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# Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI)

## Webinar with Transport Canada
## Integrating Future Climatic Design Data and Coastal Hazards into Transportation Infrastructure Design

Fiona Hill

February 1, 2021

# CLIMATE RESILIENT BUILDINGS & CORE PUBLIC INFRASTRUCTURE (CRBCPI)

Developed world-leading research and foundational science to advance the field of climate change adaptation for buildings and infrastructure

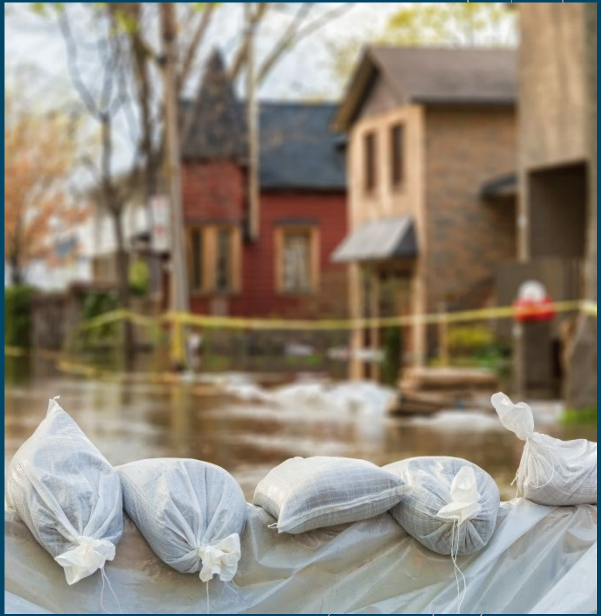
Translated this science into decision support tools, including codes, guides and models for the design of resilient new, and rehabilitation of existing, buildings and core public infrastructure in key sectors to ensure that climate change and extreme weather events are addressed

Climate Data • Roads
Buildings • Bridges
Water/Wastewater
Transit • Decision Support Tools
LCA

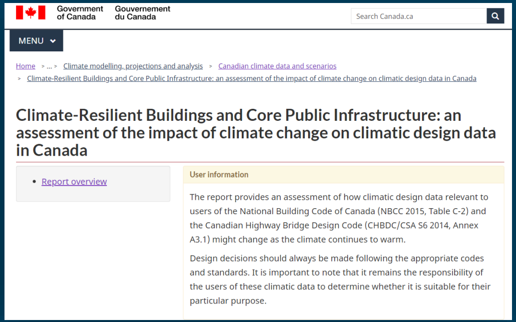
# Responding to Climate Change

## In partnership with INFC, the CRBCPI Initiative has:

- Established a network of international expertise including over **200 different collaborators**
- **Mobilized NRC expertise:** infrastructure & building science, coastal & river engineering, hydrology, aerodynamics, codes
- Significantly advanced the field of climate change adaptation for buildings and infrastructure, and is at the **leading edge of this effort internationally**
- Developed a **suite of a suite of evidence-based guidance documents** on how to adapt



# Recent CRBCPI Highlights



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## Climate-Resilient Buildings and Core Public Infrastructure: an assessment of the impact of climate change on climatic design data in Canada

- Report overview

User information

The report provides an assessment of how climatic design data relevant to users of the National Building Code of Canada (NBCC 2015, Table C-2) and the Canadian Highway Bridge Design Code (CHBDC/CSA S6 2014, Annex A3.1) might change as the climate continues to warm.

Design decisions should always be made following the appropriate codes and standards. It is important to note that it remains the responsibility of the users of these climatic data to determine whether it is suitable for their particular purpose.

**Future climatic data** for the design of buildings and bridges that considers CC:
**climate-scenarios.canada.ca**

Proposed climate change provisions for the 2025 **National Building Code** (NBC) & 2025 **Canadian Highway Bridge Design Code** (CHBDC)

**Updated historical climatic data** – NBC & CHBDC


Guidelines for Conducting **Coastal Flood Hazard and Risk Assessments**

Guide for Design of **Flood-Resistant Buildings**

**Flood loading data** – case studies from riverine, coastal and urban environments

National Guide for **Wildland Urban Interface (WUI) fires** for Canada

Standard for climate adaptation of **commercial roofs**

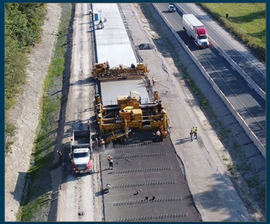
**Sustainability provisions** in the 2019 Canadian Highway Bridge Design Code

# Upcoming CRBCPI Highlights

**Prevention of overheating** in buildings

**Climate dependent** material properties for building envelopes

Adaptable housing in **remote/Indigenous communities**



Effects of heat waves on **Canadian subway systems**

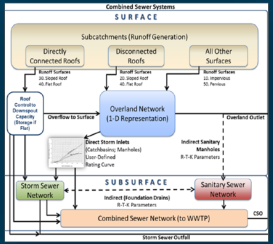
Climate Adaptation and **Asphalt Selection Tool** (CAAST)

**Pavement Adaptation** Support Tool (PAST)

Impact of extreme climate loads on **new & existing bridges,** and of ice and debris on **bridge pier stability**

Models of accelerated **deterioration of bridges & service loads**

**Satellite-based** bridge performance assessment – guidelines and tools




Guidelines on quantification of societal & environmental **consequence of flooding**

**Comprehensive cost benefit** of flood prevention infrastructure

Impact of CC on **water distribution** and **wastewater treatment systems**

## Design for the Future rather than the Past

https://www.infrastructure.gc.ca/plan/crbcpi-irccipb-eng.html

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# THANK YOU

**Fiona Hill**

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# Future Climatic Design Data for Infrastructure

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# Changing Climate

- The science is clear:
  - Human activities and GHGs
  - GHGs driving changes (global warming)
  - Changes in the Earth's climate

- The impacts are already being felt:
  - Thawing permafrost
  - Increases in heat waves
  - Wildfires and flooding


Image Credit: [Huffington Post]

# Adaptation: Climate Resilience

- Building climate resilience through infrastructure
  - Investing to strengthen **resilience**
  - **Codes**, **standards and guidelines:** Climate-resilient Buildings and Infrastructures.
- Climatic design data in codes such as NBCC(2015) and CHBDC(2019):
  - Based on historical observations.
  - No consideration of climate change.

Fort McMurray, 2016 *Jason Franson, The Canadian Press*


Canada's Top Climate Change Risks, 2019

# Projections of Climatic Design Data

- Projected changes in climatic design values provided by Environment and Climate Change Canada (ECCC-Cannon et al., 2020).
- Based on CanRCM4 – LE
  - Large Ensemble of Canadian Regional Climate Model.
  - ~50 km spatial resolution.
  - RCP 8.5 Emission Scenario.
- Baseline period of 1986-2016.
- Provided for timing of global warming for various increments of warming level ($\Delta T$).
- Multi-tiered approach:
  - Temperature-related
  - Precipitation/Rain
  - Snow, Ice, Wind, Compound Extremes.

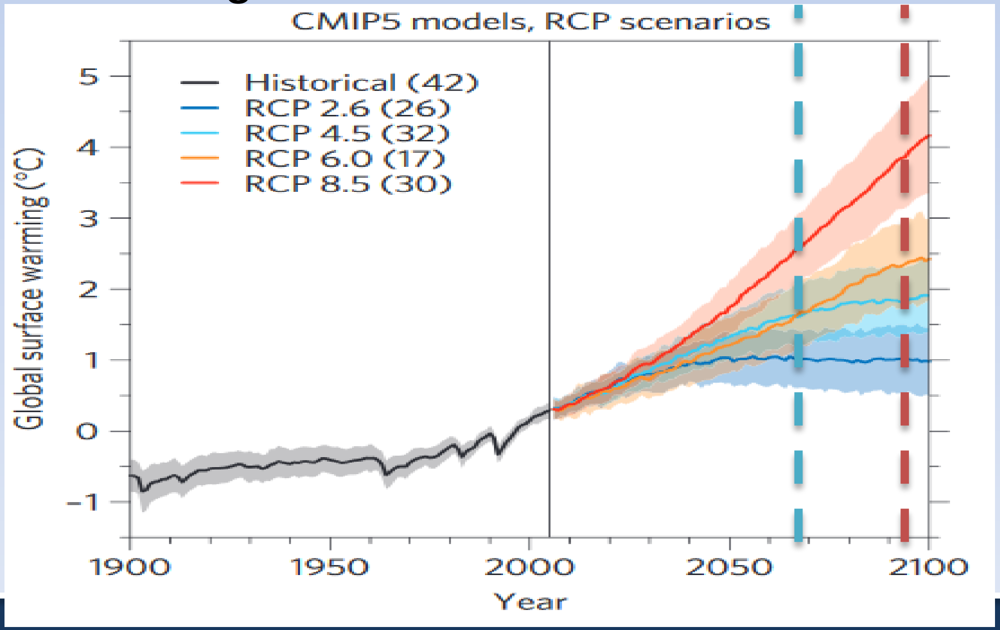
# Role of Infrastructure Design Life: RCP Scenarios

**50 years (Buildings)**

- ECCC recommended that RCP8.5 scenario to be used.
- Incremental change in design values relative to those for RCP4.5 or RCP6.0 is not large.

**75 years (Bridges )**

- Selection of RCP scenario is more complicated.
- Difference between different scenarios can be quite large.




From: Knutti & Sedlacek (2012)



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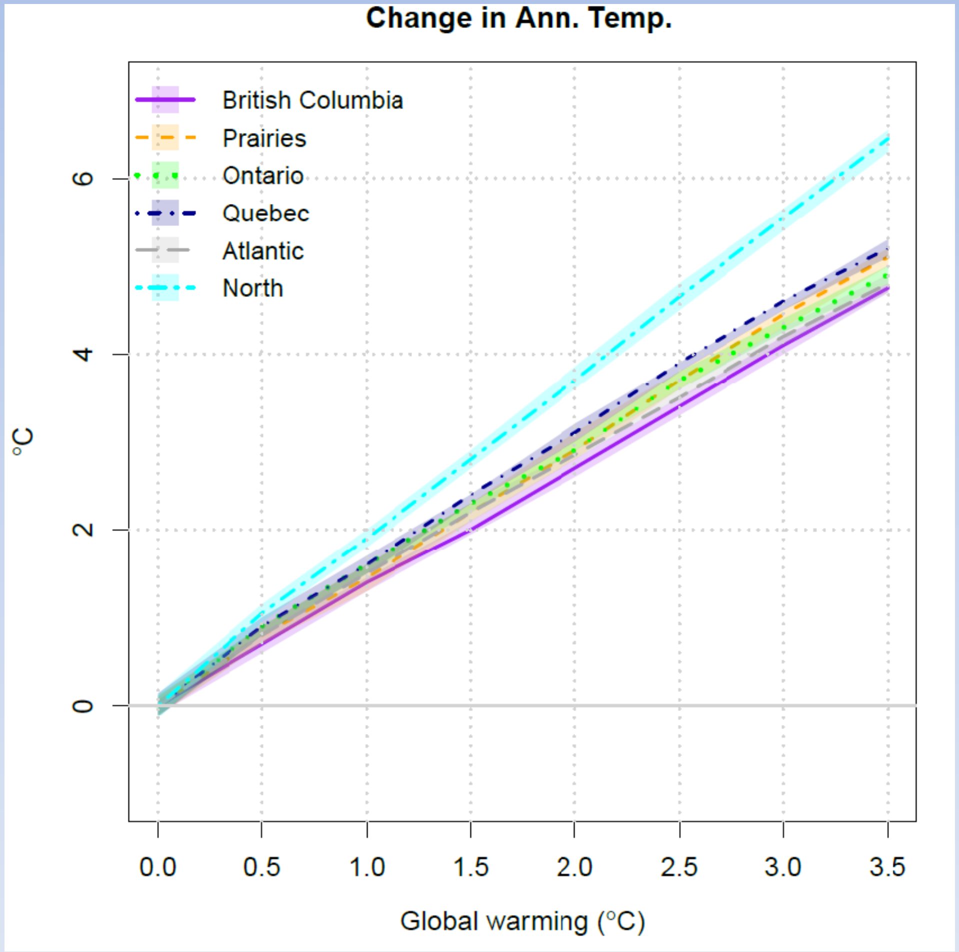
# Projected Changes:
# Global Warming and Canadian Regions Warming

## Projected changes to annual mean temperature




From: ECCC (Canon et al., 2020)



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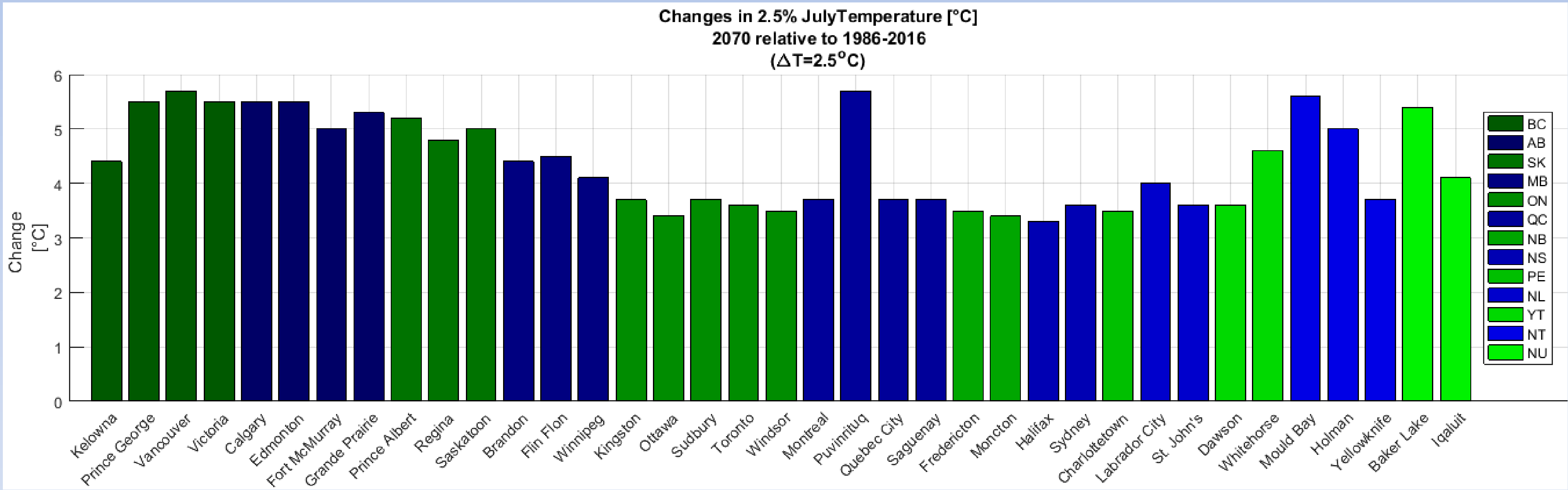
# Projected Changes in Climatic Design Values: Temperature Design Values

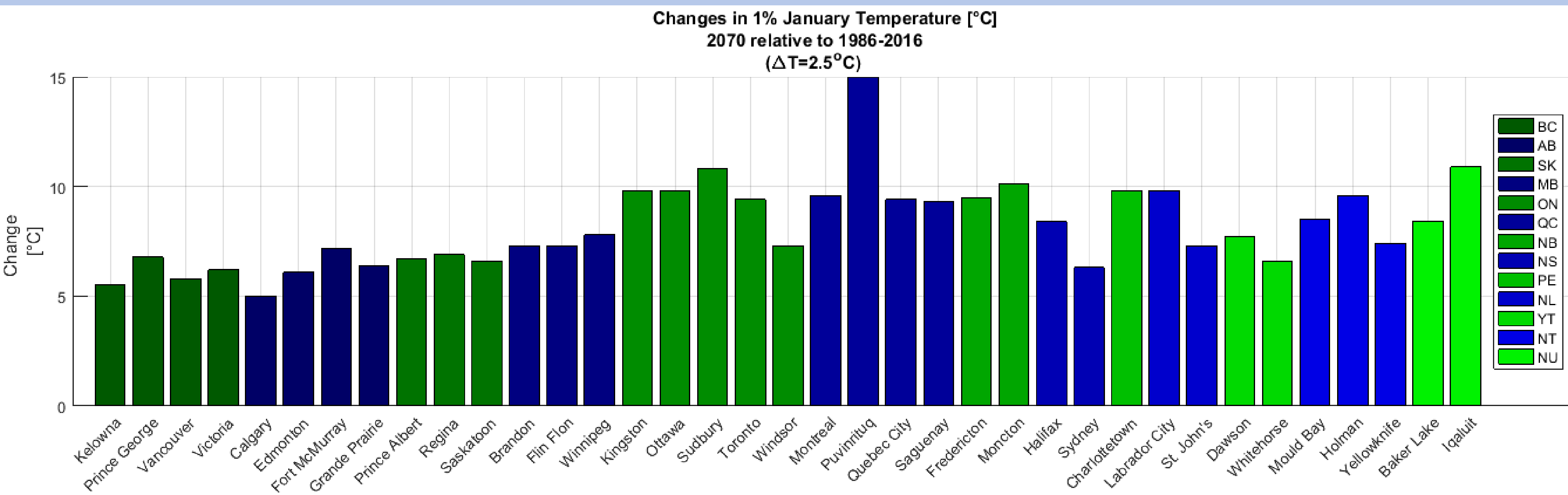
- For 2070 time horizon relative to 1986-2016.
- Increases in hot extremes across Canada.
- Hot extremes are relatively spatially uniform.




From: ECCC (Canon et al., 2020)

# Projected Changes in Climatic Design Values: Temperature Design Values

- For 2070 time horizon relative to 1986-2016.
- Large warming for cold weather and cold extremes.
- Cold weather and cold extremes: warming from south to north.




From: ECCC (Canon et al., 2020)



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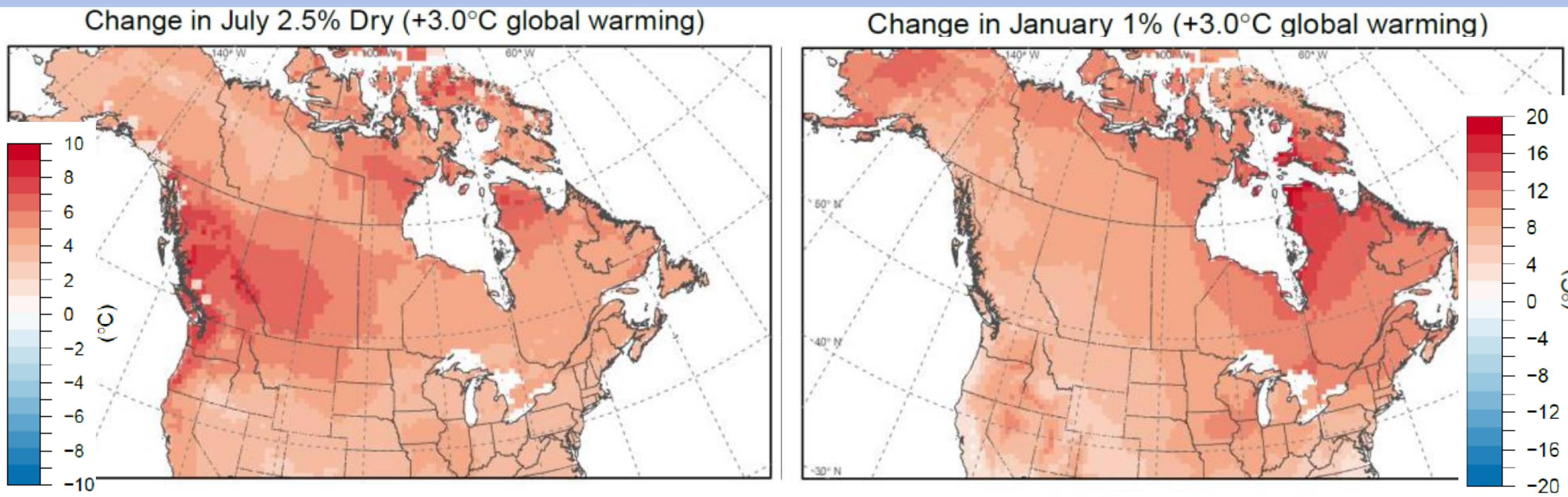
# Projected Changes in Climatic Design Values: Temperature Design Values

- Spatial pattern of changes.
- For 2080 relative to baseline period (1986-2016).




**(Hot Extreme)** **(Cold Extreme)** From: ECCC (Canon et al., 2020)

- The extreme July design temperature will increase by more than 4°C on average across Canada with higher increase at locations in the North and British Columbia.
- The January design temperature is projected to increase larger.



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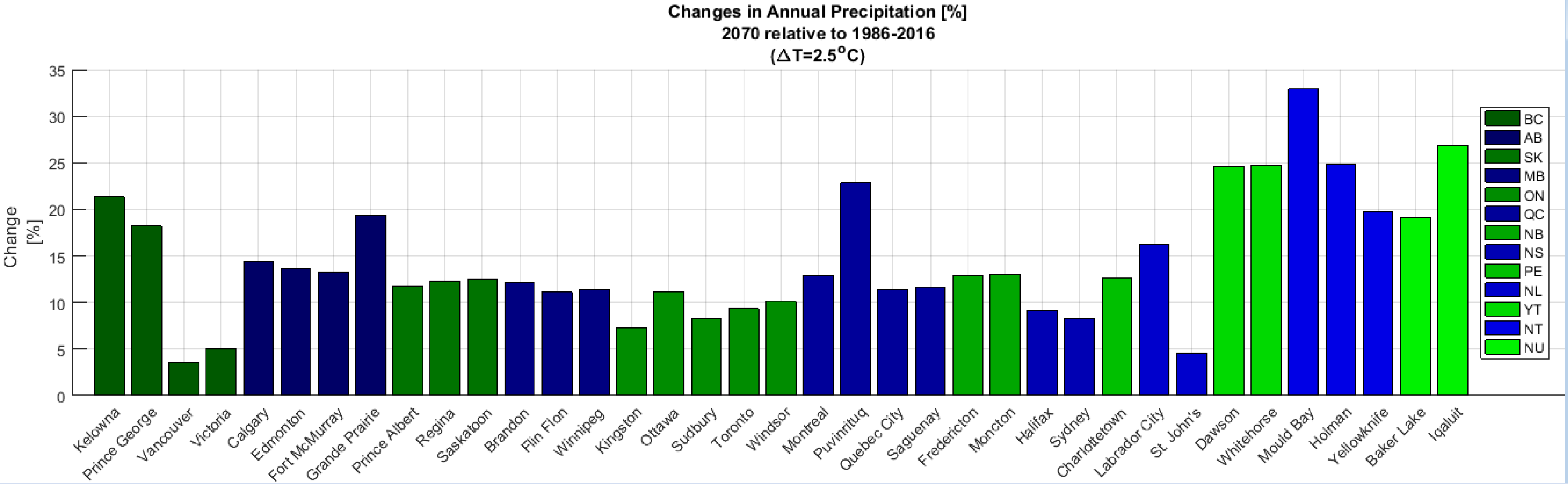
# Projected Changes in Climatic Design Values: Precipitation Design Values

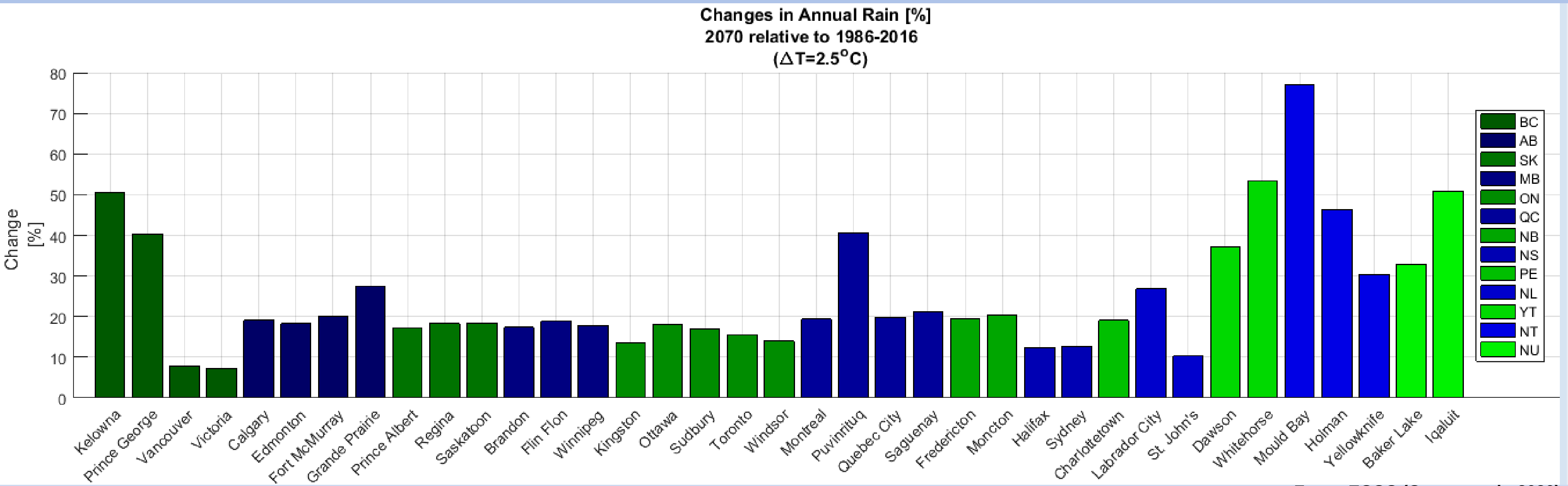
- **Cumulative/Average Parameters:**
    - Directly estimated from projected rainfall data from CanRCM4.
- For 2070 time horizon relative to 1986-2016.




From: ECCC (Canon et al., 2020)

# Projected Changes in Climatic Design Values: Precipitation Design Values

- For 2070 time horizon relative to 1986-2016.




**From: ECCC (Canon et al., 2020)**

- Annual Rain
  - Shifts from snow to rainfall is projected due to the warmer air temperature.
  - Greater intensification of rainfall in the North and British Columbia.
  - Changes between 7% to 95% across Canada.



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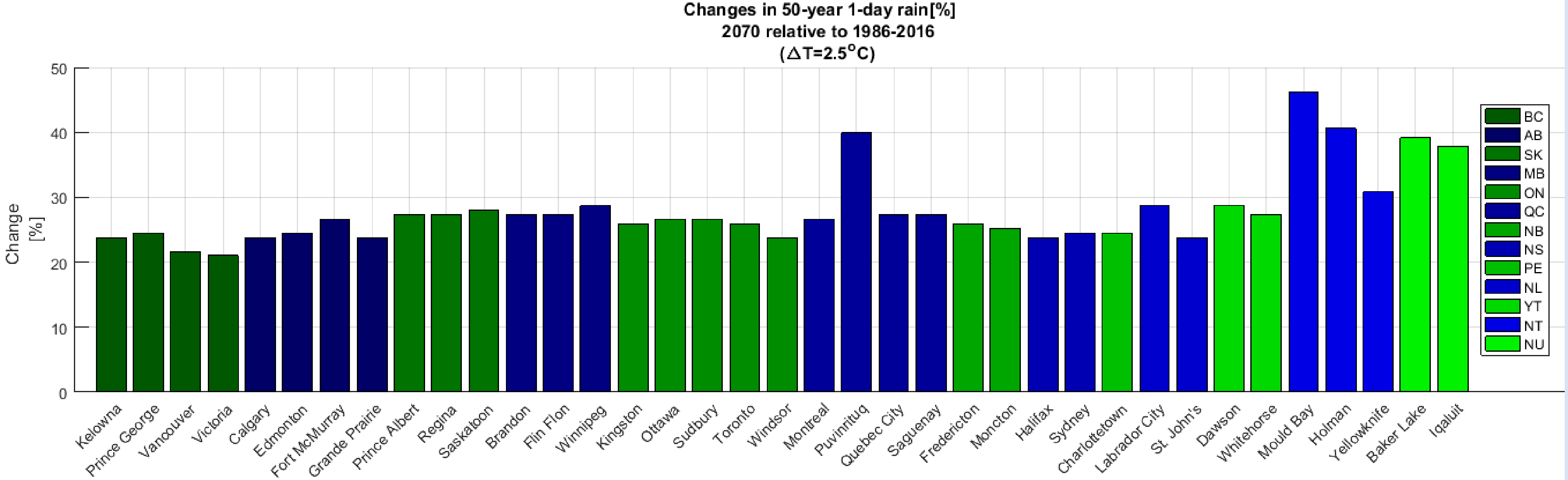
# Projected Changes in Climatic Design Values: Precipitation Design Values

- **Extreme Rainfall:**
  - Clausius-Clapeyron relationship (projected temperatures) ~7% increase per 1°C.
  - For 2070 time horizon relative to 1986-2016.




From: ECCC (Canon et al., 2020)

- 50-year 1-day rainfall (extreme rainfall)
  - Larger changes in the North and more uniform everywhere else.
  - Changes between 20% to 45% across Canada.



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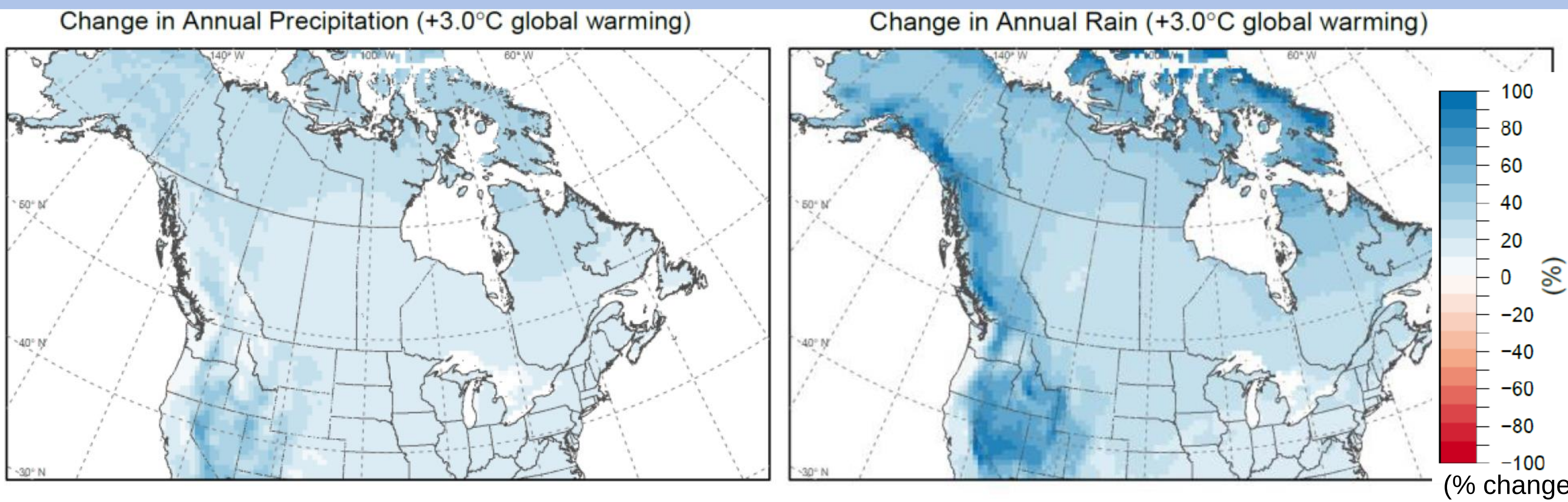
# Projected Changes in Climatic Design Values: Precipitation Design Values

- Spatial pattern of changes.
- For 2080 relative to baseline period (1986-2016).

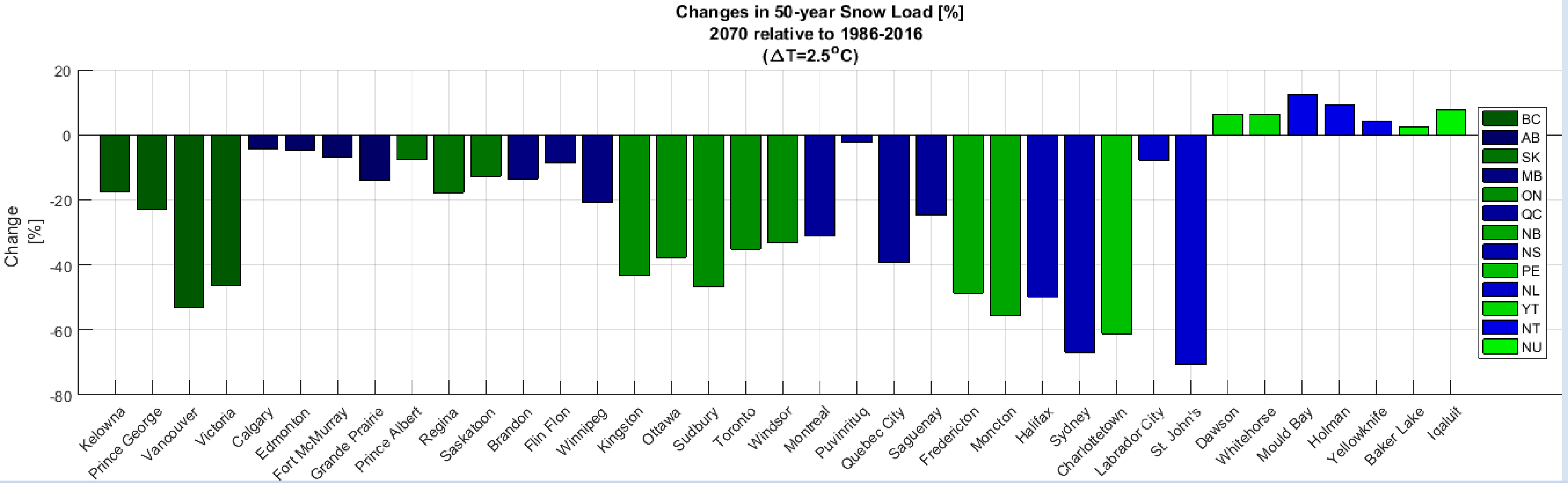



From: ECCC (Canon et al., 2020)

- Annual Rain
  - Greater intensification of rainfall in the North and British Columbia.
- Annual Precipitation
  - Larger percentage changes in the North and western mountainous areas.

# Projected Changes in Climatic Design Values: Snow and Ice Design Values

- For 2070 time horizon relative to 1986-2016.

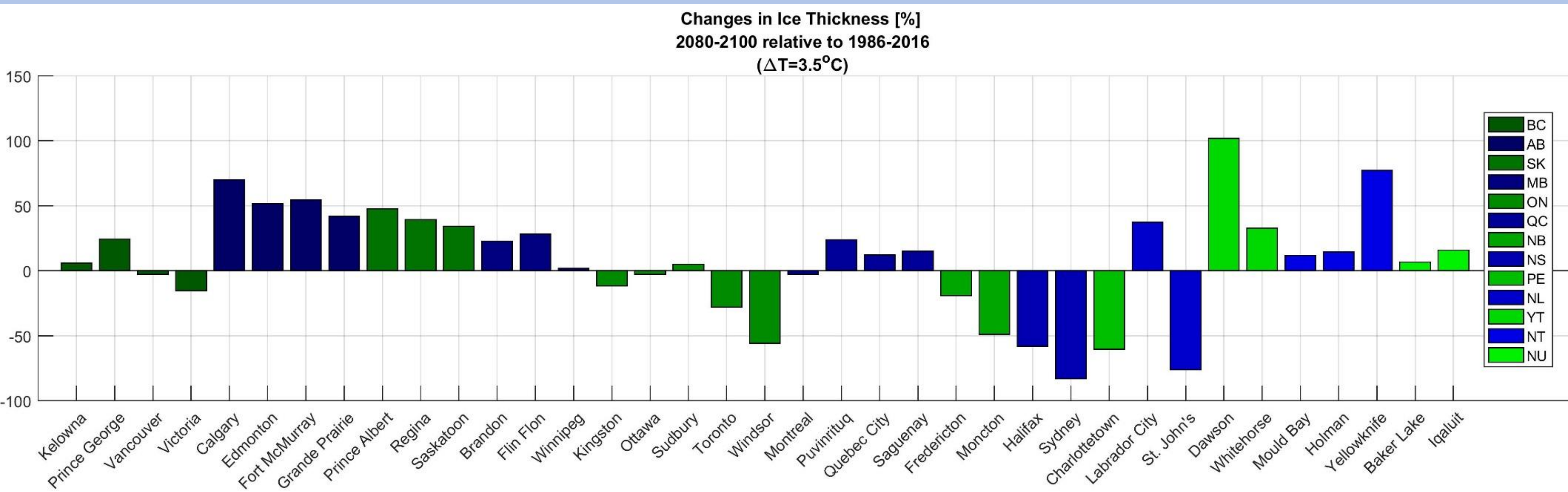



From: ECCC (Canon et al., 2020)

- 50-year Snow Load
  - Overall, snow loads are decreasing due to warmer winters except for the North.
  - Magnitude of change is more uncertain.
  - Decreases in projected snow loads are significant in southern Canada.
  - NOTE: RCP8.5 may lead to greater risk associated with the underestimation of snow loads.

# Projected Changes in Climatic Design Values: Snow and Ice Design Values

- Ice accretion: Combined extreme.
- For end of century relative to 1986-2016.

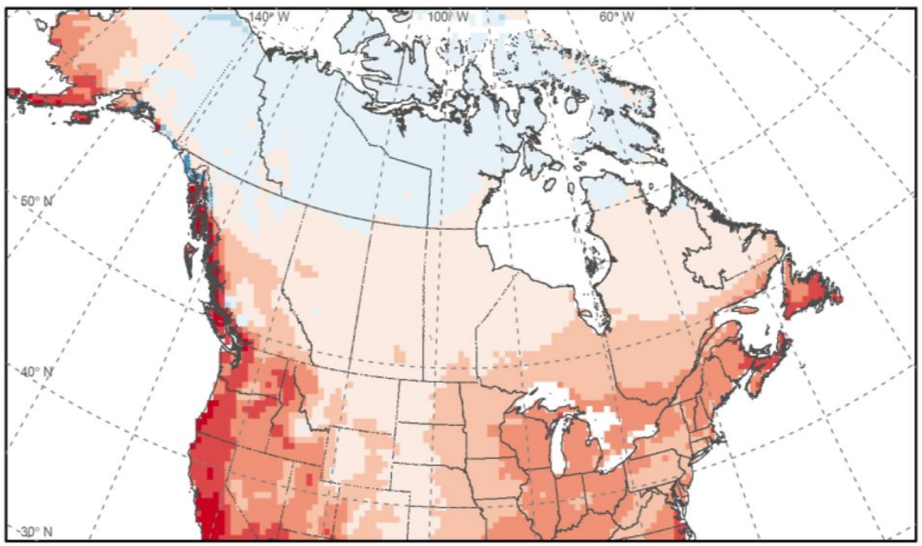


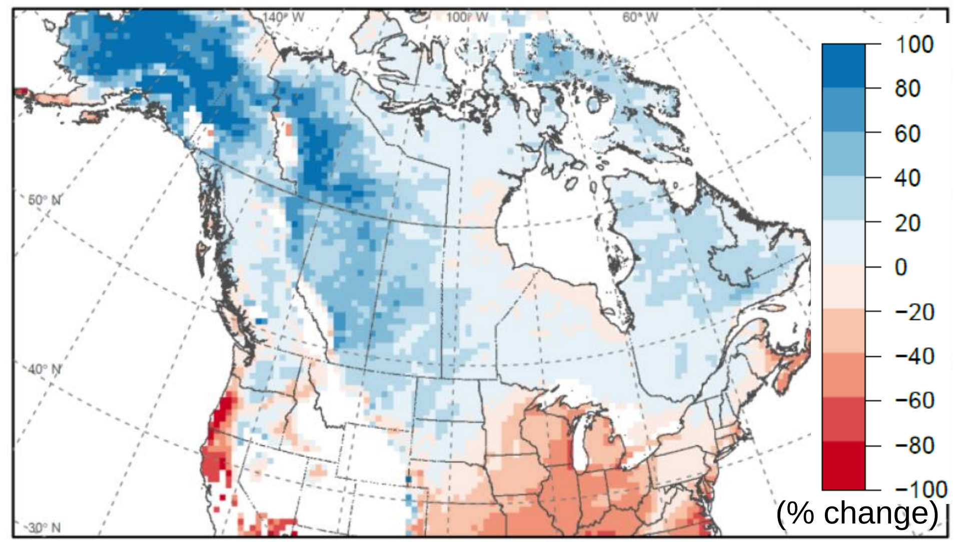

From: ECCC (Canon et al., 2020)

- 20-year ice thickness:
  - Ice accretion loads decrease over the Atlantic region, but increase over Prairies and North regions with potential substantial magnitude of increases for higher latitudes.

# Projected Changes in Climatic Design Values: Snow and Ice Design Values

- Spatial pattern of changes.
- For 2080 relative to baseline period (1986-2016).




From: ECCC (Canon et al., 2020)

- Snow loads will decrease over most of Canada, however, the magnitude of change in the snow load is more uncertain, particularly in areas with complex terrain such as mountainous areas.
- Projections indicate likely decreases in the snow load over British Columbia, Prairies, Ontario, Quebec, and Atlantic regions while slightly increases by 6% in the North.



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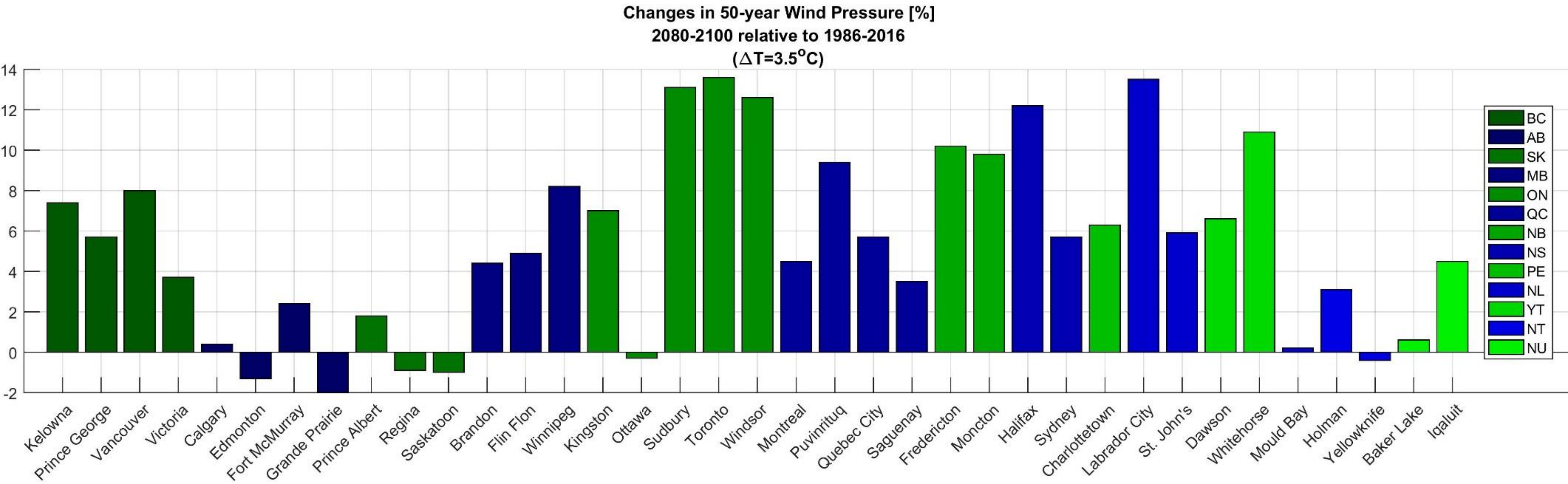
# Projected Changes in Climatic Design Values: Wind Load Design Values

- For end of century relative to 1986-2016.

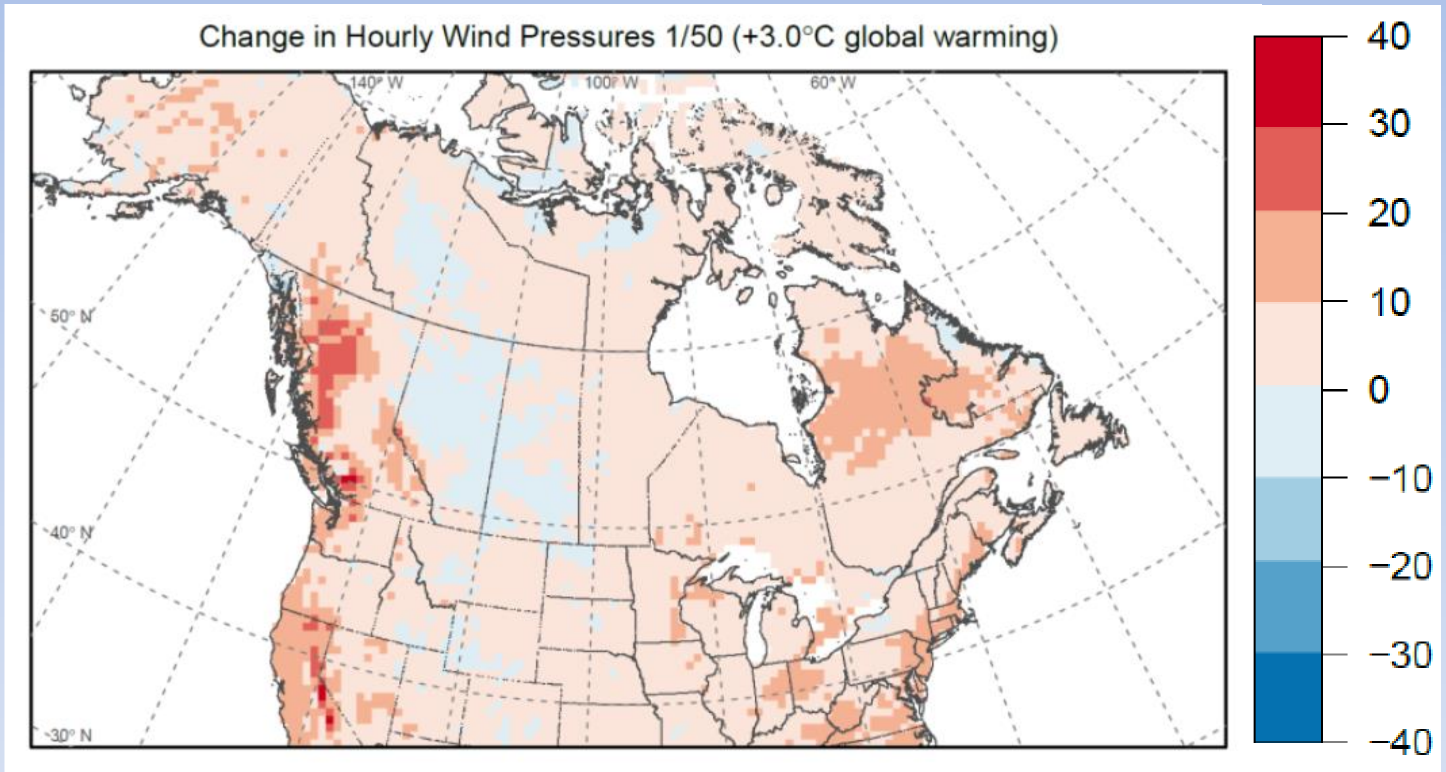



From: ECCC (Canon et al., 2020)

- 50-year Wind Load (end of century):
  - It is important for bridge infrastructure design.
  - Decreases at some stations and increases at other locations (-7% to 33%).

# Projected Changes in Climatic Design Values: Wind Load Design Values

- Spatial pattern of changes.
- For 2080 relative to baseline period (1986-2016).



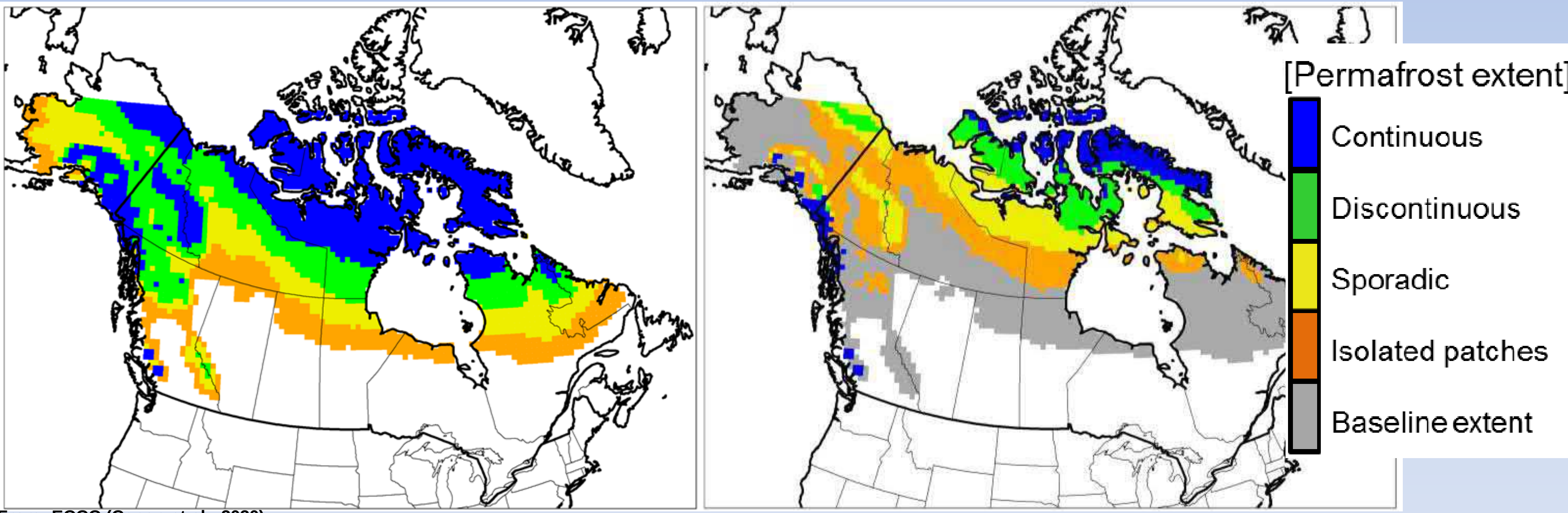

From: ECCC (Canon et al., 2020)

- Future changes in wind load over Canada will be relatively small. The wind load decreases at some stations and increases at other locations.

# Projected Changes in Climatic Design Values: Permafrost Extent

- Very high confidence in continued degradation of future near-surface permafrost extent over northern Canada.
- permafrost area decreases by around 16% per 1°C of global temperature increase.

**map of near-surface permafrost extent**




From: ECCC (Canon et al., 2020)

**1998**

**2080**
**(grey shows extent for 1986-2016 baseline period)**

# Summary

- The average warming across Canada is approximately twice the global average, with even greater warming occurring in the North.
- The extreme hot and extreme cold temperatures will increase (become warmer) across Canada, with larger warmings in locations in the North and British Columbia.
- Annual rainfall is expected to increase across Canada.
- Extreme rainfalls are projected to increase between 20% and 30% for most of the locations in Canada, except the North where the average increase is 35%.
- Snow loads will decrease over most of Canada, except for the North with a slight increase. The magnitude of change in the snow load is more uncertain, particularly in areas with complex terrain such as mountainous areas.

# Summary

- The future ice accretion loads increase in some locations while decreases in other. It is projected to increase for most of locations at higher latitudes.
- Future changes in wind load over Canada will be relatively small. The wind load decreases at some stations and increases at other locations (-7% to 33%).
- Selection of RCP emission scenario and appropriate time horizon for projection of changes in climatic design values depend on the infrastructure design life.

# Thank You

Wildfire smoke, Edmonton, Thursday, 30 May 2019
Ian Kucerak / Postmedia

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Photo credit: M. Davies

# Understanding and Adapting to Coastal Hazard Risk in Canada's Changing Climate

## 1 February 2021

National Research Council Canada | Conseil national de recherches Canada

Canada

# Coastal Hazards and Climate Change – Risk and Opportunity

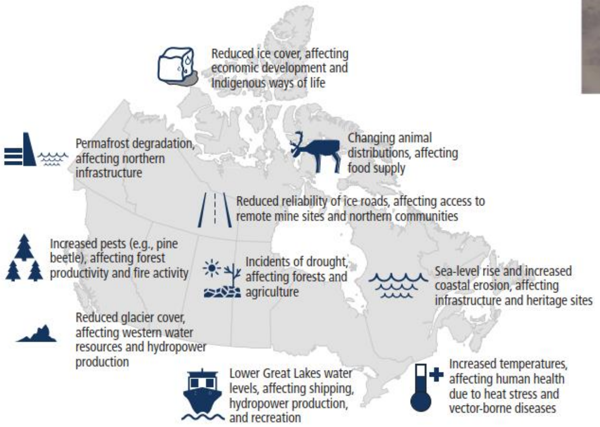
Risks to:

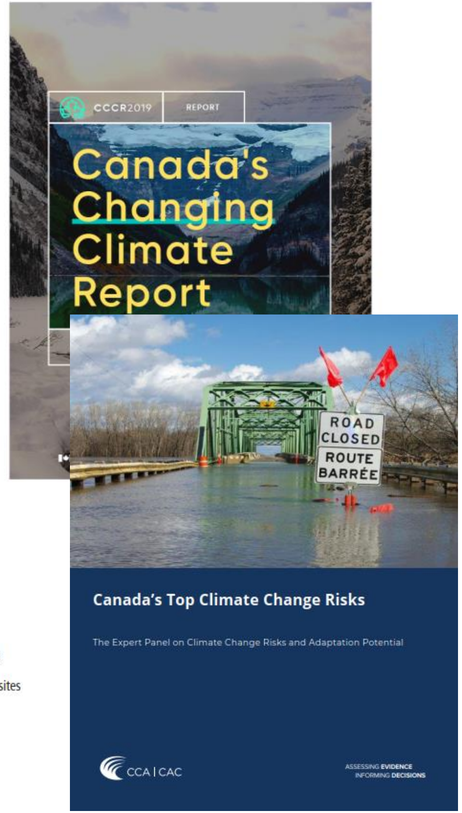
- Physical infrastructure
- Coastal communities


Photo credit: M. Davies

Opportunities to:

- Better **understand** risks
- **Adapt** (be strategic, build back better, leverage co-benefits)



# Climate-Resilient Buildings & Core Public Infrastructure

- Decision support tools, codes, guides and models for the design and retrofitting of buildings and Core Public Infrastructure to enhance climate resilience
- Flooding emerged as a key focus area
- Limited guidance on coastal flood hazard risk in building and infrastructure design codes and standards
- Opportunity to enable improve understanding of coastal flood hazard risk to support design of resilient buildings and infrastructure

# Coastal Flood Risk Assessment Guidelines

**Scope:**

- A framework and **methodology** for conducting coastal flood hazard and risk assessments to inform the design and rehabilitation of buildings and infrastructure in areas potentially exposed to coastal flood hazards.
- Identify data needs and sources
- Recommendations for establishing design criteria for buildings and infrastructure to address coastal flood risk

# Coastal Flood Risk Assessment Guidelines

**Target audience:**

- Designers of buildings and infrastructure on Canada’s marine and Great Lakes coasts
- Professionals involved in design for retrofitting of buildings and infrastructures for coastal flood resilience
- Provincial and municipal authorities or others interested in coastal flood resilience measures for buildings and infrastructure
- Owners and operators of buildings and infrastructure in coastal regions of Canada

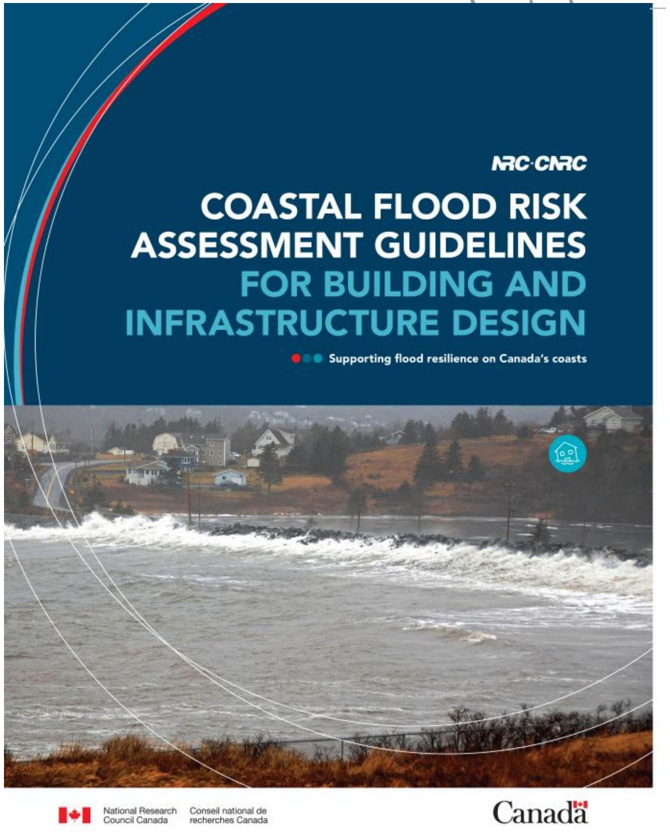
# Coastal Flood Risk Assessment Guidelines

March 2017 – Literature review and scoping study

2018 – Technical Advisory Committee engagement, scope refinement, framework development

2019 – Draft guideline content development (NRC, Ebbwater Consulting, Coldwater Consulting, Baird)

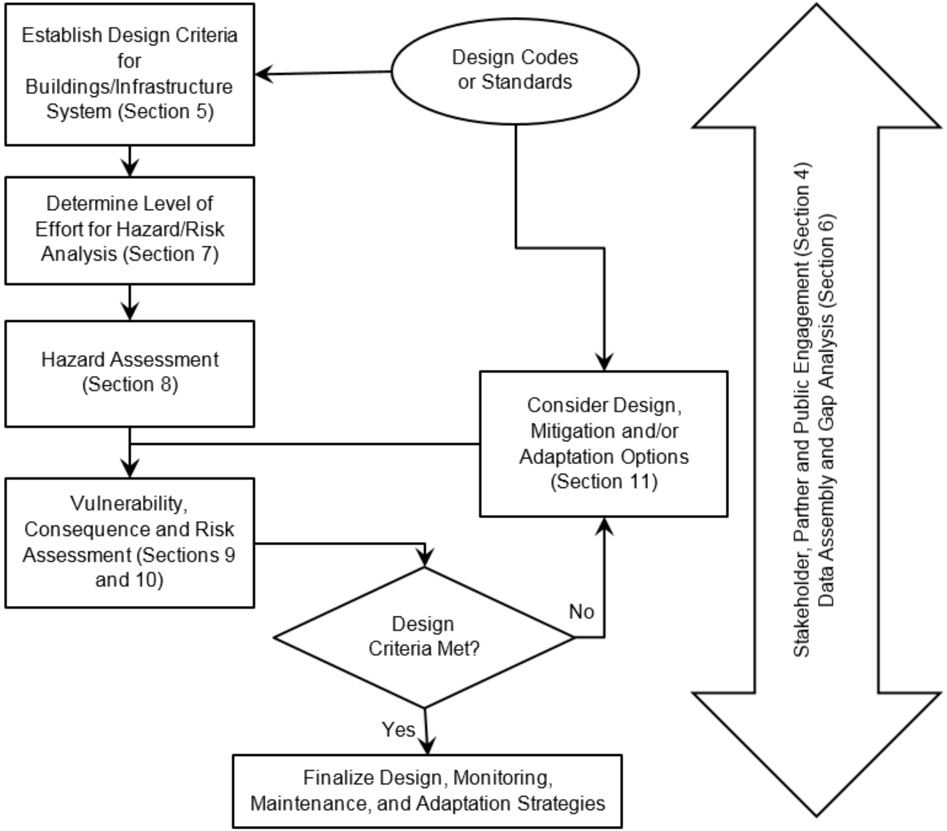
2020 – Advisory committee review of draft guidelines, copy-editing



# CFRA Framework and Guidelines

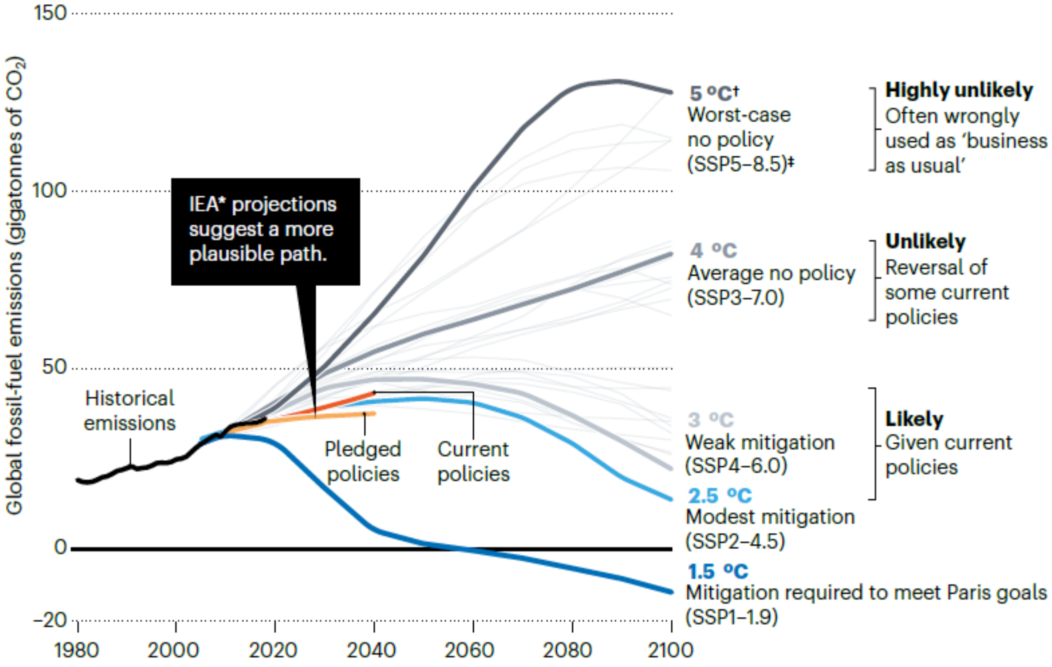
## Key steps/chapters:

- Stakeholder, partner and public engagement
- Establishing risk-based design criteria for the building/infrastructure system(s)
- Data assembly and gap analysis
- Determining appropriate levels of analysis (scalable / tailorable)
- Hazard assessment
- Vulnerability & consequence assessment
- Risk assessment



# Hazard Assessment

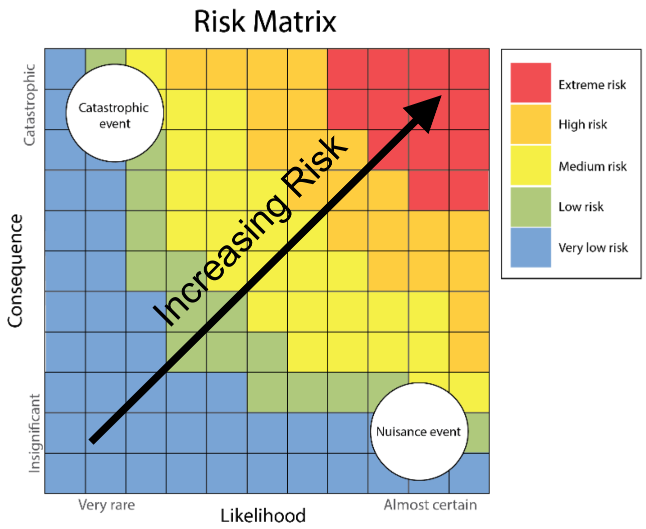
- Sources – water levels, waves, tsunami
- Pathways to flooding – e.g., direct inundation, erosion, overtopping of defences
- Hazard modelling and analysis
- Climate change effects and frameworks for dealing with uncertainty, e.g.:
  - Adaptation pathways
  - Observational method




Hausfather & Peters (2020)

# Recommendations for Risk-Informed Design Criteria

- Design to achieve strategic planning and risk management goals
- Move toward a risk-based approach
- Design considering the criticality of buildings/infrastructure
- Design considering environmental impacts
- Design according to risk tolerance
- Design to mitigate residual risk at the building/infrastructure level
- Design for dynamic future risk
- Design for multiple hazards
- Integrate design within broader flood risk management



# Risk Management Strategies and Linkages to Design

| Strategy | Measures |
| --- | --- |
| **Avoidance** | Restrict development in high risk areas, community protection schemes, early warning systems, emergency response plans, education |
| **Resistance** | Structural strengthening, elevated living areas, scour protection, water-resistant design (dryproofing), debris deflection structures, structural elements (e.g. openings, breakaway panels, mitigation walls, tie-downs, redundancy) |
| **Resilience** | Materials, finishes, construction, wetproofing techniques designed to facilitate emergency response and speedy return to service |
| **Repairability** | Materials (water absorption/retention, drying times, integrity) |

**Residual risk**

**Implementation**

Land use planning regulations, zoning, by-laws, flood protection/prevention schemes

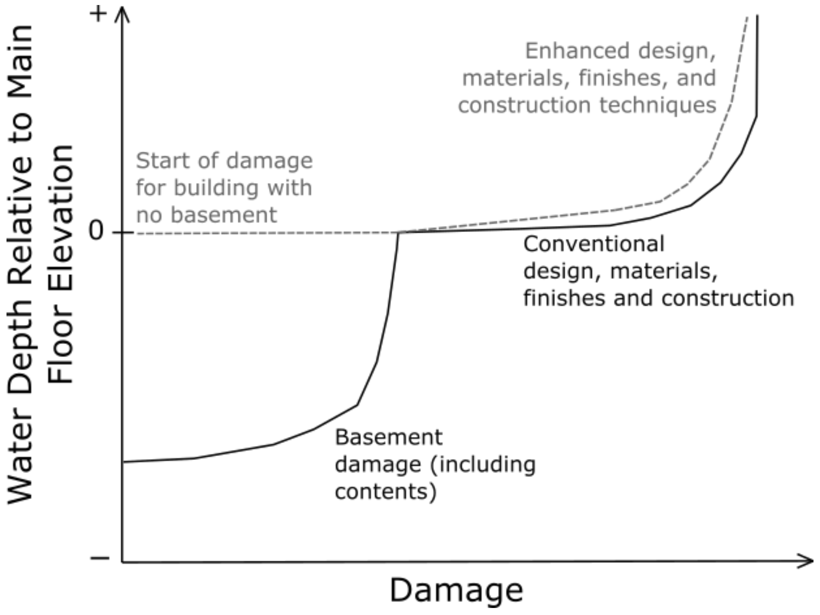
Codes, standards, specifications, design and construction guidance

adapted from Bowker et al. (2007)

# Future Needs

## Identified needs for:

- Improved vulnerability-hazard function datasets
  - ➢ Different types of infrastructure
  - ➢ Influence of design features
  - ➢ Regional differences
- New provisions in building codes and infrastructure design standards
- Integration of flood (and eventually multi-hazard) risk management practices with codes and standards
- Expanded and enhanced hazard datasets (waves, water levels, etc.)



# Future-Looking Hazard Data and Tools

## Climate change impacts on ice conditions, waves, storm surges and water levels

## Digital information systems to support risk assessment and inform adaptation strategies

- High resolution regional climate model projections
- Detailed numerical modelling to predict future ice conditions, waves and storm surges
- Statistical analyses to identify significant changes and estimate future design conditions
- Digital information systems to communicate expected future conditions to stakeholders and inform adaptation planning

**COLLABORATIONS**

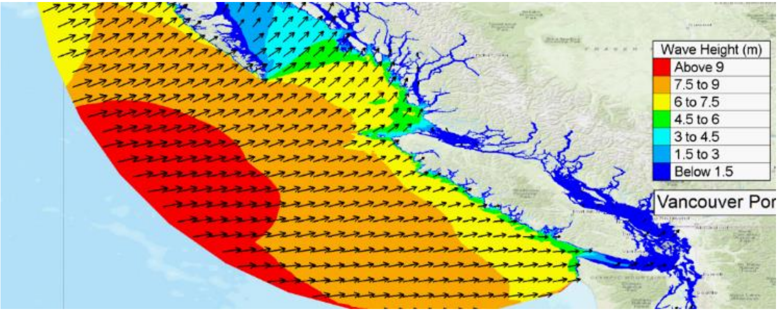
Transport Canada

DFO (Canadian Coast Guard)

University of McGill

University of Victoria

Canadian Port Authorities




# Adapting to Changing Coastal Flood & Erosion Risks – Nature-based Solutions

## Nature-Based Solutions

*"…actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits."* (IUCN Global Standard for NbS, 2020)

- Explosion of interest and research in the past two decades
- Arguably, not a new concept – founded on "whole system" principles
- Increasing understanding of societal and environmental co-benefits

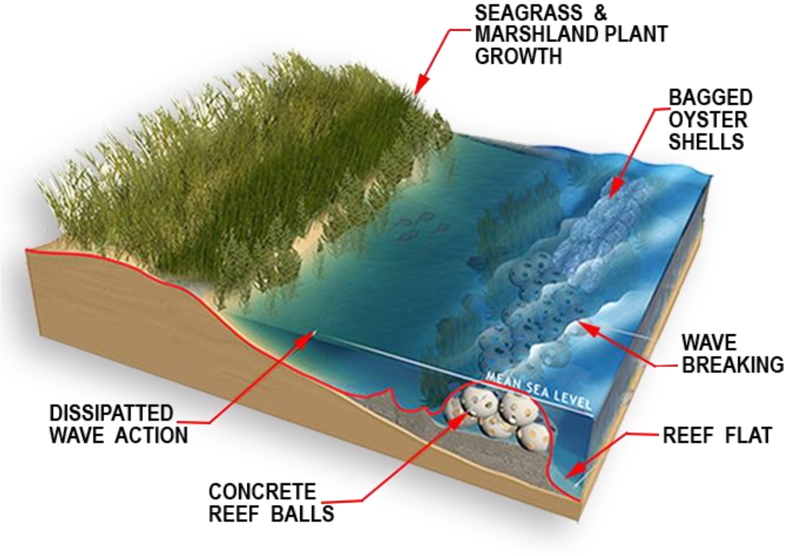
Photo credit: E. Murphy

# NbS for Coastal Hazard Risk Management

**Key principles:**

- Natural coastal systems (beaches, dunes, wetlands, reefs, islands, headlands, etc.) provide:
    - Buffers against coastal flooding and erosion (e.g. dissipate waves and storm surges, promote sediment retention)
    - Hydraulic storage capacity
    - Surface water run-off control

- Deliver variety of co-benefits (social, economic, environmental, cultural)




Source: https://ewn.el.erdc.dren.mil/nnbf.html#

# NbS for Coastal Hazard Risk Management

Natural | Hybrid | Conventional

Nature-based

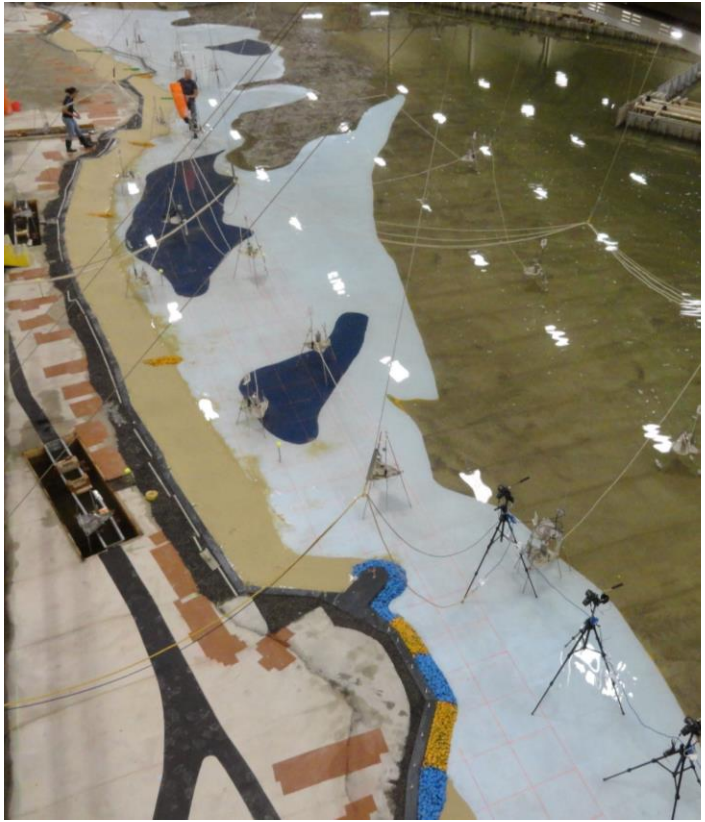
Green | Grey

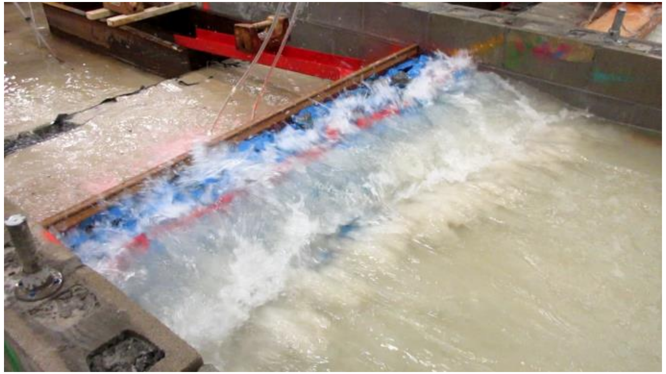
Photo credits: D. van Proosdij (left), M. Davies (centre), E. Murphy (right)

# Understanding NbS Performance in the Lab

# Understanding NbS Performance in the Lab

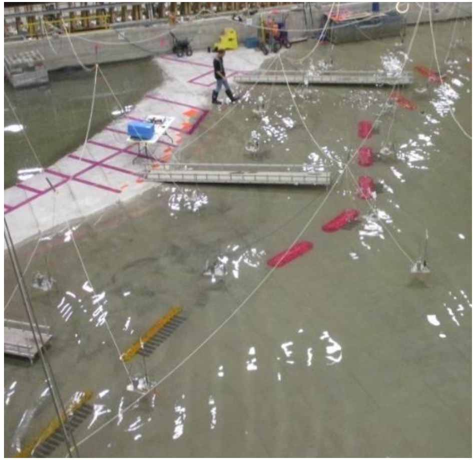
- Beach nourishment schemes
- Gravel / cobble beaches
- Buried revetments

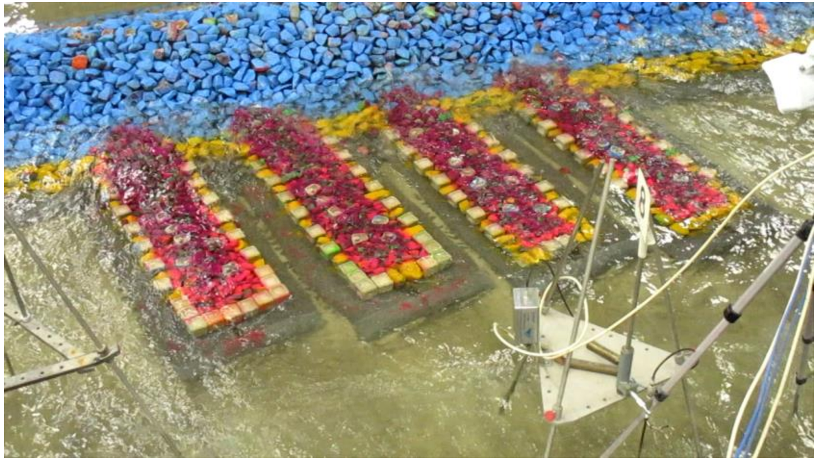




# Evaluating NbS Performance – Living Breakwaters

1.6 km long system of nearshore breakwaters to attenuate storm waves, reduce coastal erosion and flooding, and restore oyster habitat by incorporating bio-enhancing concrete blocks





# New Partnerships
# - Collaborative Research

**Research to address key knowledge gaps limiting the use of NbS for coastal flood and erosion risk management in Canada**

- Field investigations and monitoring (4+ sites in Canada)
- Digital twinning and development of numerical design tools
- Laboratory experiments
- Development of design guidance
- Demonstrate how NbS can be deployed to maximize co-benefits

Photo credit: D. van Proosdij

https://ewn.el.erdc.dren.mil/nnbf-guidelines.html

## Collaborations

International: US Army Corps of Engineers (Engineering With Nature), NOAA, Rijkswaterstaat, UK Environment Agency, HR Wallingford, Deltares, World Wildlife Fund, World Bank

Federal OGDs: DND-DRDC, NRCan, ISC, CIRNAC, INFC

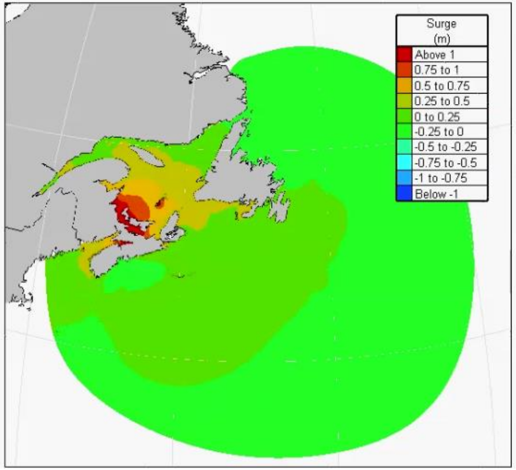
Communities: City of Surrey, Metlakatla First Nation, Semiahmoo First Nation, First Nations Emergency Planning Secretariat

Academia: University of Ottawa, Queen's University, Saint Mary's University, INRS, Dalhousie, MUN

Private / Non-Profit: CSA Group

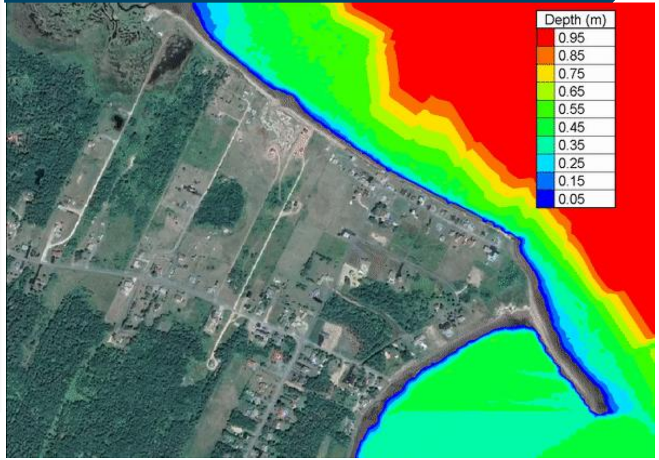
# Design of NbS is informed by scale!

## Regional



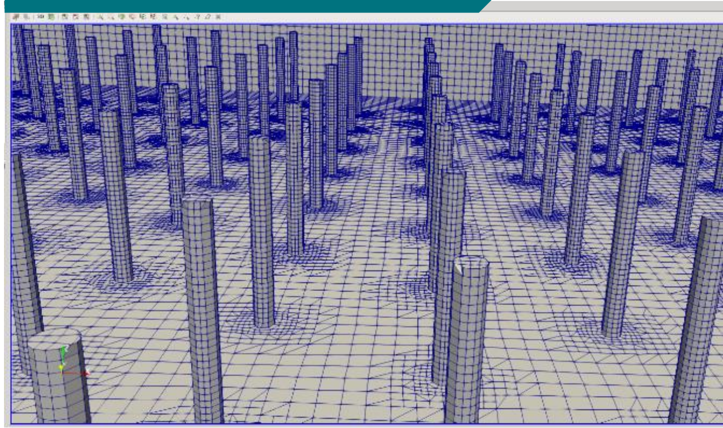

- Characterize tide- and wind-driven hydrodynamics, waves, sediment transport and morphology change
- Impacts on regional hydrodynamics

## Intermediate / Local




- Overland flow and inundation
- Storm-driven erosion
- Wave run-up, overtopping and interactions with shoreline / vegetation
- Performance of nature-based features

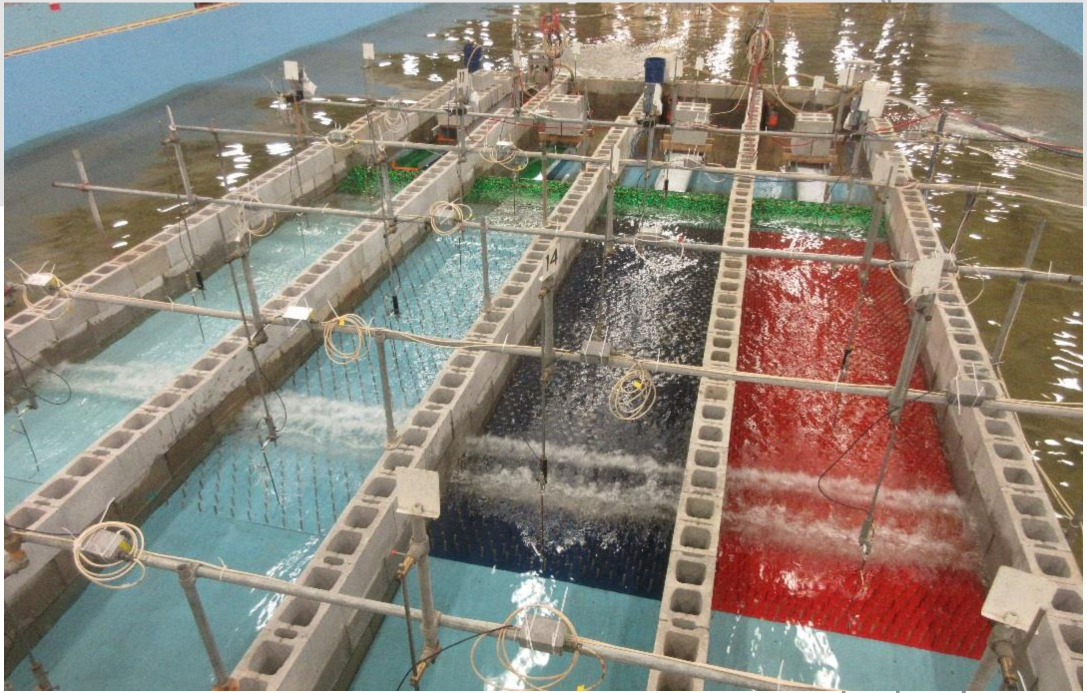
## Feature / Plant



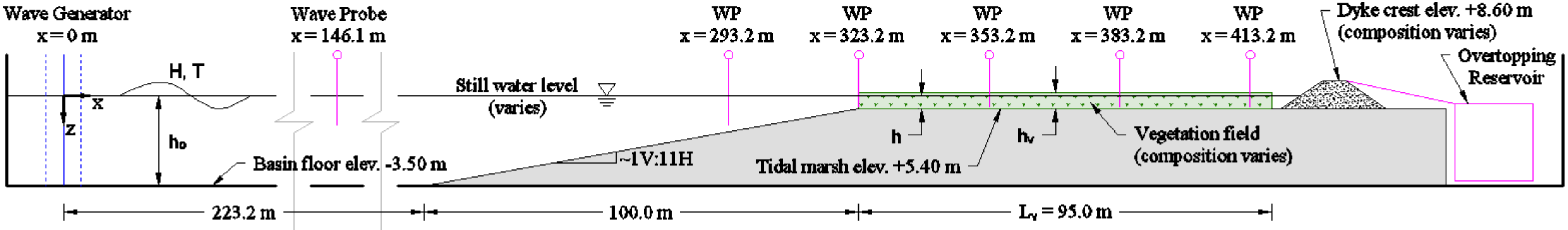
Focus on understanding key processes, e.g.:

- Attenuation of waves by vegetation
- Wave run-up, overtopping and interactions with coastal features and individual plants

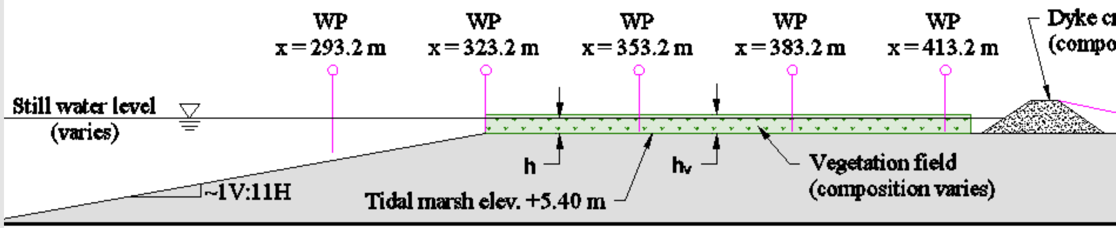
# From the Field to the Lab – Chignecto, NB



## Profile View (Scale 1V:0.5H)

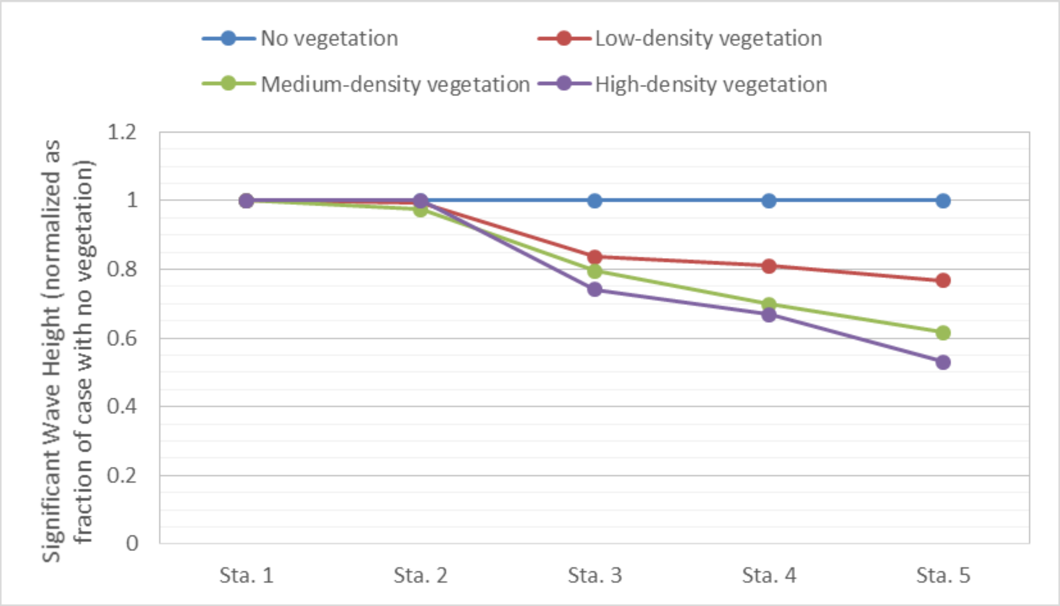


# Benefits of Marsh Systems




## Effect of vegetation density on wave attenuation

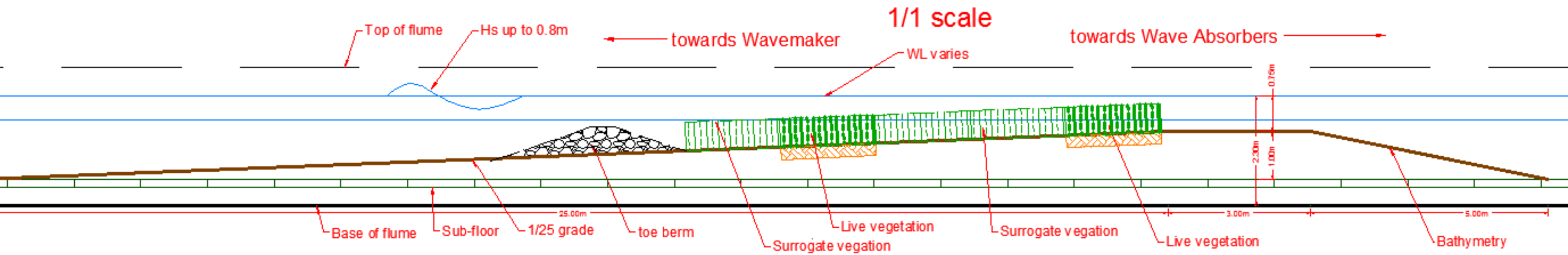
- Effect of wave breaking removed
- Data averaged across a wide range of wave heights, periods, and water depths



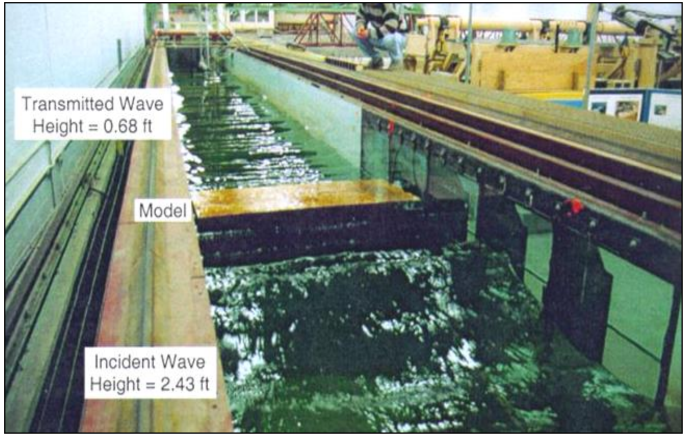

## Also investigated…

- Sensitivity to vegetation density
- Sensitivity to vegetation height
- Sensitivity to vegetation flexibility
- Sensitivity to water levels
- Sensitivity to wave conditions
- Reduction in wave overtopping
- Reduction in damage to dyke

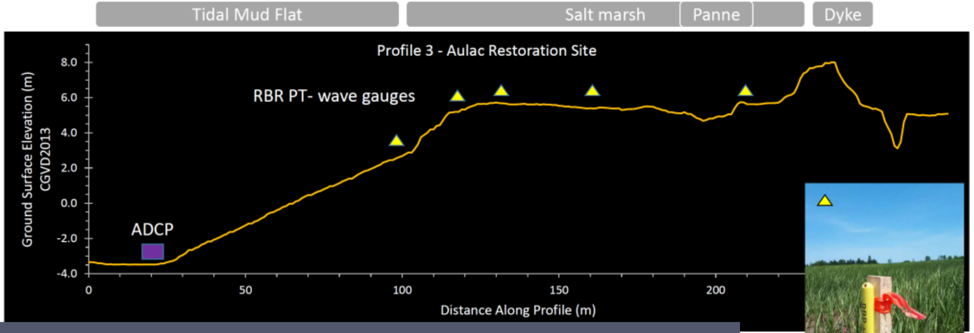
# Next Steps – Living Dike

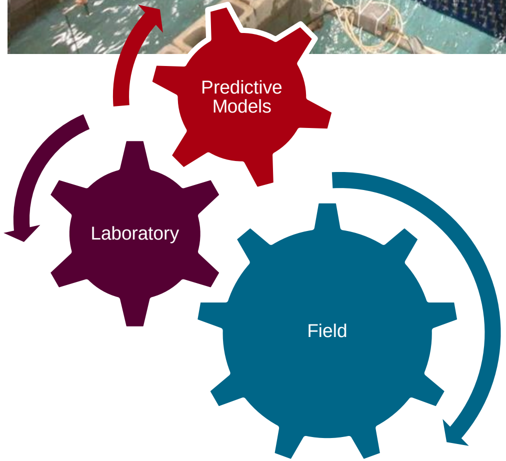


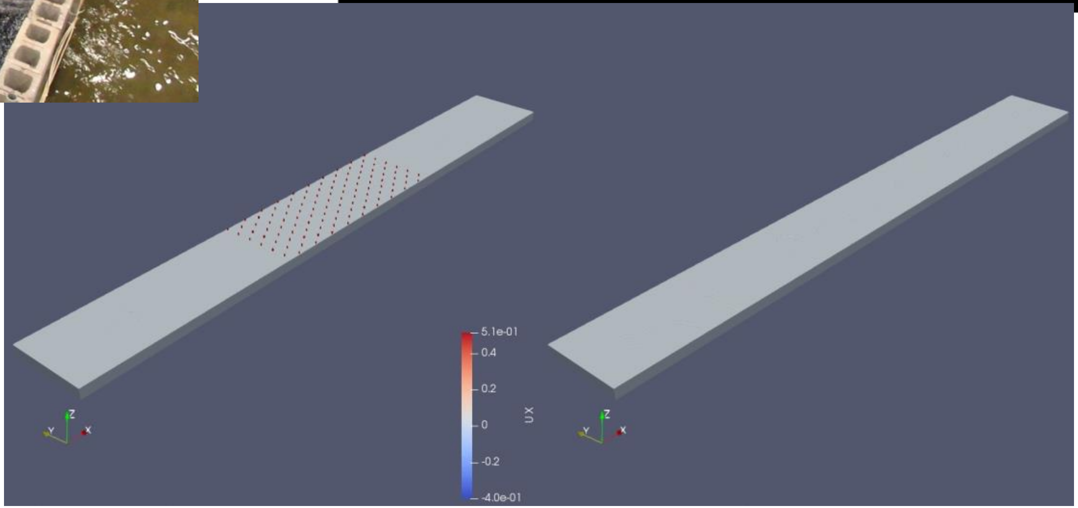

Side View



# Research Activity Linkages

# Concluding Thoughts

- Understanding hazard risk and anticipating change are vital first steps in developing resilient coastal communities and infrastructure – requires thoughtful approaches

- Nature-based Solutions can play a much greater role in supporting resilient, sustainable communities and infrastructure on Canada's coasts
- Some of the barriers/enablers to be addressed:
  - Technical (performance, distinct regional differences)
  - Coastal zone management frameworks – need for "whole system" approaches
  - Perceptions
  - Valuation of co-benefits

- Multi-disciplinary, collaborative research and solutions needed

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# THANK YOU

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