# Vulnerability and Risk Assessment of Public Infrastructure

## The PIEVC Engineering Protocol

**David Lapp, FEC P.Eng.**
**Practice Lead, Engineering and Public Policy**
**Engineers Canada**
**October 24, 2014**

# What is Engineers Canada?

## STRUCTURE

- National organization for the engineering profession in Canada
- Members - 12 constituent associations that regulate the practice of engineering e.g. Professional Engineers Ontario (PEO)
- Over 270,000 professional engineers in Canada

## FUNCTIONS

- Common approaches for professional qualifications, professional practice and ethical conduct
- Accredits all undergraduate engineering programs in Canada– 271 programs in 43 universities
- National and international voice of the profession
- Climate change work since 2001

# Guiding Principles for this Presentation

- 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
- Climate change engineering vulnerability assessment contributes to adaptation process
- Updated and improved codes, standards and practices needed

# Civil Infrastructure

**The services provided by civil infrastructure works support society in many ways…**

## Services

Shelter

Safety and security

Aesthetics

Heat, Light and Power

Mobility for people, goods and services

Health and recreation

Wealth creation

## Categories

Homes & Buildings

Transportation networks

Energy networks

Water, Waste, & Storm water networks

Industrial structures

Communications networks

Landfills and waste depots

Culture and recreational facilities

# Changing climates, changing loadings…

- Changing temperature
- Changes in seasonality and type of precipitation
- Changes in extreme wind loadings
- Intensity of precipitation
- Earlier freshet
- Sea level rise and storm surge
- More freeze-thaw cycles
- Melting permafrost

engineerscanada ingénieurscanada

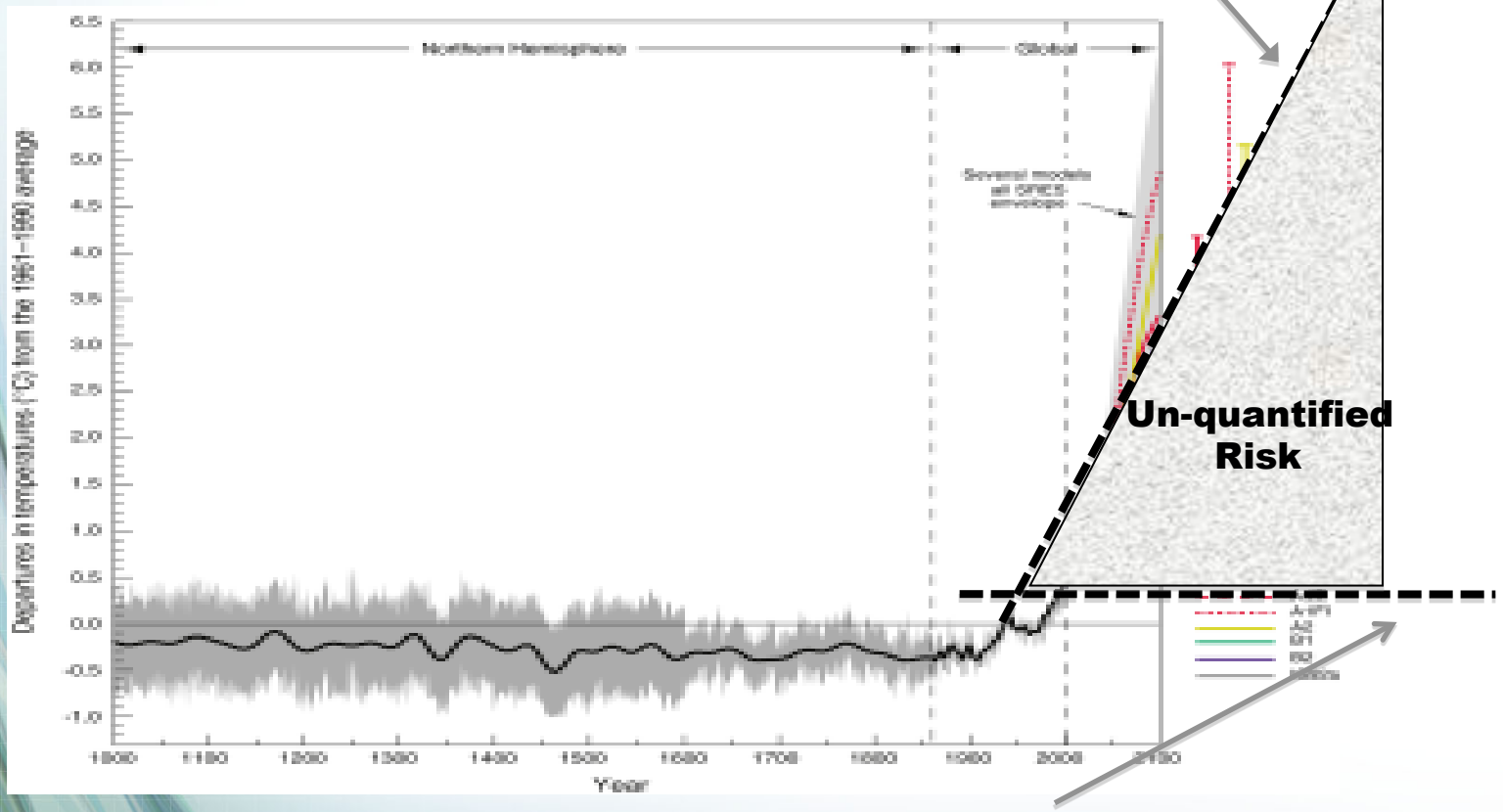
# So what is the concern with infrastructure and changing climate?

- Increasing  occurrence of extreme weather events causing damage and destruction with high cost to repair and replace
- Existing infrastructure has normally been designed using historical climate data
- Infrastructure will not be sufficiently resilient for its service life in the future climate

engineerscanada ingénieurscanada

# The Past IS NOT the Future

## Current Trend

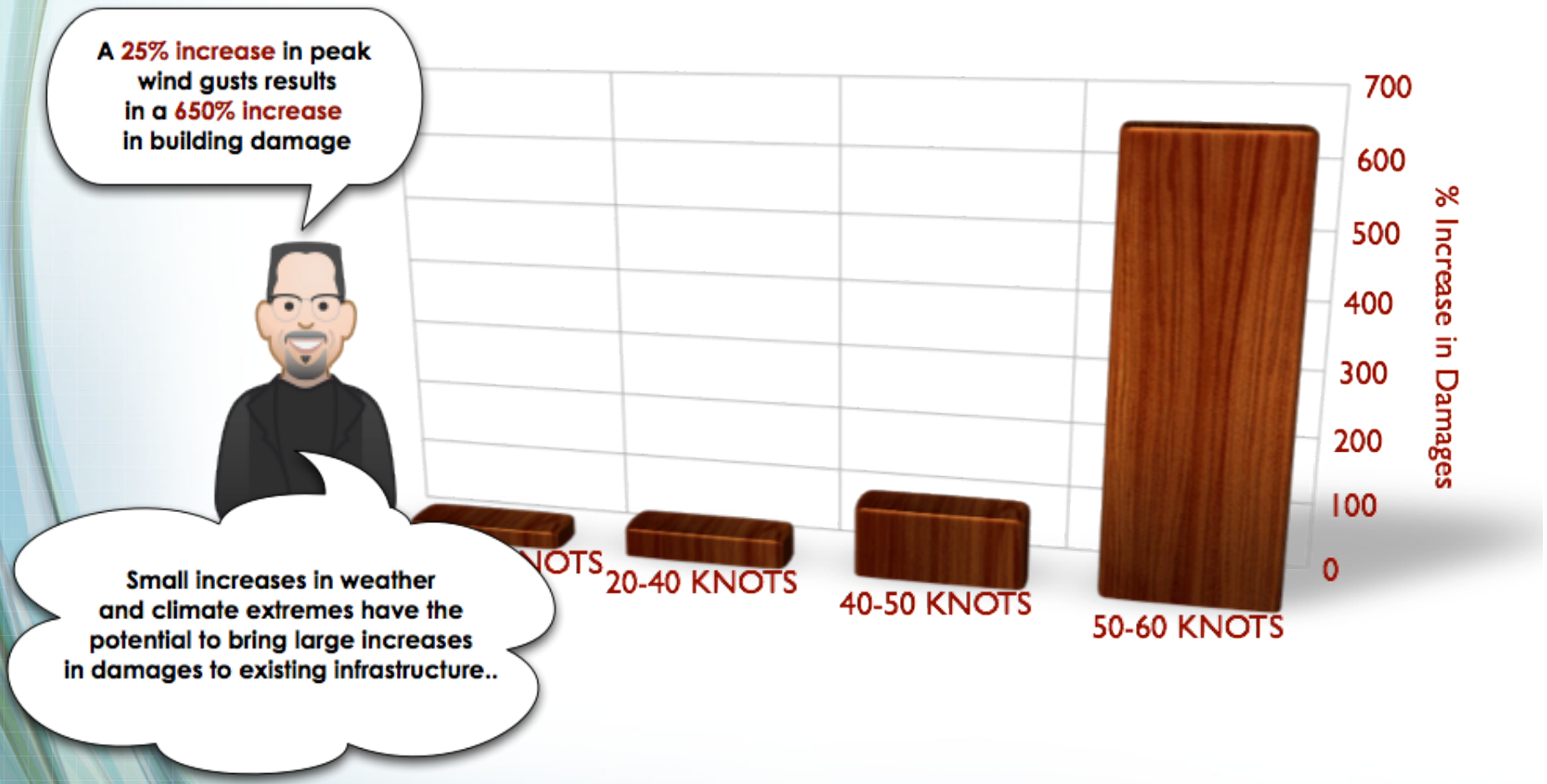



## The Past is the Future

# Risks to Various Infrastructure Types from Increasing Climate/Weather Extremes (Frequencies/Intensities)

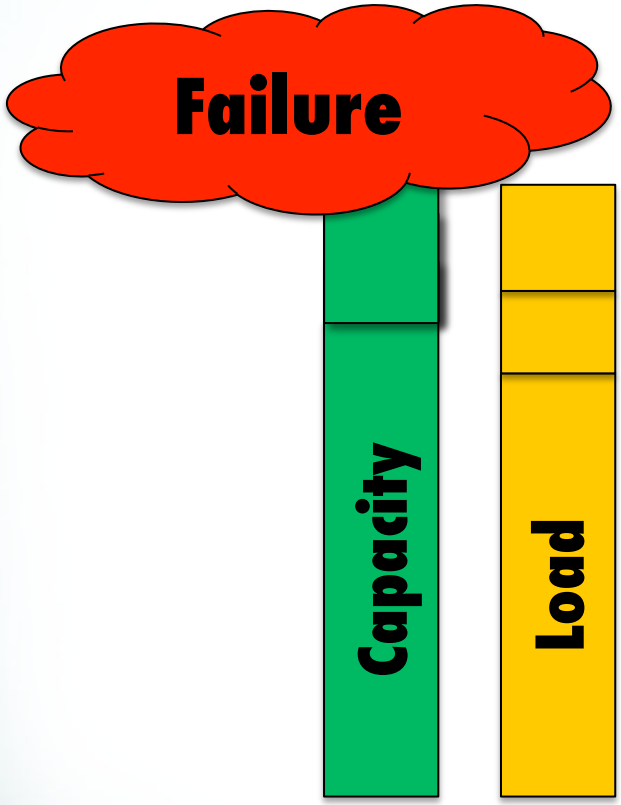
| STRUCTURES | Ice Storms and Wet Snow | Rainfall Intensity & Accum. | Extreme Winds | Summer Storms & Tornadoes | Extreme Snow |
|---|---|---|---|---|---|
| Power Lines & Transmission Structures | FAILURE ice + wind | ADDITIVE | FAILURE | FAILURE | SOME |
| Communication | FAILURE ice + wind | ADDITIVE | FAILURE | FAILURE | SOME |
| Buildings | SEVERE ICING & WET SNOW | DRAINAGE & FAILURE | FAILURE | FAILURE | FAILURE |
| Roads, Bridges | OPERATION RISKS | DRAINAGE & EROSION | OPERATION & RISKS | FAILURE RISK | OPERATION |
| Stormwater & Wastewater | POWER FAILURES | TOTAL FAILURE | POWER FAILURES | FAILURE | RISKS |
| Water Supply & Distribution | POWER FAILURES | LACK OF - DROUGHT | POWER FAILURE | POWER FAILURE | RISKS |

# Small Increases Lead to Escalating Infrastructure Damage




engineerscanada ingénieurscanada

# How do Small Changes Lead to Catastrophic Failure?

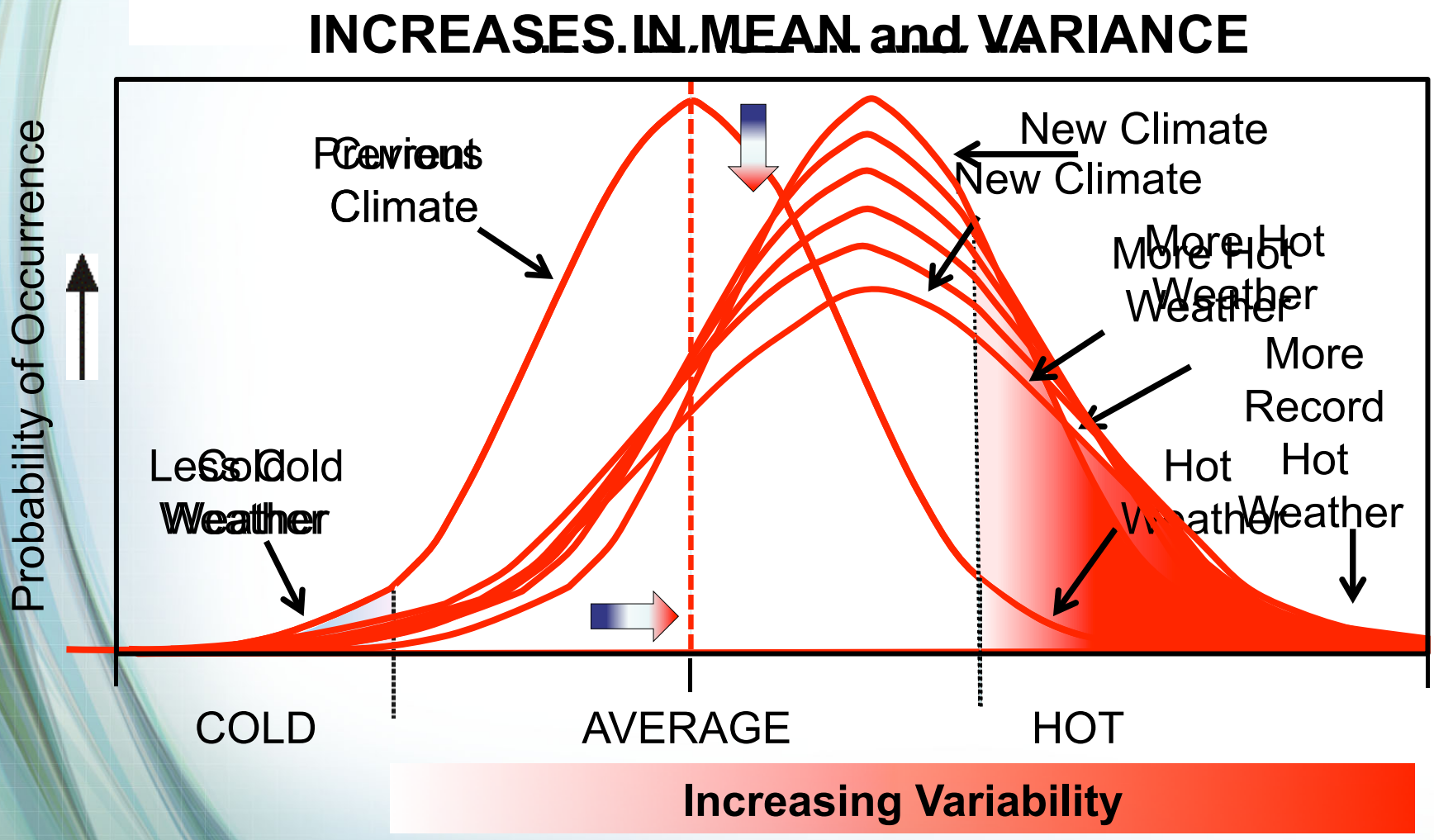


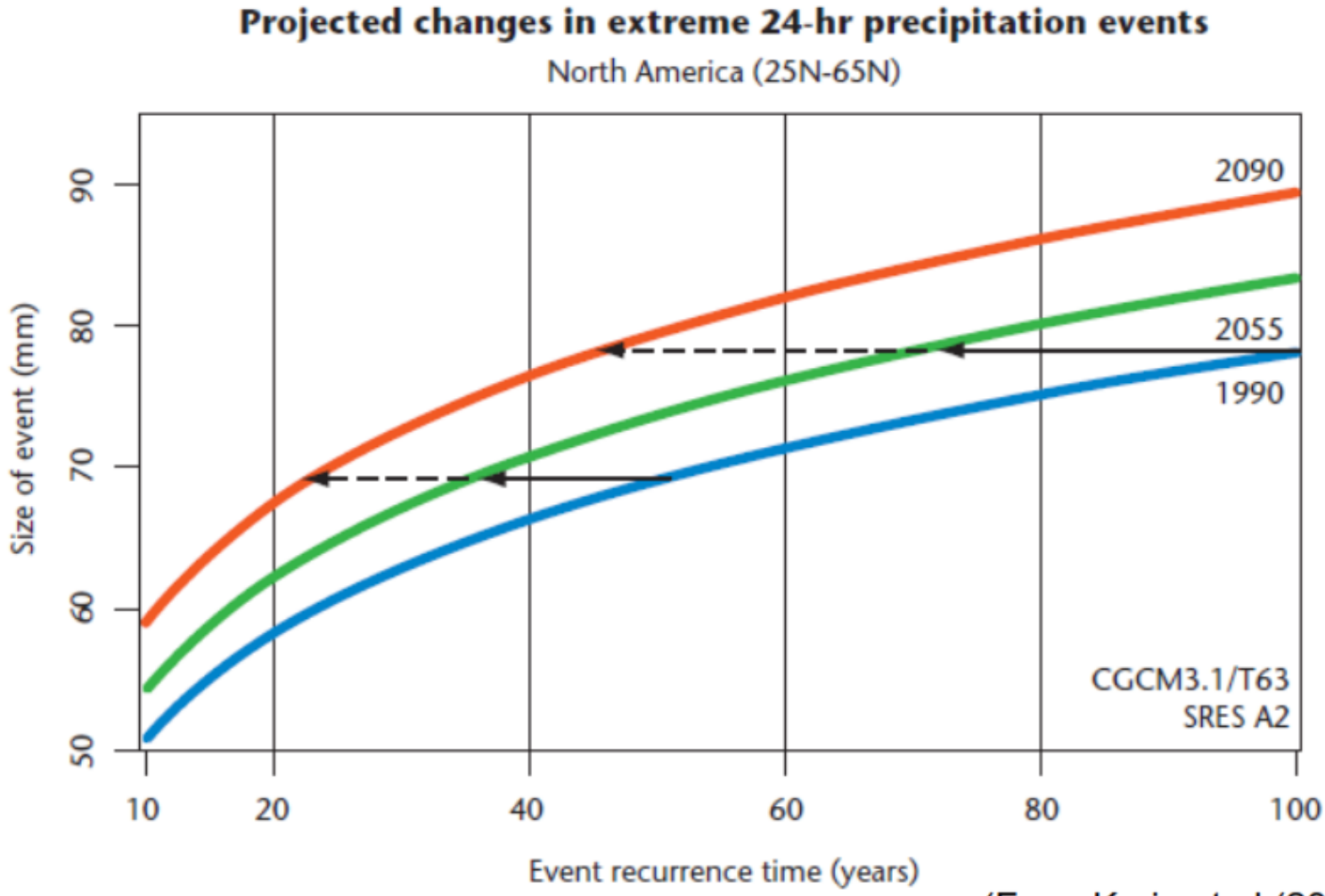

- Design Capacity
- Safety Factor
- Impact of age on structure
- Impact of unforeseen weathering

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

engineerscanada ingénieurscanada

# The probability of extremes changes in a warmer climate






(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)

engineerscanada ingénieurscanada

# Why Address Infrastructure Risks?

- Minimize service disruptions
- Protect people, property and the environment
- Optimize service
  - Manage lifecycle
  - Manage operations
  - Avoid surprises
  - Reduce costs
- First step in planning adaptation

engineerscanada ingénieurscanada

# … and furthermore

**Building infrastructure today without considering future climate impacts is incorporating vulnerabilities that will later cause service disruptions and failures thus increasing costs to government, the private sector and users.**

engineerscanada ingénieurscanada

# Changing Climate and Professional Liability?

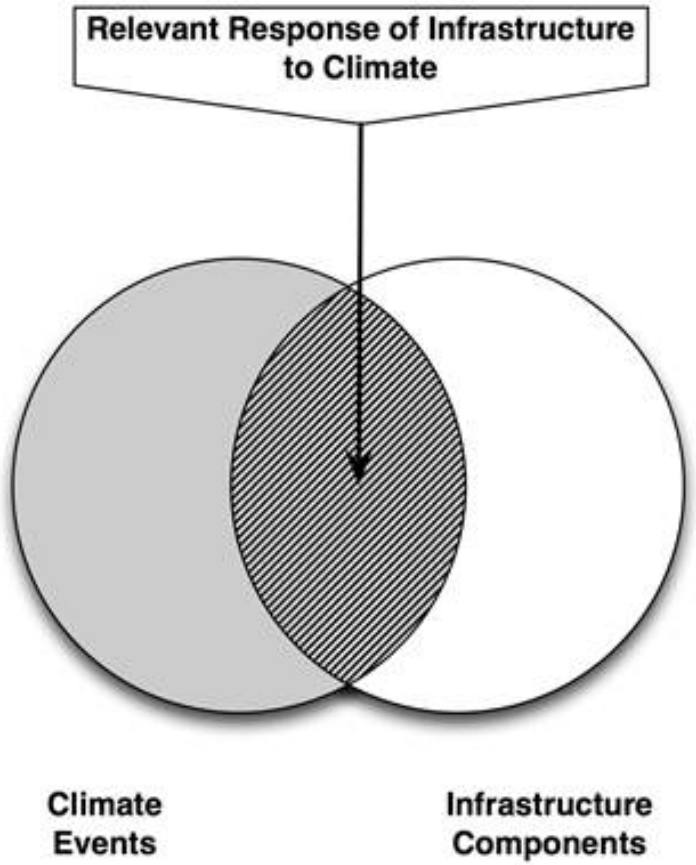
*"engineers, under their professional code of ethics, need to be involved in addressing the impacts of changing climate on infrastructure design and operations because it affects public safety and public interest." … Engineers Canada web site*

*There is a real risk that infrastructure stakeholders… could be liable to people who suffer personal injury or property damage caused by infrastructure that has been adversely affected by climate change..… Patricia Koval LLP*

*Engineering Dimensions;*
*http://www.peo.on.ca/index.php/ci_id/20321/la_id/1.htm*

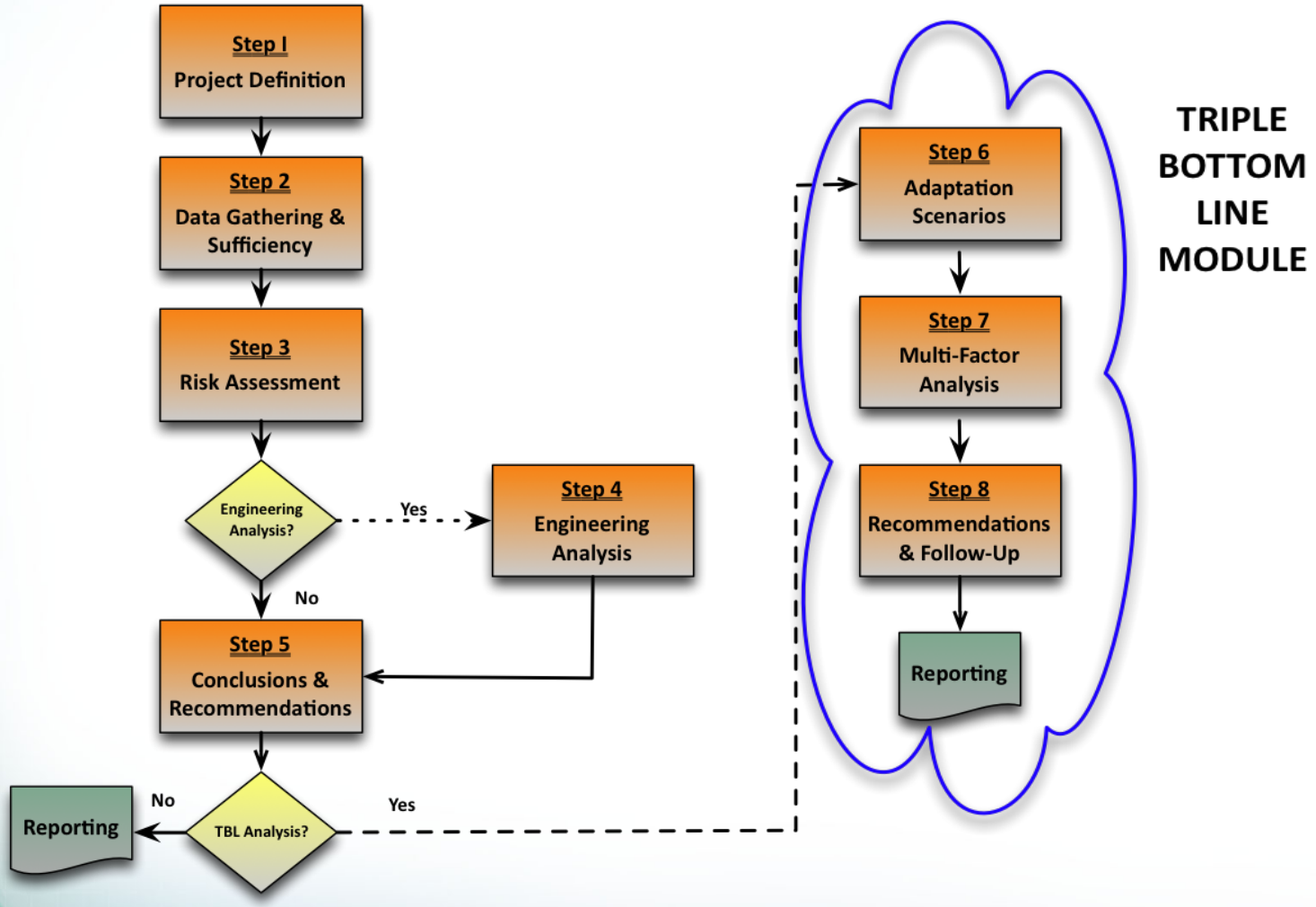
# PIEVC Engineering Protocol: a risk screening tool

- Five step evaluation process
- A tool derived from standard risk management methodologies
- Intended for use by qualified engineering professionals
- Requires contributions from those with pertinent local knowledge and experience
- Focused on the principles of vulnerability and resiliency

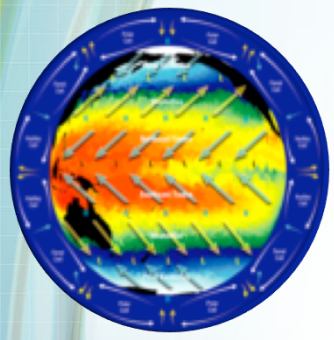



engineerscanada ingénieurscanada

# 5 Steps plus an Optional TBL Module



# Public Infrastructure Vulnerability Process



## Climatic Conditions

Character, magnitude and rate of change in climate conditions for exposed infrastructure

## Sensitivities of Infrastructure

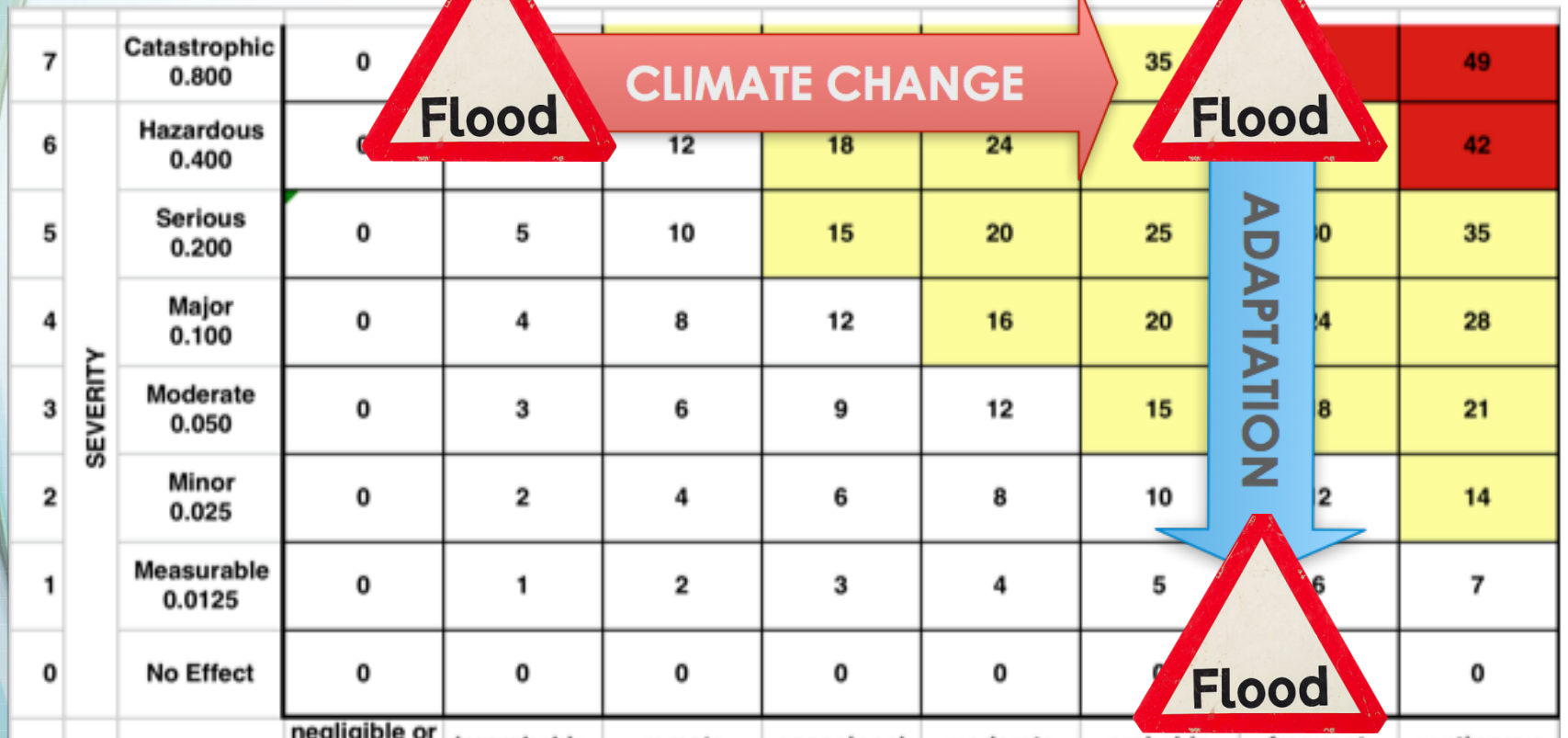
How sensitive is the infrastructure to climatic changes?

## Built-in Capacity of Infrastructure

What level of built-in capacity of infrastructure exists to absorb consequences of a changing climatic?

**Vulnerability Assessment needs to consider all 3 elements!**

# Climate Change Risk Mitigation Through Adaptation

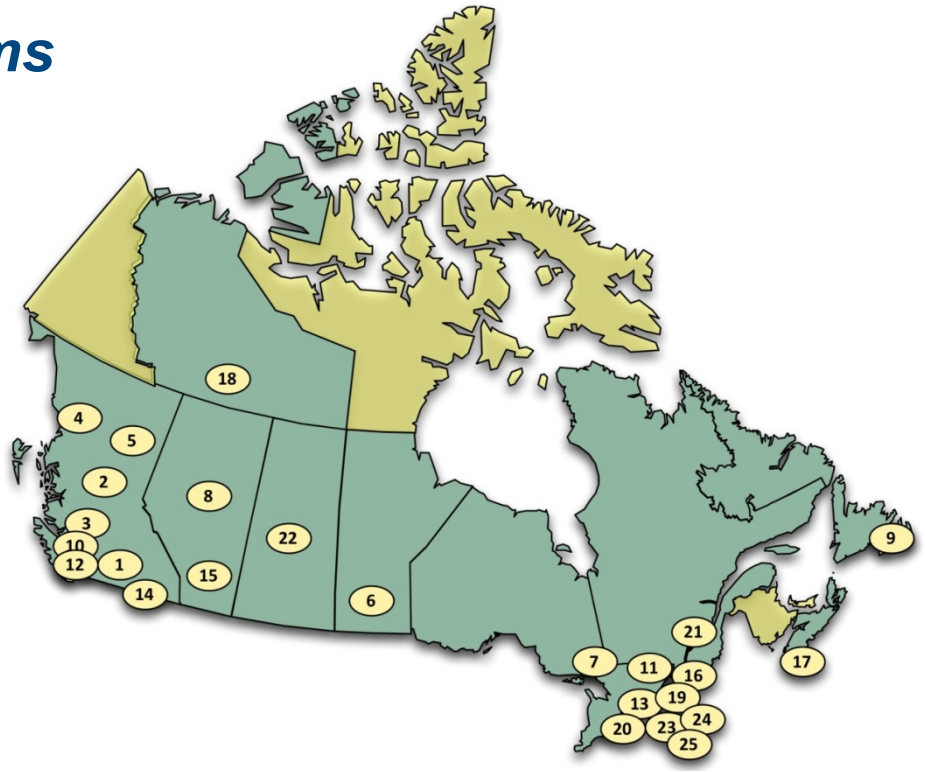



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | | Catastrophic 0.800 | 0 | | | | | 35 | 49 |
| 6 | SEVERITY | Hazardous 0.400 | 0 | | 12 | 18 | 24 | | 42 |
| 5 | | Serious 0.200 | 0 | 5 | 10 | 15 | 20 | 25 | 35 |
| 4 | | Major 0.100 | 0 | 4 | 8 | 12 | 16 | 20 | 28 |
| 3 | | Moderate 0.050 | 0 | 3 | 6 | 9 | 12 | 15 | 21 |
| 2 | | Minor 0.025 | 0 | 2 | 4 | 6 | 8 | 10 | 14 |
| 1 | | Measurable 0.0125 | 0 | 1 | 2 | 3 | 4 | 5 | 7 |
| 0 | | No Effect | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | negligible or not applicable | improbable 1:1 000 000 | remote 1:100 000 | occasional 1:10 000 | moderate 1:1 000 | probable 1:100 | frequent 1:10 | continuous 1:1 |
| | | | PROBABILITY | | | | | | | |
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

engineerscanada ingénieurscanada

# 30+ Projects and Counting …

- *Water resources systems*
- *Storm & waste water systems*
- *Roads & bridges*
- *Buildings*
- *Transportation infrastructure*
- *Energy Infrastructure*



# PIEVC Water Infrastructure Climate Risk Assessments

**ONTARIO**

- Union Water Supply System (Leamington ON)
- City of Welland – Stormwater and wastewater infrastructure
- Town of Prescott - Stormwater management infrastructure

**NATIONAL**

- Cities of Castlegar and Nelson, BC – Stormwater management
- City of Calgary – Potable water supply
- Town of Shelburne NS – New sewage treatment plant
- Metro Vancouver – Stormwater and wastewater systems

# PIEVC Transport Related Assessments

- BC MOTI – Coquihalla and Yellowhead Highways
- BC MOTI – Hwy 20 (Bella Coola), Hwy 37A (Stewart Region), Hwy 97 (Pine Pass Region)
- City of Toronto –Three Large Culverts
- City of Edmonton – Quesnell Bridge Upgrade
- City of Sudbury – City-wide assessment of roads, bridges and culverts
- City of Miramichi NB – two highways
- GNWT Department of Transportation – Highway 3 West of Yellowknife
- Greater Toronto Airport Authority – Runway Culvert and De-Icing System
- Placentia NL – Local road and coastal structures

# Lessons Learned from Infrastructure Climate Risk Assessments

## Several common issues:

- **Intensity** – short duration precipitation is almost always a concern
- Infrastructure systems are **almost always vulnerable to interruptions in power supply**
  - Severe weather events can disrupt power supply and have significant impact on the serviceability of your infrastructure
- **Combinations of events can have more impact than discrete events**
  - Rain on snow
  - High snowfall followed by rapid thaw

*Highway 404 in Toronto, Ontario July 27, 2014*
*Image: Global News*

# Lessons Learned from Infrastructure Climate Risk Assessments

- Meteorological **data used in design can often be very dated**
  - IDF curves based on 1960s precipitation data
- **Regional climate expertise** is always better
  - Climate specialists from distant locations may not be conversant with local weather phenomena
- **Multidisciplinary teams are very important**. Teams should comprise:
  - Fundamental **understanding of risk and risk assessment processes**
  - Directly **relevant engineering knowledge of the infrastructure**
  - **Climatic and meteorological expertise** relevant to the region
  - Hands-on **operation experience** with the infrastructure
  - Hands-on **management knowledge** with infrastructure
  - **Local knowledge** and history

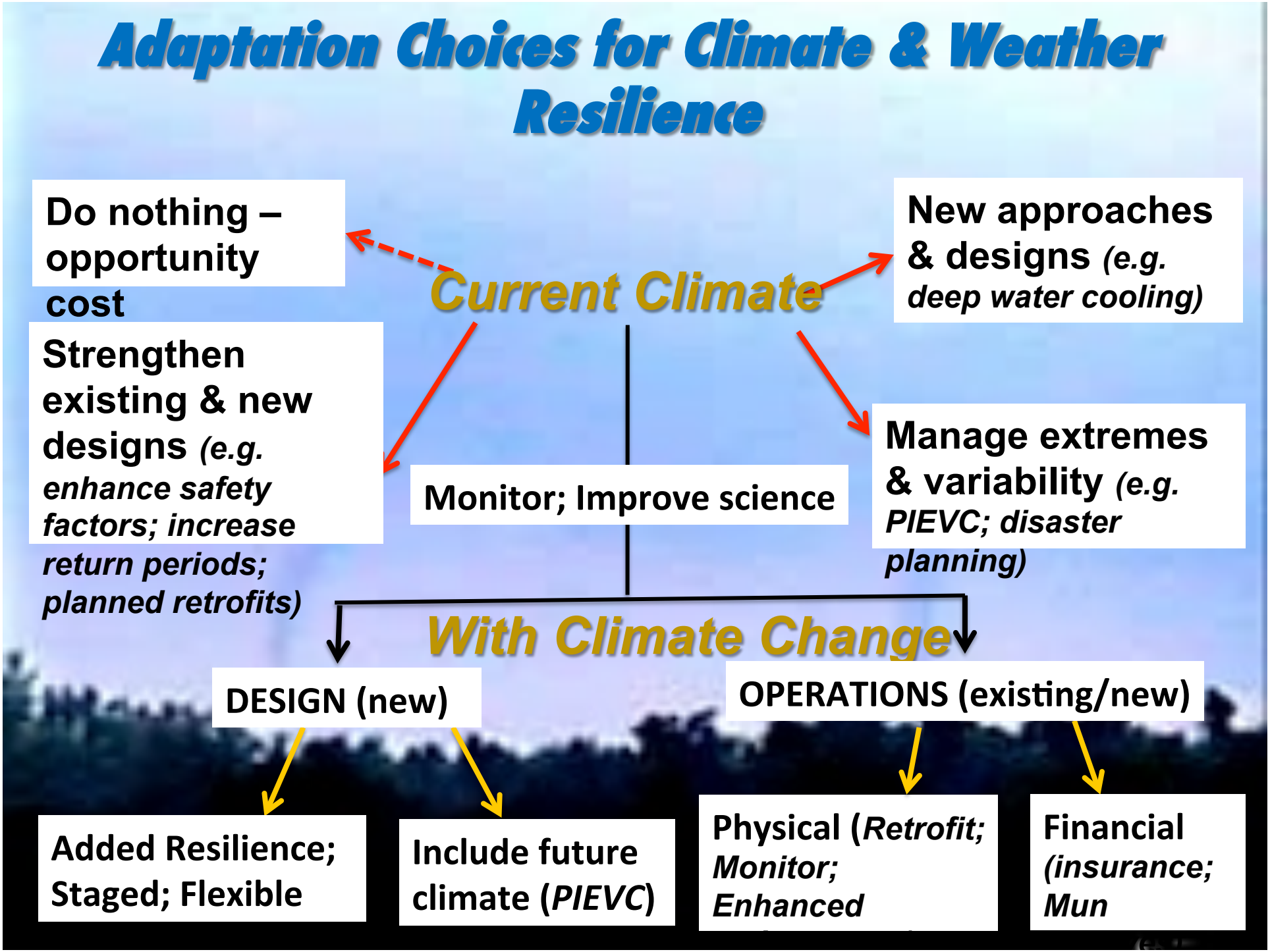
# Lessons Learned from Infrastructure Climate Risk Assessments

- Climate change projections should be based on **ensembles of model outputs**
  - There is always a temptation to use only one set of data
- Understanding your **baseline climate is critical**
  - How infrastructure has responded to historical weather events informs judgment on how it will likely respond to future, more extreme, events
- It is important to **monitor and maintain**
  - Good records of weather events
  - The impact they had on your infrastructure
  - How you responded

# Benefits of Infrastructure Climate Risk Assessment

- Identify nature and severity of risks to components
- Optimize more detailed engineering analysis
- Quick identification of most obvious vulnerabilities
- Structured, documented approach ensures consistency and accountability – **due diligence**
- Adjustments to design, operations and maintenance
- Application to new designs, retrofitting, rehabilitation and operations and maintenance
- Reviews and adjustments of codes, standards and engineering practices

# Adaptation Choices for Climate & Weather Resilience



# Thank you!

engineerscanada
ingénieurscanada

**For more information:**

**Email: david.lapp@engineerscanada.ca**

**guy.felio@engineerscanada.ca**

# What the profession is doing

- Raising awareness among engineers, other professions and decision-makers
- Continuing professional development – climate change syllabus (e.g. Climate Resilient Systems Training; http://climateresilientsystems.com/)
- Assessment  of climate risks (e.g. PIEVC)
- Developing (best) practice guidelines – Model Guide on Principles of Climate Change Adaptation for Engineers
- Constituent associations – practice guidelines for specific infrastructure categories

# What the profession is doing

- Encouraging integration of climate change into undergraduate curriculum
- Encouraging incorporation of climate risk into asset management
- Joining other professions to urge government action – regulatory and procurement policies
- Contributing reviews of design, construction and operations codes, standards, procedures and policies

# National Building Codes and Standards – climate design information today

**Climate information is included in building codes and standards for design of safe and economical infrastructure**

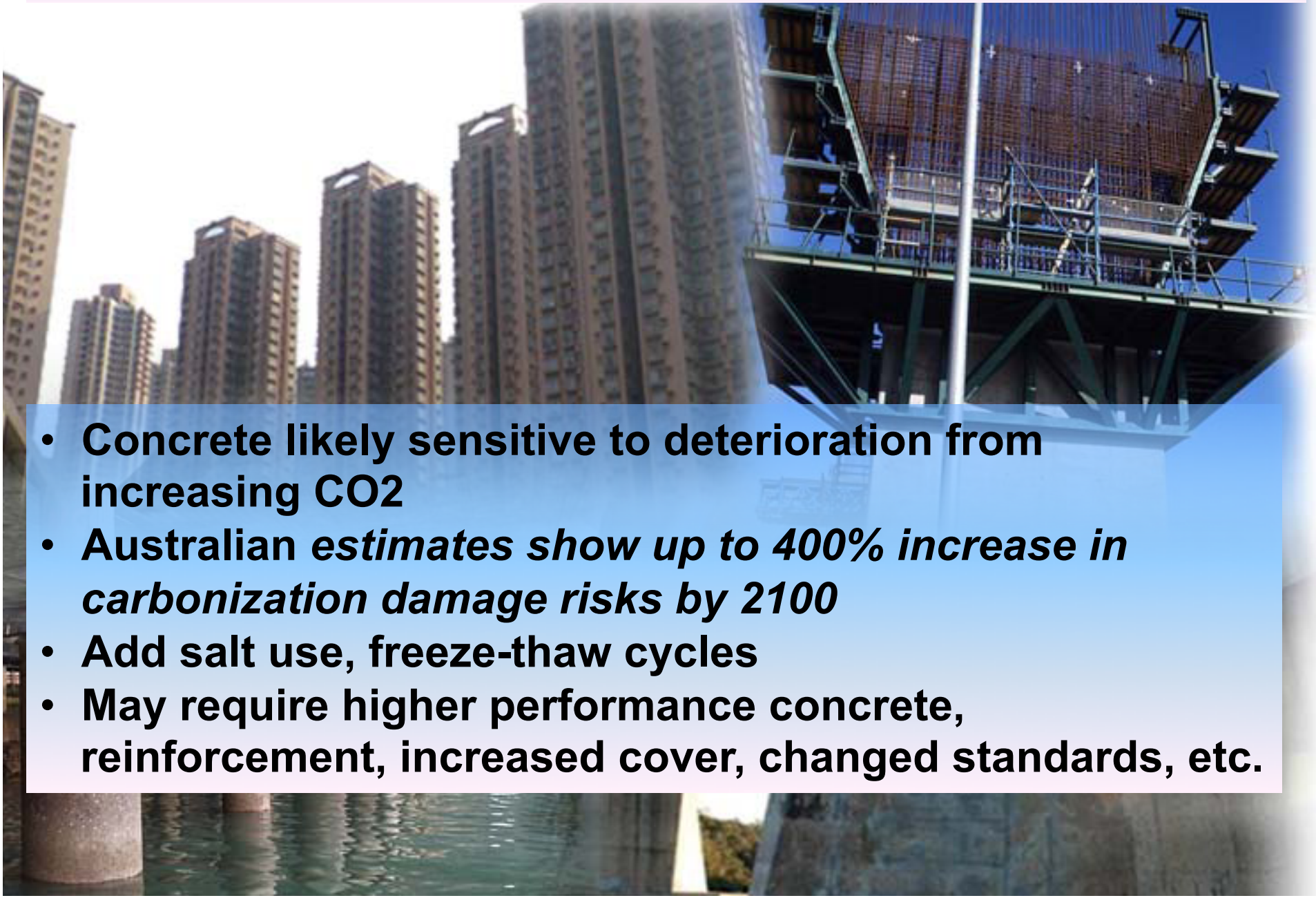
**National Building Code of Canada (NBCC) climate data needed:**

- ***Extreme winds and gusts***
- ***Extreme snow loads/weights***
- ***Extreme rainfall amounts – 15 min, 24 hour, etc.***
- ***Heating Degree Days, Cold & Hot Design Temperatures, Humidities***
- ***Weathering data – DRWP, Annual Precipitation, Rainfall***
- ***NOW, climate change risks (2015 NBCC)***

# The Interdependence of Climate Experts and Engineering Design

- An inseparable link
- Cannot work without each other
- With Climate Change, working closely together is critical for safeguarding public well-being:
  - *Reduce uncertainty on how future climate will deviate from regional historic climate*

# Premature weathering of concrete under CC?



- Concrete likely sensitive to deterioration from increasing CO2
- Australian *estimates show up to 400% increase in carbonization damage risks by 2100*
- Add salt use, freeze-thaw cycles
- May require higher performance concrete, reinforcement, increased cover, changed standards, etc.

# Flexible adaptation options working with *Infrastructure Lifecycle Timeframes*

| Structures | Expected Lifecycle |
|---|---|
| Houses/Buildings | Retrofit/alterations 15-20 yrs<br>Demolition 50-100 yrs |
| Sewer | Major upgrade 50 yr |
| Dams/Water Supply | Refurbishment 20-30 yrs<br>Reconstruction 50 yrs |
| Bridges | Maintenance annually<br>Resurface concrete 20-25 yrs<br>Reconstruction 50-100 yrs |

**Improves Asset management**

# Importance of Forensic Analyses in Increasing Resilience

- Learning through past climate-related failures
- Part of “due diligence”
- Evidence for improvements to codes and standards
- Supports improved practices and adaptation solutions
- Proactive - Reduces legal liabilities into future
- Multi-disciplinary: engineering, climate, operations, policy, codes and standards, financial decision-makers, etc
- e.g. Prototype - Climate and Infrastructure Forensic Analyses System (CIFAS)

# Increasing Climate Resilience through new and updated Codes and Standards

- Climatic design values very outdated in many codes and standards (*e.g. Highway and Bridge Code*)
- NBCC 2015 added option to include climate change adaptation – given scientific evidence
- Several new Northern CSA standards – snow loads, drainage, permafrost maintenance, thermosyphons, IDFs for Water Practitioners PLUS 4013, Permafrost Foundations PLUS 4011
- Changes to all Codes and Standards based on "**evidence**" – often forensic analyses
- Canada a leader globally in climate change, codes, standard