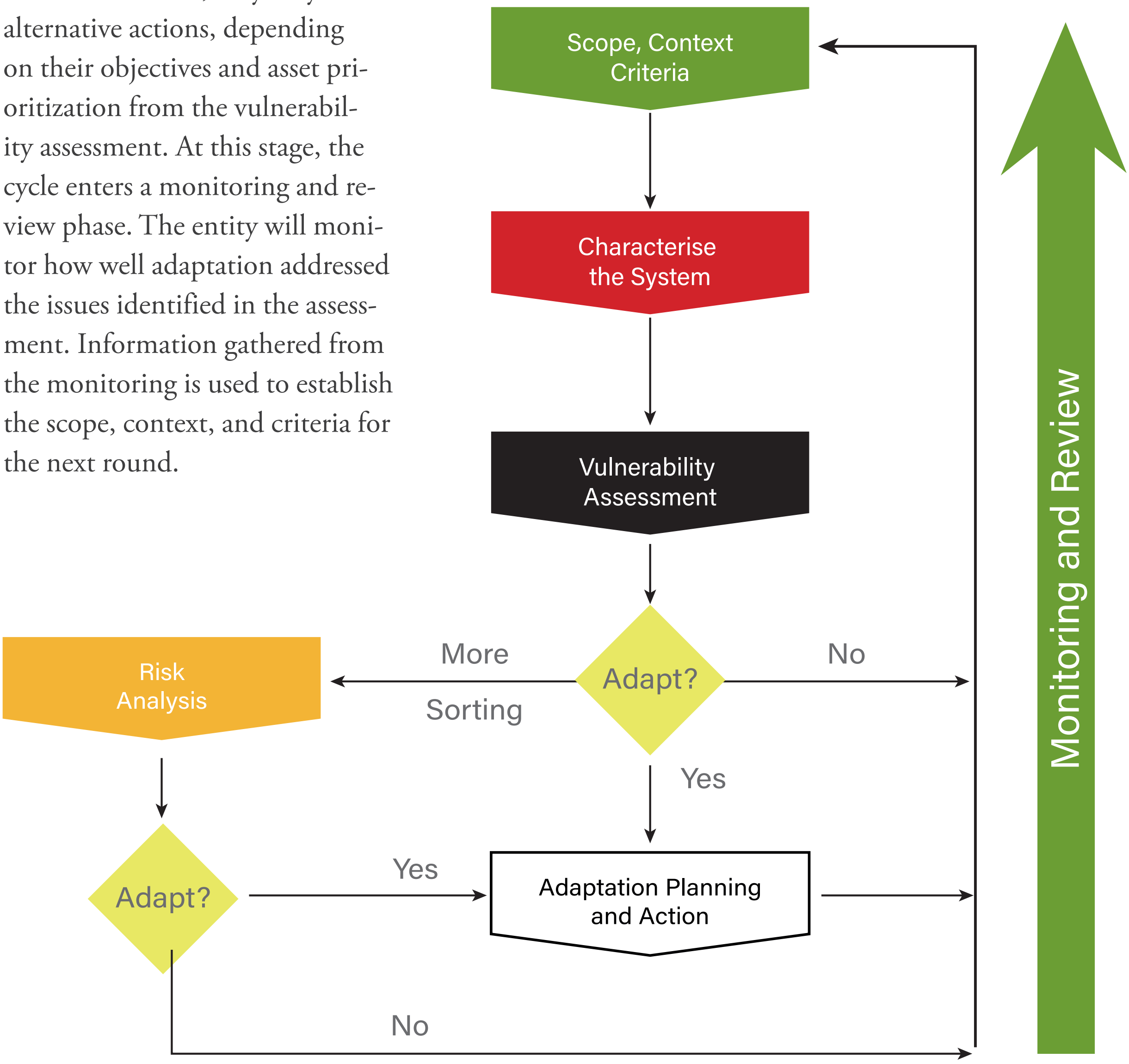
ISO defines risk as the *effect of uncertainty on objectives*. An effect is a deviation from the expected. It can be positive, negative or both. An effect can arise as a result of a response, or failure to respond to an opportunity or threat. Uncertainty is the state, even partial, of deficiency of information related to, understanding, or knowledge of, an event, its consequence, or likelihood.

2.3 Vulnerability and Risk Assessment

Vulnerability and risk assessment is one part of a greater process to adapt to climate change. Assessment informs adaptation planning and action. The work is executed with this objective. The process does not necessarily identify robust adaptation measures, but it does identify where those measures are necessary. Information from the vulnerability assessment can kick- start these activities when transferred to other professionals.

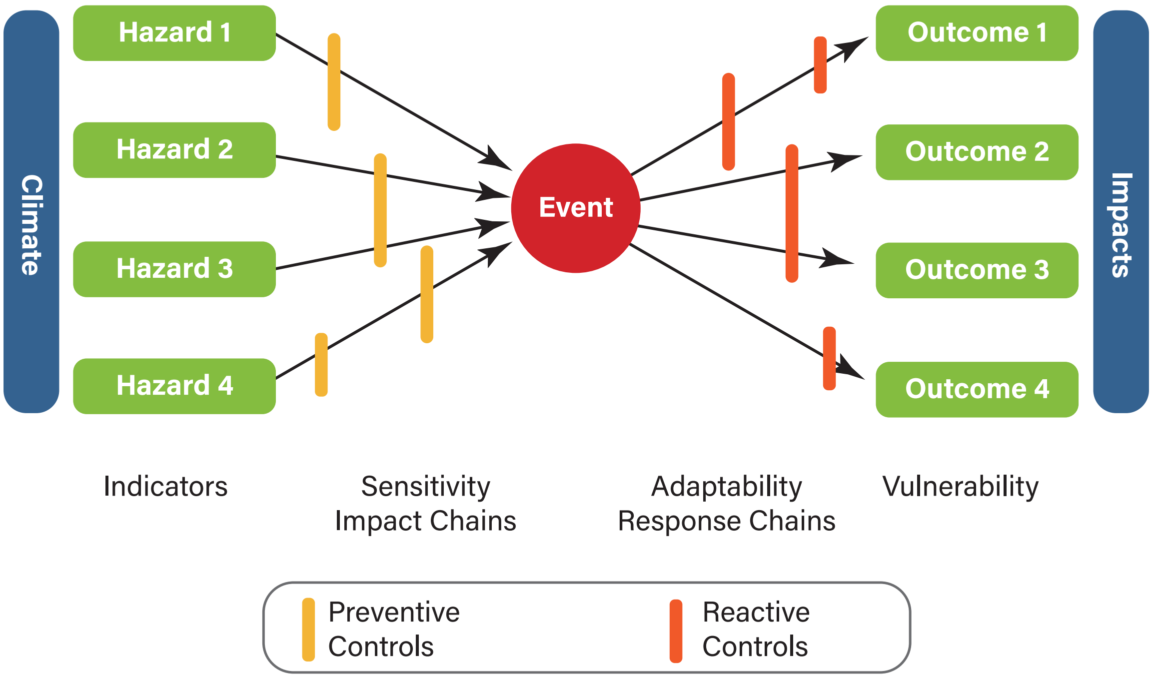
An Iterative Process

Vulnerability and risk assessment forms one part of a cycle of climate risk management. An entity will establish the scope, context, and criteria for an initial assessment. Once the assessment is complete, they will decide how to manage the significant vulnerabilities. In ISO 31000 this is deemed to be Risk Identification. The entity may opt to move forward to Risk Assessment, as described above. Or, they may take alternative actions, depending on their objectives and asset prioritization from the vulnerability assessment. At this stage, the cycle enters a monitoring and review phase. The entity will monitor how well adaptation addressed the issues identified in the assessment. Information gathered from the monitoring is used to establish the scope, context, and criteria for the next round.



2.4 Portfolio Climate Assessment Framework

The vulnerability and risk assessment process used in this manual is framed through core *ISO 31010* risk management techniques. It is based on *Failure Modes and Effect Analysis (FEMA)*, which is systematized by applying *Bowtie Analysis*. Further background on these ISO risk methods is provided in *Annex IV.*



The bowtie represents the framework through which climate hazards and portfolio assets are characterized for assessment.

Climate poses a set of hazards that impose stress on portfolio assets. These hazards interact with the asset through sequences characterized by impact chain analysis. *ISO 14091* defines impact chain as:

An approach that enables understanding how given hazards generate direct and indirect impacts which propagate through a system at risk

ISO 41091 details this approach. Its use in this process assures alignment with the body of risk and climate standards for climate vulnerability and risk analysis.

The bowtie framework depicts the impact chain by an arrow from the climate hazard to the event. The bowtie integrates the concept of preventive controls that may reduce the impact of each chain. These are features built into the system to reduce the full potential impact on the system. For example, these controls could include berms to redirect overland flooding away from an asset.

Response chains are shown as arrows from the event to the outcomes. Similar to impact chains, the framework examines how reactive controls may lessen the effect of an event. For example, an owner may have set up emergency response procedures and training to react more effectively and reduce the impact.

In portfolio analysis, impact chain and response chain analysis is used to establish a reasonable pathway between a hazard and the impact of its interaction with an asset.

Throughout the methods outlined in this manual, we refer to this framework. This ensures the consistency of the analysis and alignment with the *ISO 31000 and 14000* standards that underlie the approach.

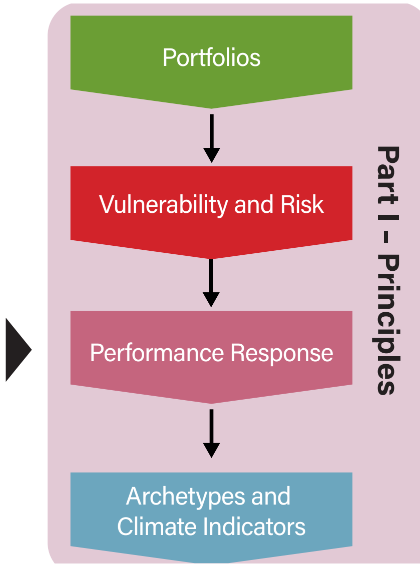
Additional Guidance

The analysis considers preventive controls as indicators of the sensitivity of the asset to the hazard. Similarly, it considers reactive controls as indicators of the adaptive capacity of the asset. These become key inputs to vulnerability analysis.

3 Performance Response

3.1 Definition

Performance response is the reaction of a system to the stress imposed by a climate hazard. It represents how well the system can cope with the stress and maintain a reasonable level of service, based on its inherent sensitivities and the attributes of the system that contribute to its ability to adapt to the stress.



Performance response is defined as:

> *The change, positive or negative, in condition or function of a system traceable to a specific stressor event.*

Here, a system could include the total asset, its components, or any other feature that is deemed relevant to the portfolio owner, based on their objectives. Performance response directly drives how acceptable risk is to an organization.

ISO 31010 states:

> *The acceptability of risk can be defined by specifying the acceptable variation in specific performance measures linked to objectives.*

And *ISO 31000* specifies that organizations should monitor for deviations in:

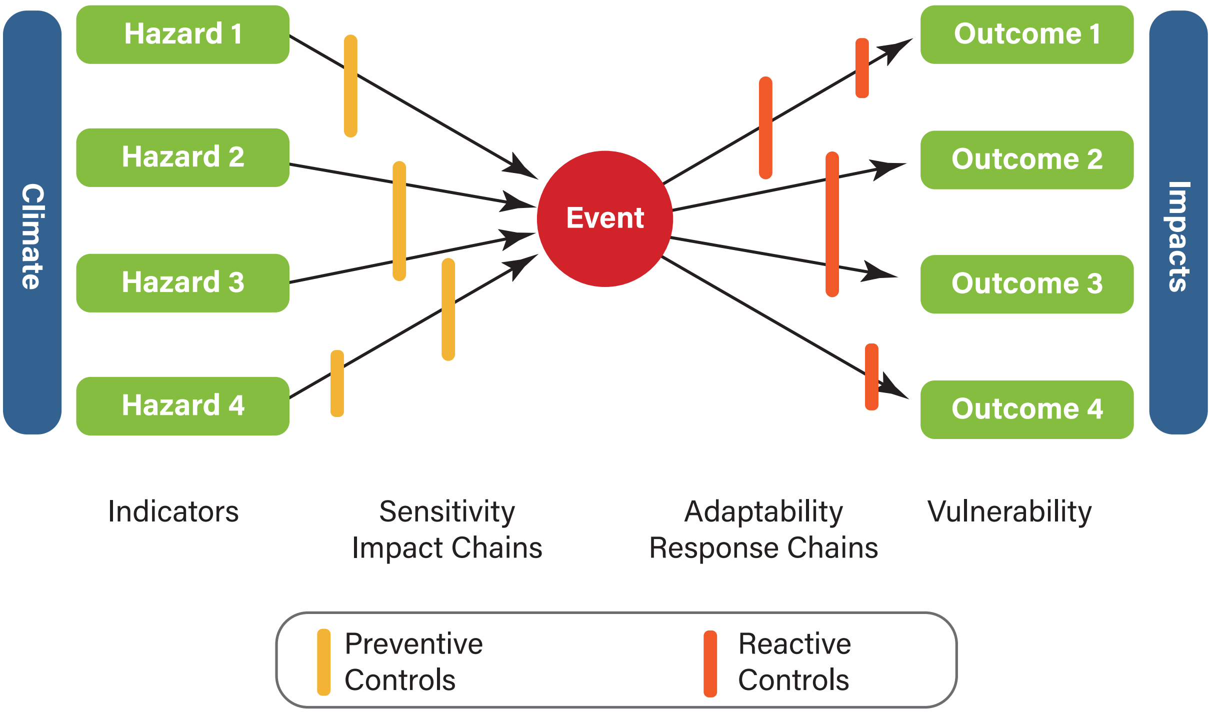
> *Performance against purpose, implementation plan, performance indicators, and expected behavior*

Sensitivity and adaptive capacity drive the performance response of a system.

3.2 Attributes

Sensitivity

As shown by the bowtie framework, *sensitivity* refers to the attributes of a system that make it more reactive to a climate hazard. In this analysis, sensitivity attributes are characterized by sensitivity indicators that offer metrics to assign scores to the sensitivity of the system.



Sensitivity indicators may include:

- Design
- Materials of construction
- Repair and maintenance history
- Region
- Age
- History of previous events
- Other factors the portfolio manager deems appropriate, based on their objectives

Adaptive Capacity

Adaptive capacity derives from the attributes of the system that allow it to respond to a climate hazard and to reduce the ultimate impact. In this analysis, adaptive capacity attributes are characterized by indicators that offer metrics to assign scores to the adaptive capacity of the system.

Indicators of adaptive capacity may include:

- Design
- Emergency response plans
- Access to supply chains
- Previous adaptations that make the system more resilient
- Experience with similar events
- Other factors the portfolio manager deems appropriate, based on their objectives

The Importance of Performance Response

Performance response considerations are key to effective large portfolio sorting and are applied in four locations during the process:

1. Developing archetype definitions
2. Defining the climate indicators
3. Conducting sensitivity and adaptive capacity analysis to support vulnerability assessment
4. Conducting consequence analysis for risk analysis

In this way, performance response permeates the process and are critical considerations for effective sorting of the large portfolio. These steps are depicted in the following flowchart. As outlined in the assessment framework, performance response characterizes the impact chains between climate hazards and eventual outcomes. This information is used to identify which climate hazards to consider in the work. These are the ones to which the system responds. This is key to setting the conditions covered by climate indicators.

Performance response characterizes way parts of a portfolio may react to climate stress. This, among other considerations outlined in this guide, informs the definition of archetypes. The archetype can then be evaluated as a single entity while still capturing the impact on the entire class of assets it contains.

Performance response also captures the sensitivity and adaptive capacity information necessary to establish vulnerabilities. This informs the first stage of the portfolio prioritization exercise described in this manual.

Performance response may be used also as a guide when assessing consequences of climate hazards.

3.3 Performance Response Classes

The following list offers a *starting point* for performance response classes to help teams set up the analysis. Not every project will use every response class. Sometimes teams may include additional categories relevant to their assessment work.

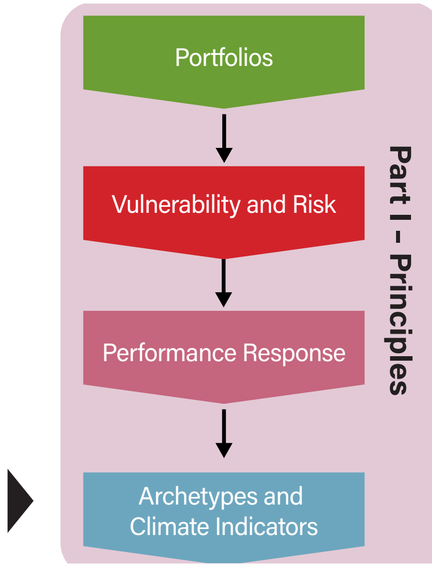
The list includes:

- Design
- Functionality
- The ability of the system to function as intended
- Serviceability
- The ability to access, maintain and repair the system
- Operations and maintenance
- Emergency preparedness

4 Archetypes and Climate Hazard Indicators

4.1 What is an Archetype?

To assess a complex portfolio, it must be first classified into manageable pieces. Archetype analysis is a way to classify complex systems to simplify work.



Portfolios are organized into groups of assets, called archetypes. Each archetype is a 'conceptual model' that represents key characteristics shared by several real-life assets. By using archetypes to reflect parts of the larger Portfolio, assessments can be done without having to assess each asset individually. Every asset has its own unique history and features. However, archetypes can represent a group of assets with comparable climate vulnerabilities.

Users must examine the assets in the portfolio to create logical and effective groupings. First, the classification criteria must represent the system's assets and the objectives of the assessment. For each archetype, users describe the included assets based on similar:

- Size
- Configuration characteristics, such as component makeup and mix
- Age
- Geography
- Capabilities and limitations
- Climate design benchmarks
- Data limitations
- Other factors, as appropriate

The user must prepare an inventory of the different assets included in each archetype. This will help users further refine the archetype. It may be necessary to reference back to assets to ensure the archetype definition captures the key performance-response characteristics of the group.

Once the assessment is done, managers may wish to "work backwards" from the archetype to select individual assets for further work. This may involve more detailed assessment, or immediate adaptation action.

Defining Archetypes for the Portfolio Assessment

Archetypes are conceptual models that exhibit defined performance response to climate hazards based on understanding portfolio asset characteristics and other factors established through the objectives of the assessment. We may group these characteristics by their contribution to:

- sensitivity, and
- adaptive capacity.

Each project will apply a unique perspective to define these characteristics for the purpose of the assessment. This perspective is established by:

- the assessment scope based on the owner's
  - objectives,
  - priorities, and
  - plans.
- The context of the assessment based on
  - Focus on internal effects arising from hazard events
    - zhose outcomes under direct control of the portfolio manager
  - Focus on external effects arising from hazard events
    - broader social, environmental, economic outcomes
- Criteria based on the team's understanding of
  - outcomes the portfolio manager deems *serious,*
  - outcomes the portfolio manager deems *significant but manageable, or moderate* outcomes,
  - outcomes the portfolio manager deems *minor.*

Archetypes are constructed to best capture sensitivity and adaptive capacity through the lens of conditions relevant to the work. Each archetype will encompass several distinct characteristics that align with these attributes. With this in mind, creating archetypes is a process of organizing portfolio assets based on performance response characteristics that are important to the current assessment. Once these characteristics are defined, the user draws from the list to build specific characteristics into each archetype model. Archetypes may incorporate every characteristic from the defined list, or may incorporate only several that may be of specific interest.

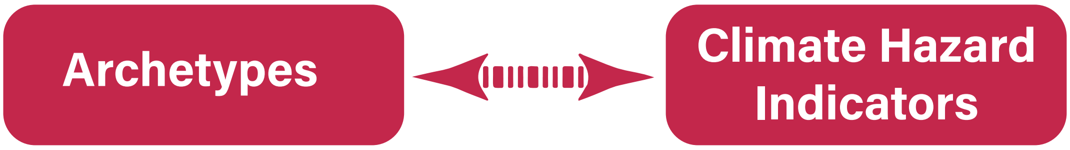
This process generates a smaller group of conceptual model assets tuned to the needs of the assessment. These will yield meaningful vulnerability and risk analysis outcomes that can be generalized to specific assets and simplify the overall sorting process.

Once the archetypes are defined, the portfolio manager can group within each archetype the assets from the portfolio that best align with the characteristics of the archetype definition. This will create an inventory of portfolio assets associated each archetype. In this way, vulnerability and risk results from the analysis may be directly linked to specific assets within the portfolio.

4.2 Establishing Climate Hazard Indicators

While defining archetypes, a similar exercise defining climate hazard indicators occurs in parallel. Climate hazard indicators establish generalized types of climate hazards at a similar level of detail to the archetypes.

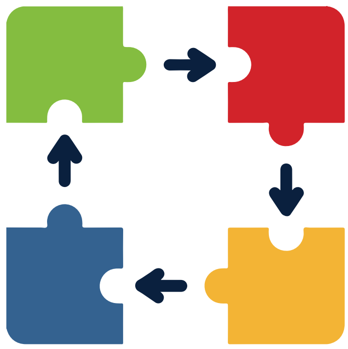
There should be a discussion between the teams working on archetypes and climate hazard indicators. As archetypes are developed, information regarding climate design values and asset histories is shared with the climate team. At the same time, the climate team may provide information about climate data availability and modelling that could affect the form of the archetypes.



Access to climate data is becoming much easier. There are several sources where historical climate data and future climate projections can be found. The climate data are sometimes available at higher resolutions than available in the past. However, gaps in historical climate data sets may lead to holes in explaining the historic climate. A climate specialist should examine data used for the portfolio assessment.

Reasonable Climate Hazards

The team must determine if the future climate hazards will reasonably occur, and that the events represent a hazard to the archetypes. Climate hazards are defined by a mix of a climate information and the threshold above which an impact may occur. These thresholds are derived from the archetype definitions, and depend on the age, components, and history of the assets in the archetype.



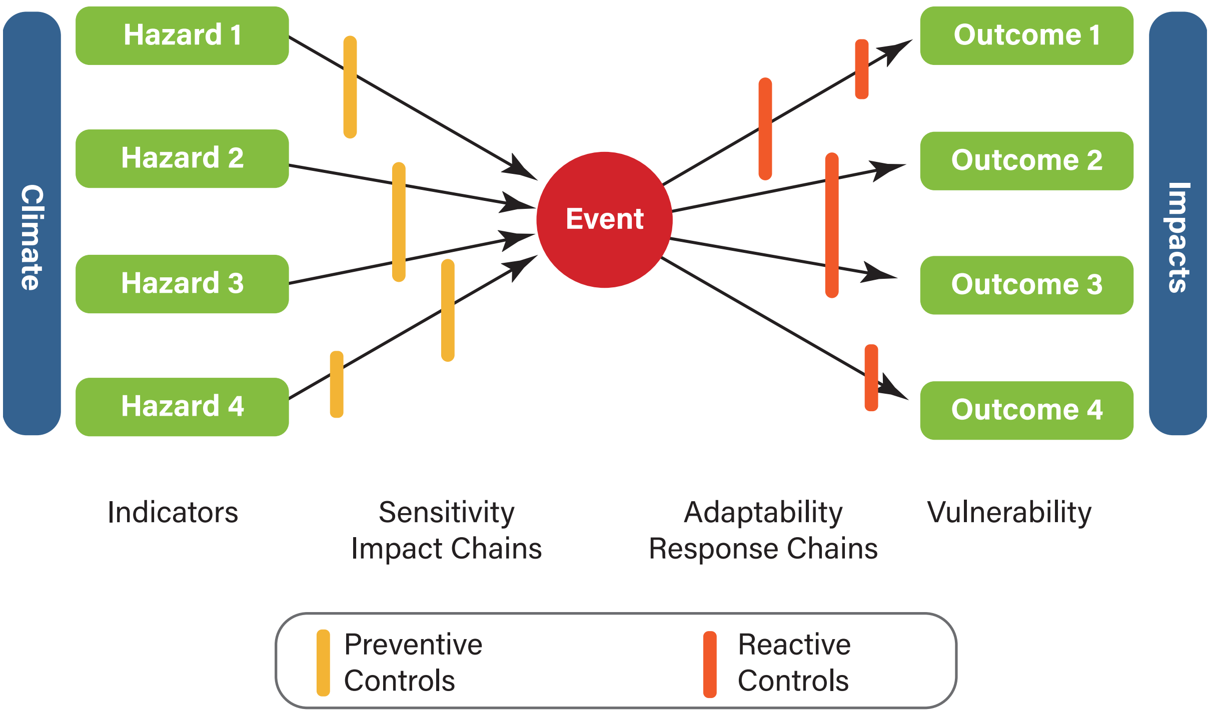
Part 2 – Methods

Procedures for conducting vulnerability and risk assessment on large portfolios of assets.

5 Portfolio Climate Assessment Framework

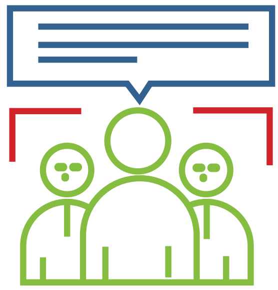
The vulnerability and risk assessment process presented in the following sections follow the climate vulnerability and risk assessment framework described in *Section 2.IV*. The steps trace the impact and response chain pathways of the framework. Further background about the framework may be found in *Section 2.IV*, and in *Annex IV*.

The bowtie represents the framework through which climate hazards and portfolio assets are characterized for assessment.

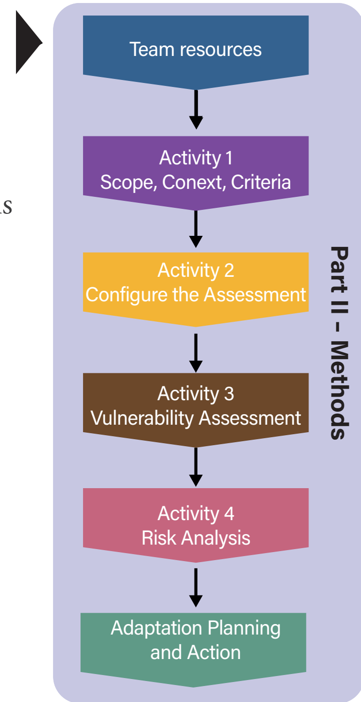


6 Team Resources

6.1 Establish the Team



Engagement with subject matter experts and stakeholders with local knowledge (including management, operations, engineering) is a constant theme throughout PIEVC. Each step of an assessment process requires a different mix of skills depending on locations and asset categories specific to the Portfolio. Further guidance on Team Resources can be found in the PIEVC HLSG.



Examples of Team Resources Include:

- Risk Assessment Specialist
- Climate Specialist
- Planning
- Technical / Engineering
- Natural Environment
- Operation & Maintenance
- Management, Finance
- Legal, Insurance
- Asset Management
- People (non-organizational stakeholders such as affect local citizens, business owners, neighbours, etc.
- Indigenous

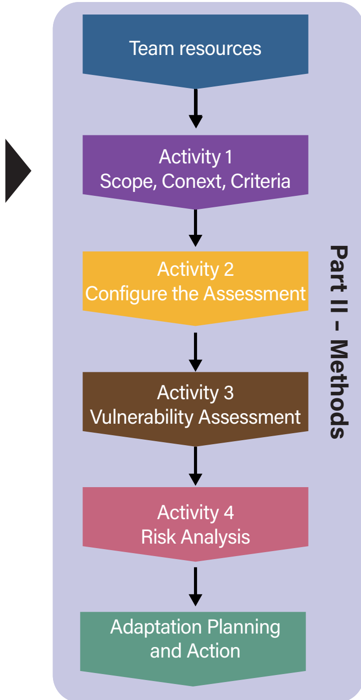
6.2 Consult with Experts

This Manual is a high-level planning document. It does not delve deeply into the various areas of expertise often necessary for skilled execution of climate assessment work. Parties are encouraged to consult with appropriate experts when planning and doing their work. This Manual offers guidance on approaches that portfolio owners may use to prioritize climate adaptation work when faced with very large groups of assets. Each project will require appropriate staffing and resourcing.

7 Activity 1 – Define Scope, Context and Criteria

7.1 Scope

The scope identifies key details and questions that should be addressed by the work. As a minimum, the scope should assign the boundaries for the assessment both physically and in time. The scope will provide information on where and what is being assessed, and over what timeframe.



The owner should give clear direction about the purpose of the work. The scope will normally identify key stakeholders who may be consulted, or even included, on the team.

Assessors should clearly understand the objectives. PIEVC provides guidance on seeking this sort of guidance as one of the main tasks during the early stages of work. Owners should have a clear picture of their objectives to provide the team with clear boundaries, focus, and expected results. These scoping considerations inform the level of complexity of the assessment and the selection of tools and resources for the work.

These scoping considerations inform the level of complexity of the assessment and the selection of tools and resources for the work. The Scope should be reviewed and followed throughout the steps of the assessment and amended if needed. This will ward off scope creep that can threaten the success of the assessment.

7.2 Context

Each project should establish if the work is looking more inward or outward. Is the focus on systems and assets under the direct control of the owner? Or is the focus on effects on other parties, or even broad social impacts? This defines the external and internal context of the work.

Context flows from the scope and helps define the project boundaries. This provides a clearer definition of the objectives of the work.

Users may use a blended approach, looking at both the internal and external context. They must consider how much weight to place on the internal and external factors to provide explicit objectives, setting the boundaries of the work.

Context must mirror the objectives and activities of the owner. When selecting assessment tools, the user must consider if the work is focusing more inward or outward. Work runs more smoothly when the context is clearly detailed before starting work.

7.3 Criteria

Every entity should identify the amount and type of risk that they are willing to take. This is, this is called risk appetite. It determines the overall risk the entity can accept. When doing assessments, care must be taken to align the work with these criteria.

The definition of risk appetite should support the values, objectives, and resources of the owner. They also need to be consistent with the owner's policies and statements about their risk management programs. The criteria should also consider the views of its key stakeholders.

Normally, criteria are determined at the beginning of an assessment process. However, assessment is dynamic, and often the team will review and amend criteria as work progresses. When the work is underway, the team may find conditions not considered when creating the original criteria. Adjusting is a normal and accepted practice in assessment.

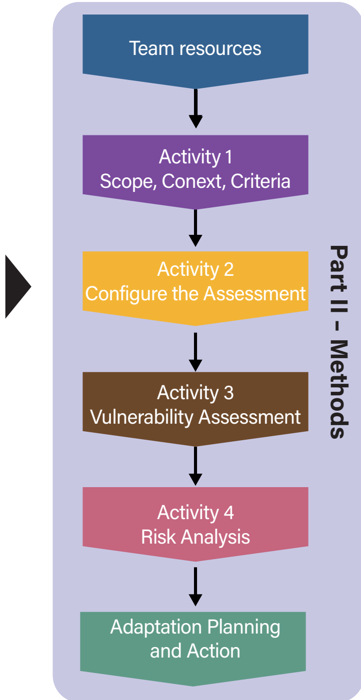
When establishing the criteria, the user should establish how consequences and likelihood will be defined and measured, the organization's capacity to respond to risk, resources the organization is willing to put into addressing identified risks and the residual risk the organization is willing to tolerate at the end of the process. Tolerance will define the budget and effort to manage identified risks.

8 Activity 2 – Configure the Assessment

8.1 Evaluate Performance Response

Aim

This activity sets the performance characteristics important to the assessment. The objectives of the assessment determine this. The work sets the groundwork for the considerations included in the sensitivity and adaptive capacity analysis, done in *Activity 3 - Vulnerability Assessment*.



The following table may be used as a starting point for the analysis

Using the Table

Enter the assessment objects in the top section of the table. This will set the filter through which performance response is reviewed. It is the first pass as setting boundary conditions for the assessment. The work is configured to address the objectives established in Activity 1.

The performance response criteria are listed in the leftmost column of the table. Asset characteristics are listed across the top of the table. The lists in the table are only a starting point. Users are encouraged to review these preliminary lists and add or delete factors they deem relevant, based on the objectives of the assessment.

Once these listings are completed, review the table and identify those the performance response criteria relevant to the system features of the portfolio assets.

Once completed, the table provides a reference to identify the key factors necessary to establish archetypes, and score sensitivity and adaptive capacity in later stages of the assessment.

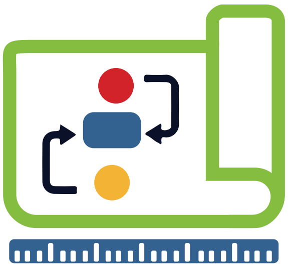
This work is an iterative process. Teams may revise the table as work moves along and they form a deeper understanding of the portfolio.

Example Performance Response Analysis Table

Objective 1 →							
Objective 2 →							
Other ... →							
Response Criteria ↓	System Features of Interest						
	Asset Type	Purpose	Age	Service Level	Asset Value	Population Density	Other
Design	✓						
Functionality		✓					
Serviceability	✓	✓					
O&M			✓	✓			
Emergency Preparedness		✓		✓		✓	

8.2 Construct Archetypes for the Assessment

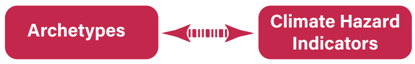
Aim



This activity establishes the definitions for the archetypes considered in the assessment.

Additional Guidance

Archetypes are best built in tandem with the development of climate indicators. Each activity uses information from the other. Ensure active discussion between the climate and infrastructure specialists in these activities.



Method

Based on the performance response criteria identified to apply to the assessment, construct a table of archetype definitions used to sort the assets into representative groupings. Each definition establishes one archetype for the assessment.

In the analysis include climate sensitivities and adaptation actions that may already be in place. This adds context into the definition. These further define the archetype to include attributes that provide a sense of the current state of climate readiness of the assets defined by the archetype.

Other attributes may also be included in the definition, based on the objectives of the assessment.

An example of two archetype definitions is provided in the following table. The table is for illustration only. Teams may add or delete from attribute lists as necessary.

Using The Table

The example uses a table to help define the archetypes.

List the attributes of interest in the leftmost column.

Under each archetype, enter a description of the attributes. For example, under *Asset Type*, teams may enter *"bridges, roads, ports, or any other asset of interest"*. These descriptions can be as general or specific as necessary.

Teams should take care to not over-define the descriptions. Very detailed lists of attributes can lead to too many archetypes that may not simplify the analysis. The aim is to establish archetype definitions that are specific enough to allow distinguishing between asset categories, but broad enough to allow meaningful aggregation. This will require the input from a team to provide different perspectives on the most meaningful set of definitional attributes.

Prepare Archetype Inventories

For each archetype, review the assets in the portfolio. Set up inventories of assets that satisfy each archetype definition. This will produce a list of assets for each archetype.

Archetype inventories address two potential needs.

1. Results from this assessment can be generally applied to each archetype inventory. Each asset in the archetype will share the same vulnerability and risk as the archetype.

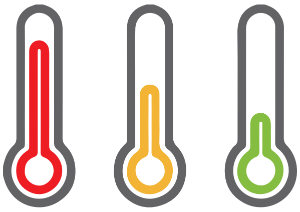
2. Inventories can streamline follow-up work. Representative assets may be selected from each archetype. Work on those assets may be generalized to the other assets in the inventory.

The inventory lists are not directly applied in the current assessment, but the information developed from the assessment may be generalized to cover all the assets defined by each archetype.

	Example Archetype Description		
Attributes ↓	Archetype 1	Archetype 2	Archetype …
Asset Type	Major Bridge	Highway	Fill in, as appropriate ↓
Purpose	Crossing wide rivers with deep gorges	Key connector between major urban centers	
Age Range	25 to 50 years	25 to 50 years	
Region	Northern Province	Northern Province	
Required Level of Service	• Critical Infrastructure • > 99% service availability	• Critical infrastructure • 95% to 99% service availability	
Asset Value	$50M to $100M	$1B to $5B	
Population Density	Rural < 5,000	Rural < 5,000	
Climate Sensitivities	• Extreme short duration rainfall • Fog	• Extreme short duration rainfall • Heavy snowfall	
Adaptive Capacity	• Emergency Response Plans • Inspection and maintenance	• Emergency Response Plans • Inspection and maintenance	
Other	n/a	n/a	

8.3 Construct Climate Hazard Indicators

Aim



These steps are used to establish climate parameters for the vulnerability and risk assessment.

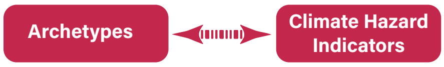
Process

This work draws heavily on the performance response analysis, which outlines the key areas where the system exhibits sensitivities to the stress from climate hazards. It also draws on the archetype definition work that is conducted at the same time.

Based on these inputs identify the climate parameters, climate hazards, and climate hazard indicators of interest for the archetypes under assessment.

Additional Guidance

Climate hazard indicators are best built in tandem with the development of archetypes. Each activity uses information from the other. Ensure active discussion between the climate and infrastructure specialists in these activities.



Identify any combination of climate hazards that may result in archetype adverse outcomes. For example, combination events may include rain on snow, high temperature coupled with high humidity, etc.

For each climate hazard, identify at least one factor that represents the magnitude and/or duration of the hazard that could result in archetype adverse outcomes.

Climate Hazard Indicators and Thresholds

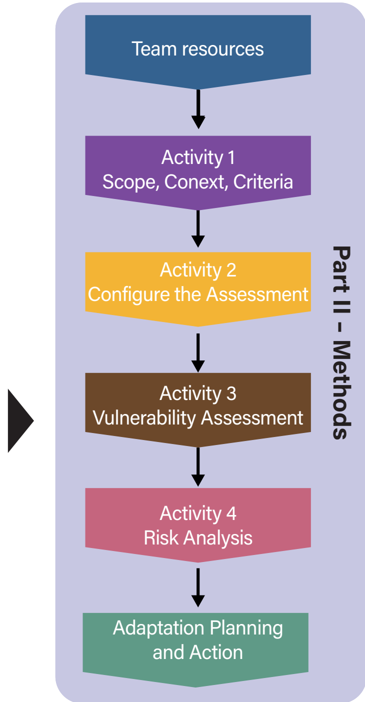
Each climate hazard indicator has a threshold value that aligns with the archetype being considered. Threshold values are established from several sources. These include design standards, operational standards, rules of thumb, maintenance guidelines, codes of practice, literature, experience, and professional judgement. For each climate hazard indicator, the team should define a corresponding threshold value associated with the archetype.

Users must examine the climate information to establish relevant indicators. The indicators must reflect the system's assets and the objectives of the assessment. For each indicator, they must describe:

- The climate zone
- The time horizon
- The climate scenario used to establish the indicators, generally RCP 8.5 (or equivalent)
- How the indicators may reasonably interact with the archetypes
- If the interaction could lead to an impact
- Baseline values
- Projected values

9 Activity 3 – Conduct Vulnerability Assessment

At this stage, the team has finished preparations for the vulnerability assessment.



The assessment is completed twice. Once for baseline climate and once for the future climate. This will establish the vulnerabilities for both current and future climates. Changes in vulnerability between the baseline and projected climate helps the portfolio manager understand how the system may be affected by climate change. This supports more efficient planning that accommodates changing climate.

The process uses a three-point scoring scales commensurate with the level of detail that may be encompassed within the archetypes and indicators. Generally, as assets and climate hazards are rolled up into categories, the fine details relative to specific locations is blended. The aggregation smooths out fine differences between individual assets, but provides a good representation of the overall response of the assets that comprise the archetype. This is acceptable at this stage of the analysis, as it is intended as a prioritization exercise. Archetypes that demonstrate higher vulnerability will need to be addressed following the vulnerability assessment, either through direct adaptation action, or further risk assessment. At these subsequent stages, the team can hone in on specific assets, gather more precise data, and conduct a deeper analysis.

9.1 Vulnerability Calculations

Vulnerability is a function of exposure, sensitivity and adaptive deficit. It is expressed by the formula:

$V = E \times S \times D$

Where:

V = Vulnerability
E = Exposure (0 or 1)
S = Sensitivity (1, 2 or 3)
D = Adaptive Deficit (1, 2 or 3)

When E = 1

Sensitivity →	1	2	3
Adaptive Deficit ↓			
1	1	2	3
2	2	4	6
3	3	6	9

Vulnerability	Score
Low	1 to 2
Medium	3 to 5
High	6 to 9

Using this formula, vulnerability scores may be calculated from the exposure, sensitivity, and adaptive deficit scores assigned by the team.

Archetypes are deemed to demonstrate low vulnerability if they score between “1” and “2”. They demonstrate medium vulnerability if they score between “3” and “5” and they have high vulnerability if they score between “6” and “9”.

These rankings can then be used to prioritize the archetypes in the portfolio.

Additional Guidance

Adaptive capacity is a positive trait. Sensitivity and exposure are negative traits. For consistency, it is necessary to consider only positive or negative attributes. This ensures that the analysis does not pull in different directions and generate inconsistent results. For this reason, this analysis looks at the negative attribute of adaptive capacity, the inability to adapt or lack of resilience in the system. This is called adaptive deficit.

For the interactions that receive an exposure score of "1", assign sensitivity and capacity deficit scores, and calculate the resulting vulnerability.

For the interactions that receive an exposure score of "1", assign sensitivity and capacity deficit scores, and calculate the resulting vulnerability.

9.2 Measure the Exposure

For each archetype, review the list of climate indicators.

Archetype Sees the Indicator	Archetype Doesn't See the Indicator
1	0

Determine if the archetype will experience the climate conditions described by the indicator, should that event take place. Generally, this is called the archetypes "seeing" the indicator. This analysis calls for professional judgment and should be reviewed or conducted with the rest of the team. This will ensure the best judgment of exposure, accounting for different experience, training and perspectives on the assessment team.

If the archetype will see the climate hazard, should it occur, assign a score of "1" to the potential interaction. Otherwise, assign a score of "0".

At this stage, the team is examining the prospect that an interaction *can* occur between the archetype and indicator. If the exposure is possible, the interaction is kept within the analysis. Otherwise, the exposure is deemed to be non-material, and the interaction is not passed through the vulnerability analysis.

9.3 High Level Sensitivity and Adaptive Deficit Analysis

Sensitivity

Referring to the Bowtie analysis describe earlier, sensitivity looks at the attributes of the archetype that make it more or less prone to damage when an interaction occurs with an indicator. These are features that can reduce the initial impact of the event. For example, more experienced staff may respond more efficiently during the event, reducing the impact on the archetype, making it less sensitive to the climate hazard.

Sensitivity (S)	Score
Low	1
Medium	2
High	3

This could include considerations such as:

- Design
- Age
- Materials of construction
- System complexity
- Component mix and type
- Experience of the staff
- History
- Maintenance
- Previous climate events
- Previous failures
- Geomorphology
- Supply chain

With these considerations in mind, archetypes that have very similar design features and services may show different sensitivity to the indicator.

Each interaction is scored on a three-point scale, based on the judgement of the team. Archetypes with low sensitivity to the indicator hazard are assigned a score of “1”. Those with high sensitivity are assigned a score of “3”. Interactions with a sensitivity somewhere between these boundary conditions are assigned a score of “2”.

This analysis requires professional judgment and should be reviewed or conducted with the rest of the team. This will ensure the best comprehensive judgment of sensitivity, accounting for different experience, training and perspective.

Adaptive Deficit

Referring once again to the assessment framework, adaptive deficit reflects the features that interfere with an archetype returning to normal after an event. These are factors that slow down recovery and increase the duration and extent of the outcomes from the event.

Adaptive Deficit (D)	Score
Low	1
Medium	2
High	3

This could include considerations such as:

- Emergency response preparedness
- Experience of the staff
- History
- Spare part inventories
- Supply chains
- Location
- System complexity
- Physical features such as drainage
- Accessibility
- Training

With these considerations in mind, archetypes that have very similar design features and services may show different adaptive deficits to the indicator.

Each interaction is scored on a three-point scale, based on the judgement of the team. Archetypes with high adaptive deficit (low adaptive capacity) to the climate hazard are assigned a score of "3". Those with low adaptive deficit (high adaptive capacity) are assigned a score of "3". Interactions with an adaptive deficit somewhere between these boundary conditions are assigned a score of "2".

This analysis requires professional judgment and should be reviewed or conducted with the rest of the team. This will ensure the best comprehensive judgment of sensitivity, accounting for different experience, training and perspective.

9.4 Intermediate Sensitivity and Adaptive Deficit Analysis

The intermediate sensitivity and adaptive capacity approaches outlined in this annex align with approaches presented in *ISO 14091*.

Sensitivity

As outlined in *Section 3*, sensitivity depends on several factors. In this level of sensitivity analysis, these factors are treated as indicators that contribute to the sensitivity of an asset.

Sensitivity indicators may include:

- Design
- Materials of construction
- Repair and maintenance history
- The region of where the assets are located.
  - This may drive the range of climate hazards relevant to the assessment. For example, sea level rise may be included as a climate hazard for coastal assets, but may not be deemed relevant assets located inland.
- The age of the assets
  - In a portfolio, this may be a range of ages in order to aggregate several assets into the representative asset archetype.
- History of previous events
  - These may have revealed system sensitivities
- Any other factor the portfolio manager believes to apply to the assessment based on its objectives.

In intermediate sensitivity analysis, relevant sensitivity indicators are tabulated, as shown in the table. Each indicator is rated based on its contribution to sensitivity of the asset. For example, the portfolio manager may have concerns about the efficacy of the design of the system and, as shown in the example, deem that the asset is highly sensitive to this indicator.

These ratings are based on the *professional judgement* of the portfolio owner, the assessment team, and other stakeholders. Judgment is guided by the objectives of the assessment. This activity is best conducted in workshop or other consultative process to ensure a broadly representative view of the sensitivity of the system to each indicator.

Once the indicators are rated, the table outlines a weighting and normalization procedure to yield an overall sensitivity score that may be directly input in the analysis outlined in *Section 9 - Activity 3*.

Sensitivity Indicator		Judgement of Sensitivity by Indicator		
#		High	Medium	Low
1	Design	✓		
2	Construction		✓	
3	O&M		✓	
4	Region			✓
5	Age	✓		
6	History		✓	
7	Other		✓	
	Total	2	4	1
	Weighted Score	H = Total x 3	M = Total x 2	L =Total x 1
		6	8	1
	Total Weighted Score (TWS)	TWS = H + M + L		
		15		
	Sensitivity Score (Rounded to Integer Value)	S = TWS ÷ Total Number of Indicators		
		2		

The total number of high-sensitivity indicators is summed, and the total multiplied by "3". Similarly, the medium and low sensitivity indicators are summed and assigned weightings of "2" and "1", respectively. The weighted scores are then summed and divided by the total number of indicators considered in the analysis. The final value is rounded to the nearest whole integer value, which will yield a score of "1", "2", or "3".

The weighted sensitivity score considers all the indicators deemed relevant to the assessment on a three-point scale.

The analysis may be enhanced further by including notes on the rationale for each sensitivity rating, and examples of the sensitivities responses that are of concern.

Adaptive Deficit

As outlined in *Section 3*, adaptive capacity depends on several factors. In detailed sensitivity analysis, these factors are treated as indicators that contribute to the adaptive capacity of an asset.

Adaptability indicators may include:

- Emergency response plans
- Access to supply chains
- Previous adaptations that make the system more resilient
- Experience managing climate hazard
- Staff training
- Continuity planning
- Site access
- Any other factor the portfolio manager believes to apply to the assessment based on its objectives.

In detailed adaptive deficit analysis, relevant adaptive capacity indicators are tabulated, as shown in the table. Each indicator is rated based on its contribution to adaptive capacity of the asset. For the reasons outlined above, this analysis focuses on the lack of adaptive capacity in each indicator, the adaptive deficit. For example, the portfolio manager may have concerns about the efficacy of the procedures used to operate the system and, as shown in the example, deem that the asset has a high adaptive deficit to this indicator.

These ratings are based on the professional judgement of the portfolio owner, the assessment team, and other stakeholders. Judgment is guided by the objectives of the assessment. This activity is best conducted in workshop or other consultative process to ensure a broadly representative view of the adaptive deficit of the system to each indicator.

Once the indicators are rated, the table outlines a weighting and normalization procedure to yield an overall adaptive deficit score that may be directly input in the analysis outlined in *Section 9.VI*.

The total number of high adaptive deficit indicators is summed, and the total multiplied by "3". Similarly, the medium and low adaptive deficit indicators are summed and assigned weightings of "2" and "1", respectively. The weighted scores are then summed and divided by the total number of indicators considered in the analysis. The final value is rounded to the nearest whole integer value, which will yield a score of "1", "2", or "3".

Adaptive Deficit Indicator		Judgement of Adaptive Deficit by Indicator		
#		High	Medium	Low
1	Procedures	✓		
2	Experience		✓	
3	Supply Chain Access			✓
4	Exiting Built Features			✓
5	Accessibility		✓	
6	Training	✓		
7	Other		✓	
	Total	2	3	2
	Weighted Score	H = Total x 3	M = Total x 2	L =Total x 1
		6	6	2
	Total Weighted Score (TWS)	TWS = H + M + L		
		14		
	Adaptive Deficit Score (Rounded to Integer Value)	S = TWS + Total Number of Indicators		
		2		

The weighted adaptive deficit score considers all the indicators deemed relevant to the assessment on a three-point scale.

The analysis may be enhanced further by including notes on the rationale for each adaptive deficit rating, and examples of the adaptive deficit responses that are of concern.

9.5 Detailed Sensitivity and Adaptive Deficit Analysis

Users may wish to establish a deeper understanding of the archetype features that contribute to sensitivity and adaptive deficit. This requires a more detailed analysis. The analysis builds onto the high and intermediate level analysis outlined above and digs deeper into the features of the archetype than can contribute to performance response.

An example calculation for sensitivity and adaptive deficit is presented in the following tables. The example considers several bridge archetypes in a portfolio defined by three sensitivity and three adaptive deficit indicators. It contemplates a *high intensity, short duration rainfall* event that could cause significant water flow at a bridge. The analysis is completed for each archetype and climate hazard in the assessment.

Each indicator is further delineated by the features that define the archetype, its:

- Sensitivity
  - Design
  - Age
  - Operations and maintenance practices
- Adaptive Deficit
  - Emergency response procedures
  - Emergency response training
  - Access to supply chains to support recovery activities

These are assigned *high, medium, and low* rankings, based on the definition of the archetype, as indicated in the following tables.

For example, this case considers bridge design as one key element of the archetype definition, and considers three different designs:

- Large culvert bridges
- Wood trestle bridges
- Concrete pier bridges

The team assigns a sensitive ranking of *high, medium or low* based on the bridge design included in the archetype.

This process is repeated for each of the sensitivity and adaptive deficit indicators considered in the analysis. A normalized sensitivity and adaptive deficit score is calculated using the same procedures describe in Section xx.

In this example, the sensitivity score was "3" and the adaptive deficit score was "2". for exposure to *high intensity, short duration rainfall* events. These values would then be applied in the vulnerability calculations describe in the next section.

Sensitivity Indicator		Sensitivity Indicator Definition High Intensity – Short Duration Rainfall		Sensitivity Indicator Ranking		
#		Description	Rank	High	Medium	Low
1	Design	Large Culvert	H			
		Wood Trestle Bridge	M	✓		
		Concrete Pier Bridge	L			
2	Age	> 25 years	H			
		10 to 25 years	M		✓	
		< 10 years	L			
3	Operations and Maintenance	**Never** been Inspected or Serviced	H			
		Inspection and Service **Once Every Five Years**	M			✓
		Annual Inspection and Service	L			
	Total			1	1	1
	Weighted Score			H = Total x 3	M = Total x 2	L =Total x 1
				6	2	1
	Total Weighted Score (TWS)			TWS = H + M + L		
				9		
	Adaptive Deficit Score (Rounded to Integer Value)			S = TWS ÷ Total Number of Indicators		
				3		

Adaptive Deficit Indicator		Adaptive Deficit Indicator Definition High Intensity – Short Duration Rainfall		Adaptive Deficit Indicator Ranking		
#		Description	Rank	High	Medium	Low
1	Emergency Response Procedures	No Procedures	H		✓	
		Procedures every 5 to 10 years	M			
		Procedures revised < 5 years	L			
2	Training	No training	H		✓	
		Staff trained once with no drills	M			
		Staff training cycle < 5 years with annual drills	L			
3	Access to Supply Chain	Rural limited access	H			✓
		Near large town - moderate access	M			
		Urban with significant access	L			
	Total			0	2	1
	Weighted Score			H = Total x 3	M = Total x 2	L =Total x 1
				0	4	1
	Total Weighted Score (TWS)			TWS = H + M + L		
				5		
	Adaptive Deficit Score (Rounded to Integer Value)			S = TWS ÷ Total Number of Indicators		
				2		

9.6 Calculate Vulnerability

The team will set up a spreadsheet and transfer descriptive information about the archetypes and indicators to the axes, as shown in the example below. This information may simply be descriptors, as in the example, or the team may decide to provide more detailed descriptions within the worksheet.

Once the archetypes and indicators are transferred, the vulnerability assessment can start.

First, review each indicator, archetype interaction in the sheet and assign exposure scores. Interactions with scores of “0” are not evaluated further. The team may wish to detail their rationale for the scores.

Archetypes	Climate Hazard Indicators															
	Indicator 1				Indicator 1				Indicator 1				→			
	E	S	D	V	E	S	D	V	E	S	D	V	E	S	D	V
Archetype 1	0				1	3	3	9	1	1	1	1				
Archetype 2	1	2	2	4	1	2	2	2	1	3	2	6				
↓																

9.7 Establish Priorities for Further Action

Once the assessment is complete, the portfolio manager can prioritize the interactions into groups for further action. This should reflect the assessment objectives set at the beginning of the project.

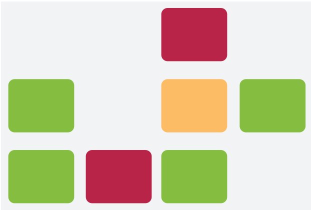
Vulnerability	Action
Low	No further action necessary at this time
Medium	Candidate for procedural response or monitoring
High	Candidate for more detailed assessment HLSG - Protocol - Other

For example, the portfolio manager may wish to take no further action on low vulnerability interactions.

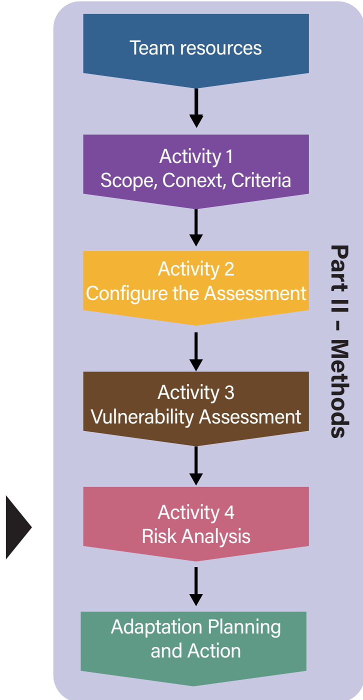
They may consider procedural responses to medium vulnerability interactions. Finally, they may opt for further action on high vulnerability interactions. Each project may have slightly different sorting outcomes, depending on the objectives.

Each archetype contains an inventory of assets that share common attributes. With this in mind, the actions set for each interaction may apply to the entire inventory in the archetype. Thus, even though the archetype was created by grouping assets, the portfolio manager can still identify which specific assets are vulnerable, likely requiring adaptive action.

10 Activity 4 - Conduct Optional Risk Analysis



Risk analysis is an optional step in the portfolio assessment process. With very large portfolios, infrastructure managers may find that the number of assets in the medium and high vulnerability categories is still very large. Thus, while vulnerability analysis can hone down the number of assets of concern, further sorting may be still necessary. In these cases risk analysis of relevant archetypes and indicators can further sort the portfolio down to a manageable number of assets.



Where the numbers of assets are not deemed to be unmanageable by the infrastructure owner, they may opt to bypass the optional risk analysis and move directly to more detailed climate risk assessment processes. These may include the *PIEVC Protocol*, the *PIEVC High Level Screening Guide*, or other climate risk assessment methods the owner deems appropriate.

10.1 What Risk Analysis Adds

Vulnerability analysis addresses the exposure, sensitivity, and adaptive capacity of the system. It does not consider the likelihood or consequences of hazards. It considers what happens if and when hazards occur. If they occur, sensitivity and adaptive capacity shows the impacts that may be expected.

Risk analysis asks if the predicted impacts are significant and how likely they are. This allows further sorting of the portfolio based on the owner's perception of impact, its significance, and likelihood.

The output further prioritizes of the portfolio assets that may have significant vulnerability.

10.2 Risk Analysis Calculations

Risk is a function of consequence and likelihood. It is expressed by the formula:

$R = C \times L$

Where:

R = Risk
C = Consequence (1, 2 or 3)
L = Likelihood (1, 2 or 3)

Likelihood → / Consequence ↓	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9

Risk	Score
Low	1 to 2
Medium	3 to 5
High	6 to 9

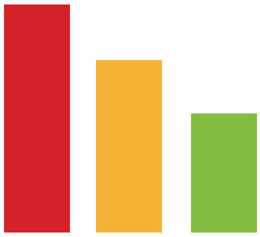
Using this formula, vulnerability scores may be calculated from the consequence and likelihood scores assigned by the team.

Risks are deemed to be low if they score between “1” and “2”. They are medium if they score between “3” and “5” and they are high if they score between “6” and “9”.

These rankings can then be used to further prioritize the archetypes in the portfolio.

10.3 Measure the Components of Risk

Consequence



Consequence is based on the sensitivity and adaptive deficit of an archetype when exposed to an climate hazard. If there is no exposure, there is no vulnerability and no consequence.

When a vulnerable archetype experiences a climate hazard, it experiences impacts based on how sensitive it is to the hazard and the adaptive capacity of the system.

Consequence is directly related to the sensitivity and capacity deficit of the system, as determined in the vulnerability analysis conducted above. However, consequence considers an additional factor, the risk appetite of the portfolio owner. Thus, consequence depends on both the physical attributes of the system (sensitivity, adaptive deficit) and of the owner's evaluation of the significance of the impacts.

Vulnerability analysis provides a gauge of how a system may respond to a hazard. It but does not contemplate the significance of those impacts on the organization. For example, a component could be highly vulnerable to a climate hazard, but failure of the component may not be significant to the organization.

In consequence analysis, the impact is evaluated based on vulnerability and significance.

The significance of the impact must be judged through perspectives of the portfolio owner.

Based on the vulnerability rankings worked out above, consequence may be determined once the owner establishes the significance of impacts. Significance is based on the owner's evaluation of acceptable and unacceptable outcomes, and may be determined from the answers to three questions.

1. What level of impact does the owner consider major?
2. What level of impact does the owner consider important but manageable?
3. What level of impact does the owner consider minor?

The owner may evaluate these questions through many lenses, based on their perspectives and the objectives of the portfolio assessment. These include:

- Financial
- Social
- Economic
- Environmental
- Health and safety
- Policy
- Strategy
- Other factors the owner believes to be relevant

The owner's responses to these questions define the level of impact they believe to be serious, significant, or minor. With this in hand, the significance of each impact may be classified through a consistent lens. This defines the significance scores on a scale of 1, 2 and 3.

Significance (S_i)	Score
Minor	1
Significant	2
Major	3

In a similar fashion, the vulnerability score for risk analysis may be input from the vulnerability analysis, conducted earlier.

Vulnerability (V)	Score
Low	1
Medium	2
High	3

Consequence can then be determined from the equation:

$$C = Si \times V$$

Where:

Si = Significance
V = Vulnerability

This will yield an overall consequence value from between 1 and 9. We can then establish the consequence score for the risk analysis from the following table.

Significance → / Vulnerability ↓	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9

Consequence	Score
Low	1 to 2
Medium	3 to 5
High	6 to 9

This approach maintains the three point scaling used in vulnerability analysis for similar reasons. The detail necessary for this level of analysis is best suited to broader categories that do not imply high levels of precision.

Likelihood

Likelihood (*L*) is determined using the scoring methods outlined in the table. This should be repeated for a baseline climate period and any future climate horizons selected. The table is based on the "*middle-baseline*" scoring method, developed for the *PIEVC High Level Screening Guide*. This approach is appropriate for the risk analysis necessary for portfolio sorting.

"*Middle-baseline*" scoring assigns likelihood to hazard indicators by establishing the baseline conditions in the historical period (e.g. 1981–2010). The mean conditions over this period are assigned a score of "*2*". For example, the climate hazard chosen is *Days with Maximum Temperature over 35 °C* and these have occurred 5 times per year. This would be represented in the baseline period by a" *2*" on the likelihood scale.

The scoring system allows for the scores to increase or decrease depending on the expected change from baseline frequency. For example, if *Days with Maximum Temperature over 35 ° C* increase in the future, the score for this future time horizon is "*3*". If the frequency is expected to decrease, the score for this future time horizon would be "*1*".

The "*middle-baseline*" scoring scenario is flexible and allows for interpretation by the Project team. It is also appropriate to use other scoring systems, with documentation and justification for the choice made by the project team.

Likelihood (L)	Middle Baseline	Score
Likely to occur less frequently than current climate	↑	1
Likely to occur on same frequency as current climate	Current Climate Baseline	2
Likely to occur more frequently than current climate	↓	3

10.4 Calculate Risk

The team will set up a spreadsheet and transfer descriptive information about the archetypes and indicators to the axes, as shown in the example below. This information may simply be descriptors, as in the example, or the team may decide to provide more detailed descriptions within the worksheet.

Once the archetypes and indicators are transferred, the risk analysis can start.

Archetypes	Climate Indicators											
	Indicator 1			Indicator 1			Indicator 1			→		
	C	L	R	C	L	R	C	S	R	C	L	R
Archetype 1				3	3	9	1	1	1			
Archetype 2	2	2	4	2	2	2	3	2	6			
↓												

10.5 Evaluate Risk Analysis Results

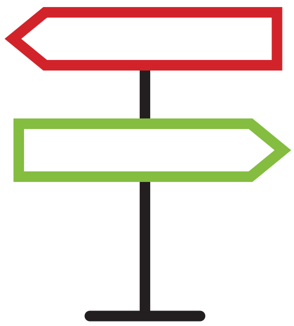
Once the risk analysis is complete, the portfolio manager can conduct additional prioritization of interactions into groups for further action. This should reflect the assessment objectives set at the beginning of the project.

The overall process sorts portfolios into three classes based on vulnerability, and an additional three based on risk. Generally, managers would use risk analysis for high vulnerability archetypes. This will further sort that group into three categories; high, medium, and low risk. This sorts the portfolio into manageable groups prior to taking action.

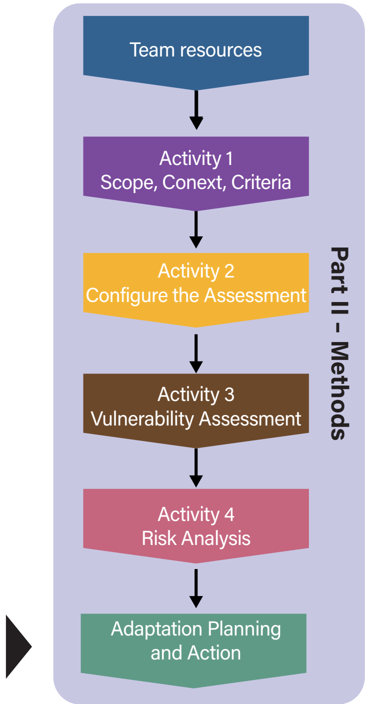
Risk	Action
Low	Candidate for long-term response or monitoring
Medium	Candidate for medium-term response or monitoring
High	Candidate for immediate detailed assessment HLSG - Protocol - Other

11 Adaptation Planning and Action

11.1 Priority Based Action



The portfolio manager has several options for addressing the high priority interactions, depending on their objectives. In this way, the sorting conducted using the vulnerability assessment and risk analysis provides for priority-based action. Action on low or even medium priority interactions may be deferred. Resources can be allocated first to high priority items.



The portfolio manager may opt to pass these items forward into a more detailed risk assessment. PIEVC offers two tools for these sorts of assessments. For additional screening, portfolio managers may apply the *High Level Screening Guide*. If they wish to have a much more detailed view of the risk, they may choose to go to a *PIEVC Protocol* assessment, which offers the opportunity for a deeper analysis of risk.

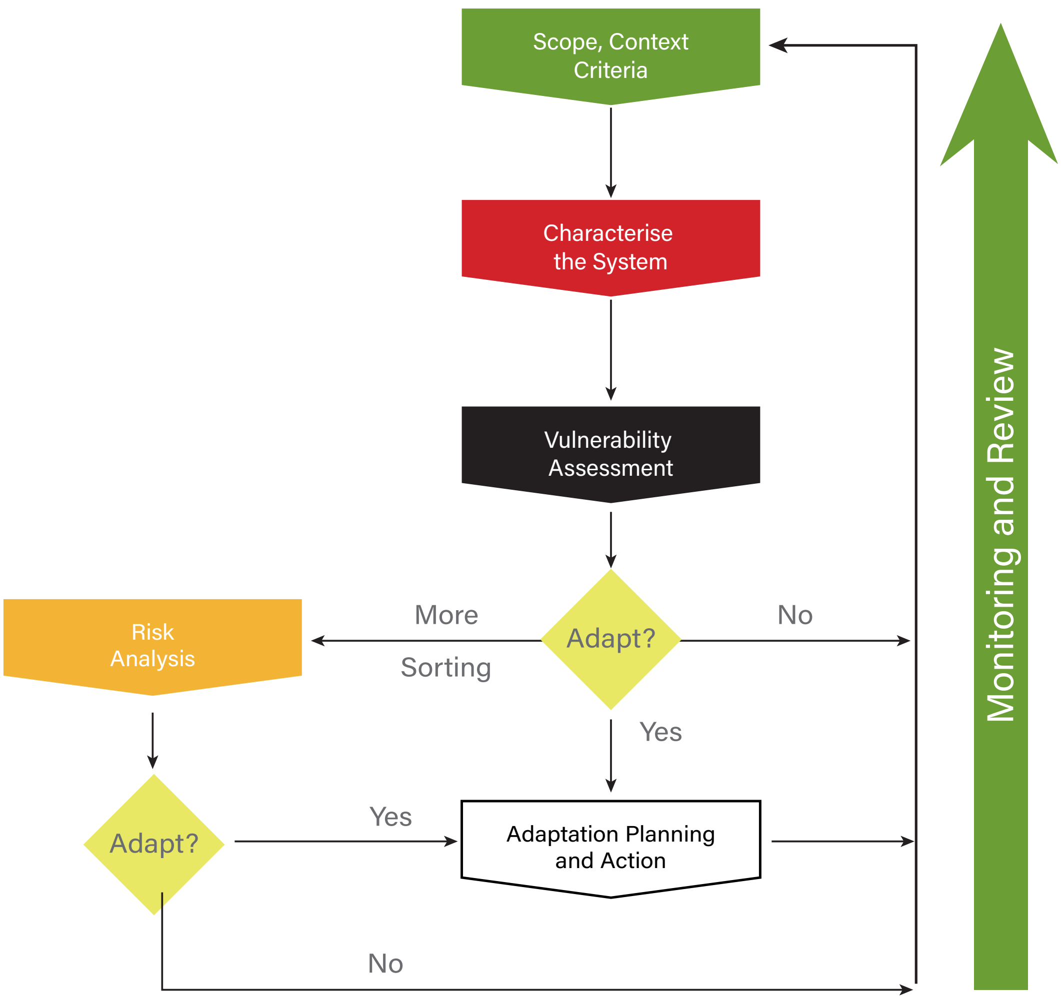
There are many other tools now available to assess risk that might also be used at this stage of the exercise. These range from proxy analysis methods, such as *PIEVC Protocol*, to far more detailed, numerically intense approaches. These are all viable options that depend on the objectives of the portfolio manager.

Sometimes, the portfolio manager may wish to take immediate action. In these cases, they may bypass further risk analysis and forward the issue, and supporting documentation to other professionals. These could include engineering teams, asset managers, modelers and others, depending on the vulnerability.

Vulnerability and risk assessment is one part of a greater process to adapt to climate change. Assessment informs adaptation planning and action. The work is executed with this objective. The process does not necessarily identify robust adaptation measures, but it does identify where those measures are necessary. Information from the vulnerability assessment can kick- start these activities when transferred to other professionals.

11.2 An Iterative Process

Vulnerability and risk assessment forms one part of a cycle of climate analysis and assessment. An entity will establish the scope, context, and criteria for an initial assessment. Once the assessment is complete, they will decide how to manage the significant vulnerabilities. In *ISO 31000* this is deemed to be *Risk Identification*. The entity may opt to move forward to *Risk Assessment*, as described above. Or, they may take alternative actions, depending on their objectives and asset prioritization from the vulnerability assessment. At this stage, the cycle enters a *monitoring and review* phase. The entity will monitor how well adaptation addressed the issues identified in the assessment. Information gathered from the monitoring is used to establish the scope, context, and criteria for the next round.



Annex

Additional background information to help you do your assessment.

1 Glossary

Vocabulary	Definition
Adaptation	Process of adjustment to actual or expected climate and its effects. • In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. • In some natural systems, human intervention can facilitate adjustment to expected climate and its effects.
Adaptive Capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Climate Hazard	Specific impactful event as related to the broader climate parameter category.
Climate Hazard Indicator	Specific climate values (TMax > 35C; Precip > 100mm; Freezing Rain > 30 mm, etc.) that are defined by their ability to impact an infrastructure system or component (i.e., exceed a threshold).
Climate Parameter	Broader categories of measurable climate conditions in relation to which specific climate hazards or indicators can be defined. Climate parameters include temperature, precipitation, sea-level rise, wind, etc.
Components	Physical elements or features of a composite system.
Consequence	Outcome of an event affecting objectives. • An event can lead to a range of consequences. • A consequence can be certain or uncertain and can have positive or negative effects on objectives • Consequences can be expressed qualitatively or quantitatively.
Decision-Maker	The person or group of individuals who is responsible for making strategically important decisions based on a number of variables, including time constraints, resources available, the amount and type of information available and the number of stakeholders involved.
Element	A distinct part of a composite system. Could include physical, planning or human resources.
Engineering Vulnerability	The shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure.
Enterprise Risk Management	The culture, capabilities, and practices, integrated with strategy-setting and its performance, that organizations rely on to manage risk in creating, preserving, and realizing value.
Likelihood	Chance of something happening. • In risk management terminology, the word "likelihood" is used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically. • The English term "likelihood" does not have a direct equivalent in some languages; instead, the equivalent of the term "probability" is often used. However, in English, "probability" is often narrowly interpreted as a mathematical term. Therefore, in risk management terminology, "likelihood" is used with the intent that it should have the same broad interpretation as the term "probability" has in many languages other than English.
Probability	Measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty.
Public Risk	The possibility that human actions, or events lead to consequences that harm aspects that humans value.
Residual Risk	Risk remaining after risk treatment • Residual risk can contain unidentified risk. • Residual risk can also be known as "retained risk".

Vocabulary	Definition
Resilience	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.
Risk	Effect of uncertainty • An effect is a deviation from the expected. It can be positive, negative or both. • An effect can arise as a result of a response, or failure to respond, to an opportunity or threat related to objectives. • Uncertainty is the state, even partial, of deficiency of information retaliated to, understanding, or knowledge of, an event, its consequence, or likelihood.
Risk Appetite	Amount and type of risk that an organization is willing to pursue or retain.
Risk Owner	Person or entity with the accountability and authority to manage a risk.
Risk Profile	Description of any set of risks • The set of risks can contain those that relate to the whole organization, part of the organization, or as otherwise defined.
Risk Tolerance	Organization's or stakeholder's readiness to bear the risk after risk treatment in order to achieve its objectives. • Risk tolerance can be influenced by legal or regulatory requirements.
Risk Treatment	Process to modify risk 1. Risk treatment can involve: • Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk; • Taking or increasing risk in order to pursue an opportunity; • Removing the risk source • Changing the likelihood • Changing the consequences • Sharing the risk with another party or parties [including contracts and risk financing; and • Retaining the risk by informed decision. 2. Risk treatments that deal with negative consequences are sometimes referred to as "risk mitigation", "risk elimination", "risk prevention" and "risk reduction". 3. Risk treatment can create new risks or modify existing risks.
Threshold	Point beyond which a system is deemed to be no longer effective: • Economically; • Socially; • Technologically; or • Environmentally. Also known as tipping point.
Triple Bottom Line (TBL)	A business concept that states organizations should commit to measuring their social and environmental impact—in addition to their financial performance—rather than solely focusing on generating profit, or the standard "bottom line." It can be broken down into "three Ps": profit, people, and the planet.
Vulnerability	Propensity or predisposition to be adversely affected Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

2 References

- PIEVC© FAMILY OF RESOURCES
  - *Catalogue - A Guide for Selecting Climate Risk Assessment Methods, Data, and Supporting Materials*
  - *PIEVC Scoping and Data Collection Tool (SDCT)*
  - *PIEVC Protocol*
  - *PIEVC High Level Screening Guide*

- ISO 31000 series of standards
  - *ISO 31000 - Risk Management - Guidelines*
  - *ISO 31010 - Risk Management - Risk Assessment Techniques*
  - *ISO Guide 73 - Risk Management - Vocabulary*

- ISO 14090 series of standards
  - *ISO 14090 - Adaptation to Climate Change - Principles, Requirements, and Guidelines*
  - *ISO 14091 - Adaptation to Climate Change - Risk Assessment Techniques*
  - *ISO 14092 - Risk Management - Requirements and Guidance on Adaptation Planning for Local Governments and Communities*

- Completed PIEVC assessments (Brazil, Canada, Costa Rica, Nile Basin, Vietnam)

3 Aligning with International Standards

ISO 31000

ISO 31000 lays out a comprehensive risk management process. Only one key part of the process involves vulnerability assessment. *ISO 31010* provides additional guidance on the various risk assessment methods that are best suited to the ISO risk management process.

Climate change poses a special case that users must blend into the wide range of risks they already manage.

PIEVC does not provide guidance on the Principles and Framework pieces of ISO.

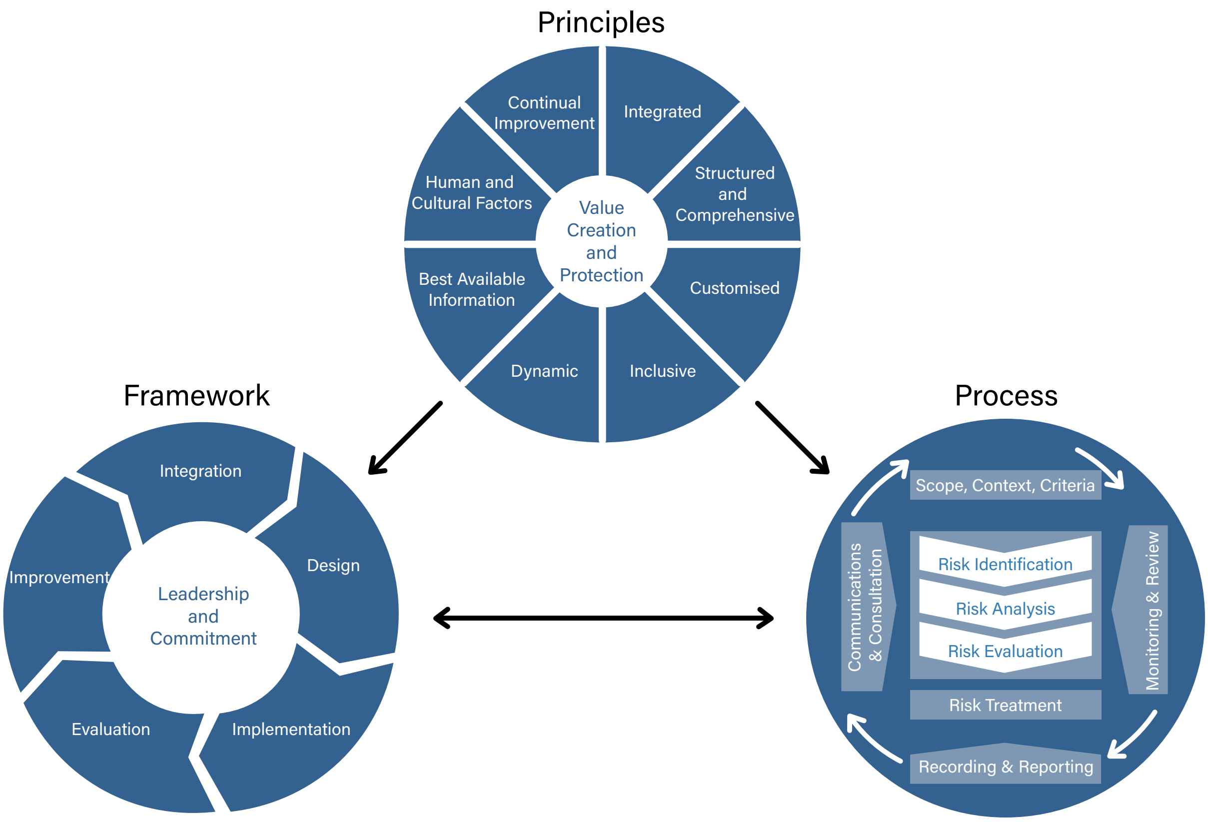
It picks up at the *Scope, Context, Criteria* stage of the risk management system. PIEVC sets objectives based on the risk management principles of the host organization. The vulnerability assessment must align with this foundational work. Hence, this guide emphasizes consultation to ensure that there is a good agreement between the assessment and risk management system. The process will not yield enough detail to support immediate risk treatment, but allows decision-makers to set priorities for adaptation action.

ISO 31010

ISO 31010 describes a range of methods to improve the way uncertainty is considered and to help understand risk. The techniques may be used to:

- Better understand what risk exists or characterize a particular risk
- Compare or optimize a range of options involving risk
- Support a risk management process aimed to identify risk treatment options

ISO 31010 offers a summary of methods and compares their uses, benefits, and limitations. It also provides references to more detailed information. The techniques can be used in a wide range of settings. Users may apply the techniques within the risk assessment steps of *ISO 31000*, and generally whenever they need to better understand uncertainty.



4 ISO Risk Analysis Methods

Failure Mode and Effects Analysis

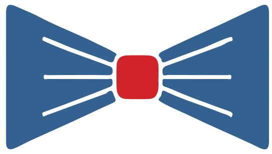
In FMEA, a team divides the system into its key elements. The team then evaluates how each element might fail; the causes and effects. The team documents their work by category.

When passed through a climate lens, FMEA categories align with climate vulnerability assessment techniques, as follows.

- Function
  - *Sensitivity* or criticality of the systems
- The mechanisms that could produce the failure
  - Climate
  - Sensitivity
- The failure that might occur
  - Event
- If the failure is harmless or damaging
  - Adaptive capacity
- How and when the failure can be detected
- The conditions that exist to compensate for the failure
  - Adaptive capacity
- The impacts of the failure
  - Impact
  - Adaptive capacity

FMEA provides the structure used for Bowtie Analysis, summarized in the next section. It outlines the points needed to set up impact and response chains. This guides the infrastructure response analysis and sets the basis for the portfolio vulnerability and risk evaluation described in this manual. These are core concepts. They track to ISO risk approaches.

Bowtie Analysis



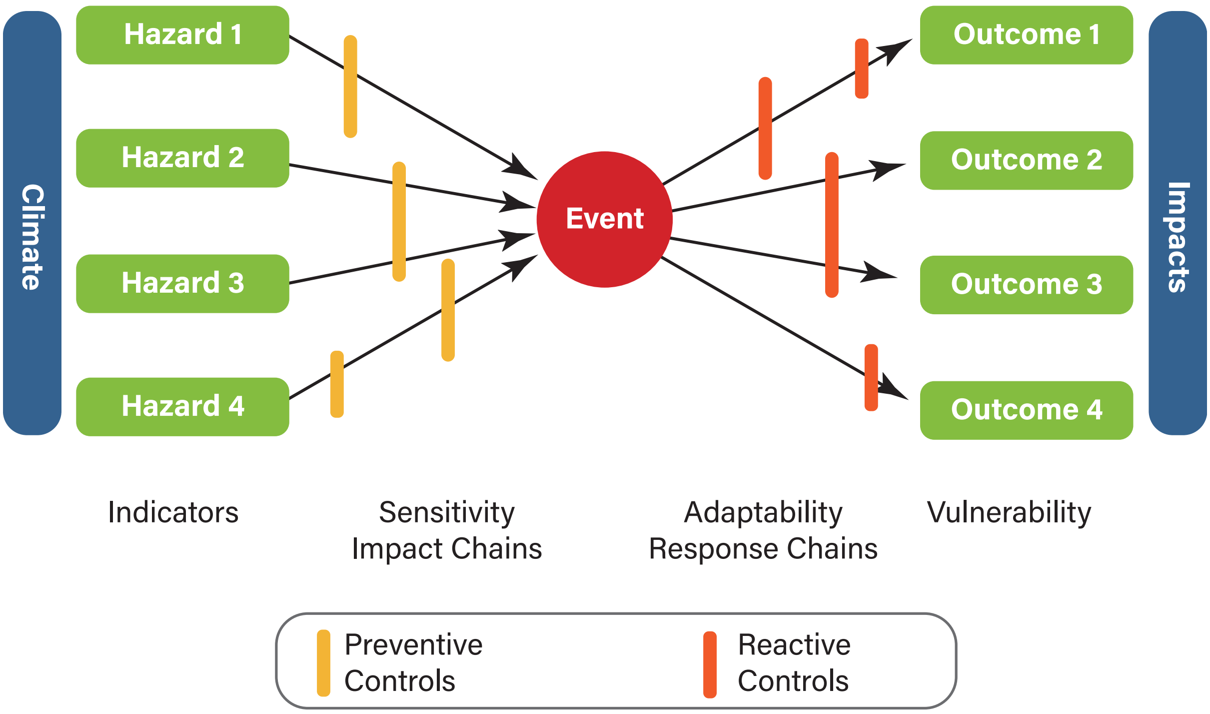
A bow tie is a graphical depiction of pathways from the causes of an event to its impacts. It shows the controls that modify the event and those that modify the impacts.

In Bowtie analysis:

- The event of interest is represented by the central knot of the bow tie.
- Sources of risk are listed on the left side of the knot and joined to the knot by lines representing mechanisms that can lead to the event.
- Barriers or controls for each mechanism are shown as vertical bars across the lines. These are often called “Preventative Controls”.
- Lines radiate out the right side of the knot to each potential consequence
- After the event, vertical bars represent controls or barriers that modify the consequences. These are often called “Reactive Controls”.

The following figure shows how Bowtie analysis is used in a climate risk scenario.

5 Climate Vulnerability Bowtie Analysis



Bowtie Analysis in Climate Vulnerability and Risk

Bowtie analysis spells out the steps of impact and response chain analysis. *ISO 14091* outlines this as a method to assess climate vulnerability and risk. Impact and response chains are conceptual models that describe cause-effect relationships in a system.

Bowtie analysis offers a way to visualize impact and response chains. It is an *ISO* standard technique that illustrates a way of thinking about the links in the chain that lead to a consequence. It also allows us to identify where preventive and reactive measures ease consequence. This ensures that these factors are considered in the analyses.

Bowtie analysis presumes that the system is exposed to climate hazards. If there is no exposure, there is no impact chain and no impact - response chains to consider.

Bowtie analysis is used throughout this manual to focus on the effects of climate hazards on a system. These concepts align with guidance offered by *ISO 31010* and *ISO 14091*.

6 Choosing the Correct PIEVC Resource

Activity	Process	Level of Detail	Approach	Data Needs – Assets	Data Needs – Climate
Portfolio asset prioritization and sorting	**Large Portfolio Assessment Manual**	Low to Medium	Vulnerability & Risk Analysis	Main asset components Archetypes	Climate hazard indices, and statistics by region.
Screening	**PIEVC High Level Screening Guide**	Medium	Risk Analysis	Asset components Elements Sub Elements	Climate hazard indices, and statistics by region.
Comprehensive Analysis	**PIEVC Protocol**	High	Risk Assessment	Asset components Elements Sub Elements	Climate hazard indices by element, and statistics by region.

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