ONTARIO CLIMATE CONSORTIUM

Welcome

Integrating Climate Change Information into Watershed Planning

Peter Love, Chair of the OCC

June 11th, 2018
Black Creek Pioneer Village

www.climateconnections.ca

With support from: York Université University, McMaster University, Western, Region of Peel Working for you, University of Guelph, Toronto and Region Conservation for The Living City

Ontario Climate Consortium

Figure 1. The OCC's Collaborative Model.

The OCC was established in 2011 as a centre of expertise providing research and analysis services to municipalities, conservation authorities, and the broader public sector.

Secretariat:

- Glenn Milner, Project Manager
- Ian McVey, Project Manager
- Frances Delaney, Research Analyst
- Jenessa Doherty, Coordinator
- Kristina Dokoska, Coordinator
- Sharon Lam, Coordinator

Toronto and Region Conservation for The Living City · YORK UNIVERSITÉ UNIVERSITY · McMaster University · Region of Peel Working for you · Western University · Canada · University of Guelph

Objectives of Today's Forum

To **understand** what climate information currently exists and how it can be included in Watershed Planning;

To **facilitate** open discussion on ideas, needs & examples on climate data and watershed planning;

To **connect** watershed planning experts in Ontario with those working in climate information; and

To **share** knowledge and experience of how climate change could be considered in watershed plans.

ONTARIO CLIMATE CONSORTIUM

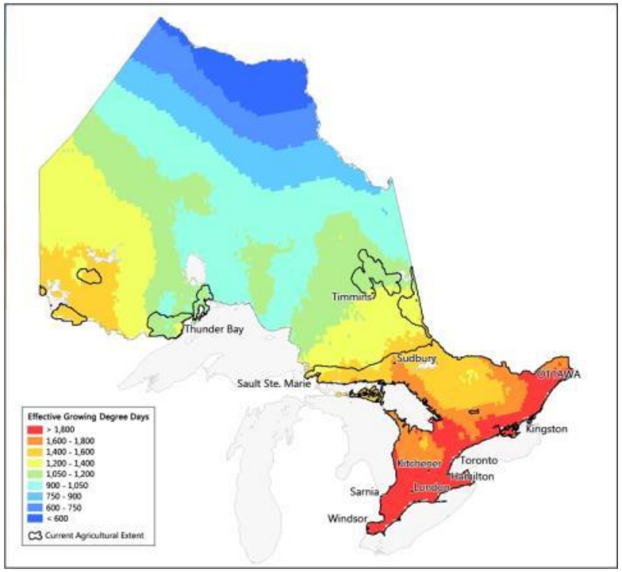
A Brief Introduction to Climate Information and its Translation

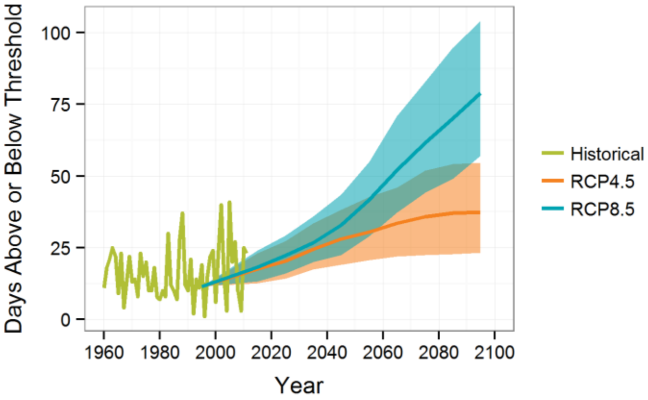
Glenn Milner, Ontario Climate Consortium

With support from: York University, McMaster University, Western, Region of Peel Working for you, University of Guelph, Toronto and Region Conservation for The Living City

What is Climate Information?

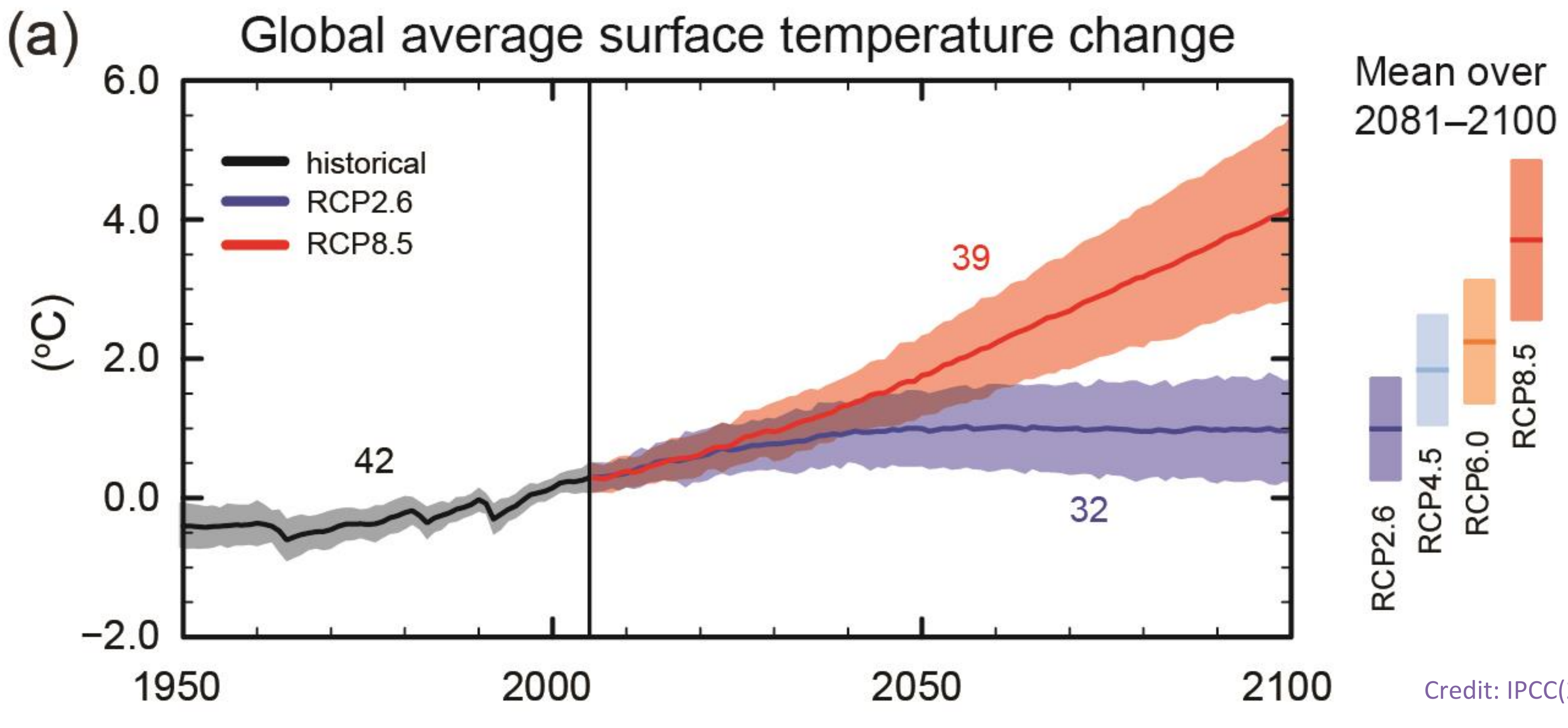
- Climate Information is the interpretation of observed and modeled data
- Information is processed and comes in a meaningful form – generates knowledge
- Confidence limits, variability, etc.





Adapted from: UNEP (2009) Climate information and capacity needs for Ecosystem Management under a Changing Climate.

Why do we need Climate Information?



Credit: IPCC(2013)

To understand the exposure to hazards to humans, infrastructure, and other systems.

Climate Information Requires Effective Communication

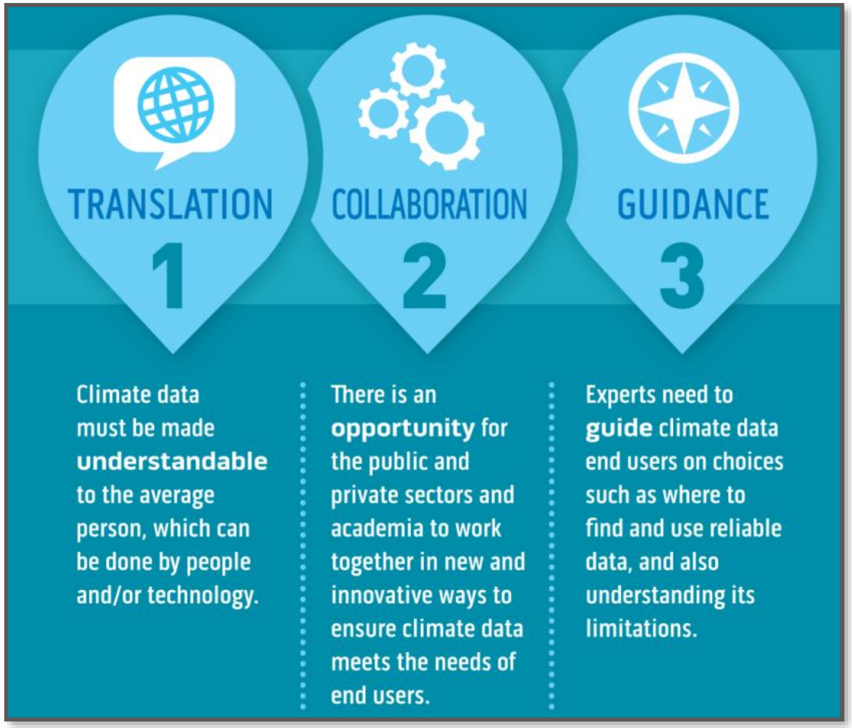
The Challenge

Confusion with climate data slows adaptation

Data on climate change can get "lost in translation"

- Environmental Commissioner of Ontario, 2015

The Response



Climate information must be communicated and transferred efficiently depending on the user 's needs to convey the optimal meaning – OURANOS (2014)

Climate change information in Studies and Plans

Increasing:

- Parameter complexity
- Resolution
- Specificity
- Level of effort
- Uncertainty

Typical uses

Basic:

General trends for adaptation planning

Intermediate:

Characterizations for risk and vulnerability assessments

Advanced:

Scenarios for modeling and quantitative analysis.

Adapted From: Charron, I. (2014). *A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions*. Ouranos, p. 86

Confidence in Climate Information

- Temperature, Extreme Heat: **Very Likely** Increase
- Extreme Cold: **Very Likely** Decrease
- Precipitation, Extreme Precipitation: **Likely** Increase*
- Wind Velocity: **About as Likely as Not** to remain unchanged

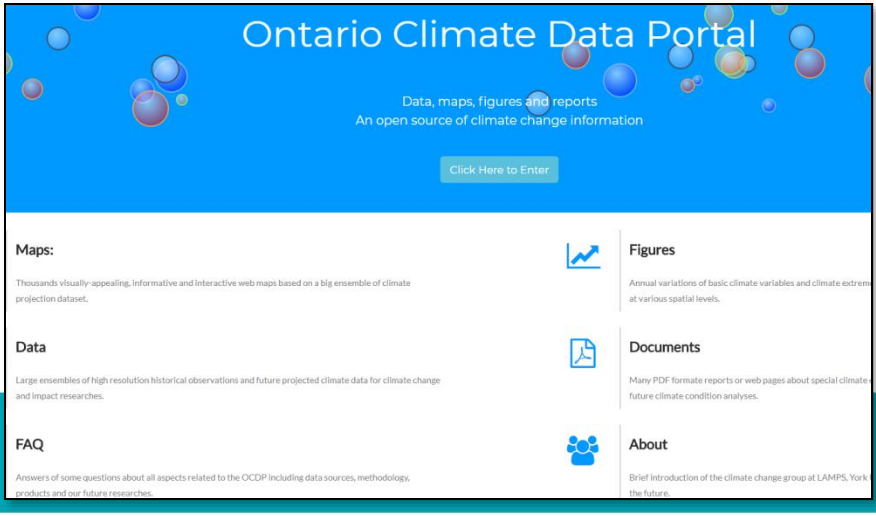
Term	Likelihood of the Outcome
Virtually certain	99 – 100% probability
Very likely	90 – 100% probability
Likely	66 – 100% probability
About as likely as not	33 – 66% probability
Unlikely	0 – 33% probability
Very unlikely	0 – 10% probability
Exceptionally unlikely	0 – 1% probability

**Likely more precipitation overall, however more will fall as short-isolated events. Greatest increases are winter & spring.*

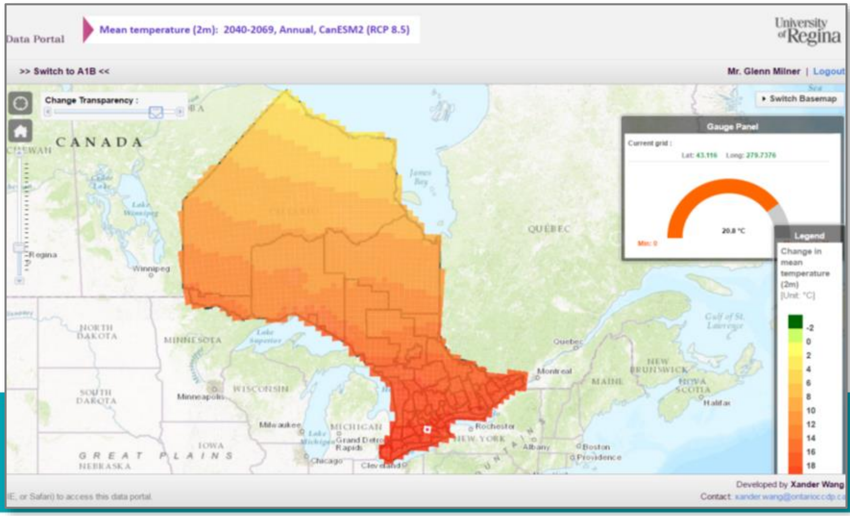
Remember…

- Climate data is **available**, and is becoming more **accessible** & **understandable** – it should be leveraged
- Climate data **cannot be used in isolation**, and a “single best scenario” does not exist (instead, think: **range of futures to stress test**).
- Consider the best use of data in specific contexts, while taking stock of broader approaches that can help address uncertainty

YorkU’s Climate Projections Portal
http://lamps.math.yorku.ca/OntarioClimate/



Ontario Climate Change Data Portal
www.ontarioccdp.ca



Watershed Planning in Ontario: Adapting to a New "Climate"

Laura Del Giudice, Senior Manager, Watershed Planning & Reporting, TRCA

Bonnie Fox, Manager, Policy & Planning, Conservation Ontario

Ontario Climate Consortium Forum
June 11, 2018

The Living City Foundation

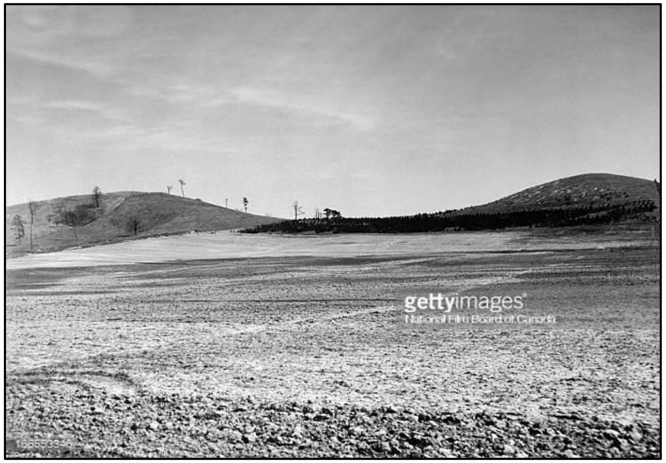
Toronto and Region Conservation for The Living City

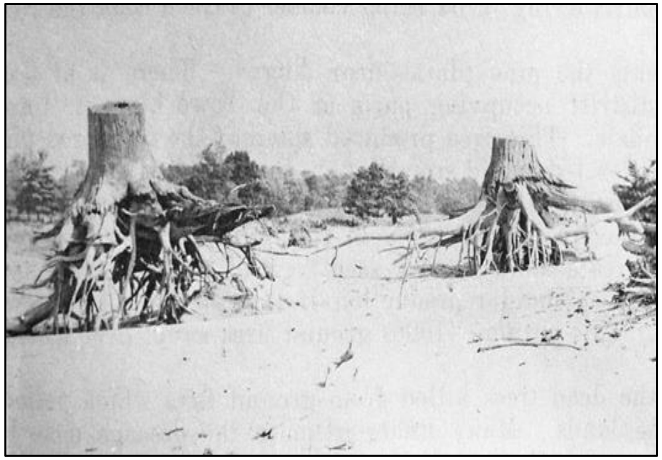
Member of Conservation Ontario

Discussion Points

1. What is watershed planning?
2. Why watershed planning needs to consider climate change
3. The evolving provincial policy context for watershed planning and direction on climate change
   - Provincial land use plans
   - Conservation Authorities Act review

History of Watershed Management



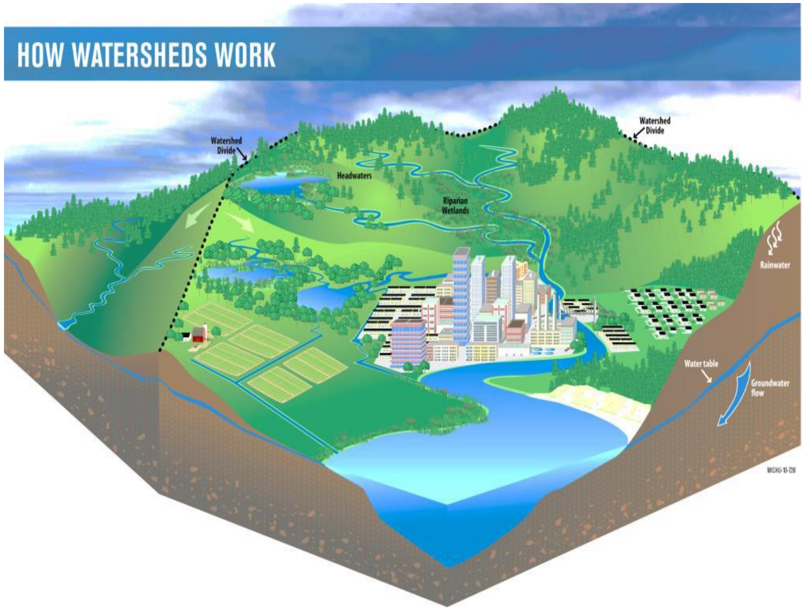


Community Dimensions

Ecological Dimensions

What's in a watershed plan?

1. Existing watershed conditions
2. Assessment of the impact of future changes
3. Recommendations for long-term, sustainable protection and restoration of watershed health



Emerging Issues

Ongoing Rapid Urbanization and Intensification

Green infrastructure

Climate change

Ecosystem Services

Climate Change and Watersheds

- More frequent severe weather events, including high intensity rainfall
- More rapid and frequent snowmelts
- More frequent and prolonged droughts
- Longer ice free periods on lakes
- Changes to stream and wetland hydrology

Some Resulting Effects

Societal Impacts:

- Increased flooding and erosion
- Poorer water quality; greater costs required to treat water
- Greater competition for water supplies
- Reduced flow and water levels in rivers, lakes, streams and groundwater

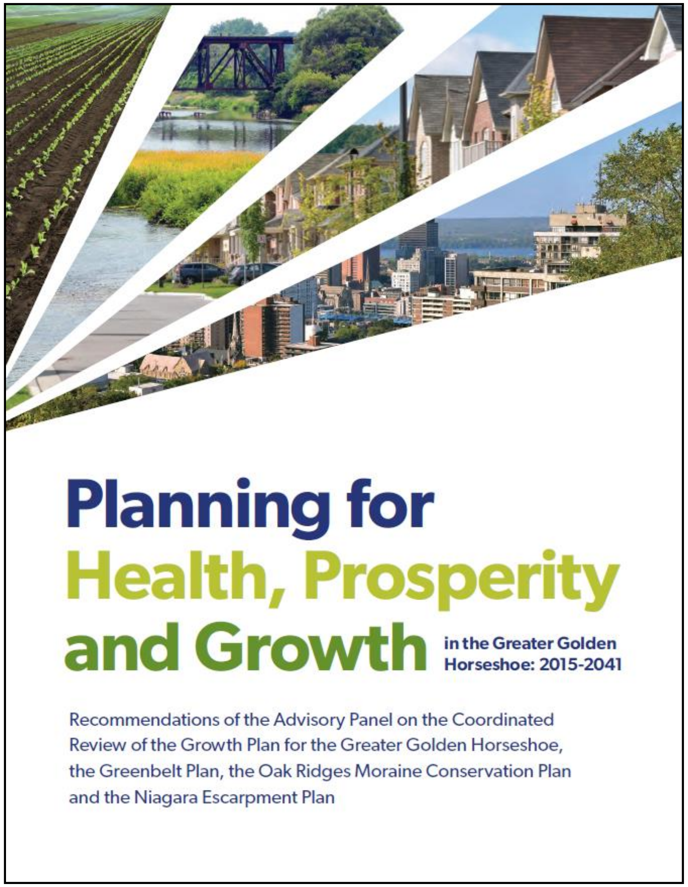
Ecosystem impacts:

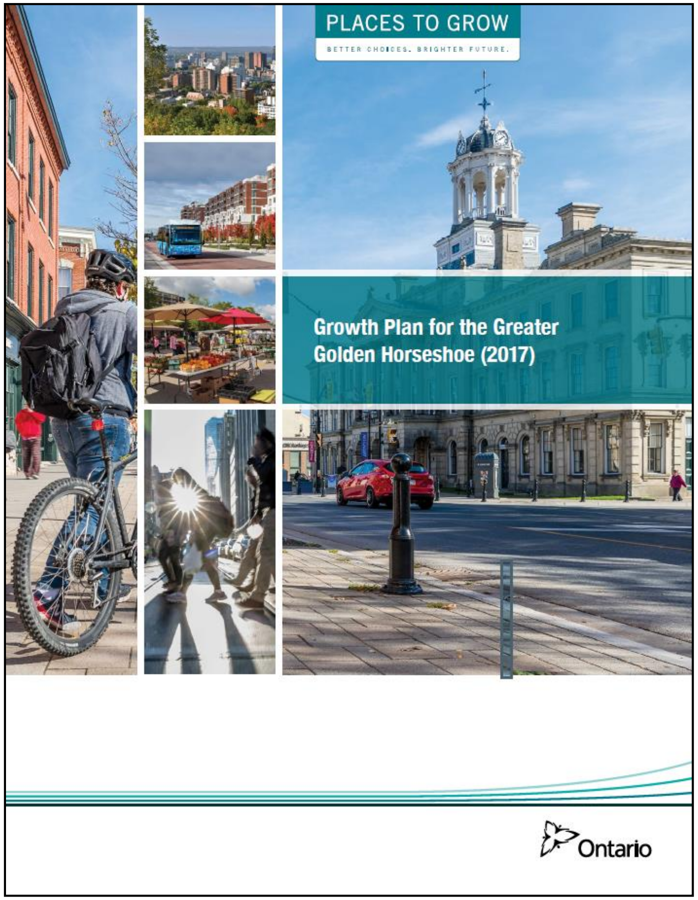
- Diminished cold water fisheries, and sensitive water-dependent wetland habitats and species
- Increase in invasive species

Preparing for Climate Change Through Watershed Planning

- Assess and prepare for the combined impacts of climate change, land use change and other factors
- Develop green infrastructure and natural heritage strategies that build resilience
- Design management actions that are viable in both current and potential future climates
- Apply **adaptive management** to evaluate and adjust on an ongoing basis

Coordinated Land Use Plan Review





Watershed Planning Now Must Inform:

- Where growth can occur
- Water and wastewater servicing
- New or expanded infrastructure
- Stormwater management plans
- Protection of water resources

Connecting watershed planning, climate change, and land use planning

Integrate climate change considerations into planning and managing growth such as planning for more resilient communities and infrastructure that are adaptive to the impacts of a changing climate…

…Recognizing that watersheds are the most important scale for protecting the quality and quantity of water, municipalities are required to undertake watershed planning to inform the protection of water resource systems and decisions related to planning for growth.

-Guiding Principles, Growth Plan for the Greater Golden Horseshoe

Formalizing Provincial Guidance

Watershed Planning in Ontario

Guidance for land-use planning authorities

DRAFT February 2018

Ontario

6.4 CLIMATE CHANGE & WATERSHED MANAGEMENT

How to do it?

Currently, there is no common list of best practices for climate adaptation, since climate change and its impacts vary from one location to another, and communities vary in their exposure and capacity to cope. Visions, risk tolerance, capacities, and other factors vary from community to community, so even those facing similar risks and opportunities may make different adaptation choices on a watershed basis.

Organizations such as ICLEI Canada have been working to assist municipalities and other planning authorities with climate change mitigation and adaptation. ICLEI has a range of useful resources and programs for municipalities to consult in undertaking climate adaptation projects. Also, organizations such as Federation of Canadian Municipalities have provided support to communities seeking to plan for and adapt to impacts of climate change. Information sources provided in this section should be consulted to gain insight into potential impacts of climate change, and potential mitigation/adaptation strategies.

The following steps provide considerations and tools for addressing climate change on a watershed basis:

Conservation Authorities Act Review Outcomes 2015-2017

Bill 139: *Building Better Communities and* ***Conserving Watersheds*** *Act* December 12, 2017

Conserving our Future: A Modernized CAA (June 2017) plan for moving forward

Purpose Statement (new)

Purpose

The purpose of this Act is to provide for the organization and delivery of programs and services that further the conservation, restoration, development & management of natural resources in watersheds in Ontario

"Powers" (retained)

21 (1) For the purposes of accomplishing its objects, an authority has power,

(a) to study and investigate the watershed and to determine programs and services whereby the natural resources of the watershed may be conserved, restored, developed and managed; …

CAA (new)

Programs and Services

The following are the programs and services that an authority is required or permitted to provide within its area of jurisdiction:

1. Mandatory programs and services that are required by regulation
2. Municipal programs and services that the authority agrees to provide on behalf of municipalities… in jurisdiction under a MOU
3. Such other programs as the authority may determine are advisable to further its objects

Addressing Climate Change in Program and Service Regulation(s) (new)

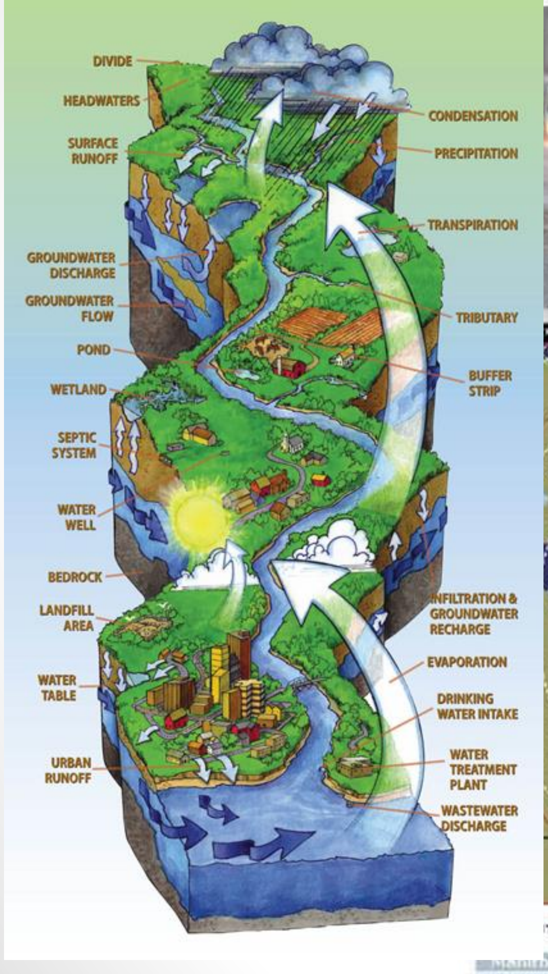
40(2) The standards and requirements established for programs and services in a regulation made under clause (1) (c) may include standards and requirements to ***mitigate the impacts of climate change and provide for adaptation to a changing climate, including through increasing resiliency.***

Conserving our Future (pp14-15)

the MNRF intends … to propose regulations to outline the roles and responsibilities of CAs, and provide greater certainty, including:

- ➢ Natural Hazard Management
- ➢ Plan Review
- o Wetland Conservation
- o Climate Change (with MOECC)
- o Watershed planning and management (with multi-ministry working group)

Watershed Planning and Climate Resilience in Ontario



In Closing…

- Approaches for effectively incorporating climate considerations into watershed planning and land use planning are needed

- Changes in provincial policy and the *Conservation Authorities Act* provide an opportunity to:

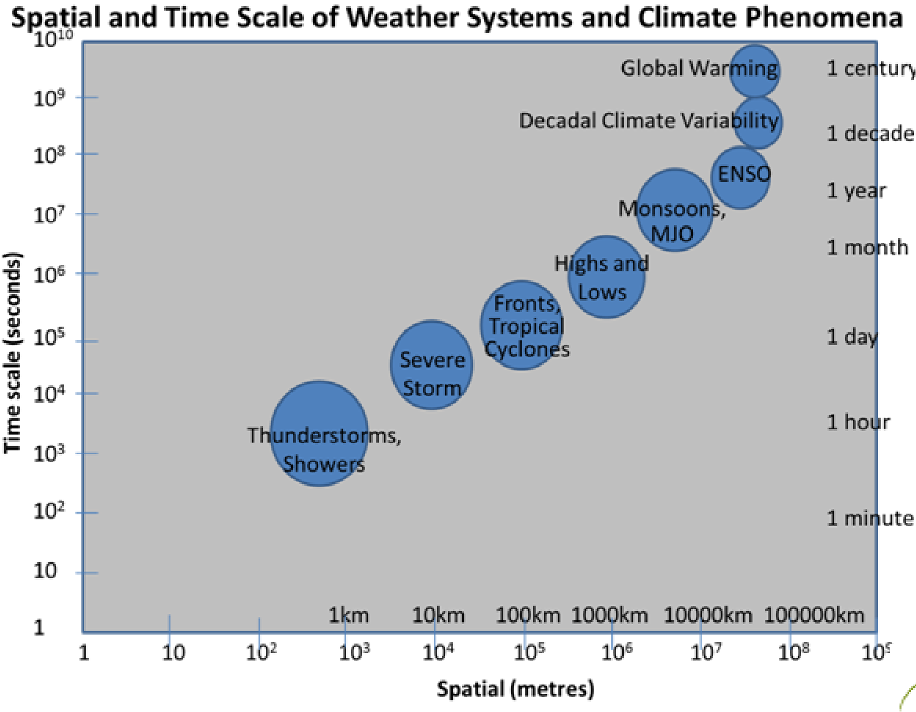
  - Work collaboratively towards common, state-of-the-art technical and non-technical approaches for considering climate and land use impacts together

  - Collectively consider how watershed planning can be a tool for building climate resilience in communities through application of these approaches

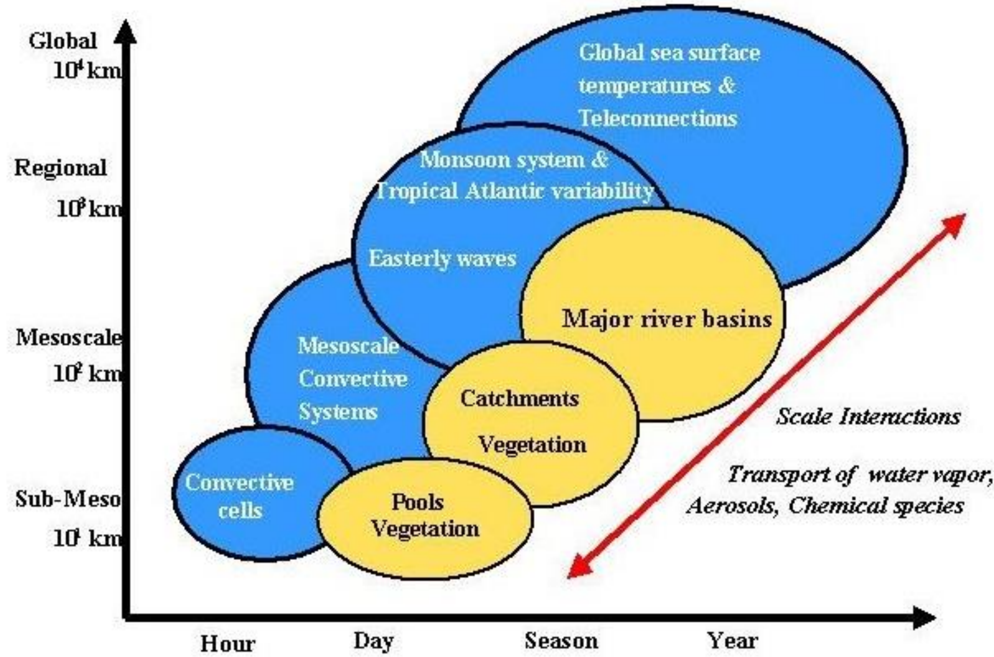
CLIMATE INFORMATION and SERVICES for WATERSHED PLANNING

Heather Auld, M.Sc.(Meteorology)
Principal Climate Scientist
Risk Sciences International

Different Spatial Scales

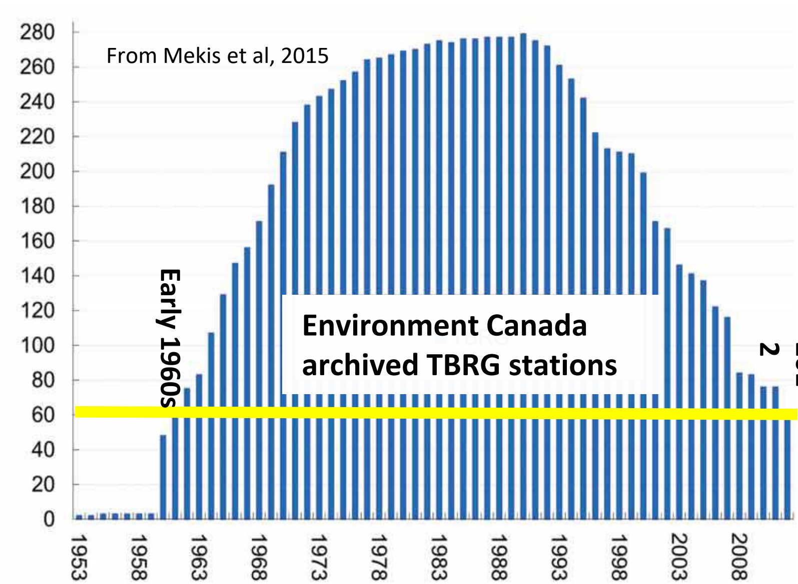


Different Temporal Scales

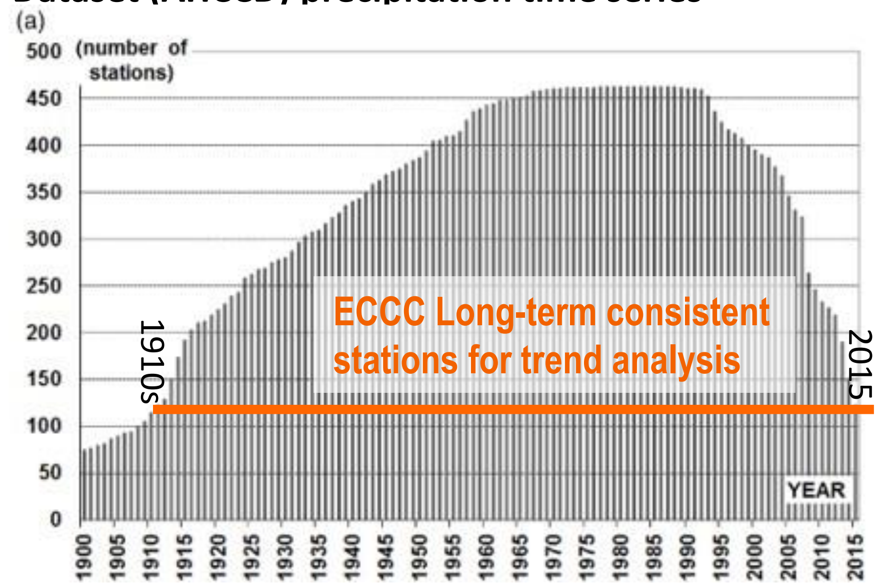


A wide variety of weather and climate events drive flood risks (drought too). Each likely responds differently under climate change.

Trends in Number of archived TBRG stations



Trends in the # of Adjusted and Homogenized Climate Dataset (AHCCD) precipitation time series



Adapted from Environment and Climate Change publications (Mekis et al, 2015, 2018)

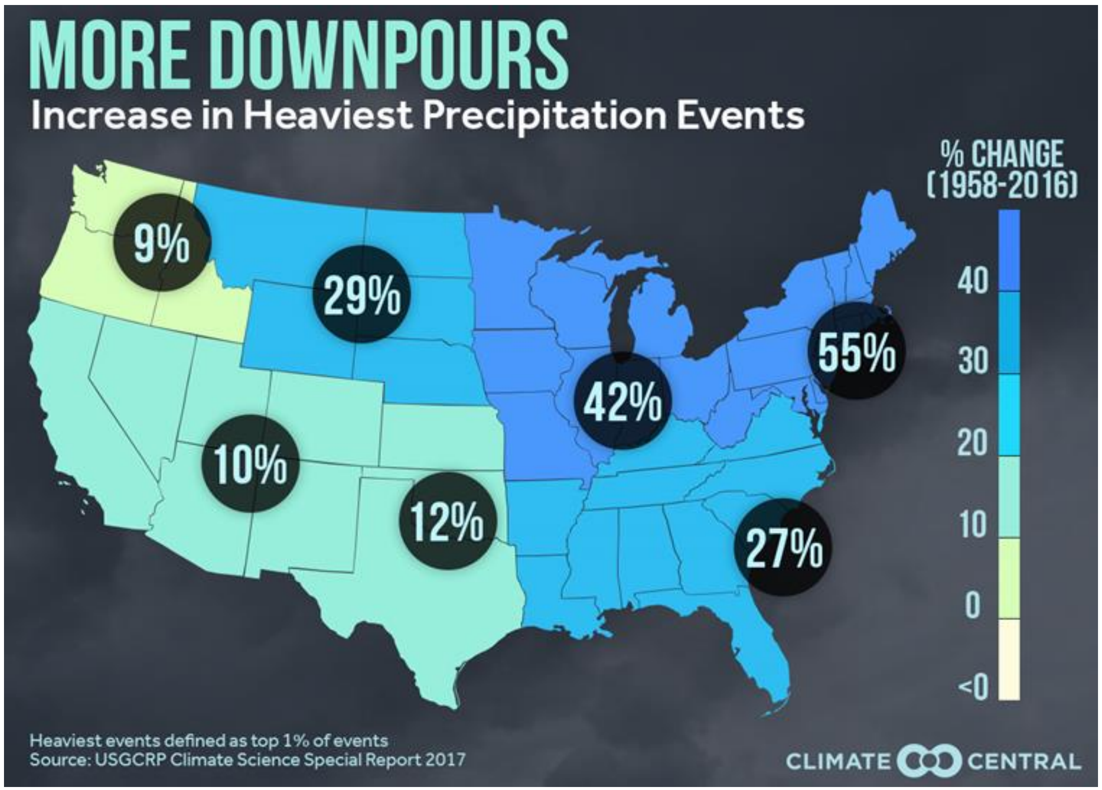
State of the Existing Climate Data – Declining # stations, Declining quality

Use of <u>outdated</u> or unrepresentative IDF curves can result in critical under-design or expensive over-design of key water infrastructure

RSI

Compare with U.S. Extreme Rainfall Networks and Climate Trends

*Mekis et al. (2015) … only two-thirds of the higher quality IDF stations used in Canada have sufficient data to compute **trends** in rainfall intensities (about 185 stations).*



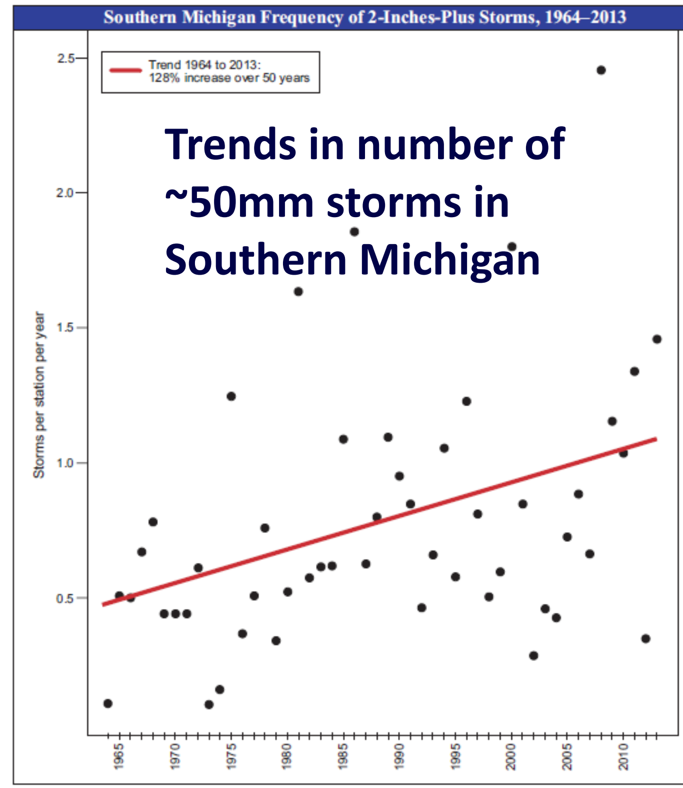


Figure 5. As Figure 1 on page 3, except with respect only to southern Michigan, defined here as the Lower Peninsula south of latitude 44 north. See the Appendix for details of sources and methodology.

Meanwhile…State of Climate Change Information in Canada? Many Portals, Sources…

https://www.slideshare.net/mediambientcat/efforts-in-the-field-of-adaptation-in-the-alpine-space-outcomes-of-the-c3alps-projects-capitalising-climate-change-knowledge-for-adaptation-in-the-alpine-space

RSI

Uncertainties in Climate Change Projections Vary

Most Confident ⟵ More CERTAINTY — Less CERTAINTY ⟶ **Less/Least Confident**

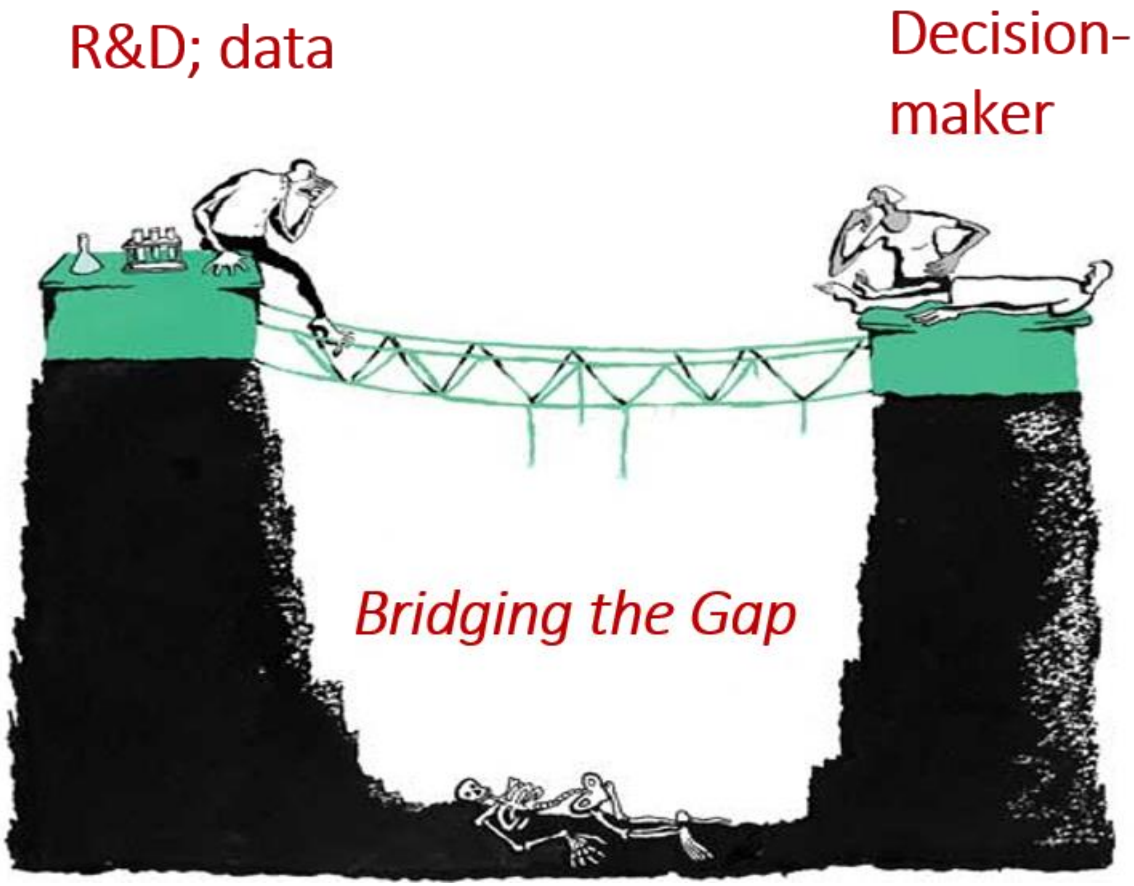
- Longer growing season
- Warmer winters
- More heat waves
- More winter precipitation
- More intense rainfall
- Snow; More severe ice storms
- Increase in wind extremes

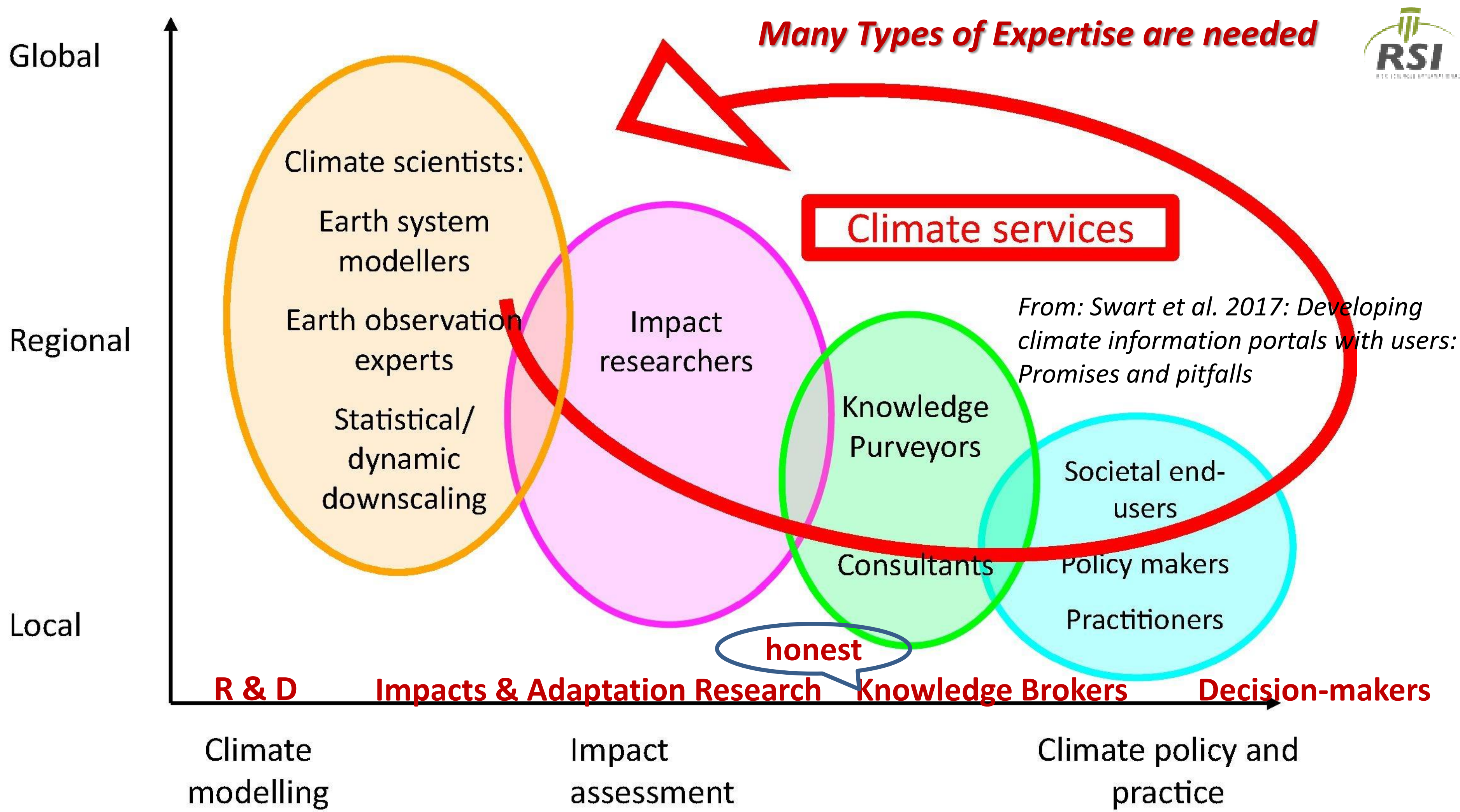
RSI

BUT…
How to get good local to regional climate information…
Bridge the Gaps?

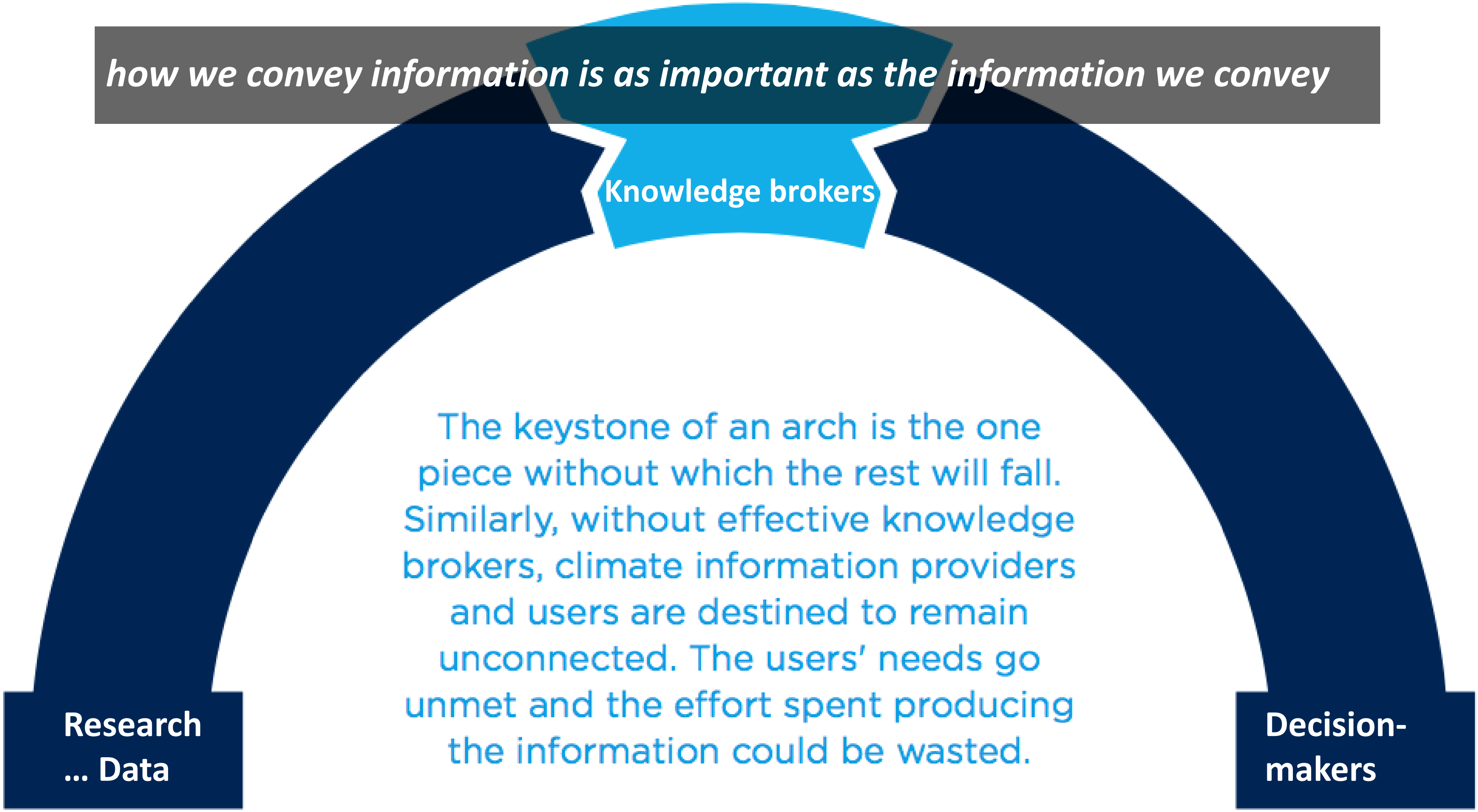
WATERSHED PLANNERS NEED:

- Good data, defensible science
- Decision relevant information
- Some longevity/consistency to information
- Gaps in baseline data "fixed"; more complete data network
- Understanding of uncertainties





Many Types of Expertise are needed
RSI
Global
Regional
Local
Climate scientists:
Earth system modellers
Earth observation experts
Statistical/ dynamic downscaling
Impact researchers
Climate services
Knowledge Purveyors
Consultants
Societal end-users
Policy makers
Practitioners
From: Swart et al. 2017: Developing climate information portals with users: Promises and pitfalls
honest
R & D
Impacts & Adaptation Research
Knowledge Brokers
Decision-makers
Climate modelling
Impact assessment
Climate policy and practice


how we convey information is as important as the information we convey
Knowledge brokers
The keystone of an arch is the one piece without which the rest will fall. Similarly, without effective knowledge brokers, climate information providers and users are destined to remain unconnected. The users' needs go unmet and the effort spent producing the information could be wasted.
Research … Data
Decision-makers

Realities:

- Scientific community agrees climate will continue changing… safety margins needed
- BUT, significant uncertainties over LOCATION, TIMING, MAGNITUDE, sometimes DIRECTION

Assessment of flood hazard projections for Europe – their causes, consequences for decision-making

Conclusion:
Confidence in climate model projections DOES NOT support projections of **amounts** of changes to flood occurrence and flood zone risks (Kundzewicz et al, 2017)

European Flood and CC Risk Studies: An Assessment

- Concluded that many of the CC projection results were not robust and often not supported by observed trends.
- **Recommended Adaptation Approaches:** Iterative policies, flexibility, ability to make adjustments based on new information and learning, diversified flood risk strategies, risk based decision-making and safety margins
- Resilience to floods enhanced if multiple Flood Risk Management Strategies implemented simultaneously and aligned i.e. Increased BACKUPs

Contact:

Heather Auld
Principal Climate Scientist
Risk Sciences International

Email: hauld@risksciences.com

Integrating Climate Information into Watershed Planning

Regional Municipal Perspectives

Christine Tu,

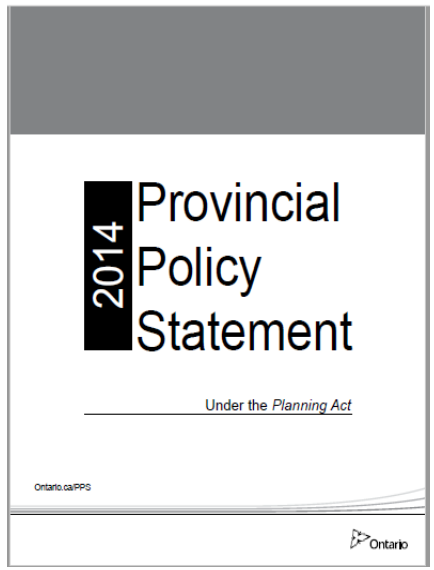
Director, Office of Climate Change and Energy Management

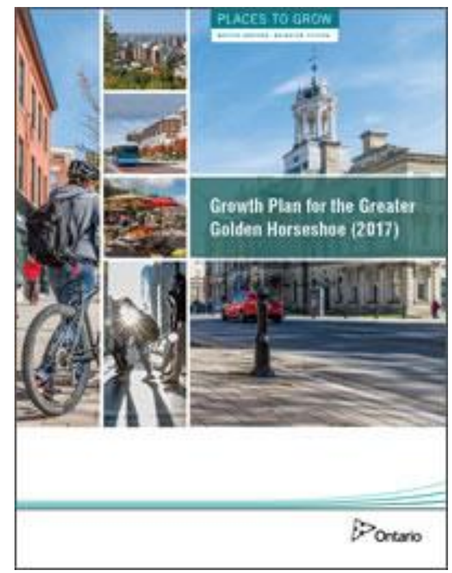
Teresa Cline, Senior Planner, Long Range Planning

Region of Peel working with you

York Region

Land Use Planning Context





Planning **decisions** need to **conform** to Provincial Plans

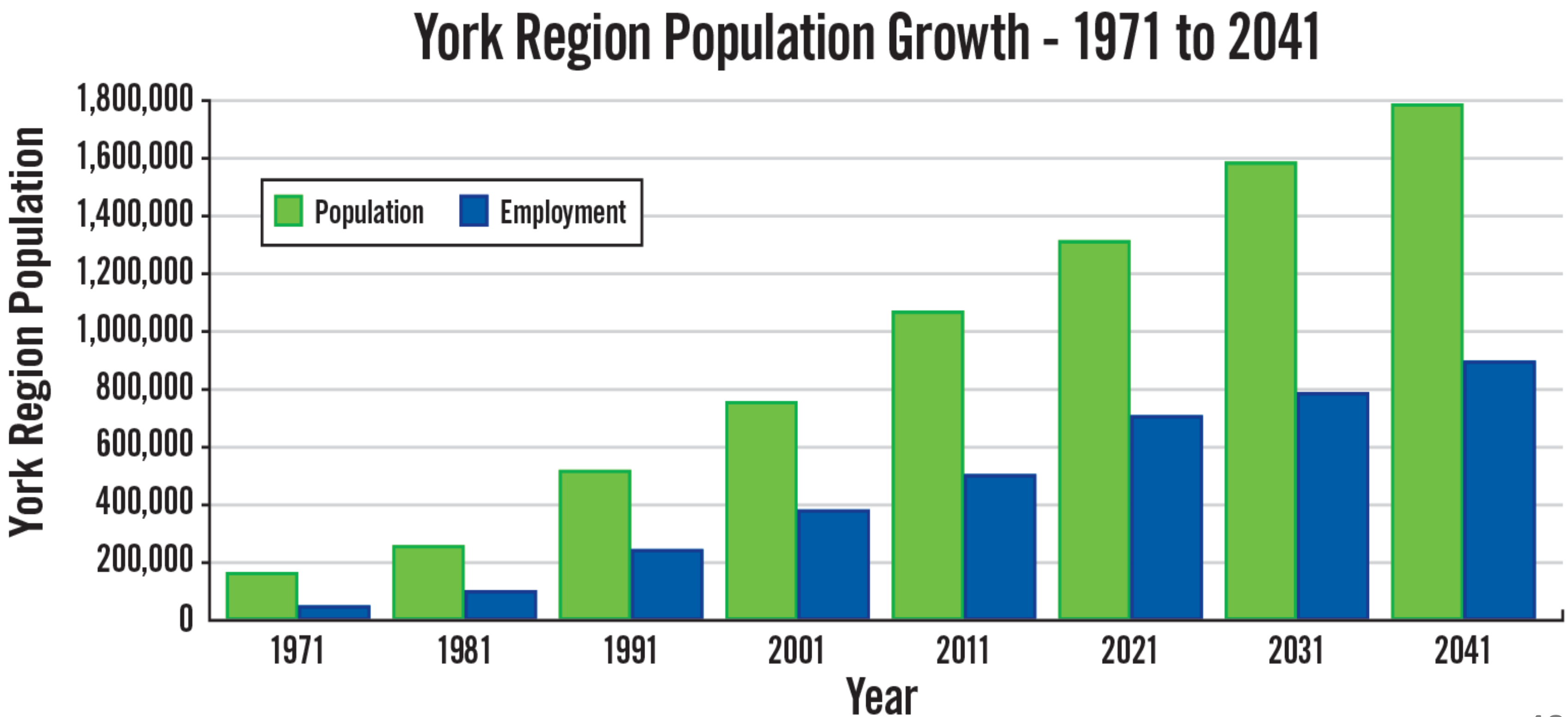
York Region Growth Context

York Region's **population** is expected to grow from

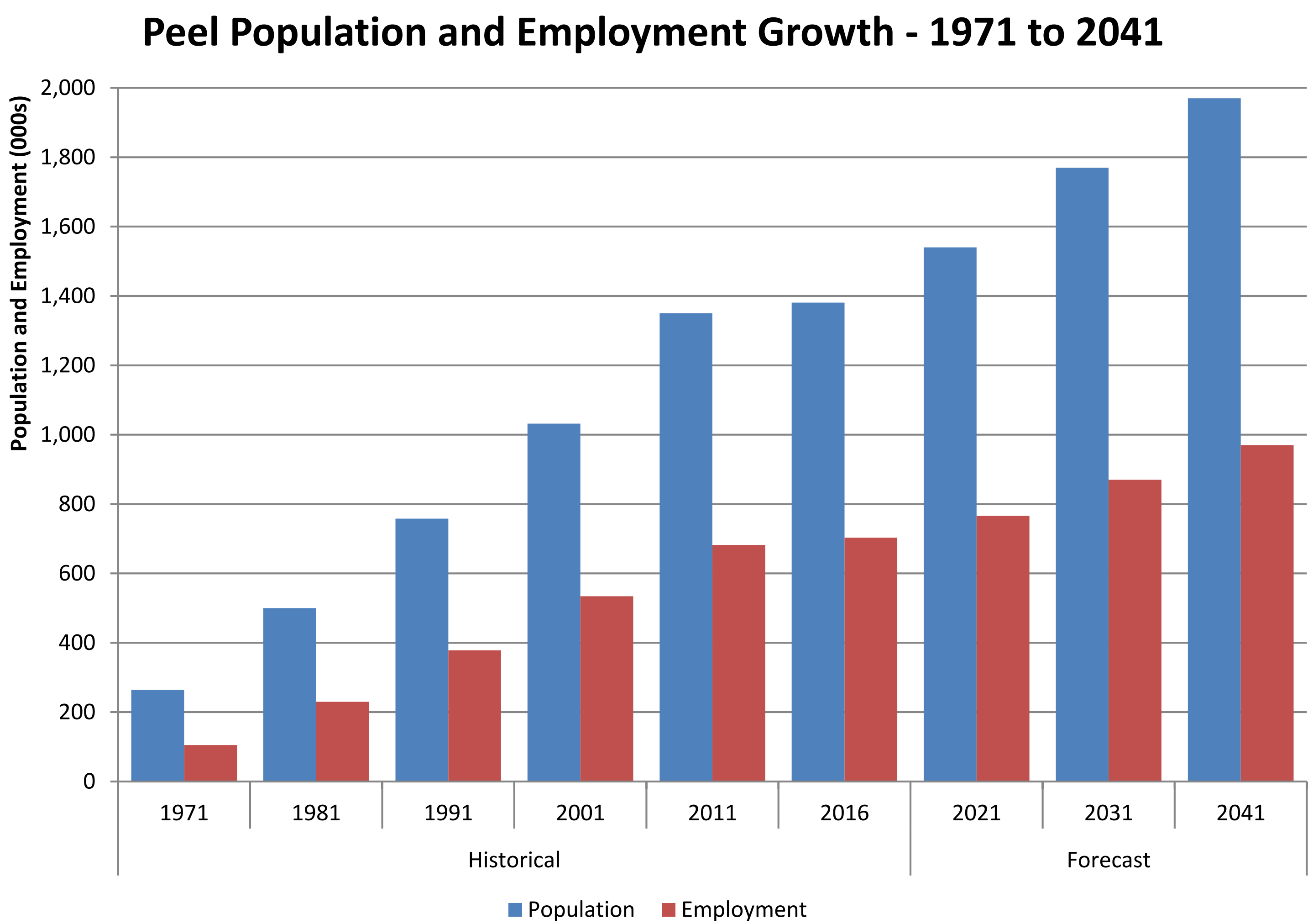
1.2 MILLION in 2017 to 1.8 MILLION in 2041

York Region's **employment** is expected to grow from

621 THOUSAND in 2017 to 900 THOUSAND in 2041



Peel Region Growth Context

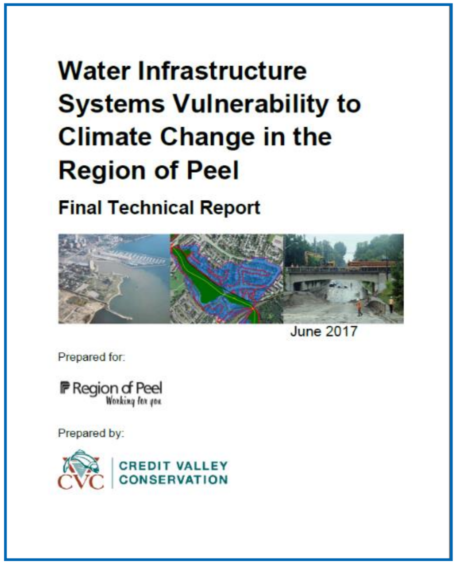


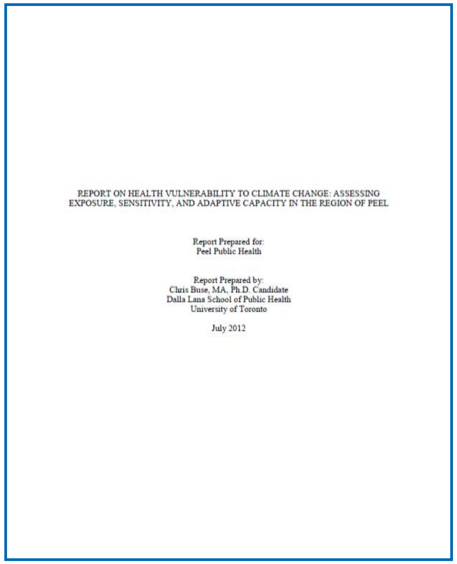
The continued **success** of both Region's depends on responsible **planning for growth**

State of Practice in Flux

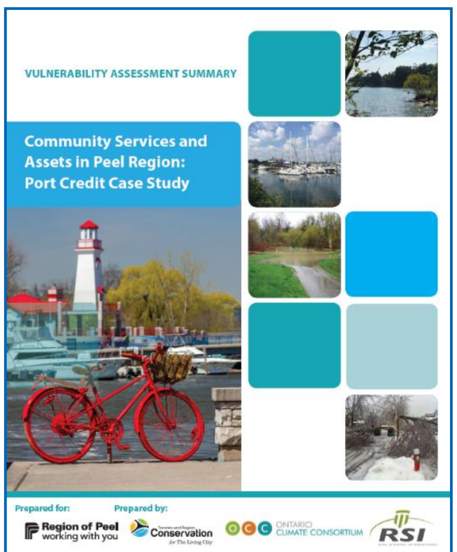
Uneven Playing Field

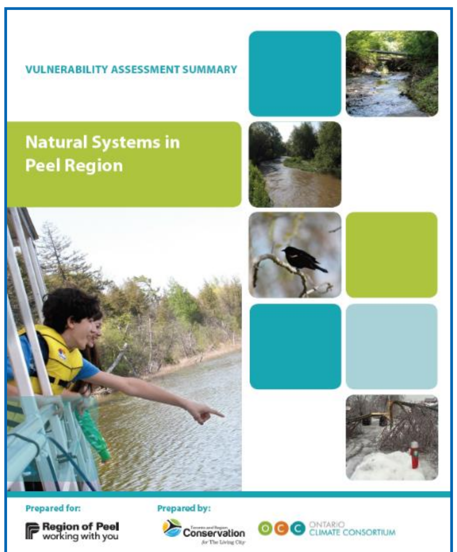
Vulnerability Assessments in Peel

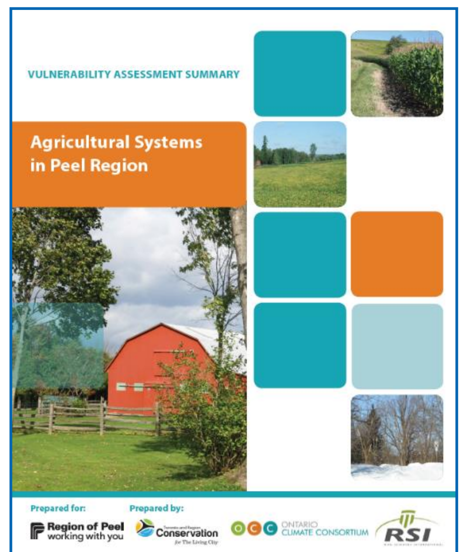




Vulnerability Assessments conducted across sectors to provide baseline for municipal risks related to climate change



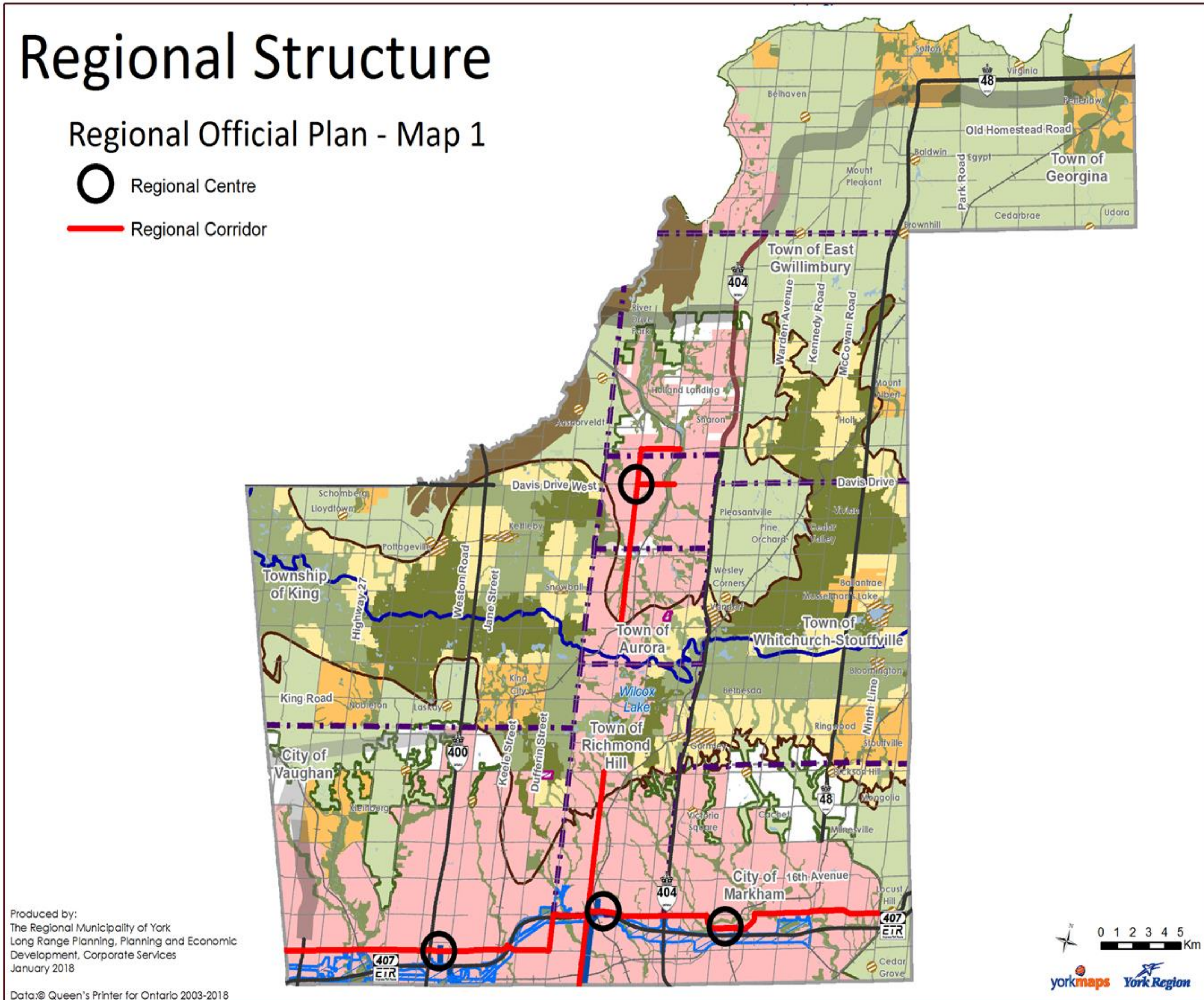




Balancing Multiple Priorities

Regional Structure

Regional Official Plan - Map 1



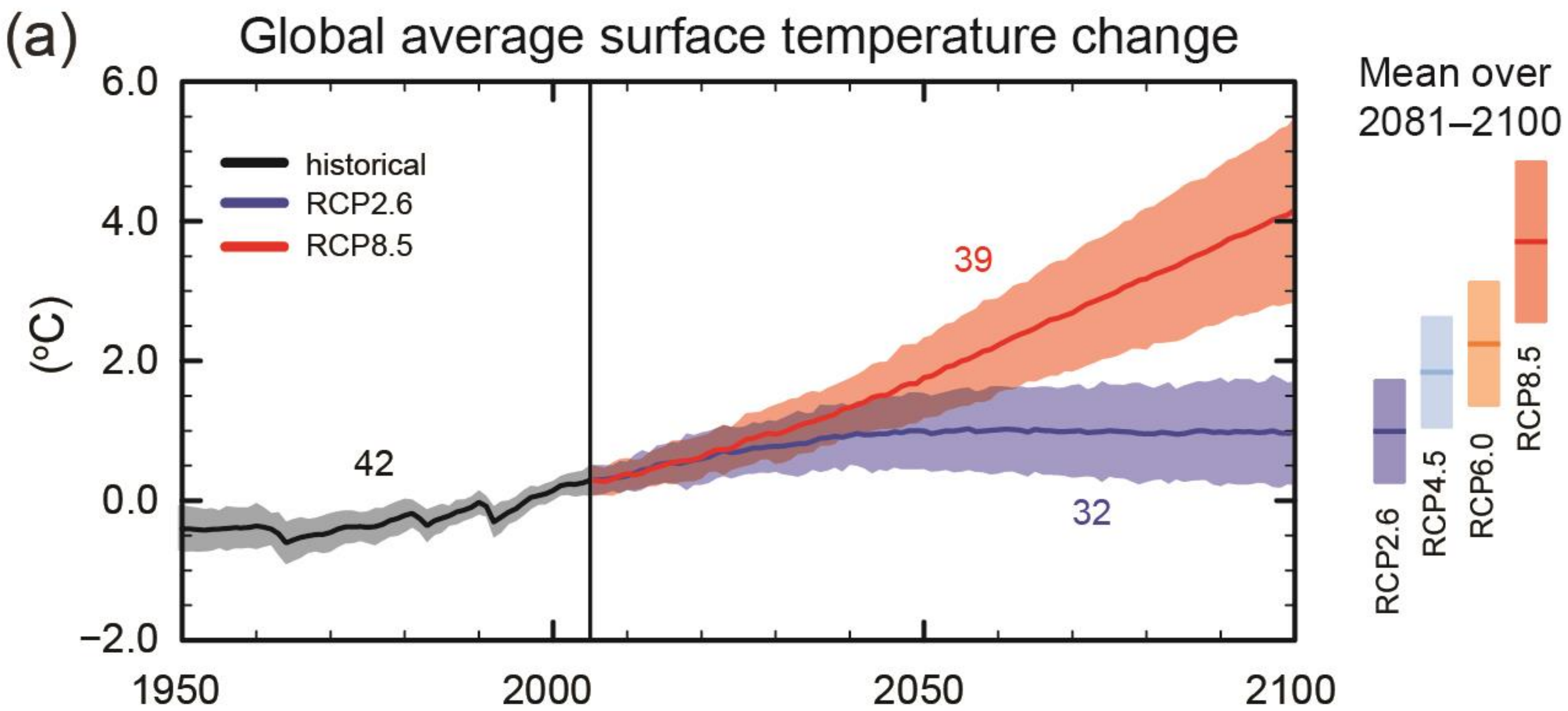
Time is of the Essence

Opportunity to Chart the Course

THANK YOU

For more information
Contact Name
Email, extension

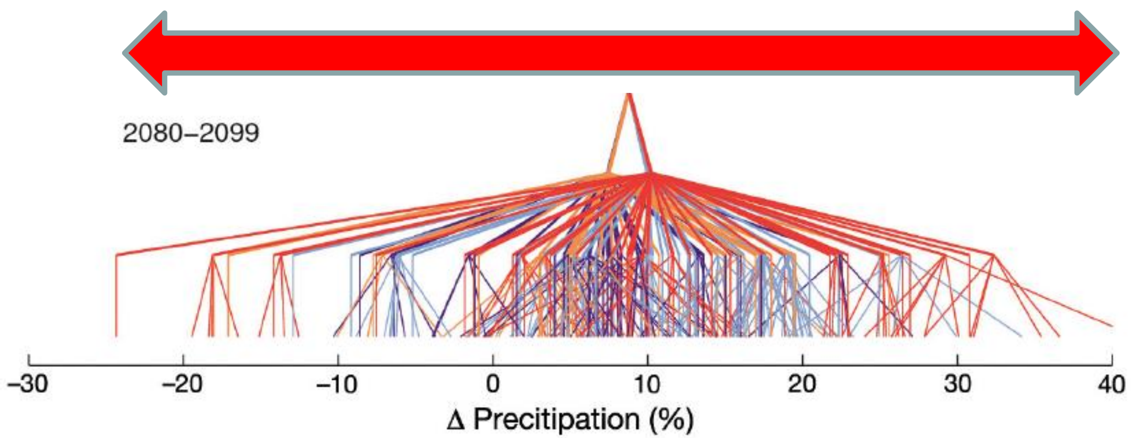
Scenario Analysis – Stationary Climate



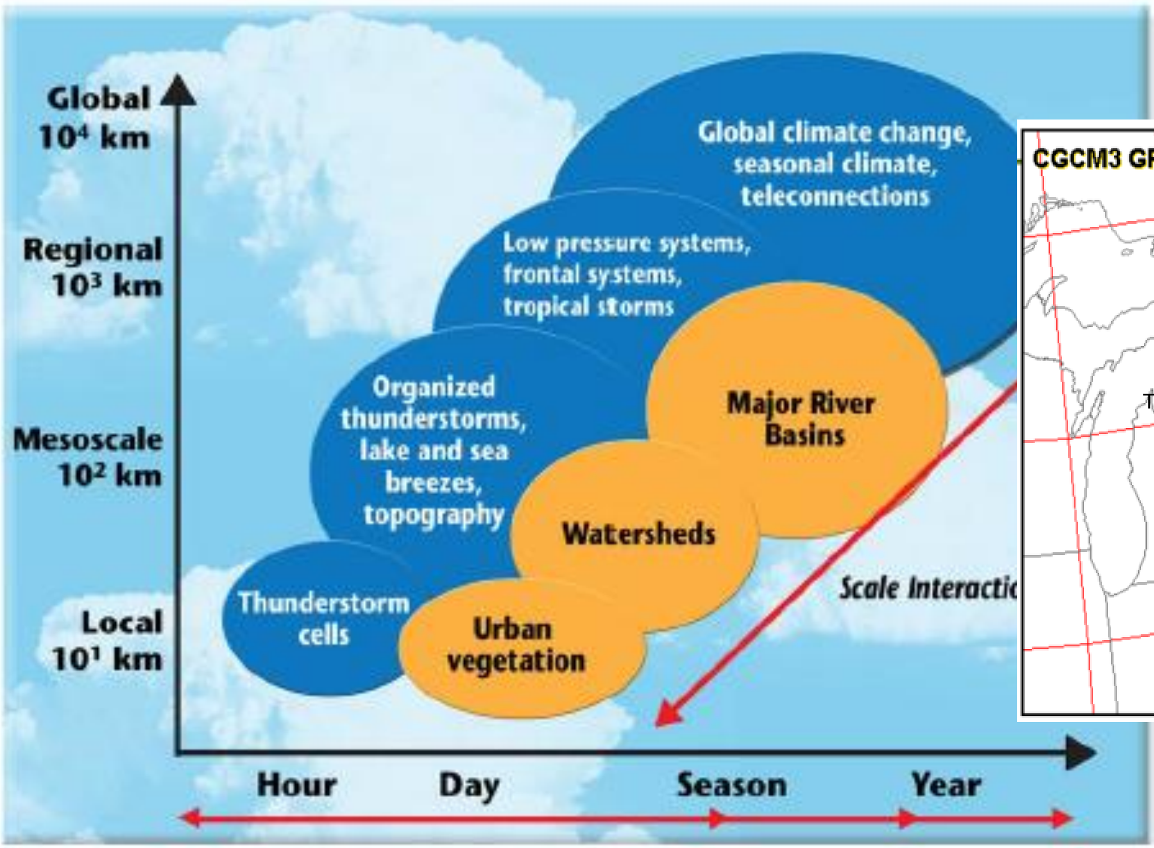
Credit: IPCC(2013)

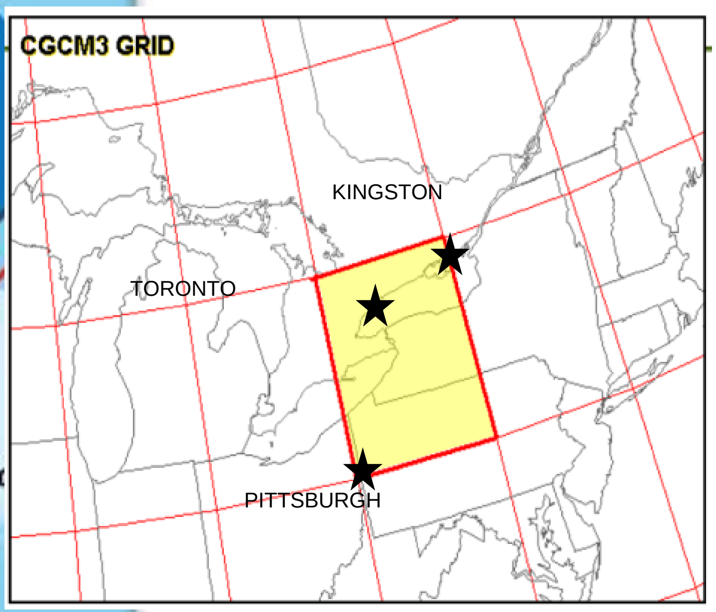
Challenge: Uncertainty

-25% +40%

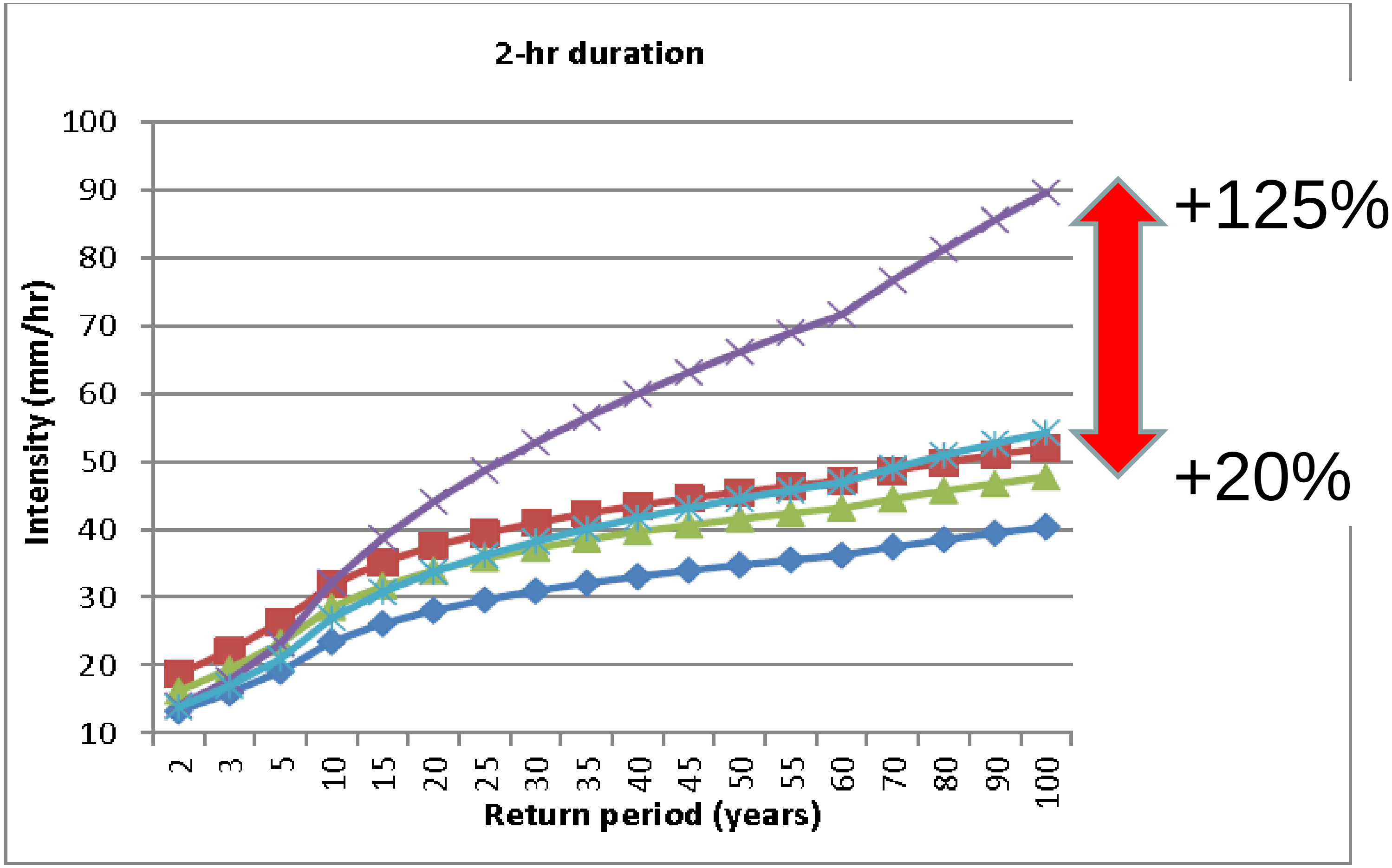


Challenge: Scale

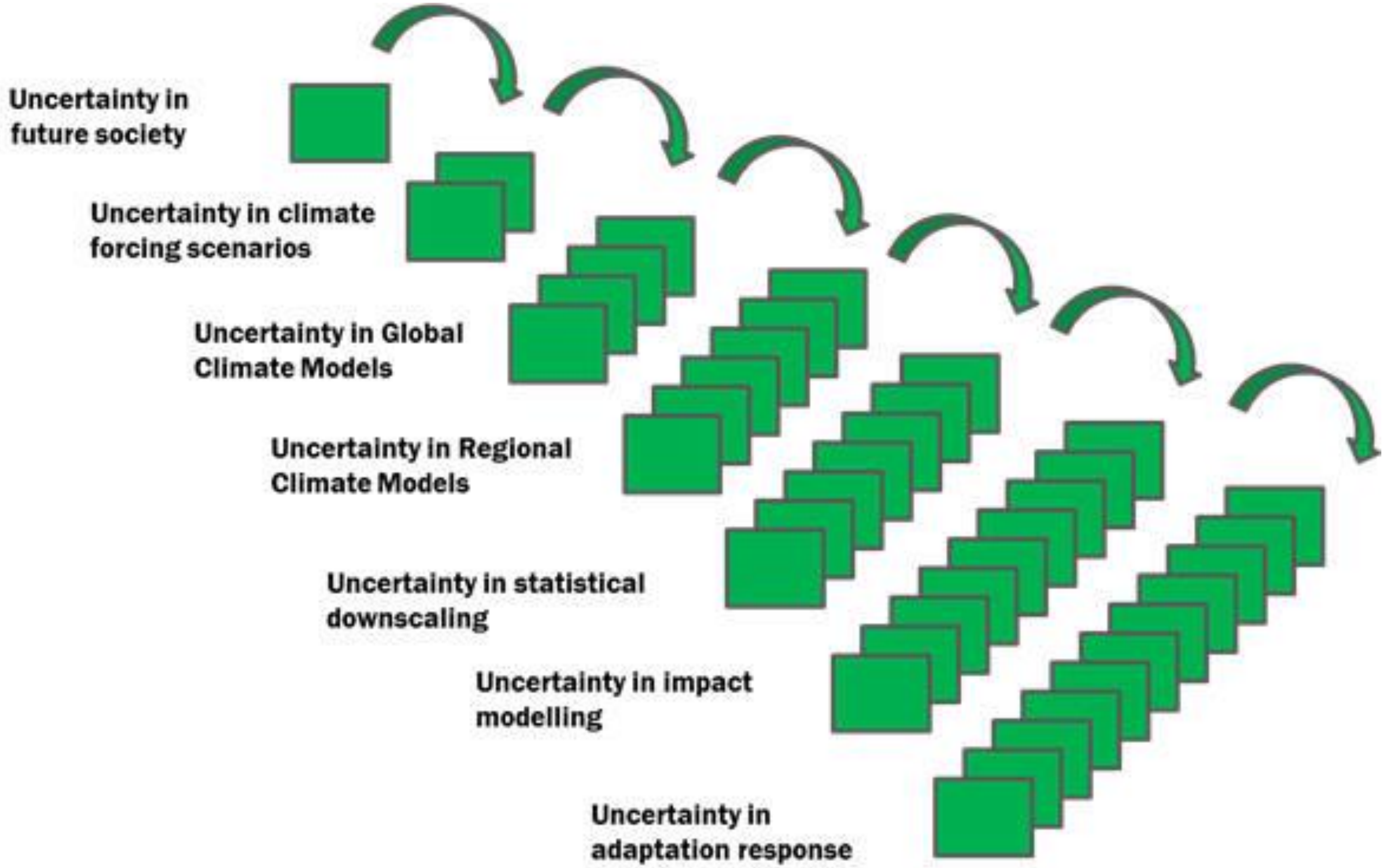




Challenge: Uncertainty + Scale



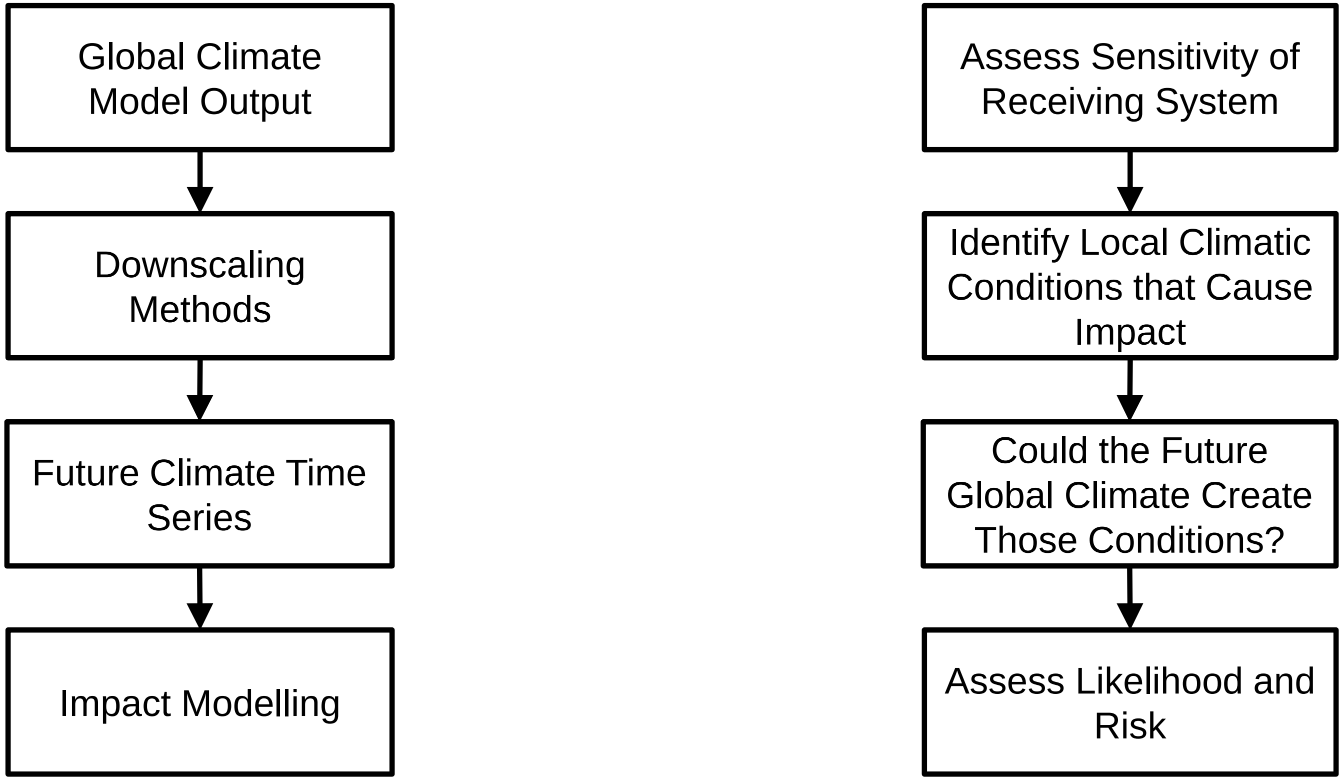
Challenge: Uncertainty + Scale



“Reverse-Engineer” Decision-Making

Conventional / Top-Down

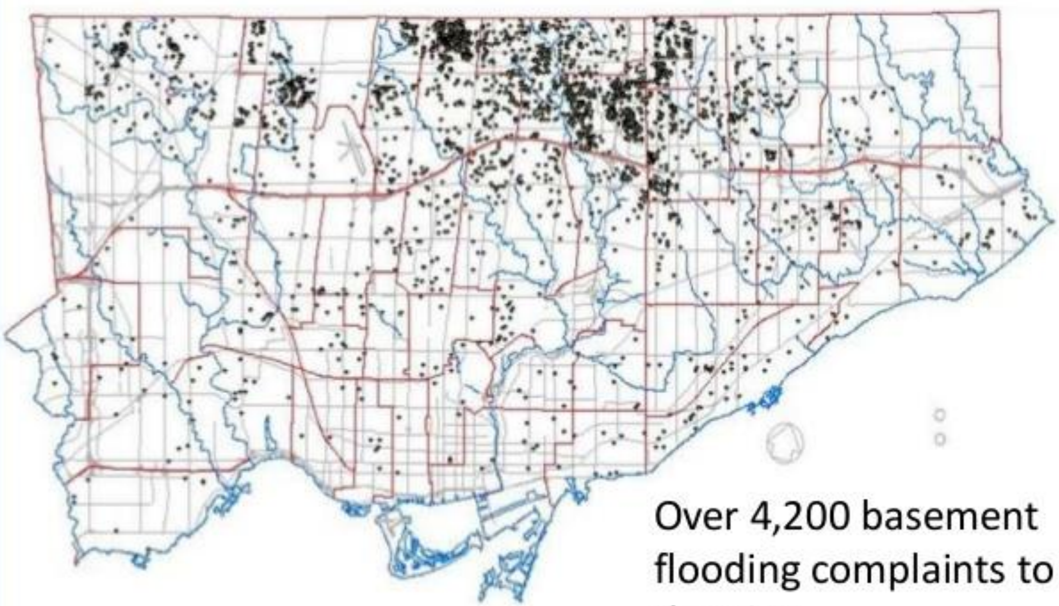
Bottom-Up / Risk Based



Today’s Risks are Tomorrow’s Risks

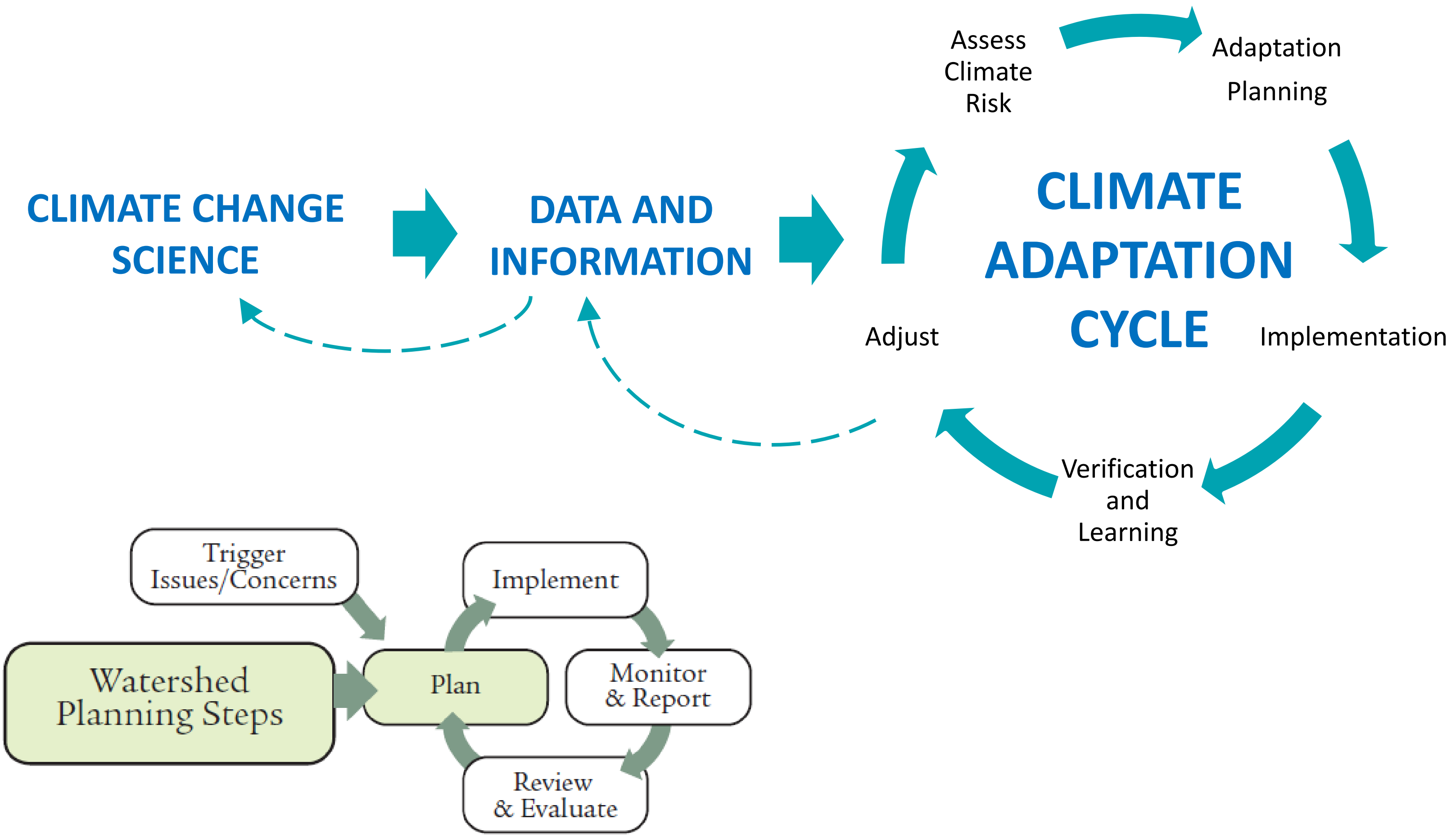
History

Basement Flooding Complaints (August 19, 2005)



Over 4,200 basement flooding complaints to the City

Adaptive Management!



Decision Scaling approach to Climate Risk Assessment

Alec Bernstein, M. Umit Taner, Casey Brown and Bill Werick
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Hydrosystems Group

Ferry Point Bridge
St. Stephen NB, Calais ME

Overview

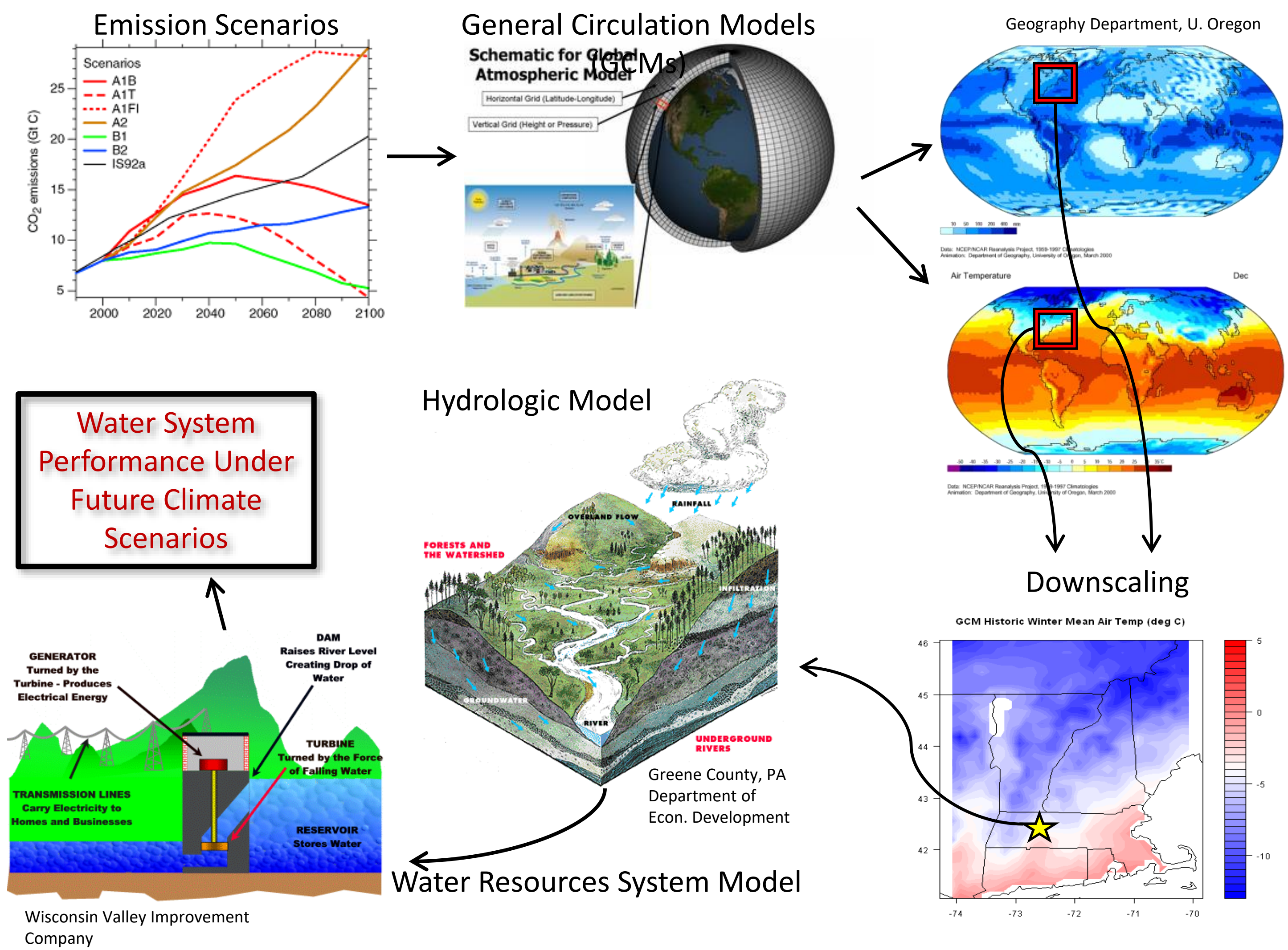
- Climate Change poses significant risks for water resource systems (rivers, lakes, water supply systems)
- Uncertainty of climate change at a particular location is largely irreducible, paralyzes traditional planning approaches
- Decision Scaling was developed to address this challenge during the International Upper Great Lakes Study – producing a new regulation plan
- Generalized as the Climate Change Guidance Framework for the International Joint Commission

Why is the future climate uncertain?

1. We don’t know the future emissions of ***Green House Gases (GHG)***
   - Only really significant after 2050
   - Irreducible
2. We aren’t certain about climate ***sensitivity to GHG emissions***
   - Significant
   - In theory, reducible
3. We are limited in our in ability to ***model the climate system***
   - Significant
   - No uncertainty reduction in sight (could increase)
4. There is large natural ***variability of the climate system***
   - Significant, dominant at scales of adaptation
   - Irreducible

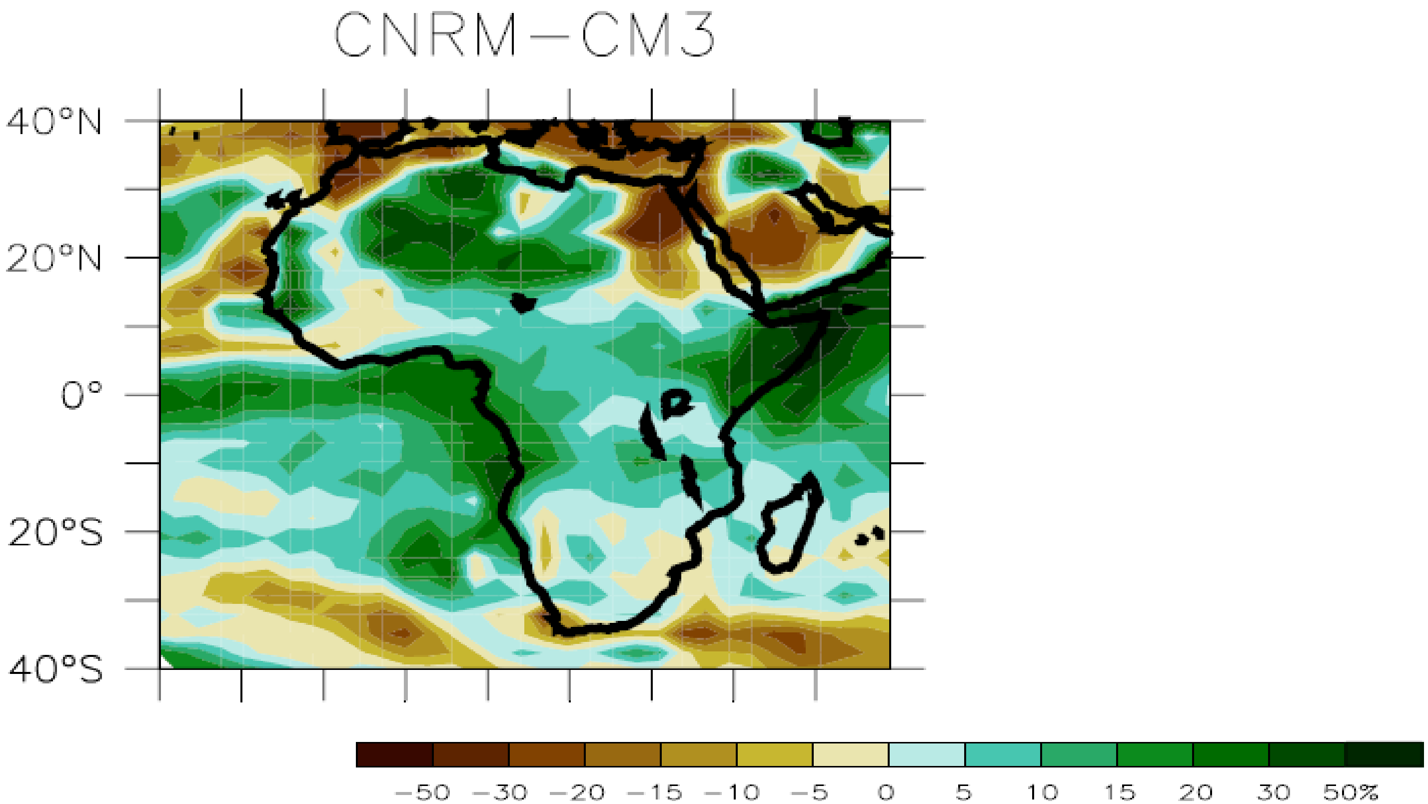
What has been the typical approach?

And how has that gone for us?



Emission Scenarios
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
CO_2 emissions (Gt C)
General Circulation Models (GCMs)
Schematic for Global Atmospheric Model
Horizontal Grid (Latitude-Longitude)
Vertical Grid (Height or Pressure)
Geography Department, U. Oregon
Air Temperature
Dec
Downscaling
GCM Historic Winter Mean Air Temp (deg C)
Hydrologic Model
RAINFALL
OVERLAND FLOW
FORESTS AND THE WATERSHED
INFILTRATION
GROUNDWATER
RIVER
UNDERGROUND RIVERS
Greene County, PA Department of Econ. Development
Water System Performance Under Future Climate Scenarios
Water Resources System Model
GENERATOR Turned by the Turbine - Produces Electrical Energy
DAM Raises River Level Creating Drop of Water
TURBINE Turned by the Force of Falling Water
TRANSMISSION LINES Carry Electricity to Homes and Businesses
RESERVOIR Stores Water
Wisconsin Valley Improvement Company

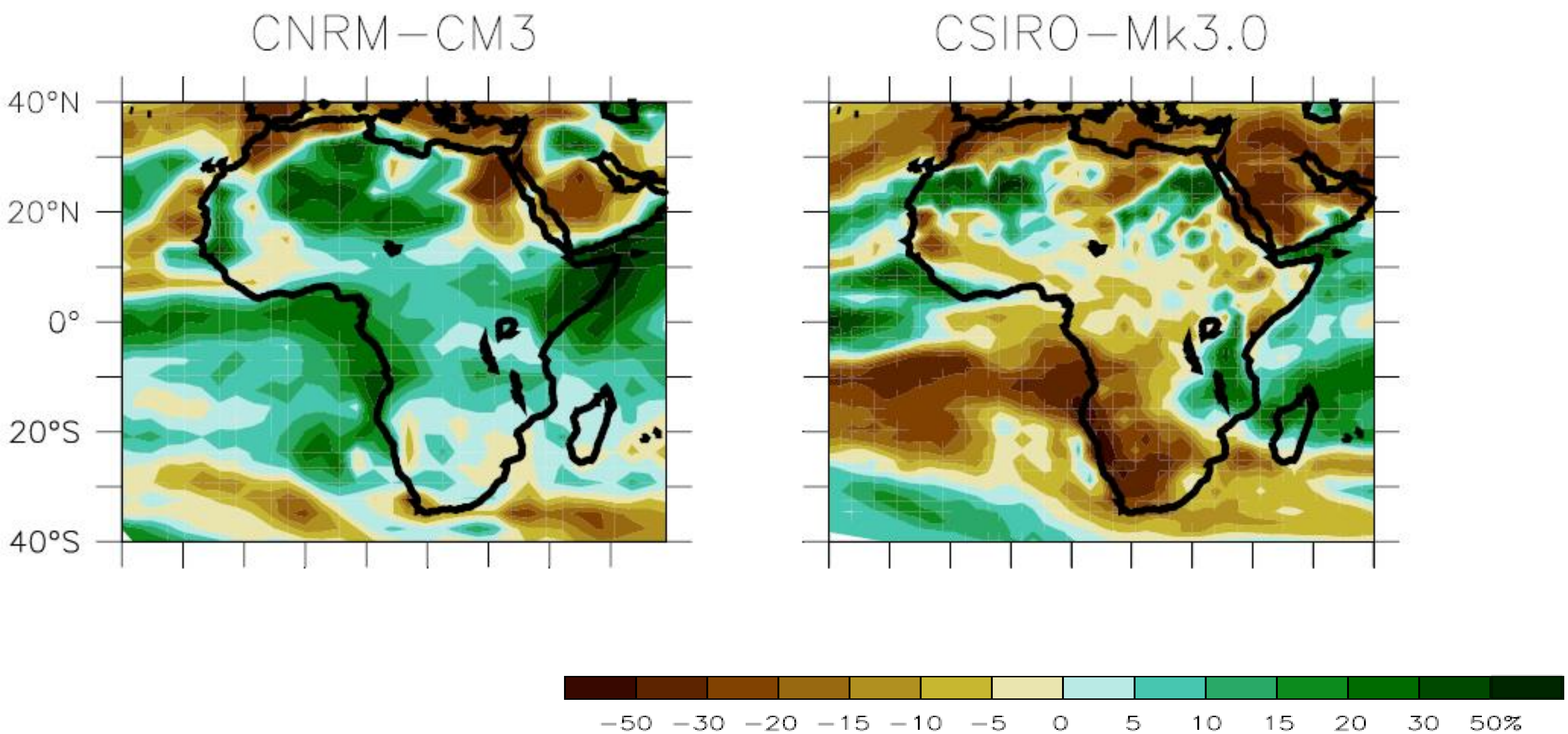
Climate Change: what future to plan for?



from S. Hallegatte

The Meteo-France model, from IPCC

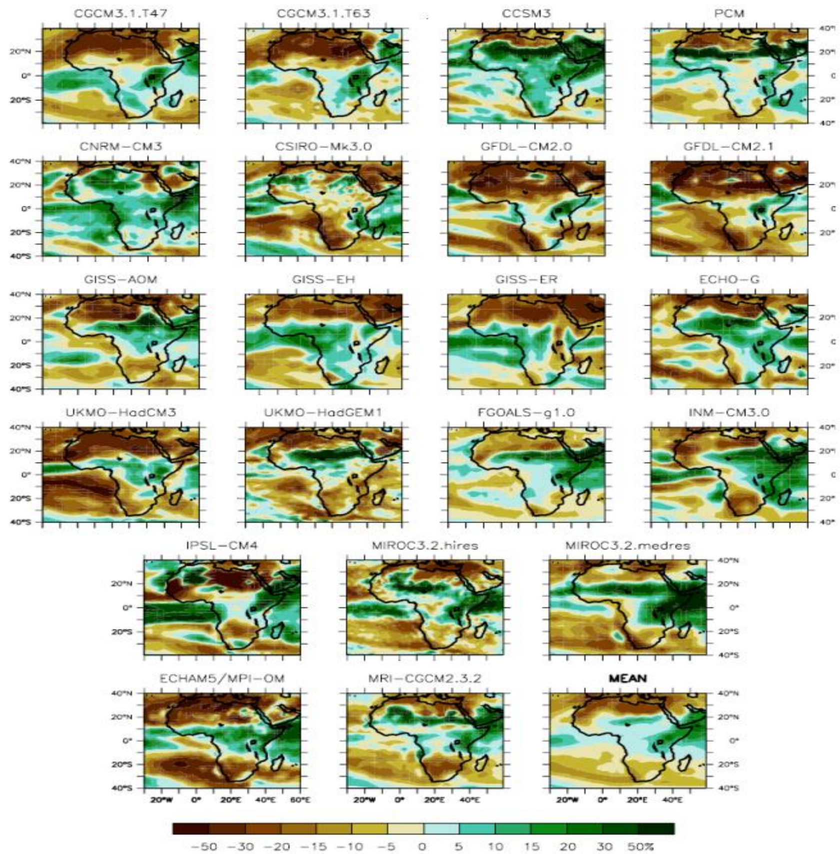
Climate projections disagree



from S. Hallegatte

The Meteo-France and the Australian model, from IPCC

… and we have a lot of models…



from S. Hallegatte

… and future climates depend on future climate policies and socio-economic trends…

Motivations for a Bottom-up Approach

http://commons.wikimedia.org/wiki/File:Lake_mead_july_2009.jpg

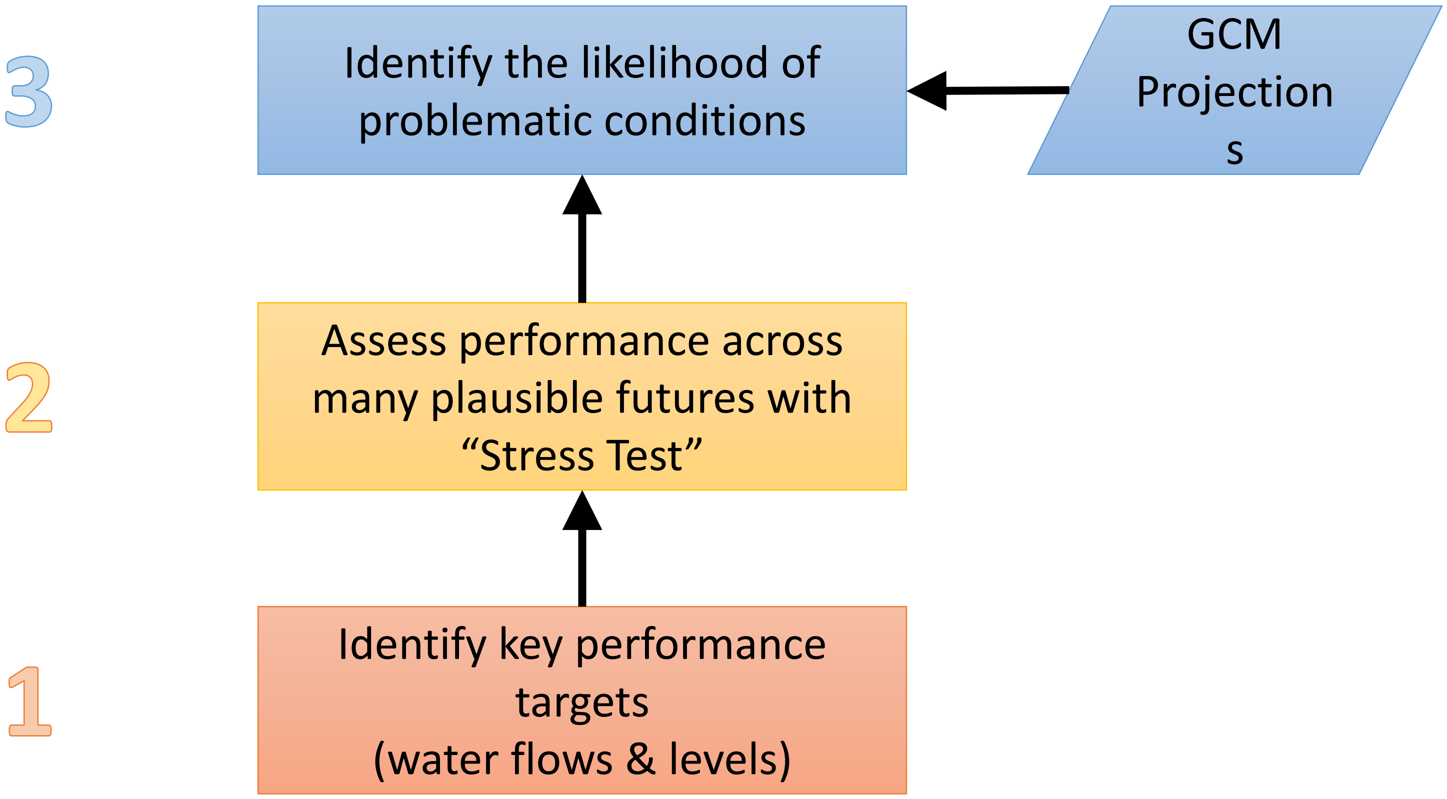
There might be less water than we expect

http://www.politico.com/news/stories/1012/83043.html

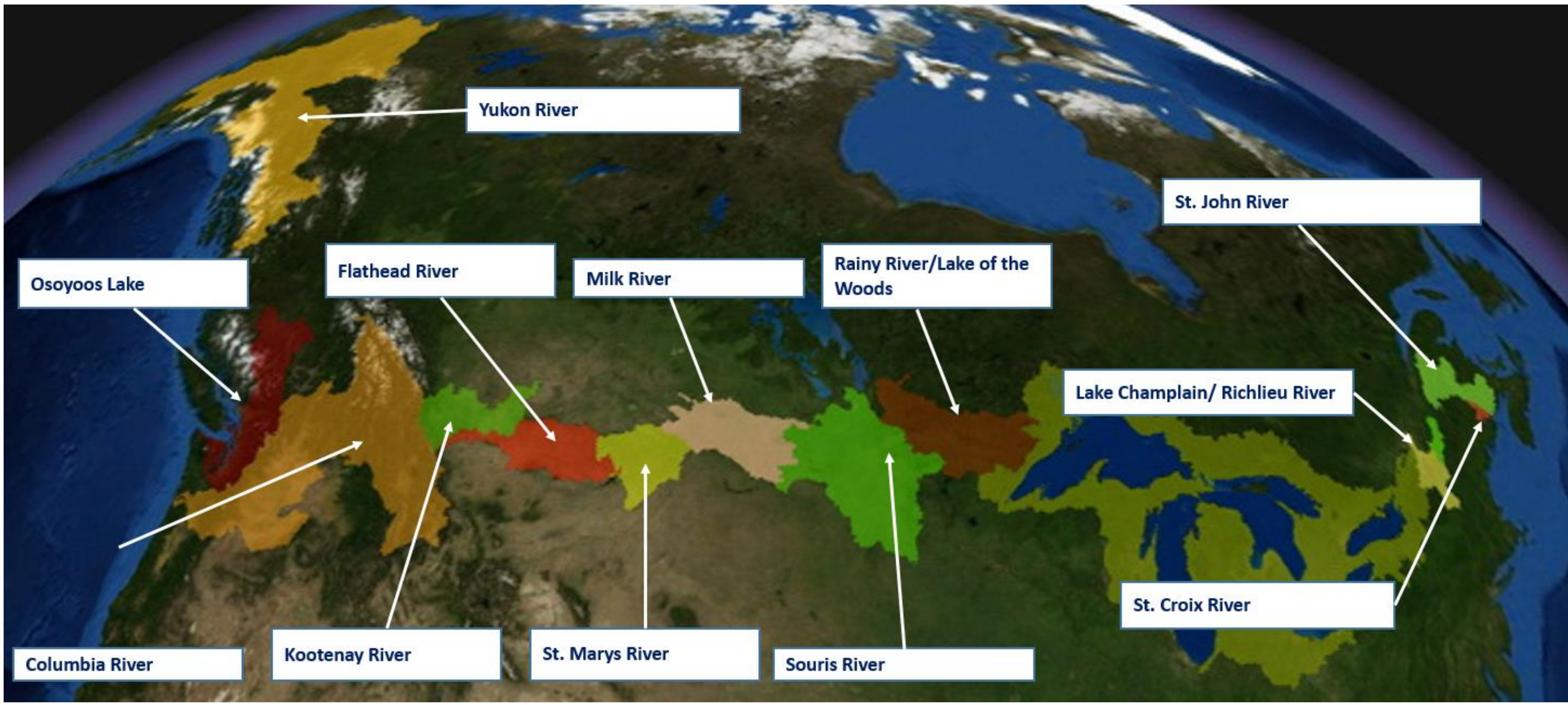
Or there might be more

We don't try to guess what the future conditions will be, we try to be ***robust*** and ***flexible***.

Bottom-up approach

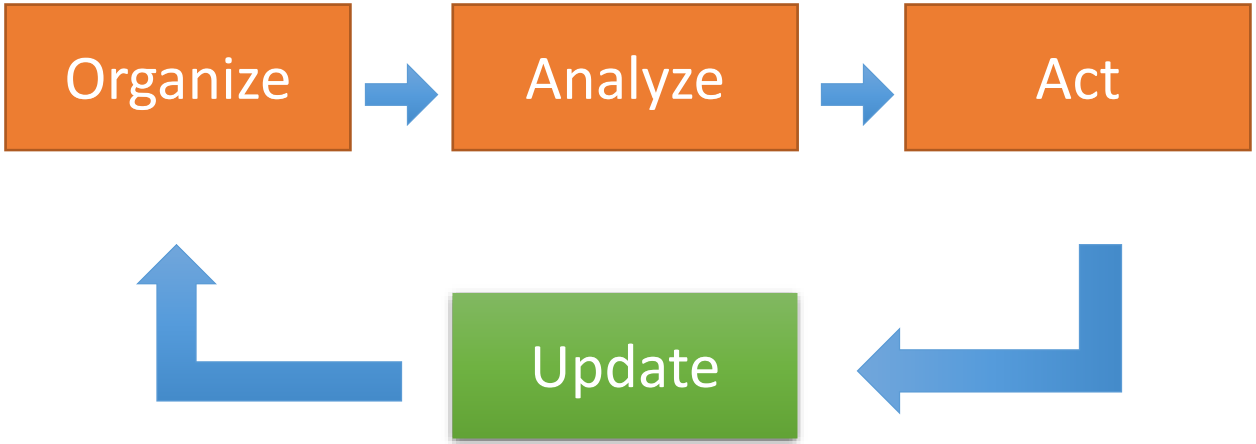


International Joint Commission Boundary Waters

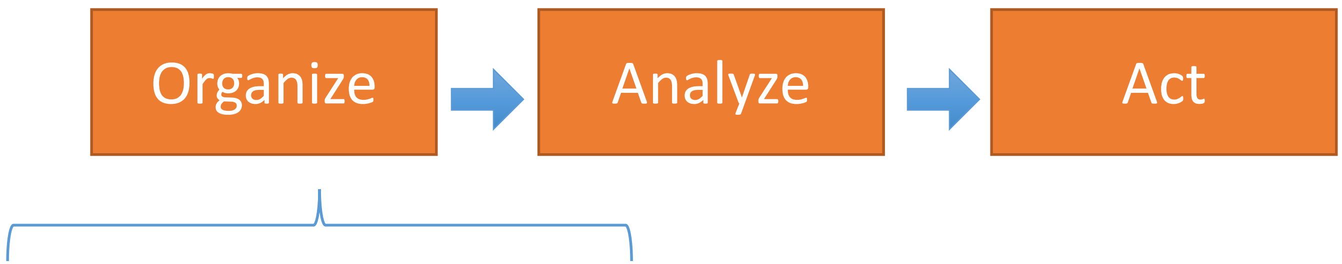


Board Self Assessments

Framework Overview

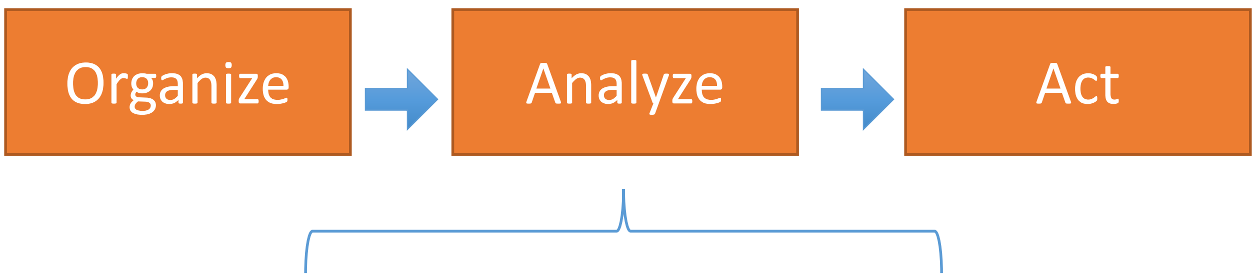


Framework Overview



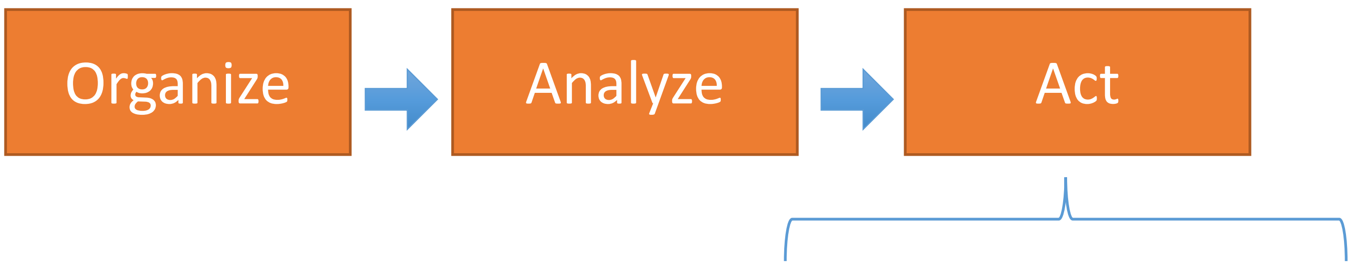
- Define objectives, measures of success, thresholds
-Define uncertain factors that can affect the system
-Compile what has been done, is being done

Framework Overview



- What climate changes, trends, etc., could affect ability to meet objectives?
-Is there evidence of problematic climate changes?
-What is the importance and uncertainty of the possible effects?

Framework Overview



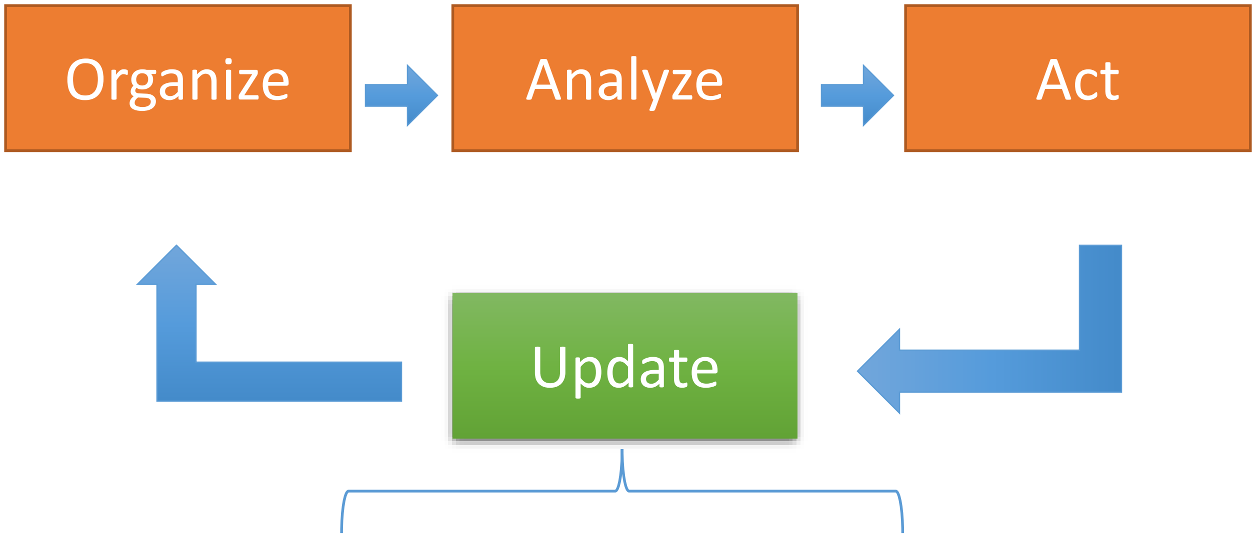
-Consider and decide possible actions:

-Plan for additional monitoring of key uncertain factors

-Commission vulnerability assessment

-Communicate current efforts

Framework Overview

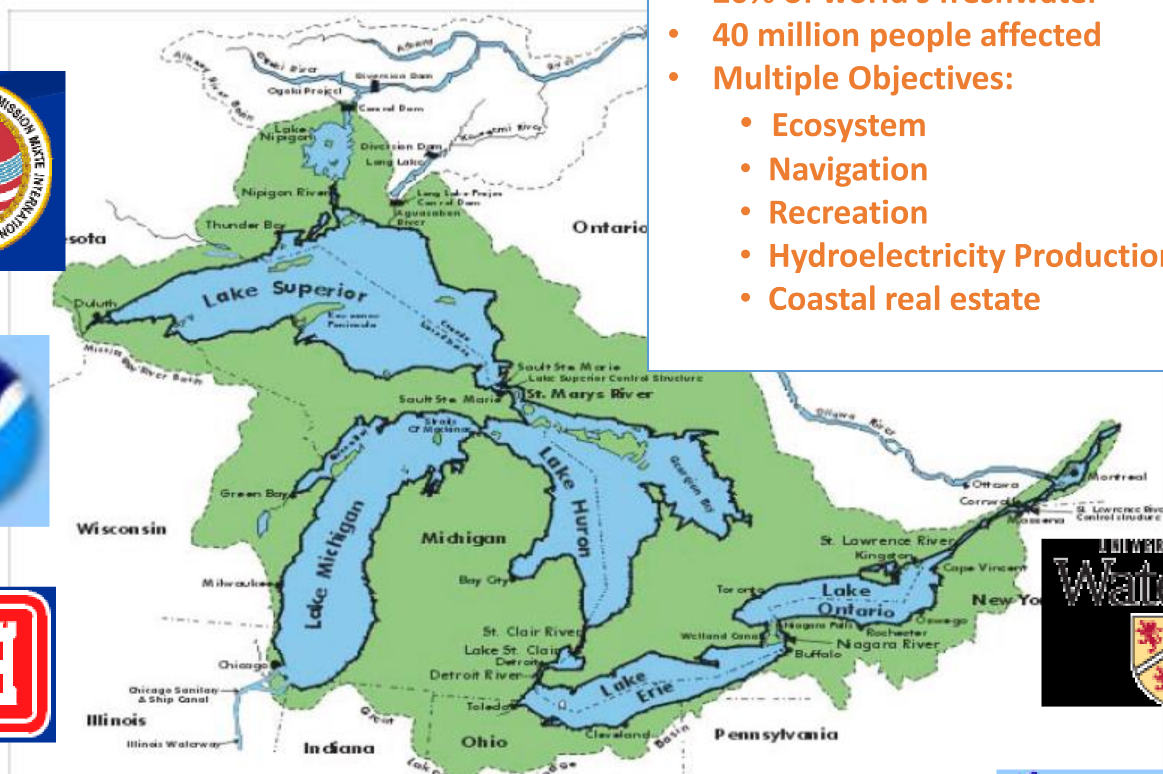


Informal and/or formal monitoring of key uncertainties and status of performance indicators

International Upper Great Lakes Study

International Upper Great Lakes Study

- 20% of world's freshwater
- 40 million people affected
- Multiple Objectives:
  - Ecosystem
  - Navigation
  - Recreation
  - Hydroelectricity Production
  - Coastal real estate



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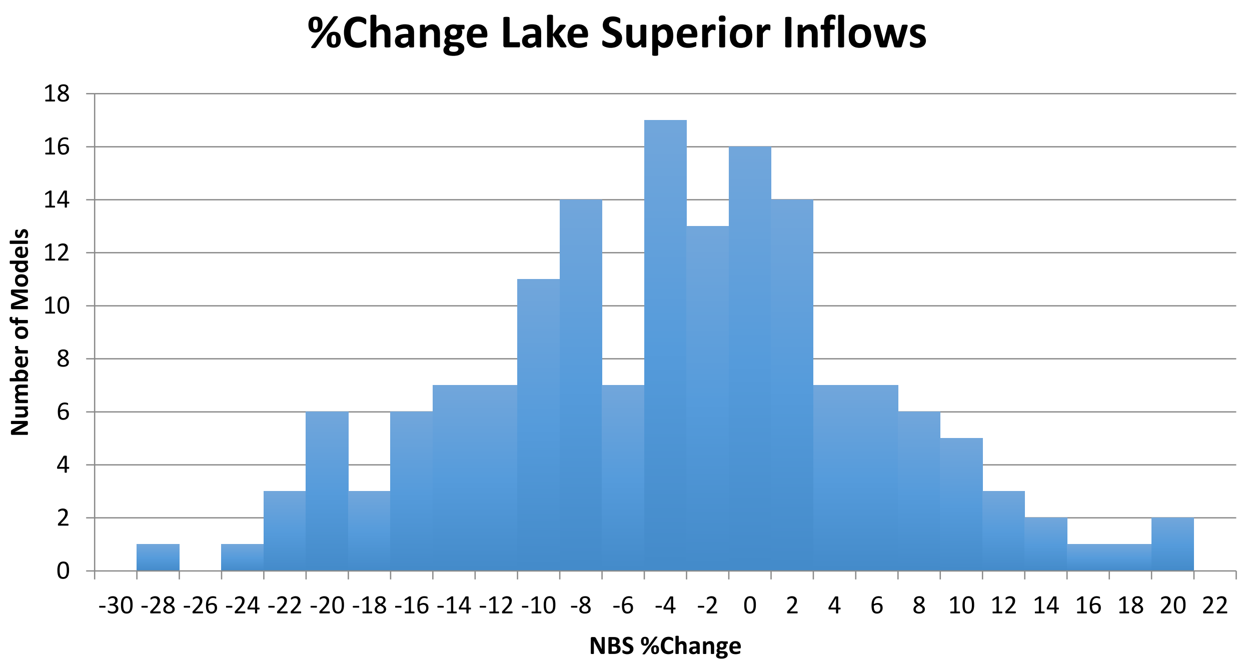
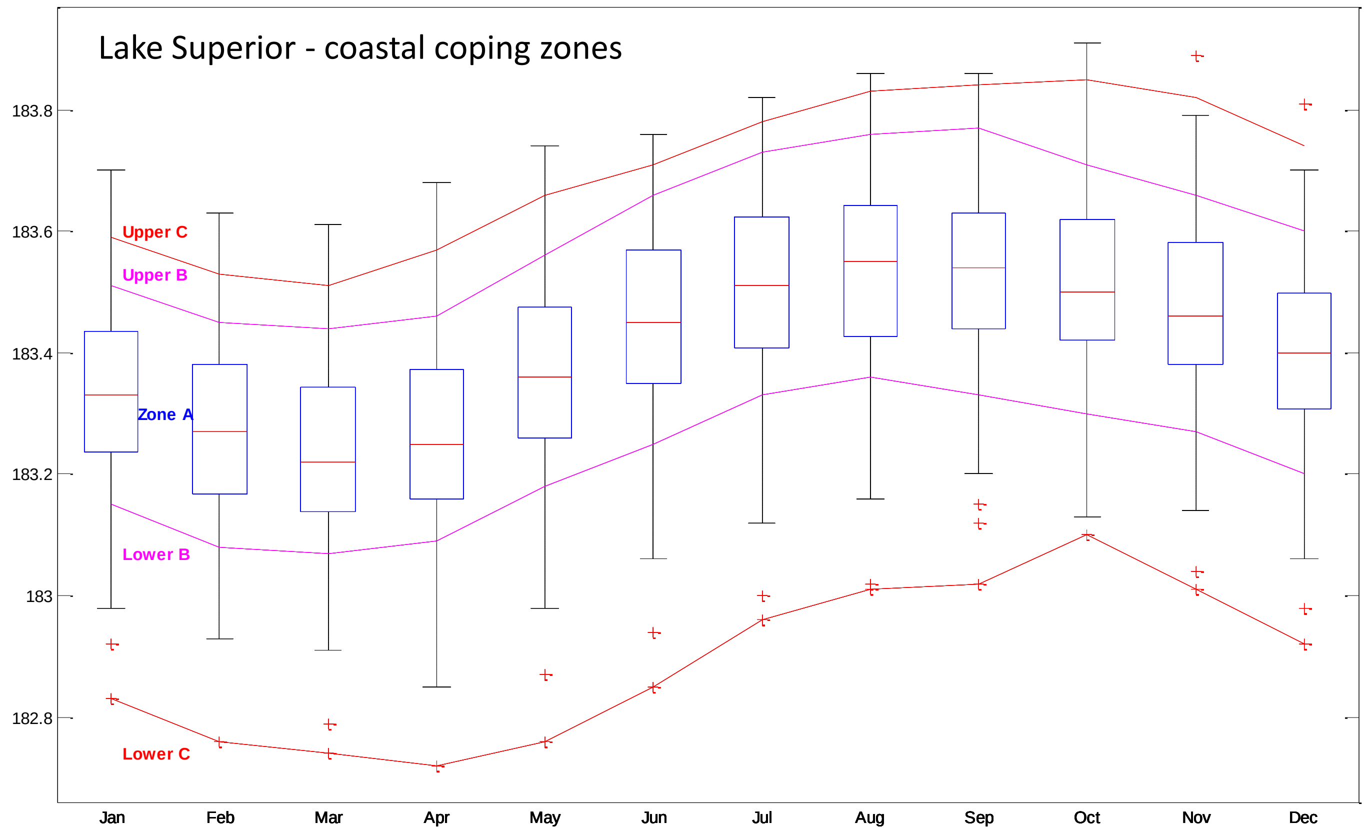
GLERL

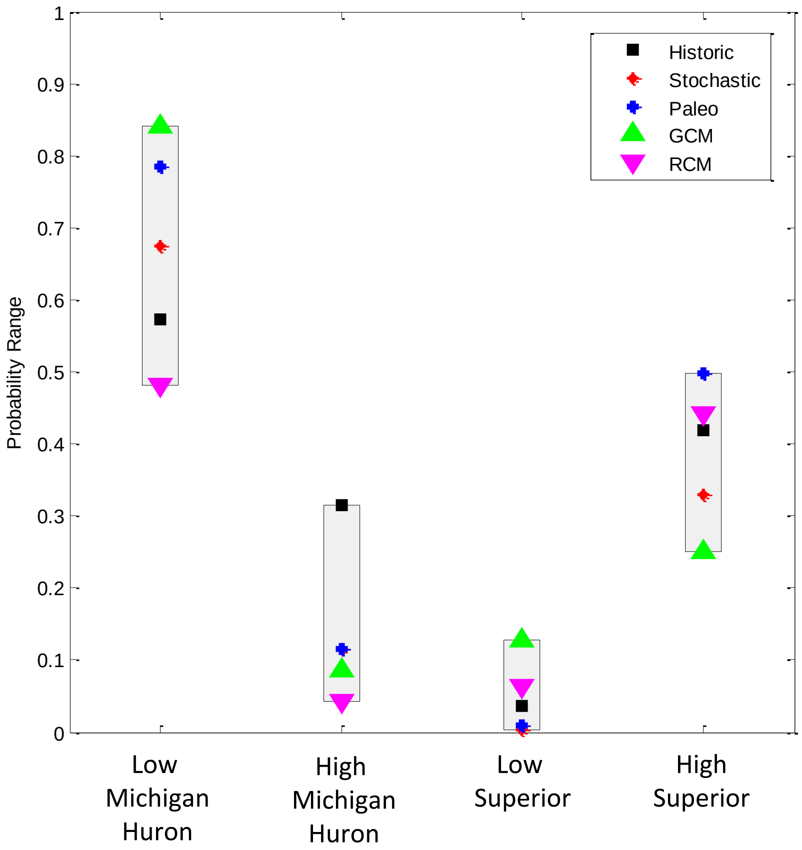
Climate Change Projections 2050



Stakeholder defined risks: threshold lake levels

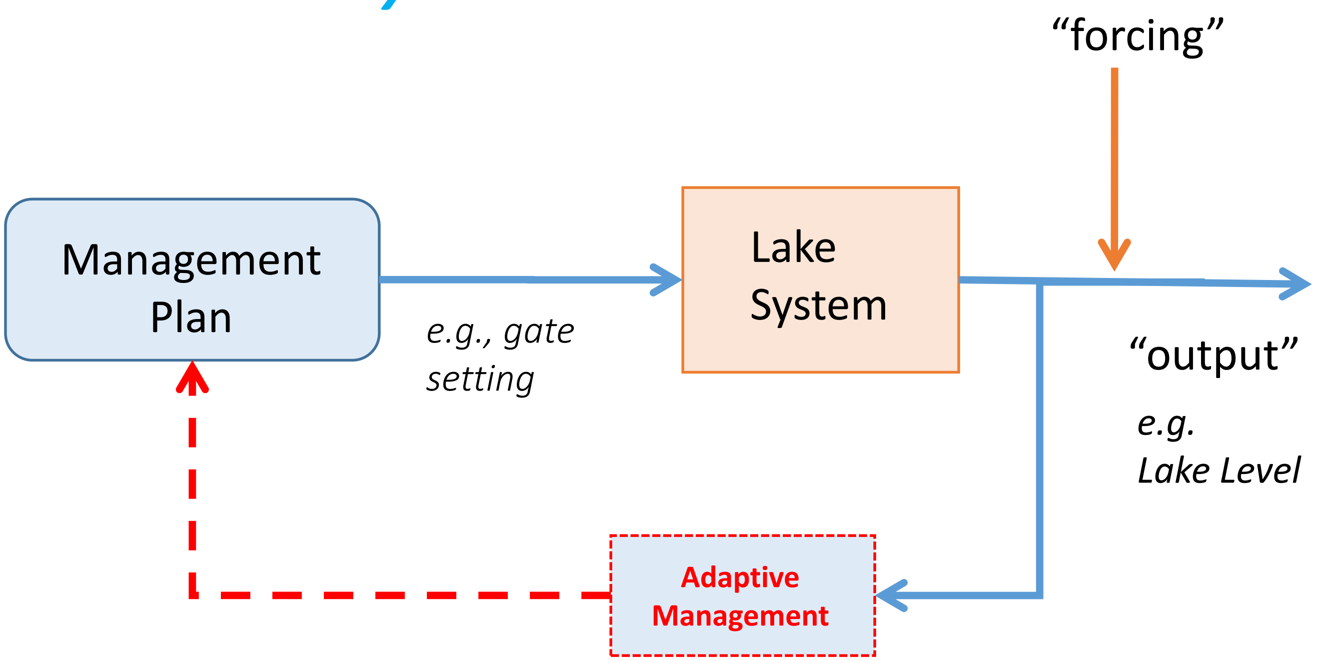


Residual Climate risks by Climate Info Source



Current Management of Lake Superior Regulation

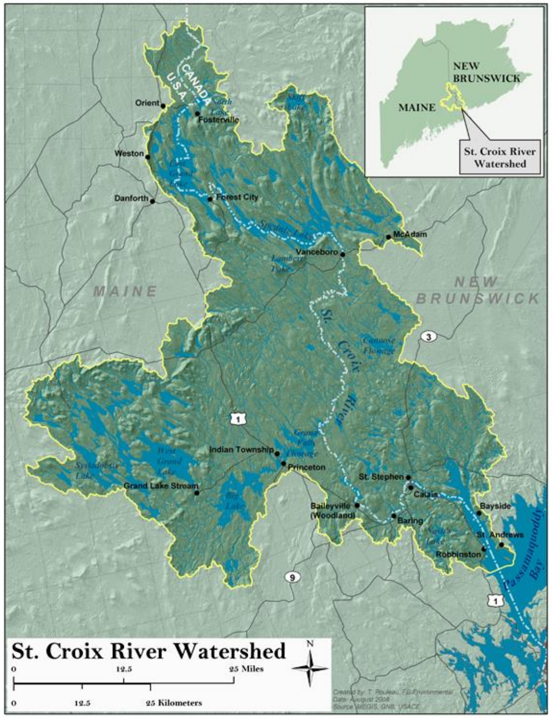
Cycle Period = 30 years



IF *Complaints* **>** *Tolerance* then Study for new Management Plan

St. Croix Watershed

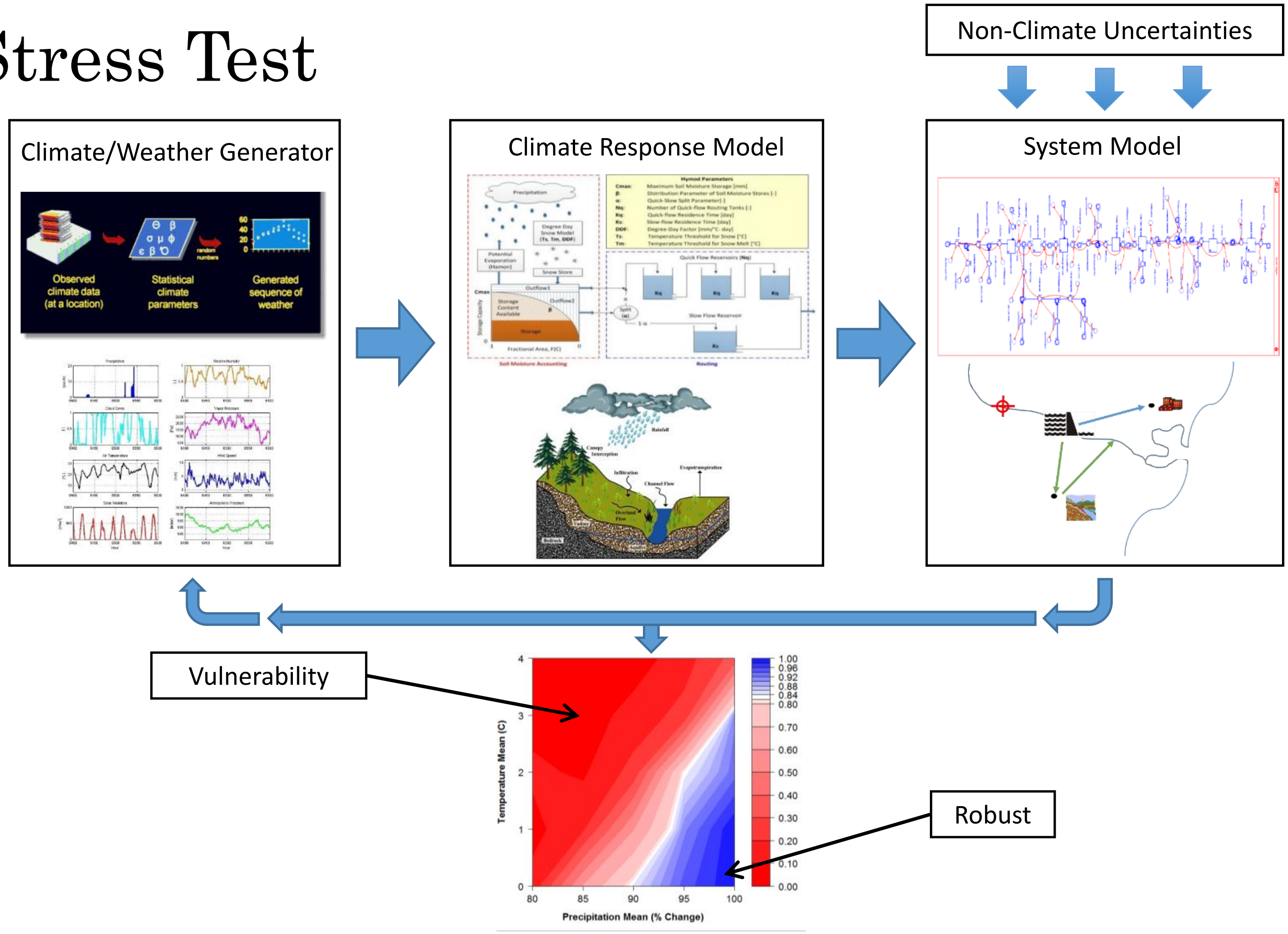
Transboundary river along the Canada and United States border between New Brunswick and Maine



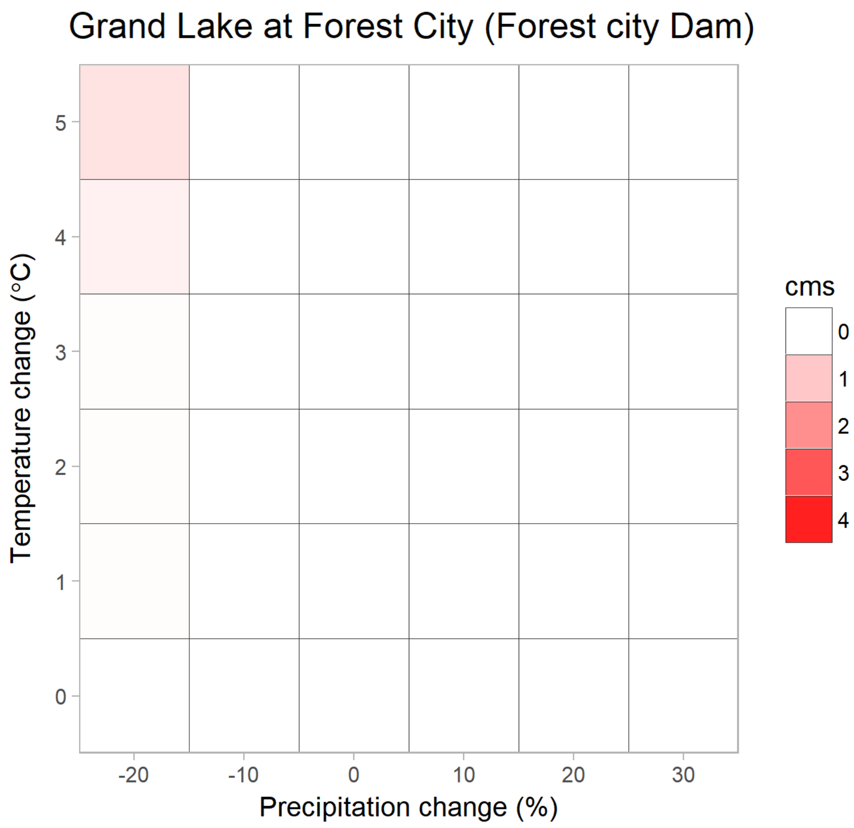
IJC mandates for the St. Croix Watershed

Location	Mandate	Minimum
Forest City Dam	Discharge	2.12 m^3/s
Vanceboro Dam	Discharge	5.67 m^3/s
St. Croix at Baring	Discharge	21.2 m^3/s

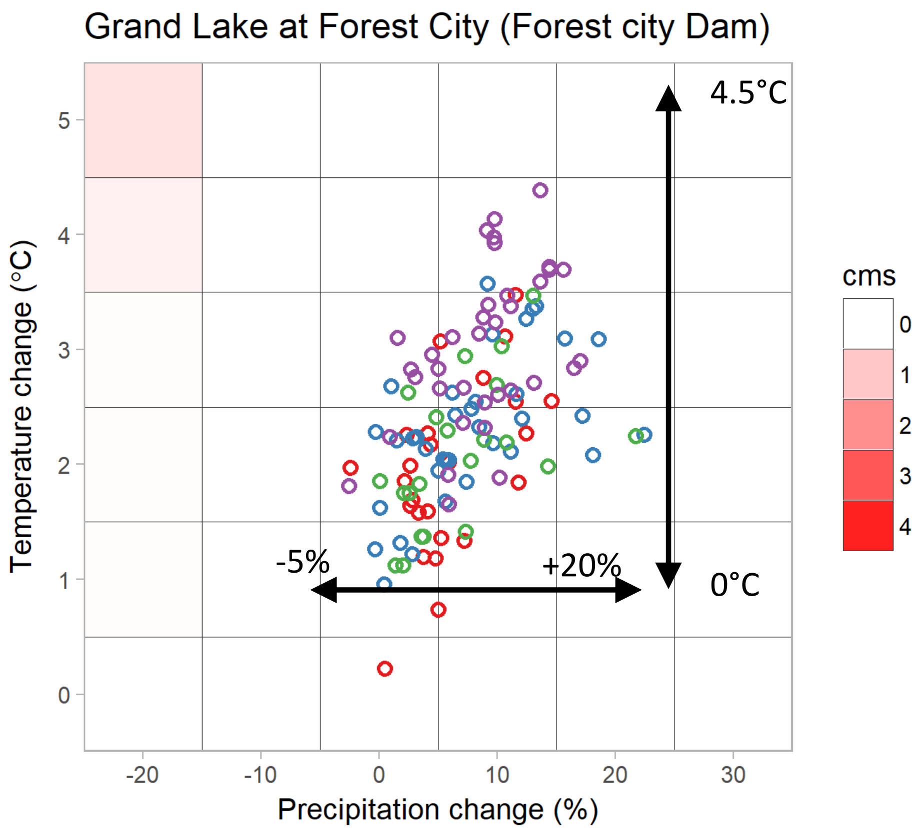
Stress Test


Non-Climate Uncertainties
Climate/Weather Generator
Observed climate data (at a location)
Statistical climate parameters
Generated sequence of weather
Climate Response Model
System Model
Vulnerability
Robust
Temperature Mean (C)
Precipitation Mean (% Change)

Minimum flow violations

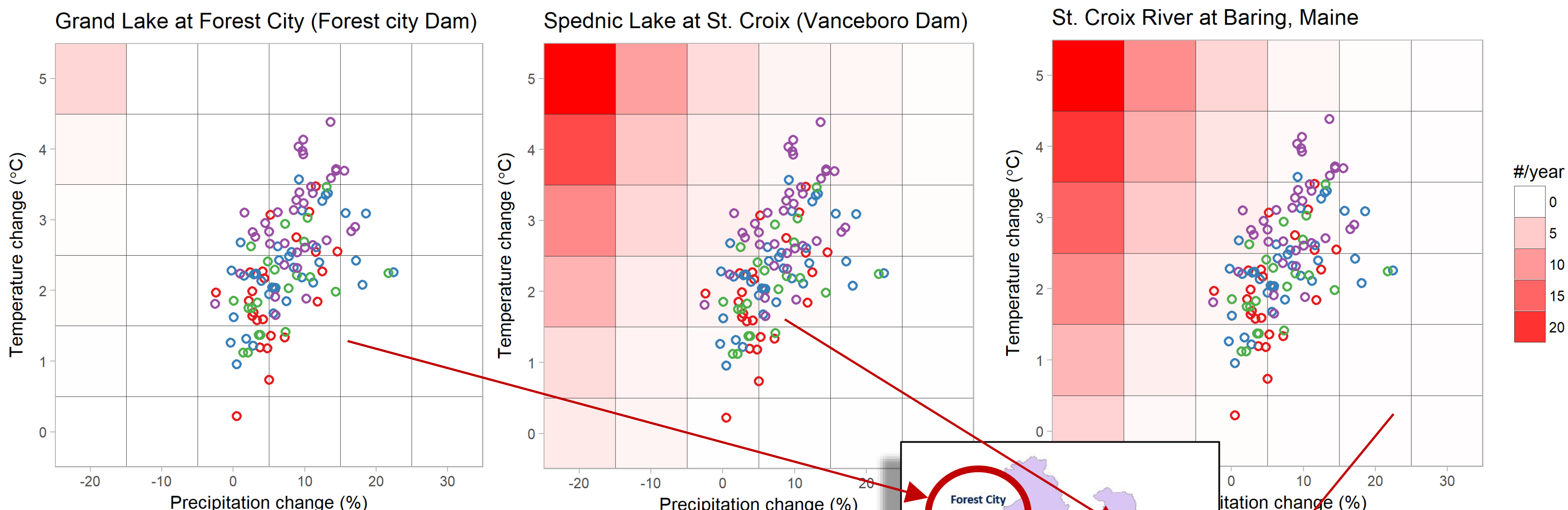


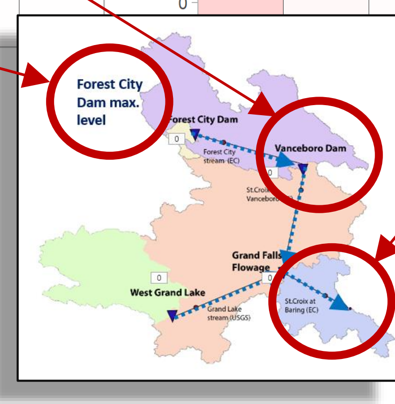
Minimum flow violations



Very low risk of violating the mining flow mandate (only under extreme dry & warm futures)

Minimum flow violations





Risks of not maintaining min. flow requirement is **higher** at the downstream locations.

Final Remarks

- Decision Scaling approach is a stakeholder driven bottom-up approach to climate change risk management.
- Stakeholders perform a key role in the process: define what “successful performance” looks like
- Climate model information is incorporated at the final stage of the analysis.
- The framework can be used to gain a better understanding of how climate uncertainty affects project performance
- Implemented on Great Lakes and with IJC basins.

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Incorporating Climate Change into Water Resources Modelling – A Case Study

Integrated modelling in the Great Lakes

Craig McCrimmon, Luis Leon, Ram Yerubandi (ECCC-WSTD)
Laxmi Sushama, Oleksandr Huziy (McGill University)

Ontario Climate Consortium 2018 Forum: Integrating Climate Information into Watershed Planning

June 11, 2018

Climate Change Adaptation Modelling Overview

Research Questions

- How does climate influence nutrient loadings from tributaries to the Great Lakes?
- How does climate control the physical, chemical, and biological regimes of the Great Lakes?
- Are current BMPs (beneficial management practices) and nutrient targets adequate in the future climate?

Study Design

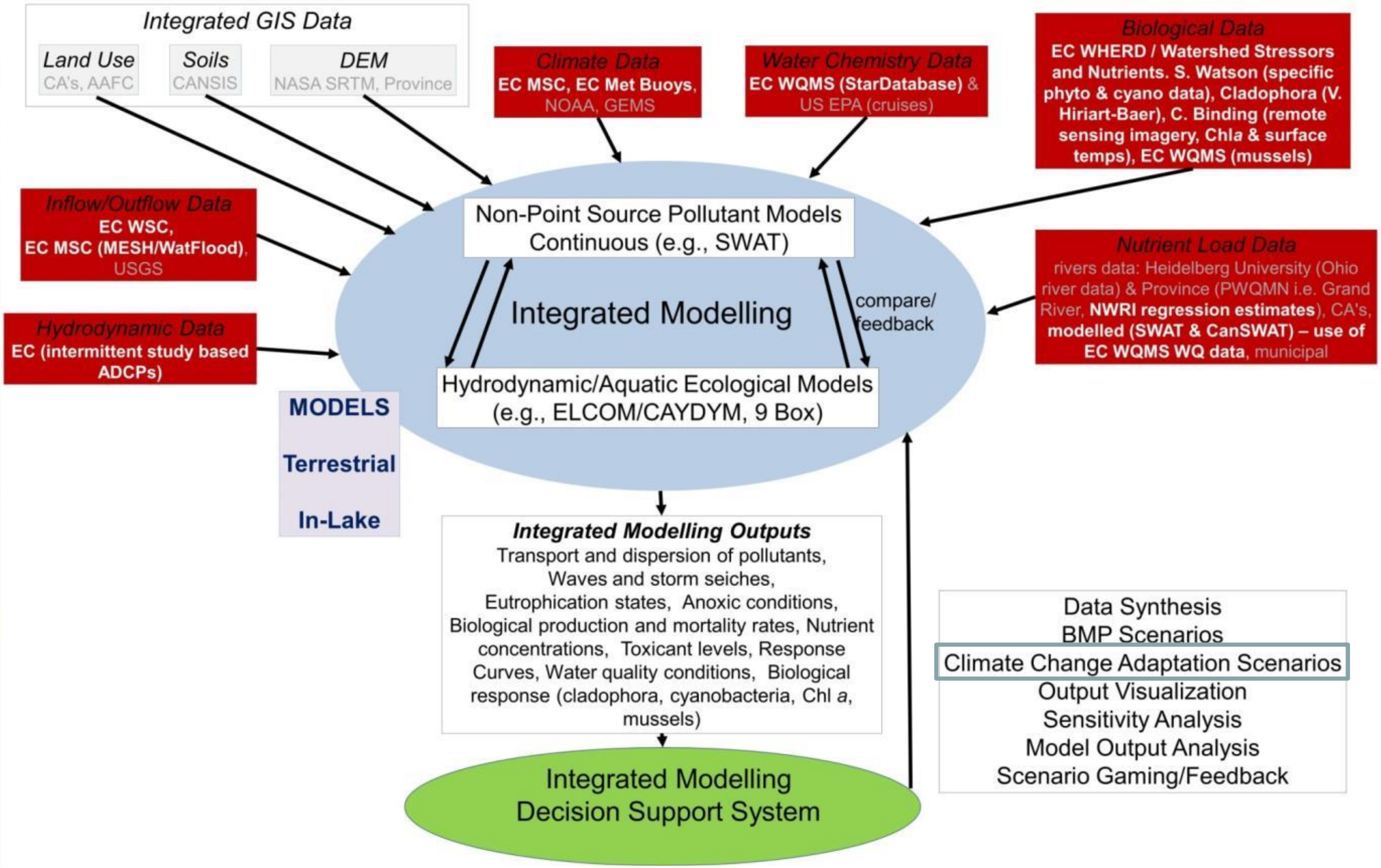
- Measure/analyze lake surface processes (e.g. evaporation), tributary loadings, and limnology
- Model watersheds; identify pollutant hot spots; BMP and climate scenarios
- Contribute to next generation coupled climate-lake models
- Evaluate Great Lakes future climate ecosystem health (e.g. HABs, hypoxia)

Outputs

- Lake data sets: water temperature, DO, chla, energy budgets
- Models and decision support tools for assessing climate change impacts
- Input to HABs tracking Bulletin and Lake Erie climate change impacts (Annex 4 & 9-GLWQA)

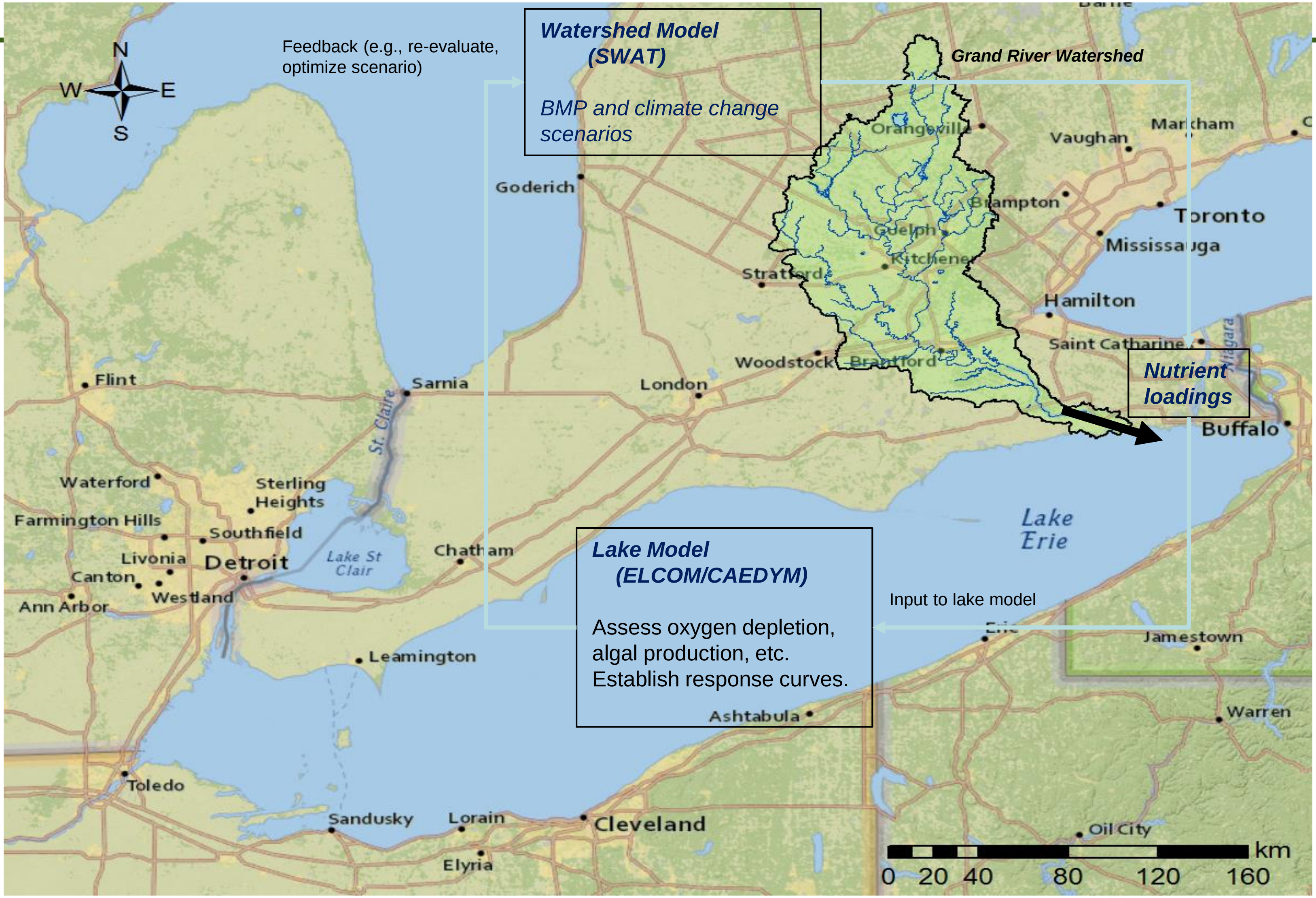
Background

Great Lakes integrated modelling framework



Example: Great Lakes Nutrient Initiative (GLNI)

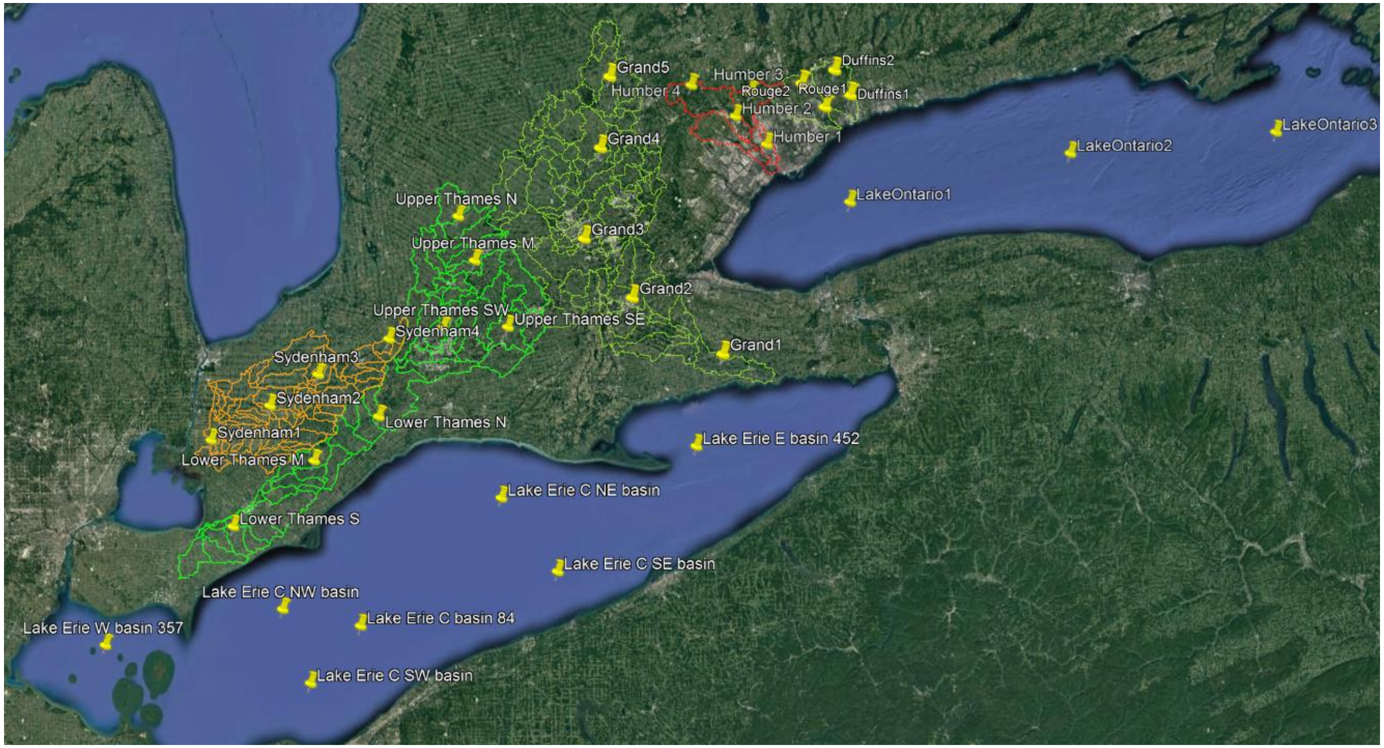
- watershed and lake model integration with focus on Lake Erie and e.g. Grand River



Climate Change Adaptation

Objective: Contribute to ensure Canada will have data, information and knowledge needed to assess present and future adverse effects of climate change on aquatic ecosystems & identify, quantify and predict effects of climate change on water fluxes, water quality and aquatic ecological health, in the Great Lakes regions, to inform adaptation strategies and support water policy development and decision making.

- Impacts on flow and TP in Grand River watershed & Lake Erie: climate change scenarios for two future time periods: (1) mid-century (2050-2062) and (2) end-century (2088-2100). Other watersheds include Thames, Sydenham
- Ideally use data from a number of climate models to get uncertainty of outputs. Time consuming to build data sets. ELCD lake model computation time lengthy.



Locations of extracted meteorological parameters (air temperature, precipitation, humidity, wind speed and solar radiation) from Climate Change scenarios model output used in SWAT for watersheds and ELCOM-CAEDYM for lakes.

Modelling Climate Change Forcing

Expected under climate change in the Great Lakes:

- changes in the frequency, timing and intensity of storms on nutrient loading with longer growing periods...
- potential impacts of reduced ice cover and increased water temperatures resulting in increased evaporation, lower water levels and changes in ecosystem health…

Current Collaboration with UQAM (L'Université du Québec à Montréal)

- CRCM5 model developed includes lake models Hostetler (1D), NEMO (3D).
- Goes step further to simulate water balance of lakes – inflow, outflow, impact on stream flow.
- Lakes dampen increases in air temperature, particularly near the lakes.

Climate change model: 5th generation of the Canadian Regional Climate Model (CRCM5) driven by Canadian Earth System Model (CanESM2) at the boundaries for Representative Concentration Pathway 8.5 emissions scenario (RCP8.5: business as usual).

Watershed and lake model climate inputs

Watershed Model, SWAT (Soil and Water Assessment Tool)	Lake Model, ELCD (Elcom-Caedym)
Daily climate inputs: • Air temperature max and min • Precipitation • Solar radiation • Wind speed • Humidity • Atmospheric CO2	Sub daily climate inputs: • Air temperature • Solar radiation • Wind speed and direction • Relative humidity • Incoming longwave radiation • atmospheric pressure

Watershed and lake model simulations/objectives:

Assess climate change adaption scenarios

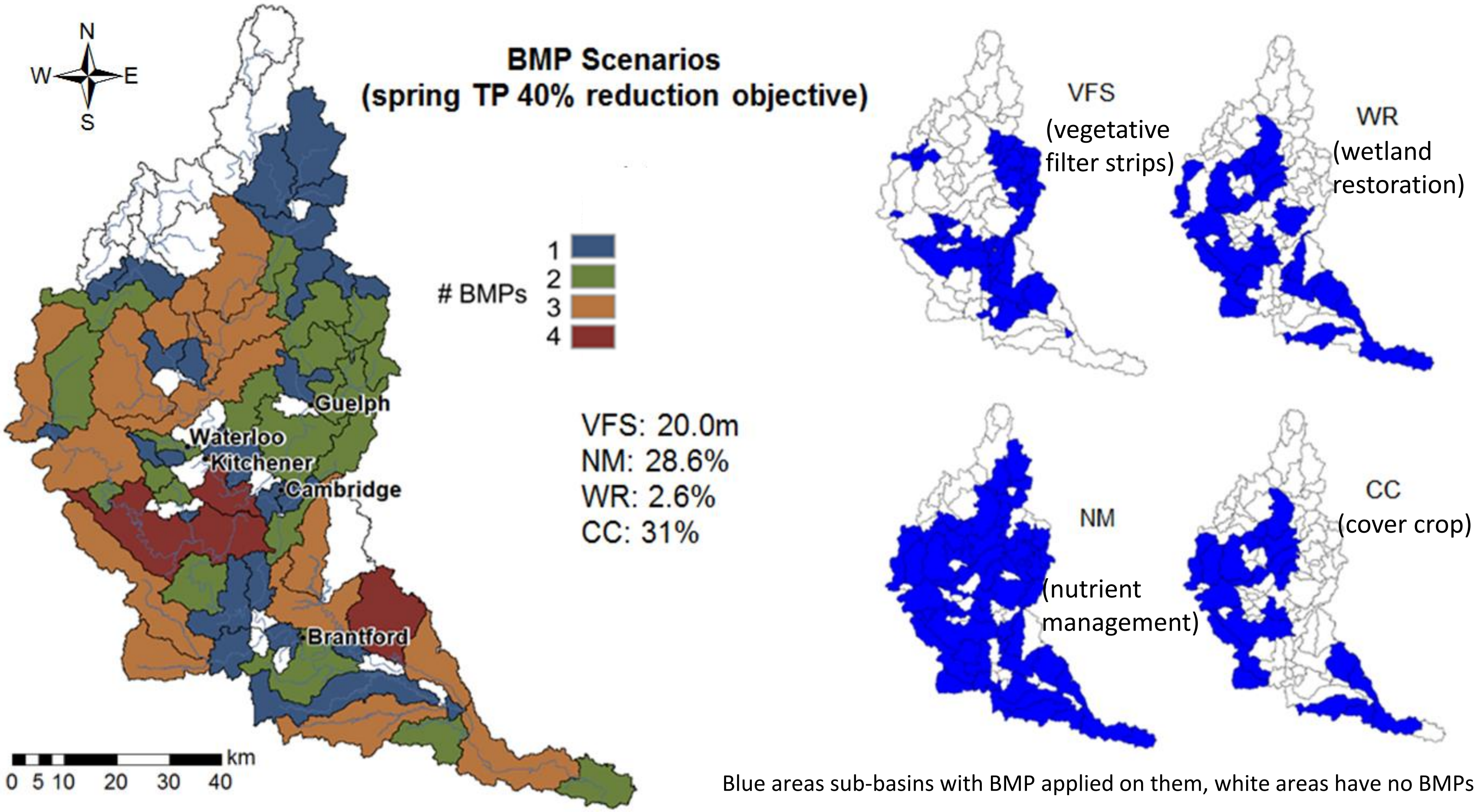
Assess combined BMPs and climate change scenarios

Climate Change data - Grand River watershed

- "delta change" method: changes in mean monthly values between baseline and future periods, typically 30 years each (Charron, 2014)
  - calculated fraction changes or differences (for air temperatures).
  - delta changes applied to the baseline datasets to obtain the future climate projection.
- Statistical Downscaling Climate Scenarios from PCIC (Pacific Climate Impacts Consortium) (http://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios).
  - Provide downscaled model climate outputs, based on combinations of the emission scenario, downscaling method, and model ensemble.
  - Based on Global Climate Model (GCM) projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and Canadian historical daily gridded climate data.
  - Daily precipitation, and minimum and maximum daily air temperature, downscaled to a gridded resolution of approximately 10 km across Canada. Precipitation, followed by air temperature, are the dominant climate inputs for the SWAT.
- Changed atmospheric CO_2 : SWAT default 330 ppm vs future 716 ppm
- We chose a climate model representative of worst case (MPI)
- Compared base case 1990-2014 to future late century

Watershed - Scenario Modelling

Current case with BMP scenarios.



Blue areas sub-basins with BMP applied on them, white areas have no BMPs

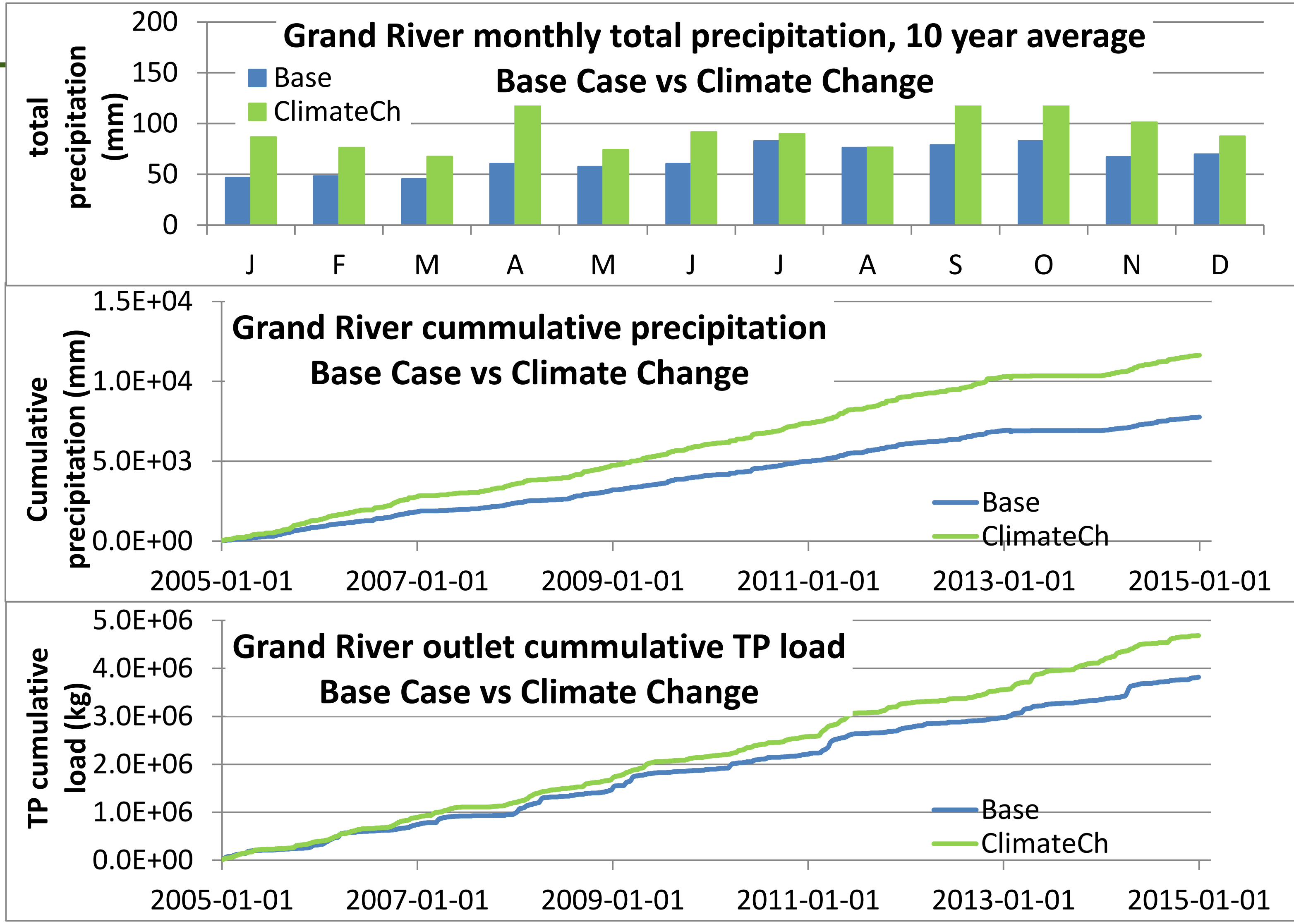
Modeling different beneficial management practices (BMPs) in the Grand River watershed to achieve nutrient objectives for the east basin of Lake Erie and reduce phosphorus loads at the watershed outlet.

→ Multiple BMPs scenarios developed using CanSWAT

→ Will combine BMPs with climate change scenarios

Watershed - Scenario Modelling

Preliminary results…



Grand River CanSWAT model output at watershed outlet 1989-2014 simulation and with end of century Climate Change (MPI model + CO_2 716 ppm + point sources future population)

Climate Change data - Lake Erie ELCD model

Assess the impact of proposed best management practices (BMPs) and climate change adaptation strategies on the lake's water quality, HABs/hypoxia for effective management.

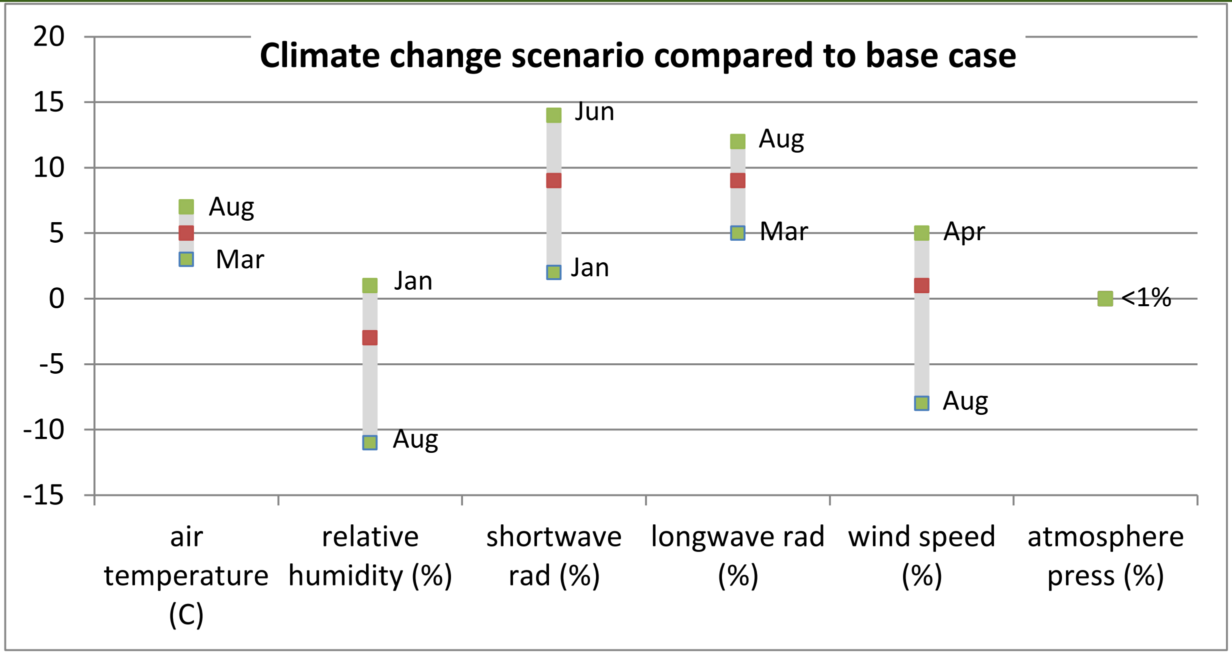
Base case forcing:

- mostly from observations (buoys, both US & Canadian),
- multiple gaps filled with data from land stations and climate models output (i.e., CRCM5)

1st climate change modelling inputs:

- "delta change" method
- PCIC + World Data Center for Climate for the same scenario used for the climate change scenario (http://cera-www.dkrz.de/WDCC/ui/EntryList.jsp?acronym=MXEL)

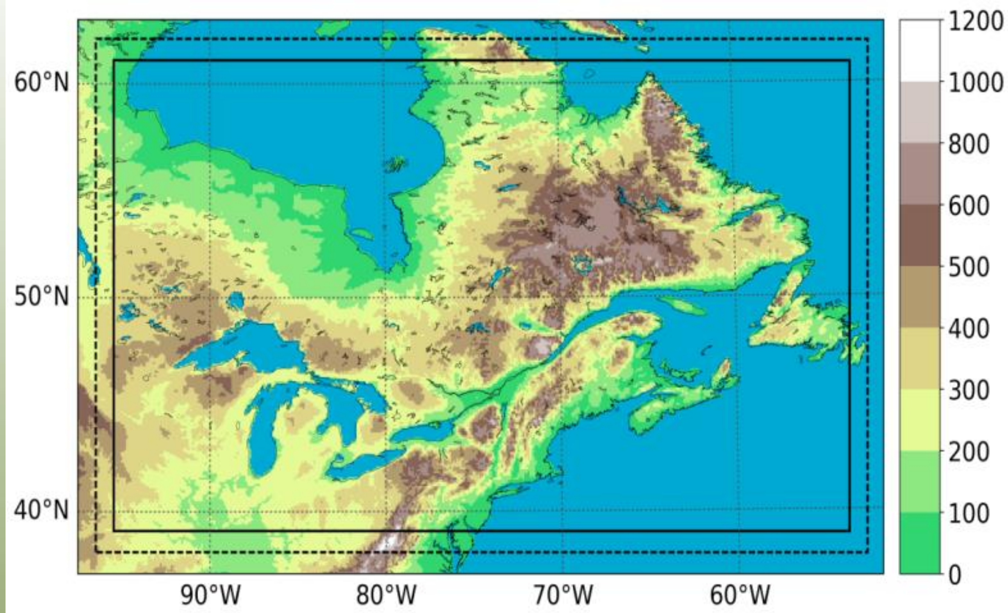
Lake modelling [multi-year simulations]

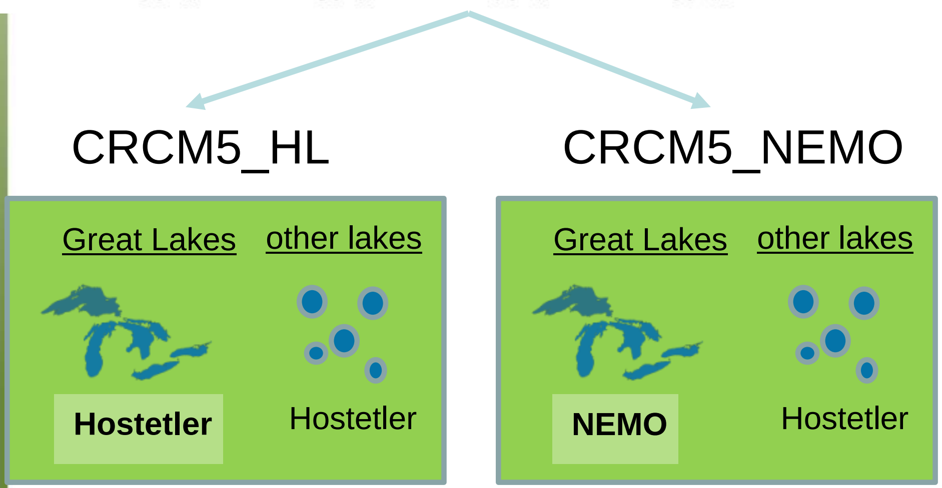


1st climate change dataset monthly average changes:

- **2nd Climate scenarios:** CRCM5 +Hostetler or +NEMO
- Simulation at 2km grid resolution for 6yrs$_{2008\text{-}2014}$
- Selected two future periods and extract 6yrs forecast datasets: one around mid-century$_{\sim 2056\text{-}2062}$ and other at end-century$_{\sim 2088\text{-}2094}$

Modelling Climate Change Forcing





- future climate from **Regional Climate** models (compared to currently observed)
- two coupled models for the **Great Lakes** analyzed…

Climate scenario: Huziy, O. and Sushama, L., 2016. Lake–river and lake–atmosphere interactions in a changing climate over Northeast Canada. Climate Dynamics, pp.1-20.
Climate scenario data: Centre ESCER (Étude Simulation du Climat à l'Échelle Régionale), University of Quebec at Montreal, Montreal, QC, Canada

Canada

Modelling Climate Change Forcing

Climate model with Hostetler 2070-2100 compared to 1980-2010 (Huziy and Sushama, 2016)

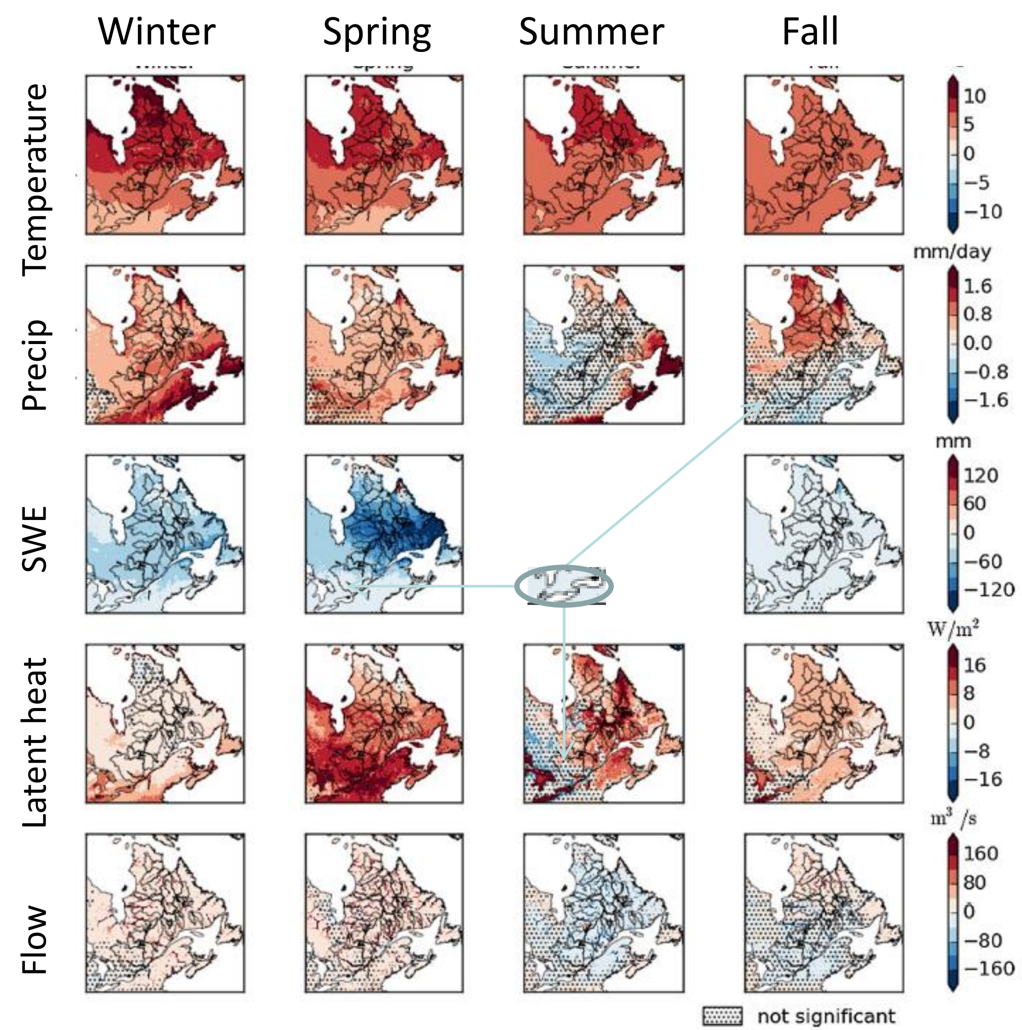


Fig. 9 Projected changes for the 2070–2100 period with respect to the 1980–2010 period to 2-m air temperature (°C), total precipitation (mm/day), SWE (mm), latent heat flux (W/m²) and streamflows (m³/s); the grid-cells where the changes are not significant at the 5 % significance level are indicated with *dots*. The changes are based on CanESM2-CRCM5-L simulation results between 1980–2010 and 2070–2100 periods

Environment and Climate Change Canada

Comparison of Climate Data for Observed (base case), CRCM5 +Hostetler and CRCM5 +Nemo

Met forcing:

WEST		2002-14		midC 2050-2062		endC 2088-2100	
Air_Temp	BaseCase-Obs	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO
max	32.1	*38.1*	33.7	*40.1*		*43.2*	
min	-24.3	*-14.8*	-21.2	*-13.5*		*-6.8*	
avg	10.3	*13.7*	10.9	*16.1*		*18.8*	

CENTRAL		2002-14		midC 2050-2062		endC 2050-2062	
Air_Temp	BaseCase-Obs	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO
max	31.9	*35.8*	30.6	*38.4*		*40.9*	
min	-24.5	*-14.5*	-21.4	*-12.3*		*-5.9*	
avg	9.7	*13.4*	10.5	*15.8*		*18.5*	

EAST		2002-14		midC 2050-2062		endC 2050-2062	
Air_Temp	BaseCase-Obs	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO	CRCM5-Hostetler	CRCM5-NEMO
max	31.5	*34.7*	31.0	*37.1*		*40.8*	
min	-24.8	*-16.8*	-21.1	*-14.4*		*-6.9*	
avg	9.4	*12.8*	9.9	*15.2*		*17.9*	

NOTES:

1 Hostetler right out the bat overestimates current base case period (W+6, C+4, E+3)

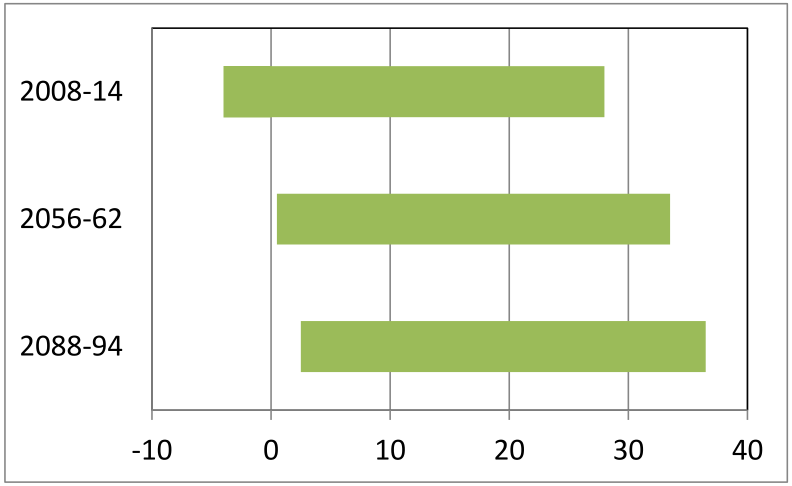
2 In contrast, CRCM5-NEMO matches way better current climate (UQAM-CC sims in progress)

3 In bothe cases, warming is consistent with latitude gradient from west to east (OK)

Model output (ELCOM):

forced with CRCM5-Hostetler

	Water Temperatures		
	Min	Max	Avg
2008-14	-4	28	12.00
2056-62	0.5	33	16.75
2088-94	2.5	34	18.25



Central Lake Erie water temperatures ranges

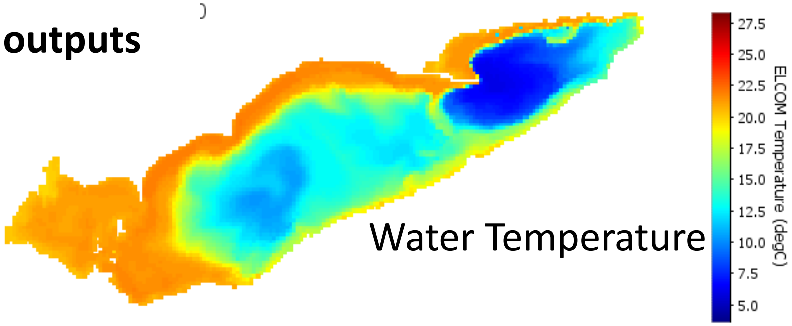
Lake Erie Modelling [ELCOM-CAEDYM]

3D hydrodynamic and bio-chemical modeling in Lake Erie.

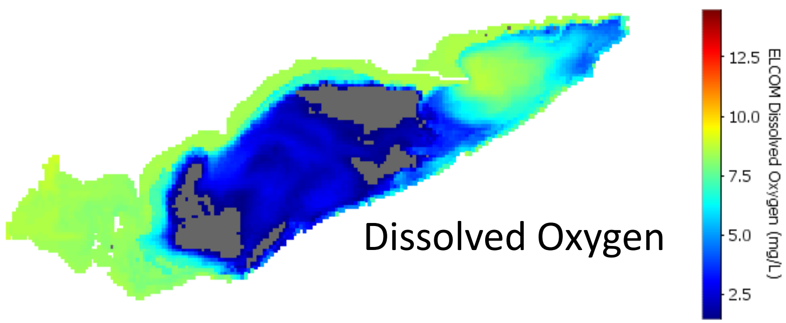
Part of an ensemble of models for binational GLWQA 2012 Annex 4 (Nutrients)

Lake Erie ecosystem objectives → phosphorus load-response curves for Lake Erie relating phosphorus loads to basin-wide phytoplankton biomass and extent-duration of hypoxia in the central basin.

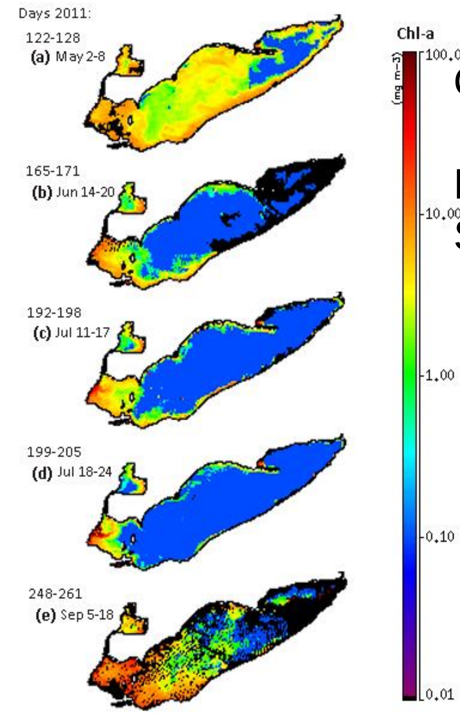
Base Case outputs



Water Temperature

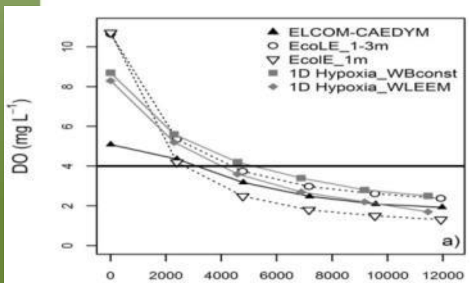


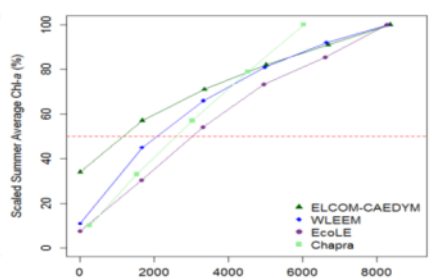
Dissolved Oxygen

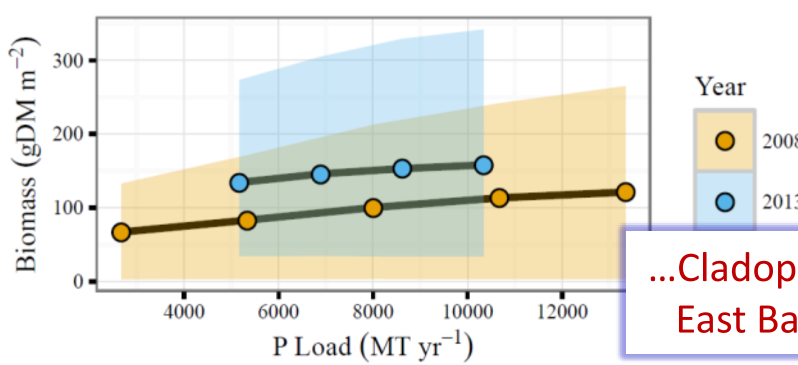


Chlorophyll_a

May to September





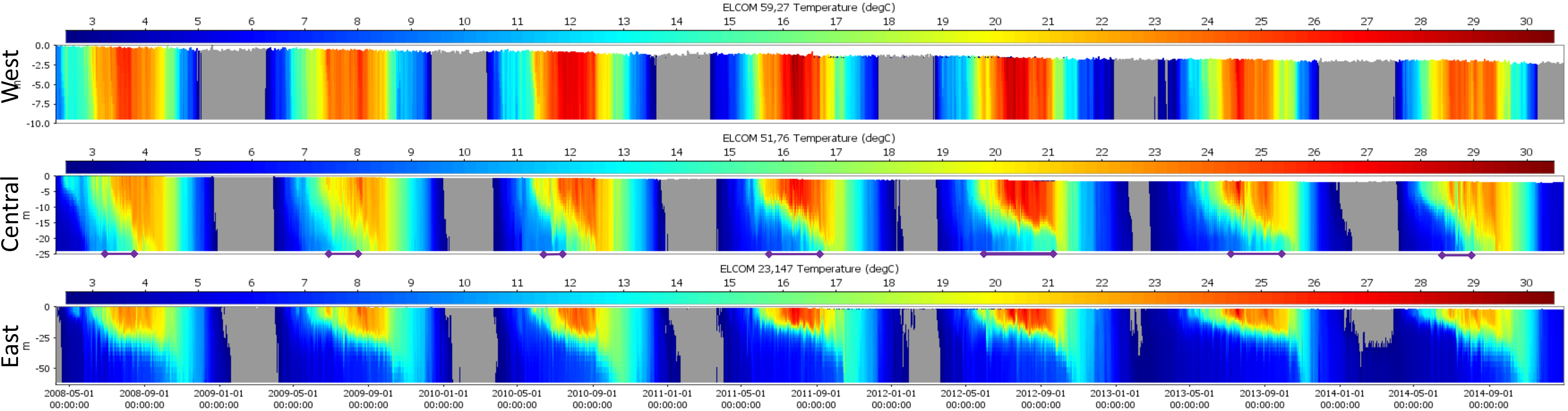


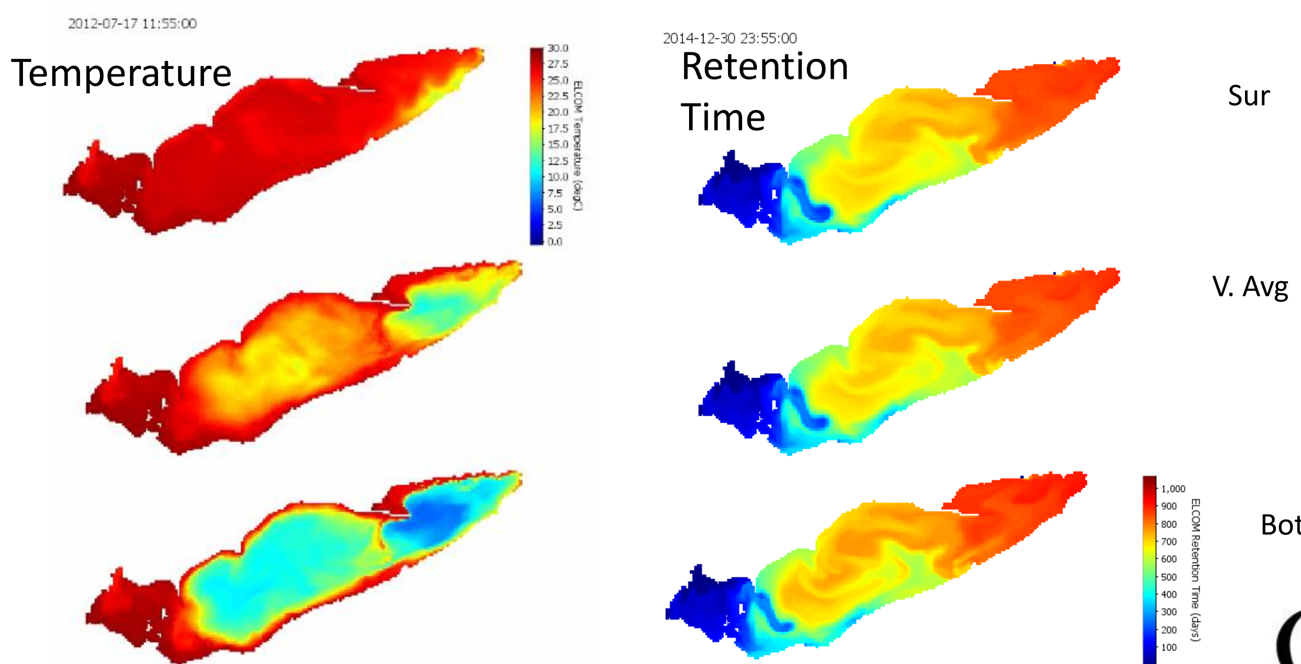
Load response curves for Annex 4 study

…Cladophora East Basin

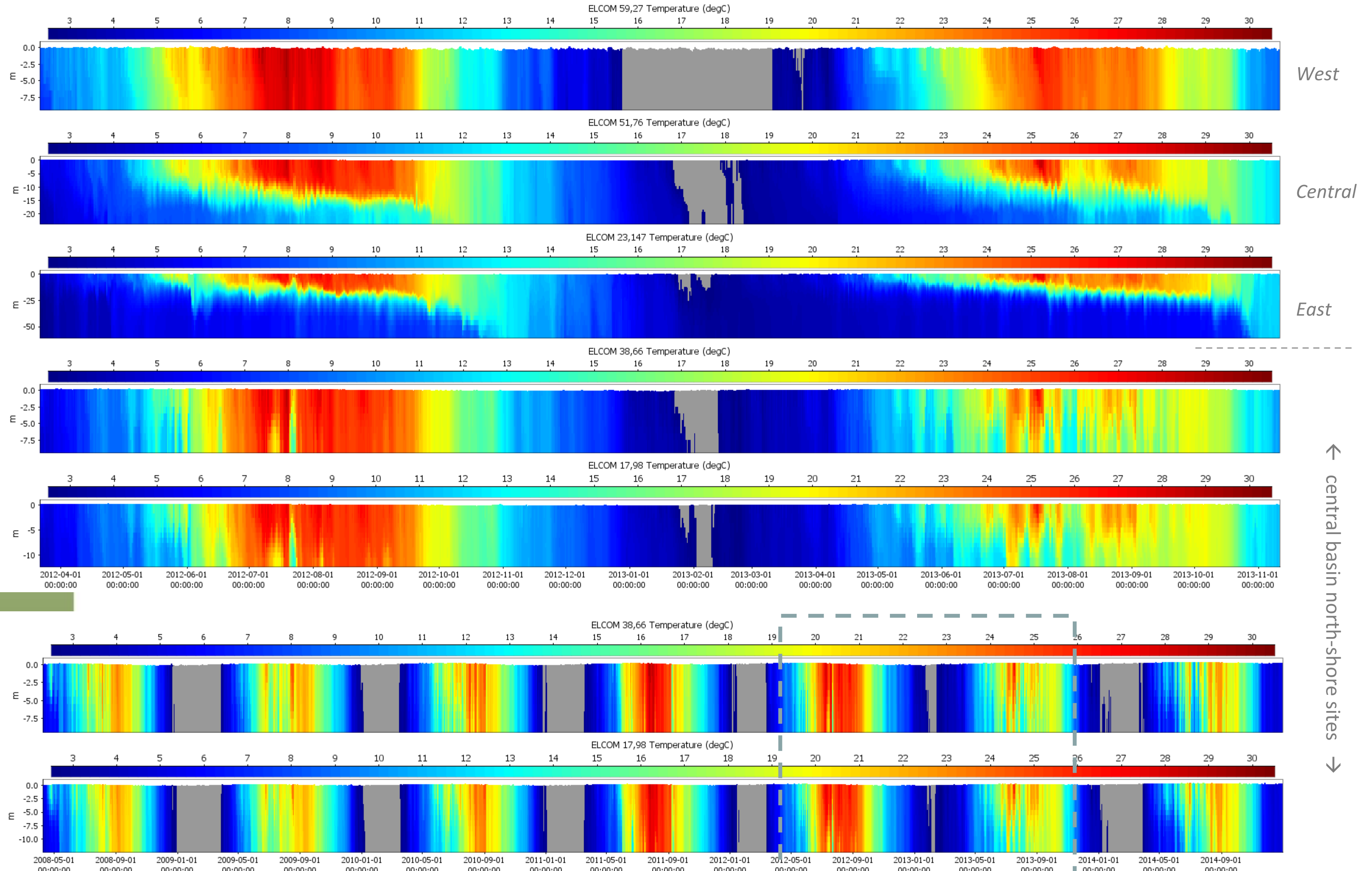
Base case 2008-2014

Water temperature 2008-2014: low temperature threshold grey area <2.5° C (~ spring initial conditions)





…some zoomed in time periods (upwelling, thermocline depth, etc.)

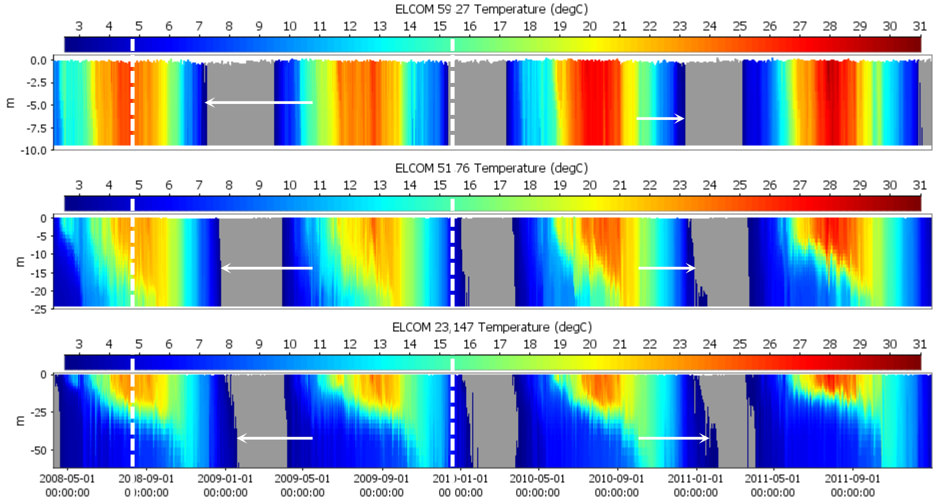


ELCOM Climate Change Output (end of century)

CRCM5 Hostetler RCP 8.5… greenhouse gas emissions continually increasing

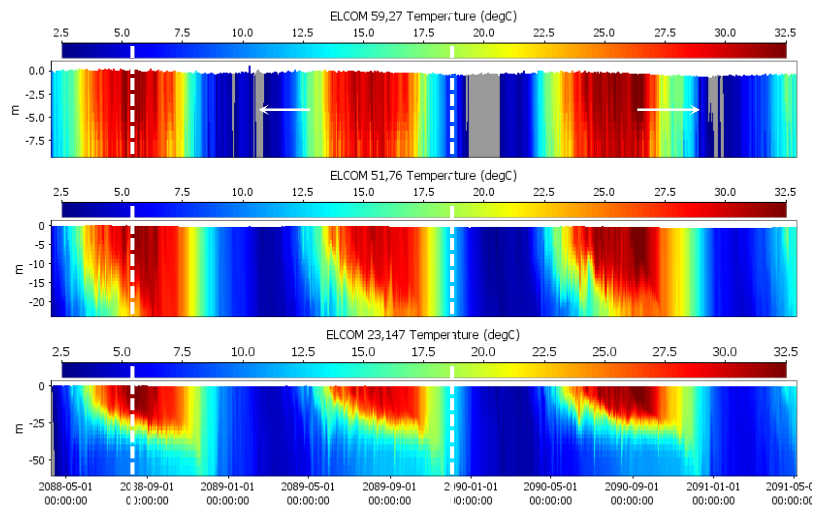
Current Climate: 2008-2014

…markers @ random date variation for bound/duration (<2.5° C)



Climate Change – end of century: 2088-2094

…showing warming (+3° C) no ice; CB shorter stratification period; deeper thermocline; earlier mixing?…



Environment and Climate Change Canada

Environnement et Changement climatique Canada

Canada

Water Quality-ELCD

Preliminary results…

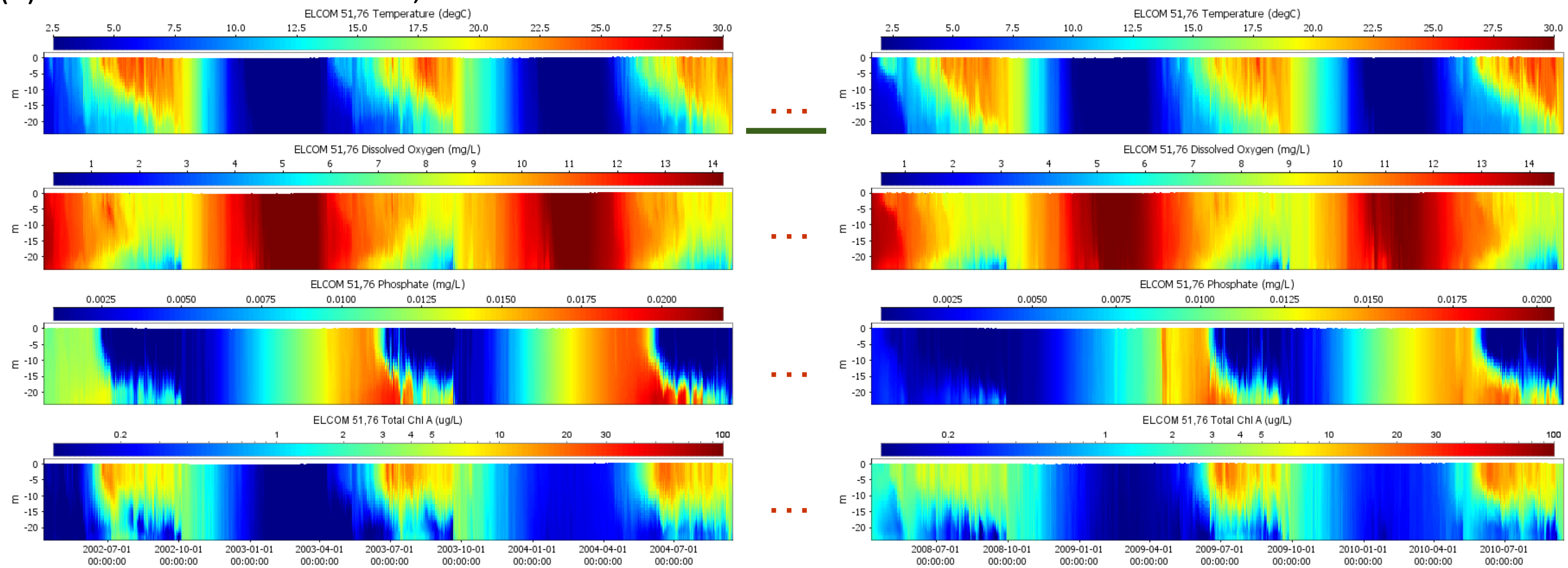
(a) Present Climate: 2002-04; 2008-10

Temp

DO

SRP

Chla



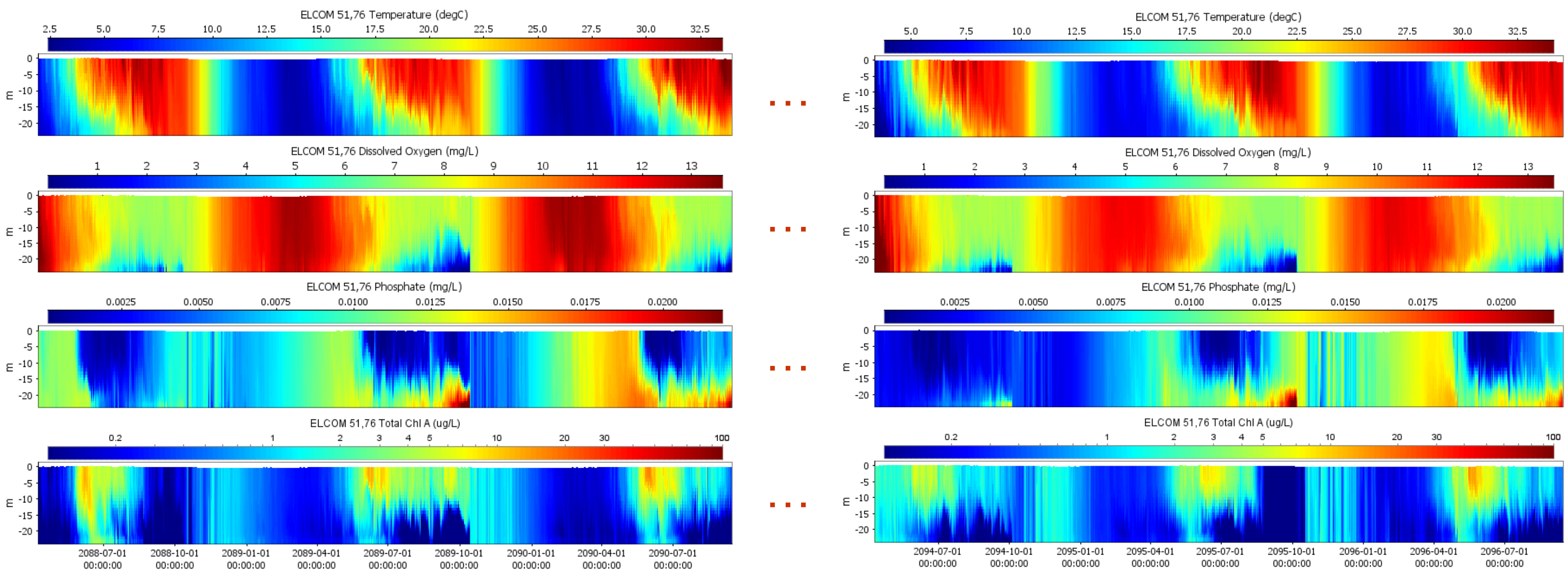
(b) Climate Change – **end of century**: 2088-90; 2094-96*: warming (+4 ° C); CB show stronger stratification period; deeper thermocline; strong evidence of increased hypoxia…seasonal shifts in TChl-a (results for 3 phytoplankton groups)*

Temp

DO

SRP

Chla



Summary

- We have used a few different climate models for the watershed and lake modelling
- Seeing increase in flow and loadings to the lake; less ice cover in lake
- Climate models that include lake models appear to be important for our areas of interest
- Ideally would like to run more models for better uncertainty analysis
- Still to run watershed and lake models with same climate change model and use watershed climate change loading as input to lake
- Planning to test using climate model output directly in watershed model (instead of delta change method)
- Several GTA watershed SWAT models ready to go for climate change scenarios - Rouge, Duffins, Carruthers, and Humber (almost)

Closing Remarks

What did we hear today?

- Uncertainty in climate data remains challenging, but doesn't mean we can avoid addressing climate change.
- Need to "take stock" more broadly of the state of practice in climate related assessments and consider the best use of data in specific contexts.
- New approaches based on risk-tolerance and decision making under uncertainty could be opportunities to be used in watershed planning

- Stay tuned for more…

Next Steps for OCC

- **Synthesis** of what we documented and heard today
- **Summary Report** identifying examples, key barriers, information gaps and ideas to overcome them
- **Information sharing** to attendees and others in the community