Principles of Risk Assessment and Overview of the **PIEVC Protocol**

Resilient Infrastructure in a Changing Climate

Prince George, BC

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Guiding Principles

- The climate is changing
- Climate change threatens the ability of engineers to safely and effectively design resilient infrastructure to meet the needs of Canadians
  - Design, operation and maintenance practices must adapt
  - Growing liability concerns for profession
- Updated and improved codes, standards and practices needed
- Climate change engineering vulnerability assessment contributes to adaptation process

Context

Fundamentals of Engineering Vulnerability Assessment

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Engineering Vulnerability

- In the Protocol, vulnerability is defined as:

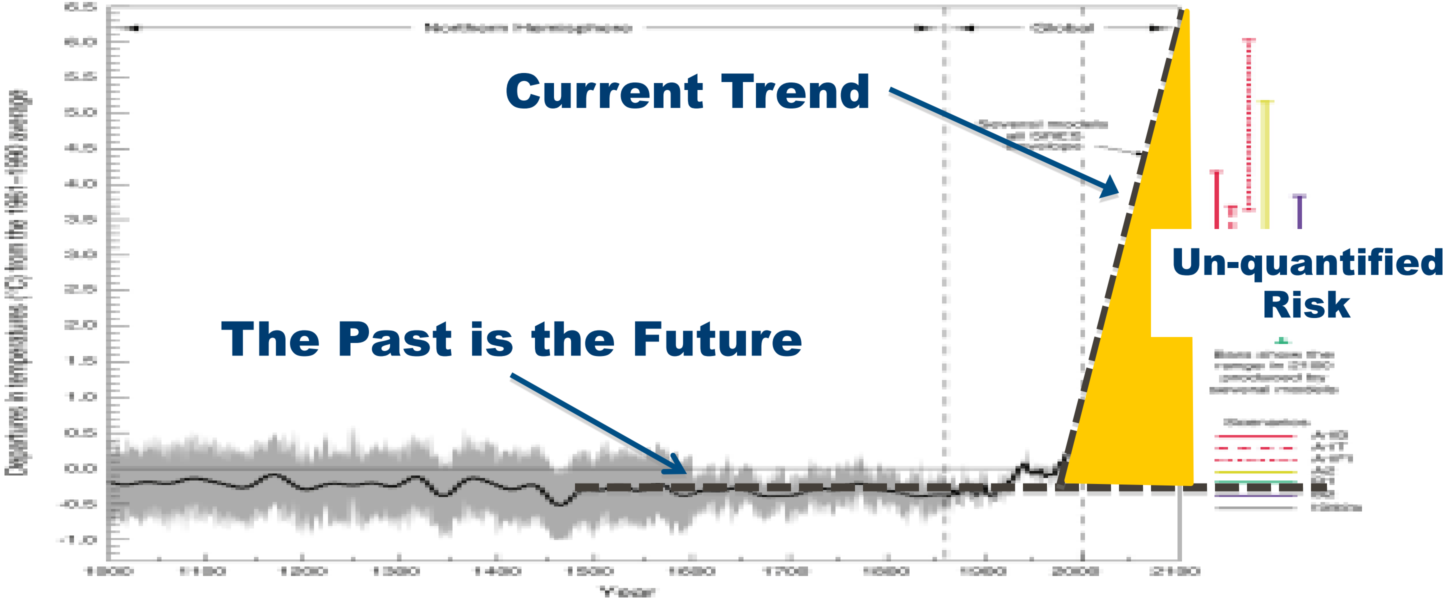
  “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.”

Vulnerability Assessment Parameters

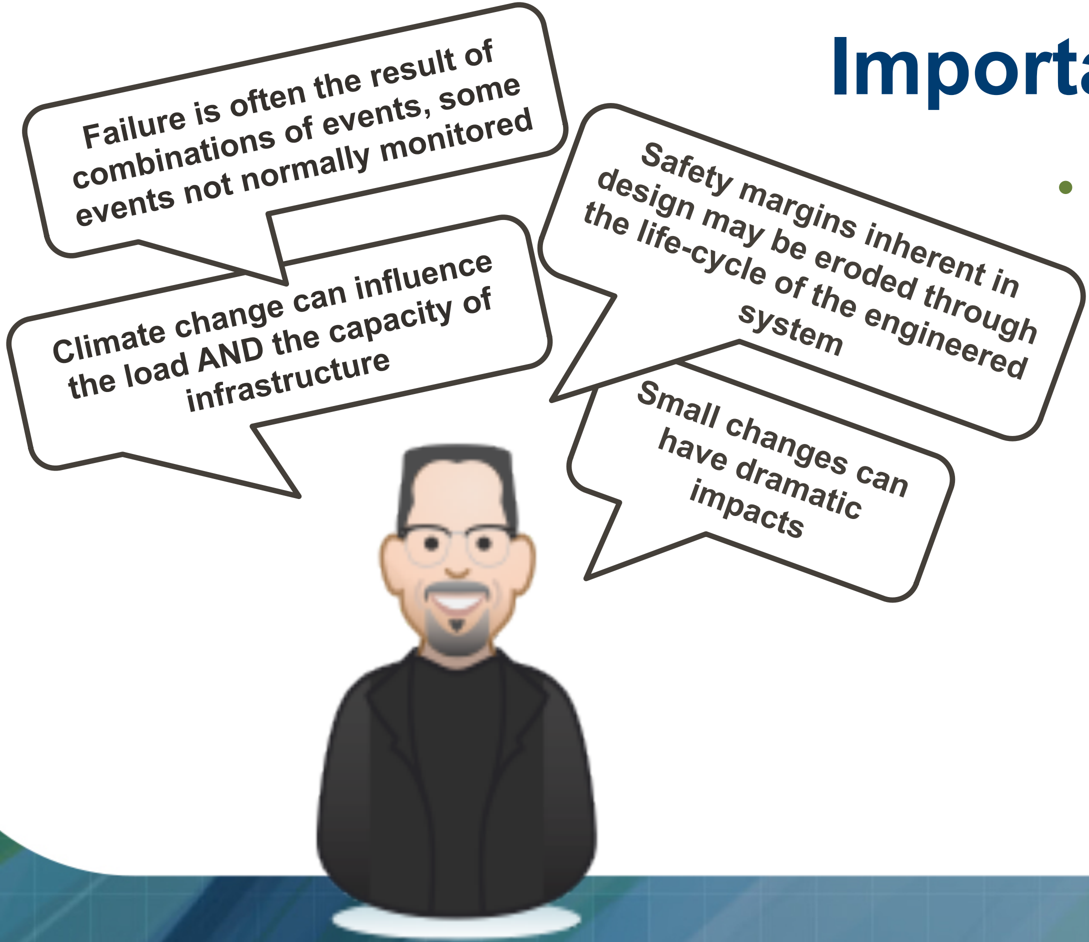
- Climatic conditions:
  - Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed (over its life cycle)
- Sensitivities of the infrastructure:
  - What is the condition of the infrastructure?
  - How sensitive is the infrastructure to climatic changes?
- Built-in capacity of the infrastructure:
  - What level of built-in capacity of infrastructure exists to absorb net consequences from changing climatic conditions?

From an Engineering Design Perspective

- Past climate is not a good predictor of the future



Important Considerations



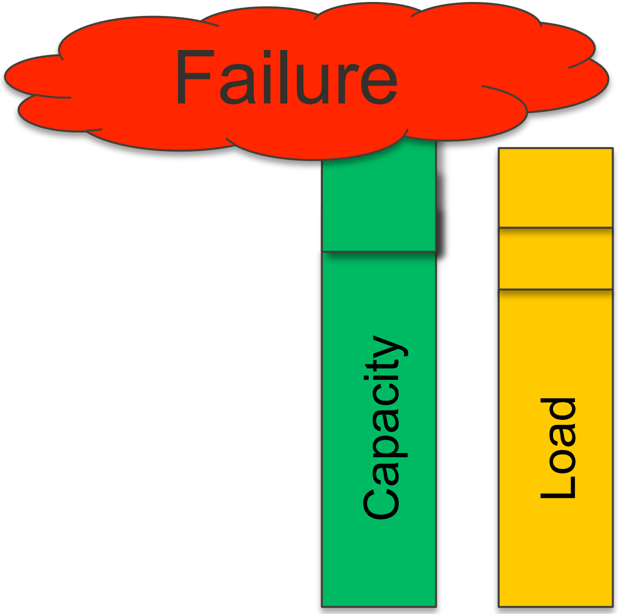
- Some adaptations to mitigate risk can be quite minor but important to know where your vulnerabilities lie:
  - Sometimes just change in maintenance or procedures
  - Sometimes additional monitoring for critical triggers (storm flows, stream flows)

Small Increases Lead to Escalating Infrastructure Damage

A 25% increase in peak wind gusts results in a 650% increase in building damage

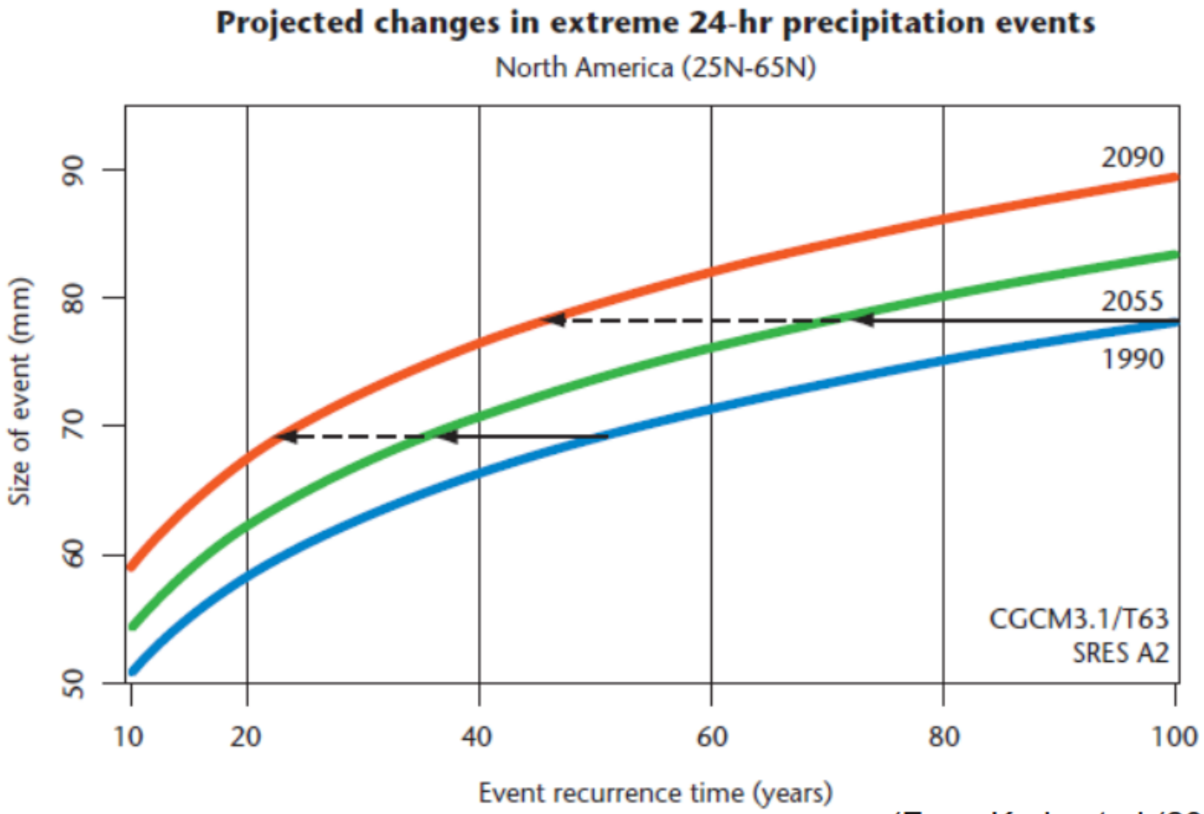
Small increases in weather and climate extremes have the potential to bring large increases in damages to existing infrastructure..

How do Small Changes Lead to Catastrophic Failure?



- Design Capacity
- Safety Factor
- Impact of age on structure
- Impact of unforeseen weathering

- Design Load
- Change of use over time
  - e.g. population growth
- Severe climate event

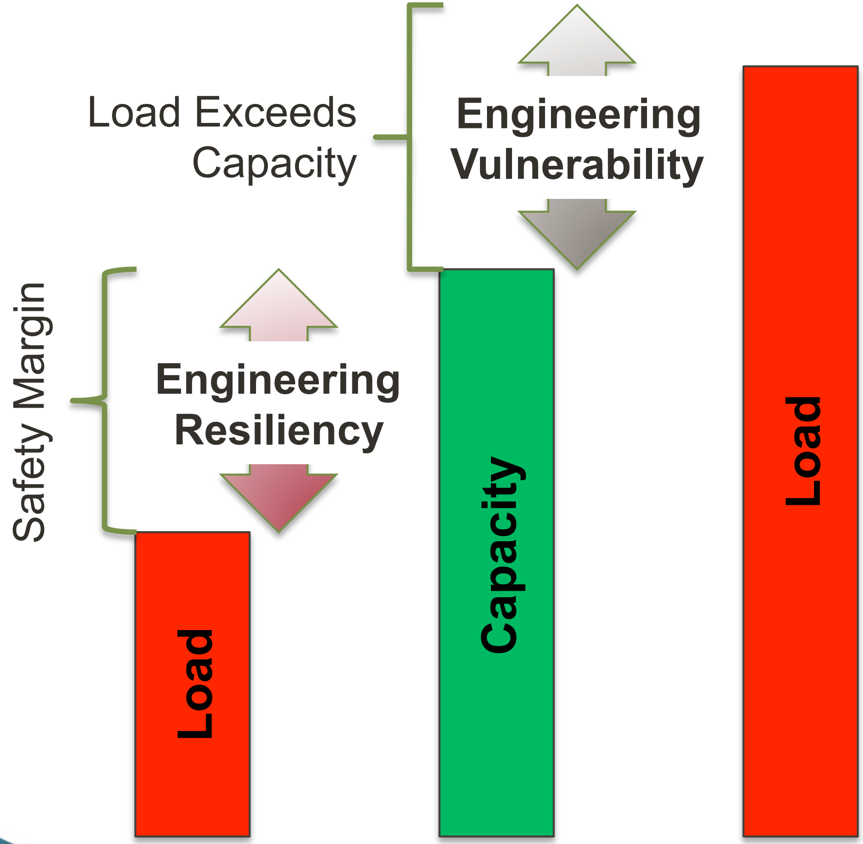


(From Karin et al (2007))

Projected changes in extreme 24-hour precipitation amounts and return periods for mid to late 21st century compared to 1990 values (SRES A2)

Summary of Important Observations

- A small change can have a dramatic impact
- Design safety margins may not last through the full operational life of an infrastructure system
  - Margins may be consumed by day-to-day uses/activities
- Failure often arises from a combination of events
  - Many of which we do not normally monitor
- Climate change can affect both the load and capacity of a structure
- Smaller measures can mitigate risk if we act early
  - Changes in maintenance practice
  - Measuring and monitoring



Definitions

Resiliency

- If a safety margin between forecast capacity and forecast load is predicted, then this identifies potential for future non-failure condition

Vulnerability

- If a gap between forecast capacity and forecast load is predicted, a potential future failure condition exists

Additional Comments on Vulnerability

- A vulnerability assessment is predictive
- Contemplating POTENTIAL failure modes based on forecast information – how much confidence in the prediction?

- To effectively address the issue, need to conduct assessment of:
  - Likelihood of event
  - Level of service disruption
- Vulnerability assessment required for risk management

How to Assess Vulnerability/Resiliency

- One tool: the PIEVC Engineering Vulnerability Protocol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PIEVC Engineering Protocol

For

Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate

PRINCIPLES and GUIDELINES

Revision PG-10

May 2012

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- The PIEVC Protocol leads practitioners through a formal, documented process to identify vulnerabilities and resiliency
- Applies standard risk assessment processes to climate change concerns

Defining the Risk

In the PIEVC Protocol, Risk (R) is defined as the product:

$$R = P \times S$$

Where:

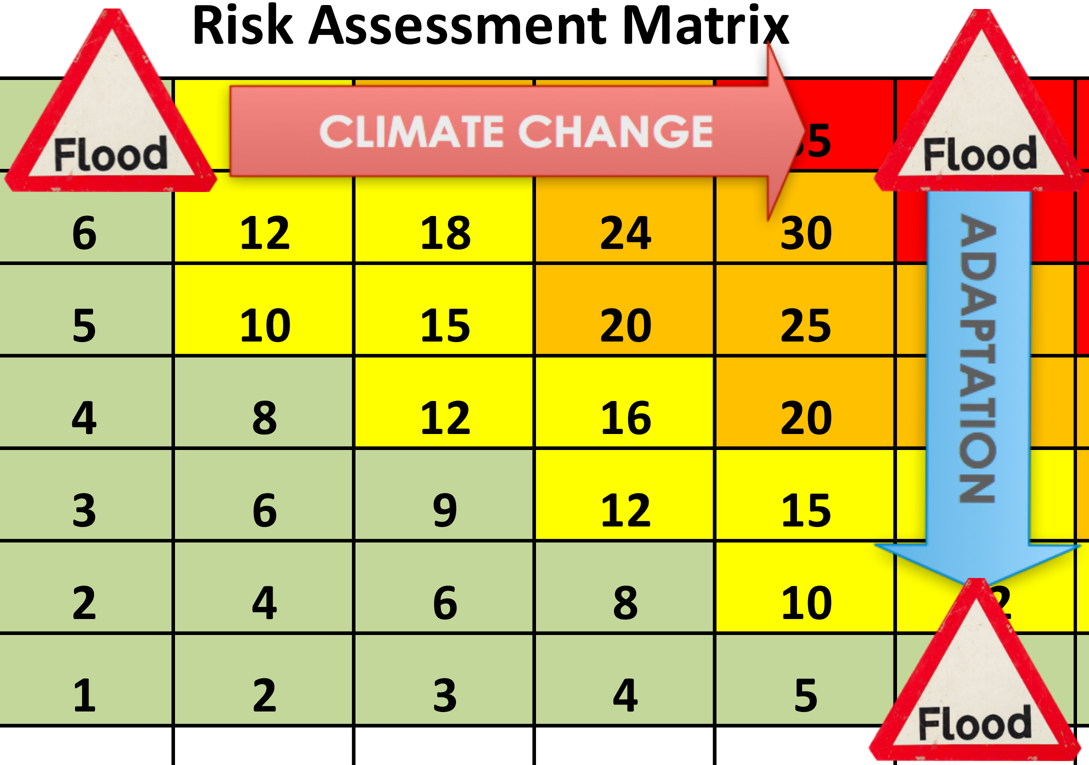
P is the probability [rating] of an event occurring

S is the severity of the impacts of the event on the [performance of the] infrastructure, should this event occur

Risk Assessment Matrix

Consequence	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
	6	6	12	18	24	30	[illegible]	42
	5	5	10	15	20	25	[illegible]	35
	4	4	8	12	16	20	[illegible]	28
	3	3	6	9	12	15	[illegible]	21
	2	2	4	6	8	10	[illegible]	14
	1	1	2	3	4	5	[illegible]	7
		1	2	3	4	5	6	7

Probability of Occurrence



Comments on Risk

- Since risk is the combined effect of probability and severity <u>both</u> elements must be considered
  - Very low likelihood and high severity can still be a serious risk
  - Very high likelihood and low severity may be a very low risk
- Most people have an intuitive understanding of risk but need guidance to sort out and assess the relative significance of:
  - Likelihood
  - Severity
- The protocol guides practitioners through the process of assessing both probability and severity in a structured and rigorous manner

PIEVC Engineering Protocol

www.PIEVC.ca

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The PIEVC Engineering Protocol

- A tool derived from standard risk management methodologies tailored to climate change vulnerability
- Five step evaluation process
- Data quality and availability assessed throughout
- Applied to vulnerability assessment of multiple infrastructure case studies across Canada
- The protocol is a useful tool in the hands of a qualified professional

When Data and Resources are Limited

- Not every application of the Protocol has all an ideal set of resources
  - Data
  - Computer models
  - Technical expertise
- This need not deter infrastructure owners from completing an assessment
- The Protocol identifies which questions to ask
  - Does not dictate the method that practitioners “should” use to answer those questions

Resources are Always Limited

- There are usually gaps
- Models may not cover the region being assessed
- Meteorological data may not have been collected
- Operational records may not exist
- Staff turnover
  - Experience gap
  - Corporate memory lapse

Filing the Gaps

- Engineering Vulnerability Assessment is a multidisciplinary activity
  - Team structure is a critical element of filling the gaps
- Must have:
  - Expertise in risk/vulnerability assessment
  - Directly relevant engineering knowledge of the infrastructure
  - Climatic and meteorological expertise relevant to the region
  - Operational experience
  - Hands-on management knowledge of the infrastructure
  - Local knowledge

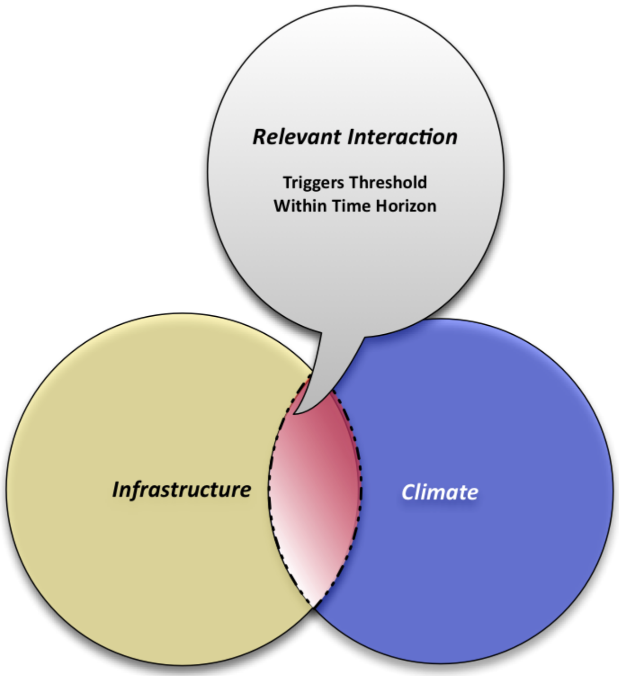
Importance of Local Knowledge

Local knowledge, filtered through the expertise of the assessment team, can often compensate for data gaps and provide a basis for professional judgment of the vulnerability of the infrastructure.

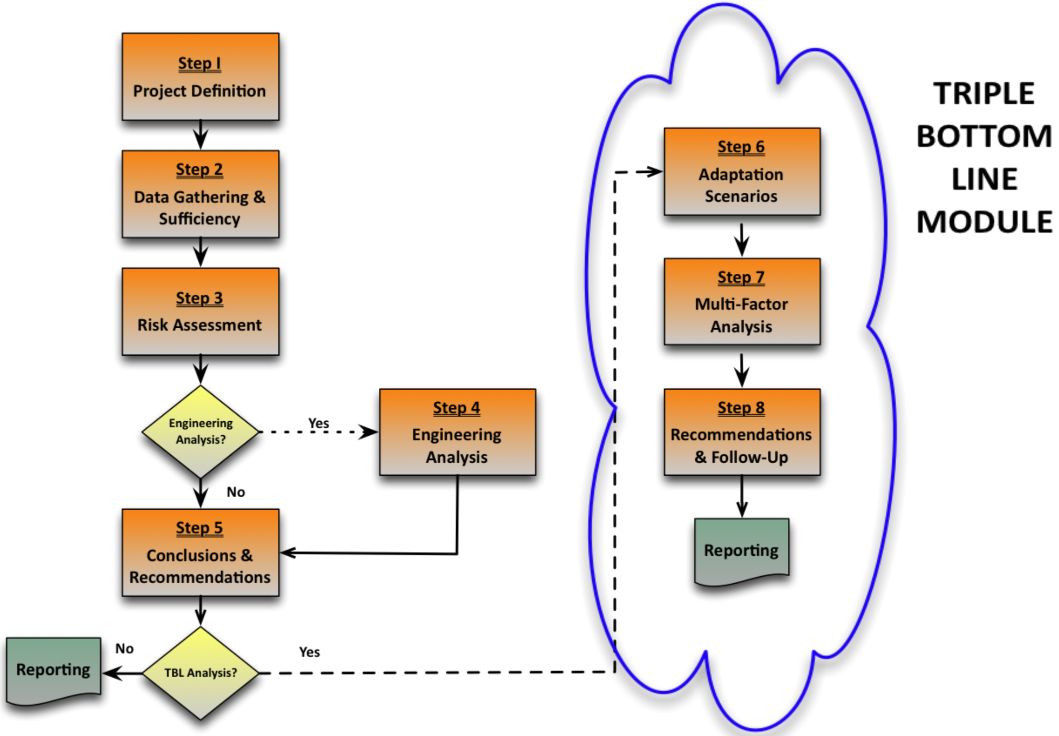
Source: Palm Beach Post

PIEVC Protocol Principles

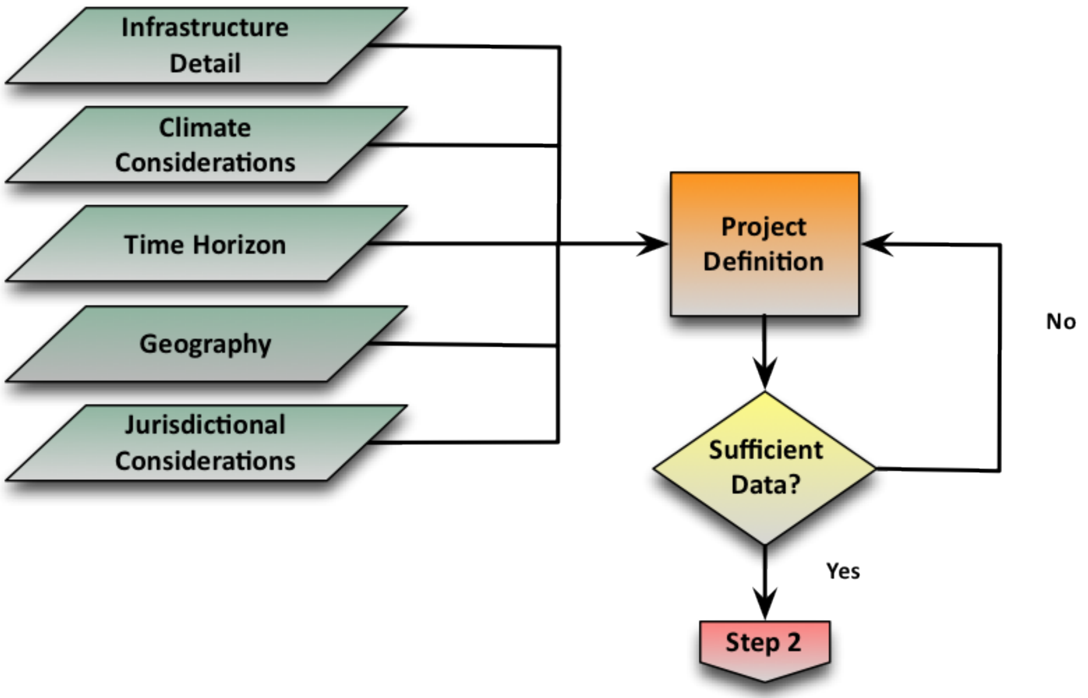
- The PIEVC Protocol is a step by step process to assess impacts of climate change on infrastructure
- Goal:
  - Assist infrastructure owners and operators to effectively incorporate climate change adaptation into design, development and decision-making



PIEVC: 5 Key Steps + Optional TBL Module



Step 1: Define Baseline Parameters



Example: Infrastructure Ontario Buildings

- Assessment of existing infrastructure vulnerability (2012)
  - Southern Ontario climate
  - Application of PIEVC Protocol to 3 institutional buildings
- Design criteria for future adaptation
  - Asset level → re-engineering, retrofit/renewal, or retirement
  - Organizational level → policy development, management actions
  - Regulatory level → codes & standards development, and/or updating
- Verification of adaptive capacity
  - Linkage to building durability

IO Candidate Properties for PIEVC

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Owner Perspective – Infrastructure Ontario

St Catharines
1998 – 330K SF

Brantford
1850 - 45K SF

London
1982 -16K SF

Source: Golder Associates, *Climate Change Vulnerability Assessment for Infrastructure Ontario, Case Study* Report to Infrastructure Ontario, June 2012 (access at www.PIEVC.ca)

IO Building #1: Garden City Tower

- 301 St. Paul St, St. Catharines, ON
- 11 floor office tower
- Office space for government operations including Ministry of Transportation Headquarters
- Bus terminal included as part of structure
- Achieved BOMA BEST Level 3 certification in 2008

IO Building #2: Brantford Courthouse

- 105 Market Street & 50-70 Wellington Street, Brantford, ON
- Various additions including the construction of a land registry office in 1919
- Recently underwent heritage restorations in 2006
- Building is considered a significant historical building and continues to operate as a courthouse, jail and land registry office

IO Building #3: Police Facility

- 6355 Westminster Drive in London, Ontario
- 16 acres of land with several buildings including the OPP Headquarters Building as well as garage and salt storage buildings (not considered in this study)

Building Components Considered

- Major infrastructure categories:
  - Building envelope & structure
  - Mechanical systems
  - Electrical systems
  - Exterior landscaping & walkways
  - Stormwater & wastewater

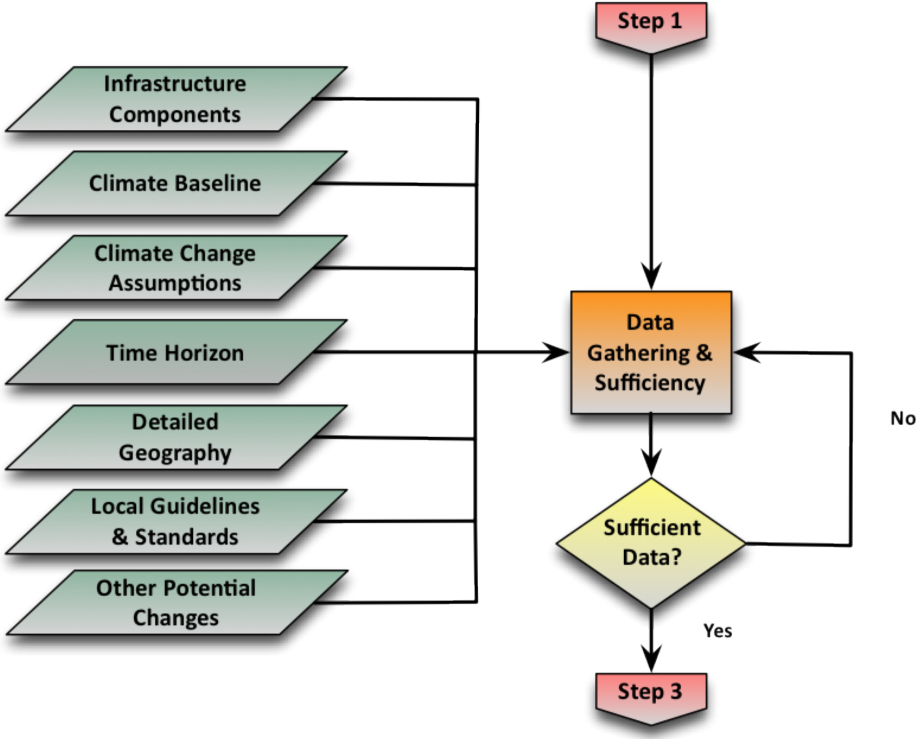
Example of Overall Climate Trends

Event Category	Climate Parameter	Trends
Drought	Frequency of Drought	No Trends
Freeze-Thaw	Freeze-Thaw Cycles	Slight increase based increasing winter precipitation and average temperatures
Humidity	High Humidity Periods	Slight increase based on increasing precipitation from analysis of all models, and increase in temperatures.
Rain	Frequency of Rainfall	Trend is unclear due to unknown distribution of rain events in future projections
	Heavy Rain	Slight increase based on higher rainfall volume in the summer season
	Total Rainfall	Increase of ~50 mm annually above historic baseline
	Freezing Rain	Slight increase in temperature will create a vertical temperature profile that is conducive to freezing rain events

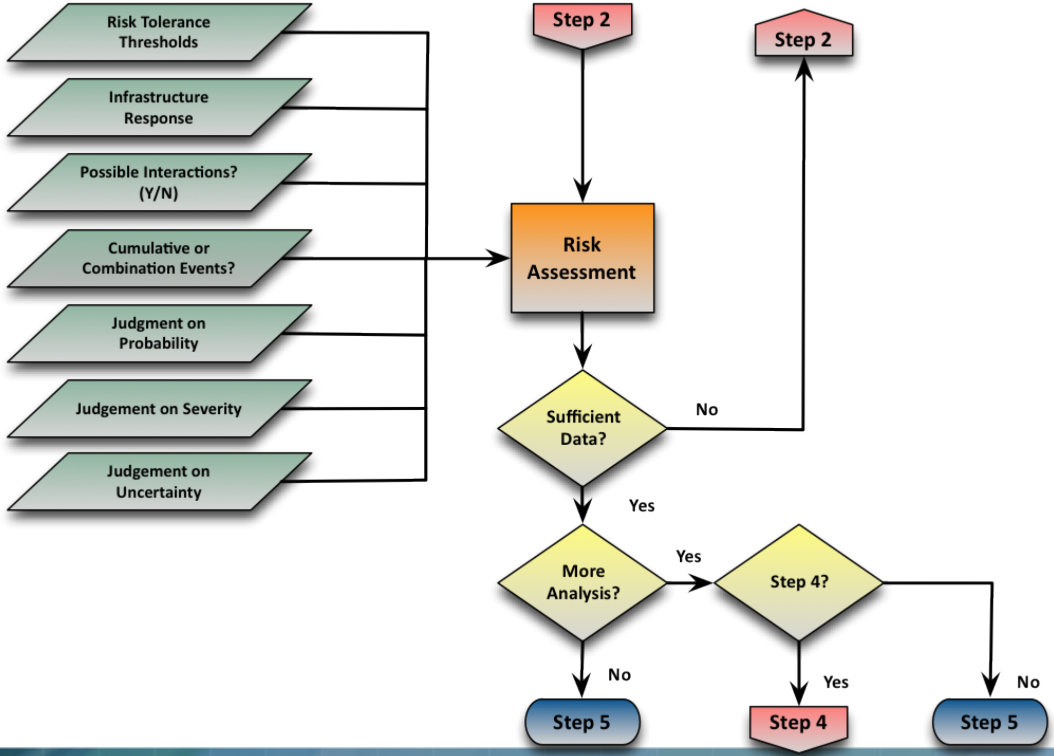
Performance Considerations

- Structural integrity
- Functionality
- Operations & maintenance
- Emergency response
- Policies & procedures
- Tenant comfort
- Insurance considerations
- Health & safety
- Environmental effects

Step 2: Gather Data



Step 3: Risk Assessment



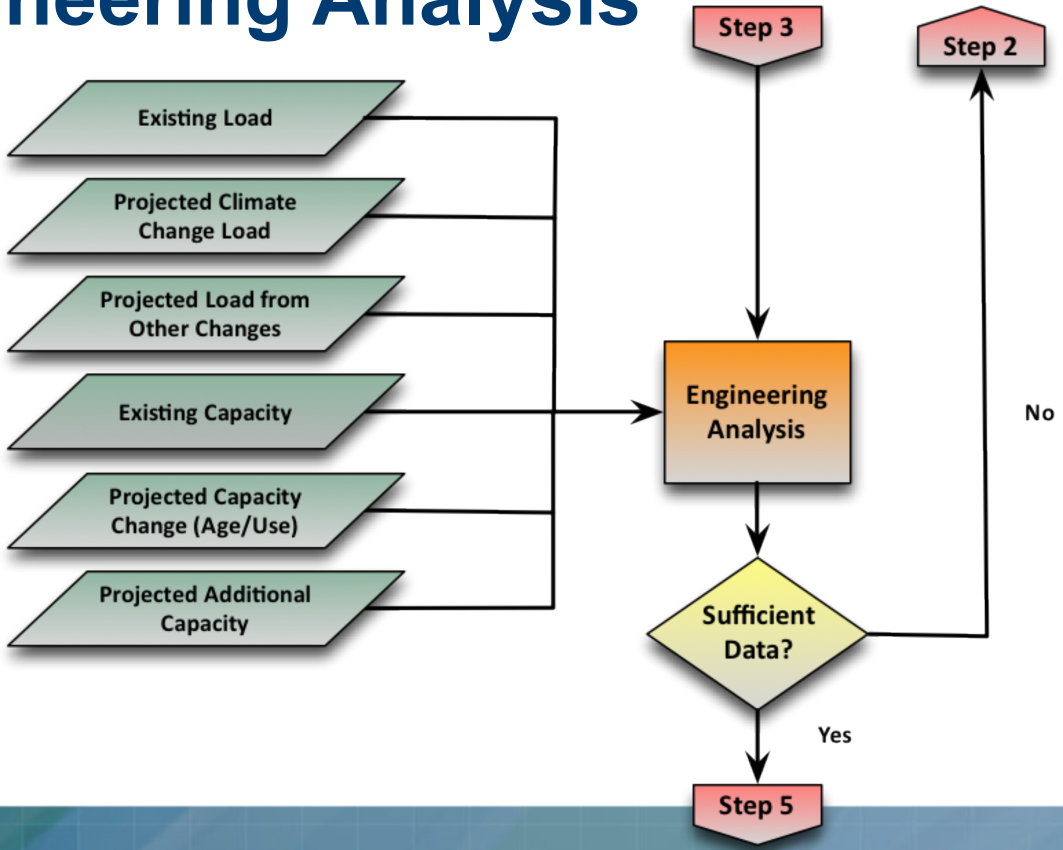
Infrastructure Ontario (2012 Study) - Brantford Site – Example of Interactions

Infrastructure Component	Climate Factors						
	Freeze-thaw	Humidity	Rain	Snow	Sun	Temperature	Wind
	Slight increase based on increasing winter precipitation and average temperatures	Slight increase based on increasing precipitation from analysis of all models, and increase in winter temperatures.	Increase annual rainfall of ~50 mm Slight increase in frequency of heavy rain, and freezing rain, and rain on snow events	Trends Unclear	Trends Unclear	Average temperature rise of 2.5 degrees Increase in extreme heat and cooling degree days Decrease in extreme cold and heating degree days	Slight decrease in wind speed on average, however summertime events have the potential for gustier conditions due to increase in atmospheric energy for thunderstorm events
Infrastructure System	**Y/N**	**Y/N**	**Y/N**	**Y/N**	**Y/N**	**Y/N**	**Y/N**
Cladding & Insulation	Y		Y	Y	Y		Y
Glazing			Y		Y	Y	Y
Water & Wastewater Systems			Y	Y		Y	
Structural Elements		Y	Y	Y		Y	Y
HVAC System		Y	Y	Y	Y	Y	Y
Roof			Y	Y	Y		Y
Exterior Elements	Y		Y	Y		Y	Y
Electrical Systems						Y	
Supporting Infrastructure	Y		Y	Y		Y	

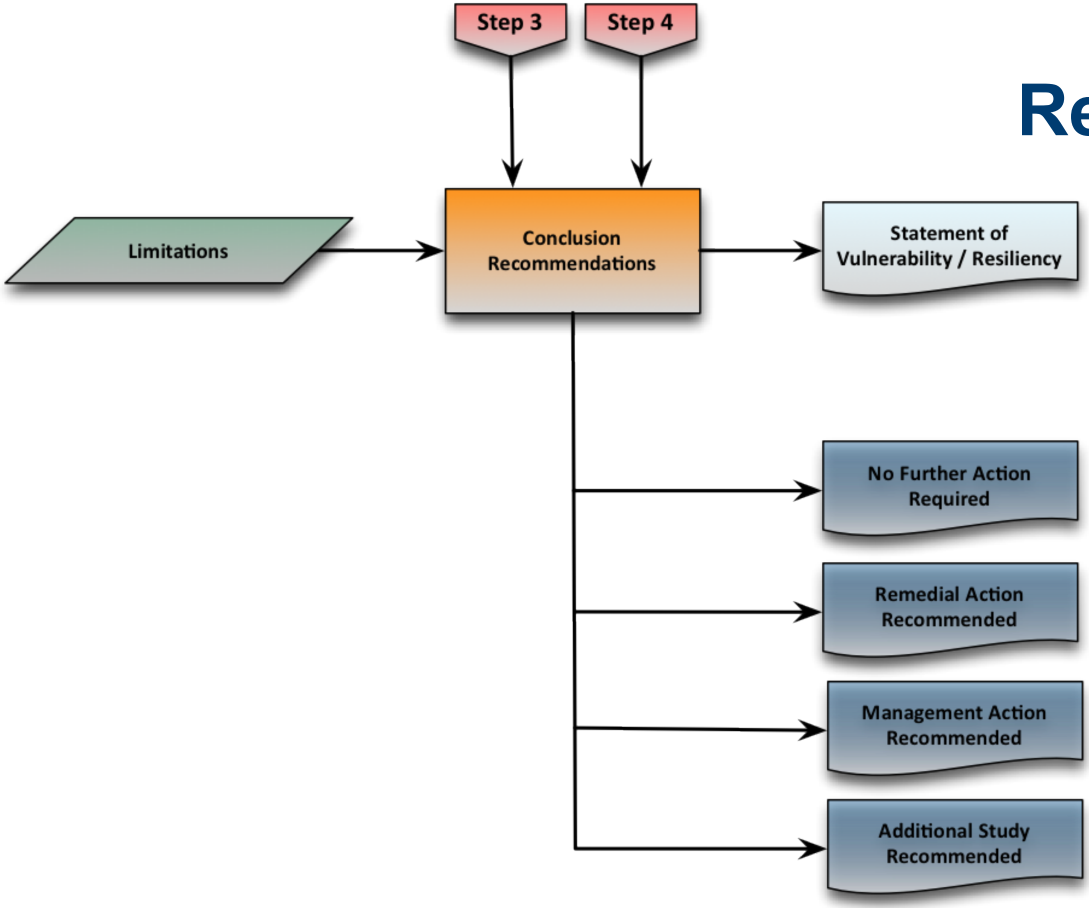
Infrastructure Ontario (2012 Study) - Example of Risk Scores

Infrastructure Component / Sub-component	St. Catharines (Max. Score)	London (Max. Score)	Brantford (Max. Score)	General Description of Interactions
Chillers and cooling systems	42	18	18	■ Extreme hot temperatures and humidity could overwhelm the capacity of the cooling systems to support the facility demands. ■ Average temperature increase could increase Cooling Degree Days (CDD) leading to increased operation & maintenance costs. ■ Change in wind strength and direction could increase or decrease cooling loads due to air leakage.
Air Handling Systems	35	18	18	■ Increased snow fall on outdoor equipment could hinder maintenance and result in reduction in life expectancy. ■ Change in wind strength or direction can alter static pressure and affect operation of air handling system.

Step 4: Engineering Analysis



Step 5: User Recommendations



Infrastructure Ontario (2012 Study) – Example of Recommendations, St. Catharines Site

Recommendation Category	Recommendation	Timeframe
Management Action	■ Maintain accurate log of thermal comfort complaints. ■ Maintain accurate log of water penetration events, and failed IG locations. ■ Commission a review of the curtain wall system to determine air leakage pathways and drainage capabilities. ■ Investigate strategies for reducing solar gain from curtain wall ■ Current emergency plans and redundancy should be assessed for effectiveness. ■ Ensure that regular maintenance efforts address high and medium risk systems identified in this study and include documentation of regular inspections.	■ Ongoing, beginning immediately ■ Ongoing, beginning immediately ■ 6 months to 1 year ■ 6 months to 1 year ■ 6 months to 1 year ■ 6 months to 1 year

Infrastructure Ontario (2012 Study) – Example of Recommendations, St. Catharines Site

Recommendation Category	Recommendation	Timeframe
Re-engineering & retrofit	■ Replace flat roof sections. Employ proper design and use qualified trades with adequate Quality Assurance.	■ 6 months to 2 years
	■ A full re-commissioning of the building upgrades of the chillers to meet 100% load requirements should be undertaken.	■ 6 months to 1 year
	■ Rebalance the Building Air Distribution Systems, especially those serving areas experiencing thermal comfort issues	■ 6 months to 1 year
	■ Check fastening details on metal panels for adequacy under high winds, and for corrosion protection.	■ 6 months to 1 year
	■ Investigate risk to on-site transformer and electrical systems from extreme temperatures, including potential system to monitor transformer core temperature and system redundancy.	■ 1 to 2 years

Thank you!

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