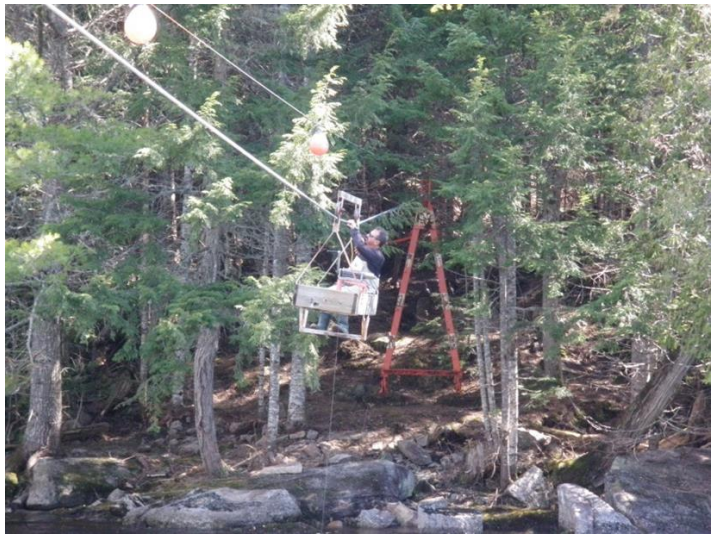


Modernizing ECCC's National Hydrological Service

Dealing with shifting trends, technologies and evolving stakeholders

Alain Pietroniro, Ph.D, P.Eng

Contributions from

- ECCC Atmospheric Research
  - Vincent Fortin, Pierre Pellerin, Stephane Belaire, Vincent Vionnet, Etienne Gaborit
- MSC numerical Model Development
  - Veronique Bouchet, Dorothy Dunford, Wei Yu
- National Hydrological Service
  - Bruce Davison, Frank Seglenieks, Dan Princz
- University of Saskatchewan
  - John Pomeroy, Martyn Clark, Kevin Shook, Mohammed Elshamy
- McMaster Univeristy – Paulin Coulibaly

Discussion

- Understanding the Canadian Policy Landscape in Water management
- Description of the newly formed National Hydrological Service (2015)
  - Hydrometric Monitoring
  - Transboundary Water Management
- Hydrological Services Renewal (2018)
  - Modernization
  - Forecasting and prediction
- Collaboration and community modelling

Shared Jurisdictional Mandates for Water

- *The British North America Act* gives provinces responsibility over the natural resources, including water, in their jurisdictions.
- However, ECCC has the mandate through *the Environment Act, Canada Water Act, International River Improvements Act* and the *International Boundary Waters Treaty Act* among others to monitor and provide advice on domestic and international transboundary water levels and flows in Canada's inland waters as well as on Federal lands.
- ECCC/MSC delivers on this mandate through two sub-activities.
    - Water Management: focuses on transboundary water management engineering services.
    - Hydrometric Program: focuses on hydrometric (i.e., water quantity) monitoring and services, the larger of the two functions within the NHS.

Hydrometric Monitoring (Water Survey) over 100 years of service

100 years ago. Minister of the Interior at the time was Frank Oliver – MP from Edmonton

- Sir Wilfred Laurier was PM.
- Deputy Minister was W.W.Cory
- First published Data :"Report of Progress of Streamflow for Calendar Year, 1909" by P.M. Sauder, Chief Hydrographer.

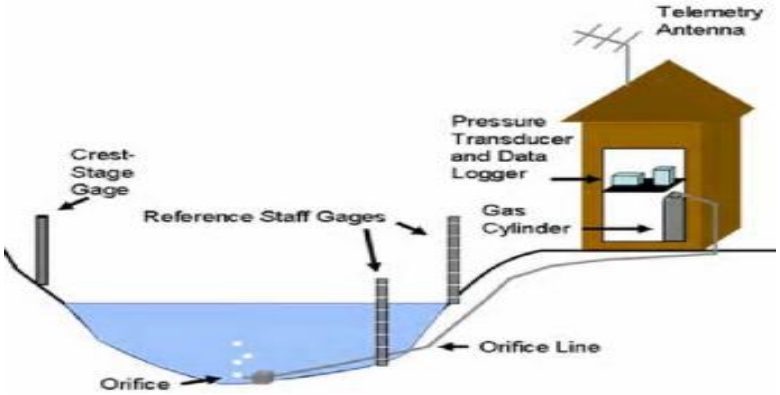
- **"The first appropriation made by Parliament for hydrographic work was in 1908"… …. as this vote was not available until the season was too far advances, only a part of it was used in purchasing equipment in 1909"**
- **"In Organizing the Hydrographic Surveys, it was realized with the funds available, it would be impossible to make complete investigations of the whole water supply "**
- **Spent two years in Montana with USGS**

.

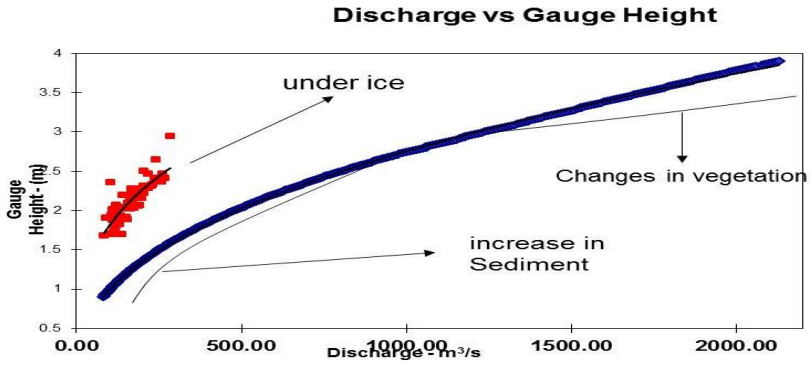
1908 2008
Water Survey
Relevés hydrologiques

Water Survey of Canada Hydrometric monitoring 101

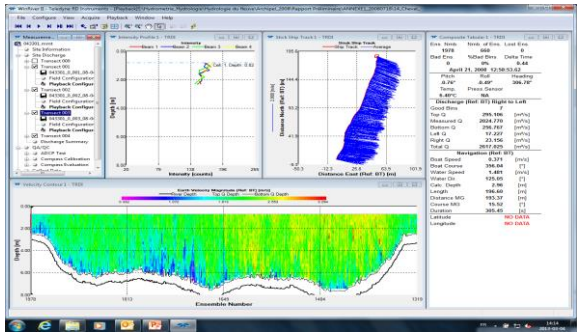
- Measuring Water Levels



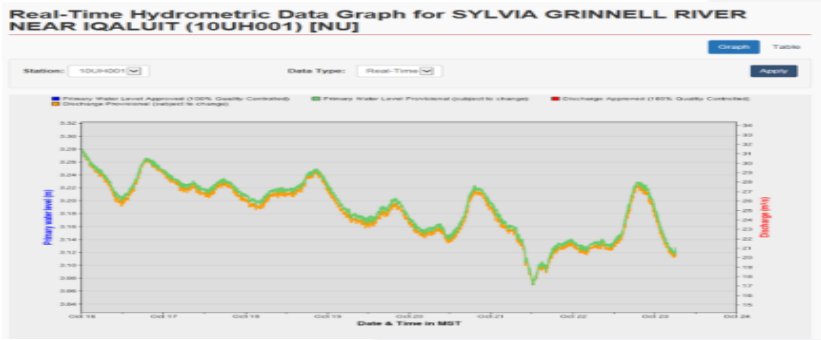
- Calculating Discharge



- Measuring Discharge

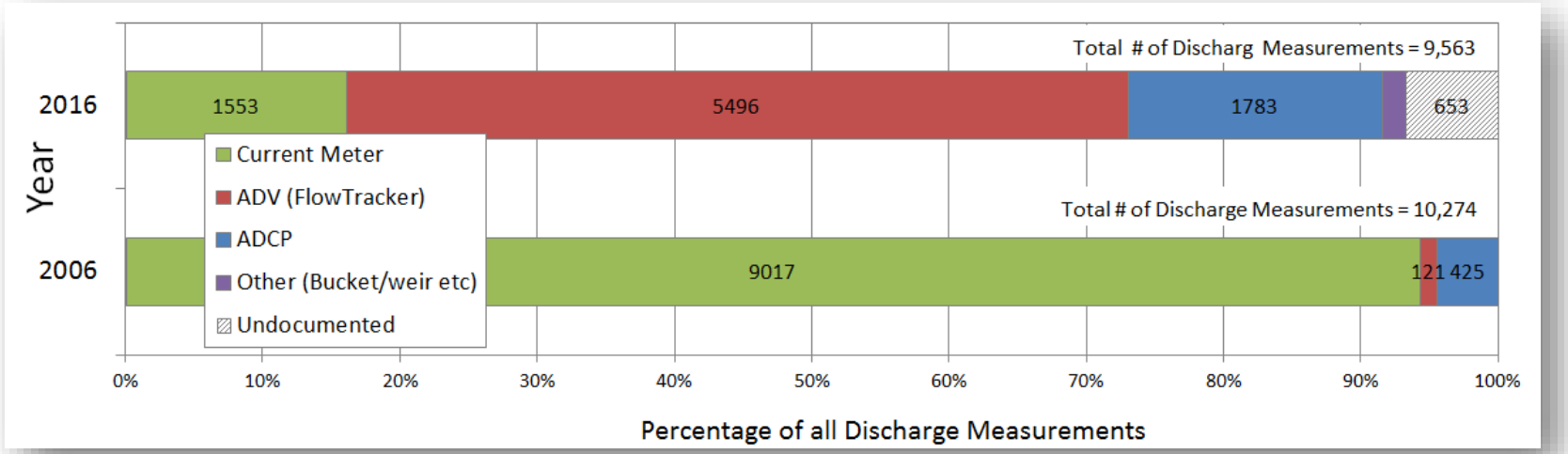


- Publishing data



Technological Change

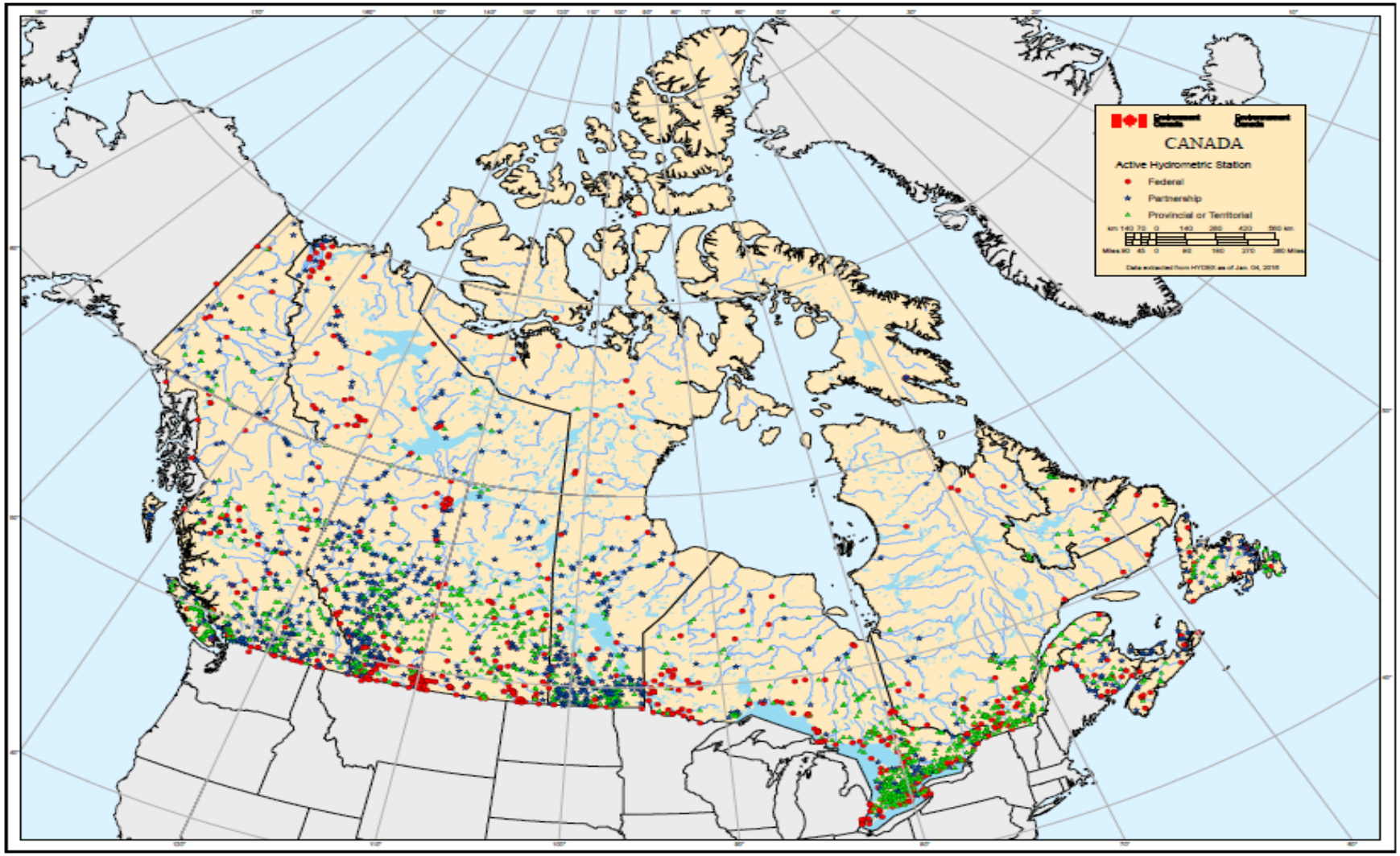
a challenge and an opportunity



- Significant change in how we measure discharge in the last 12 years.
- Technological advances outside our business affects how we do our work. Ex. cameras
- Non-contact methods like LSPIV are evolving to eventually meet operational demand and requirements
- The good and the bad of technological diversity and change
  - The paradox of choice ("why more is less" or maybe less?)
  - Market driven change (Change for change's sake)

Under Ice……..

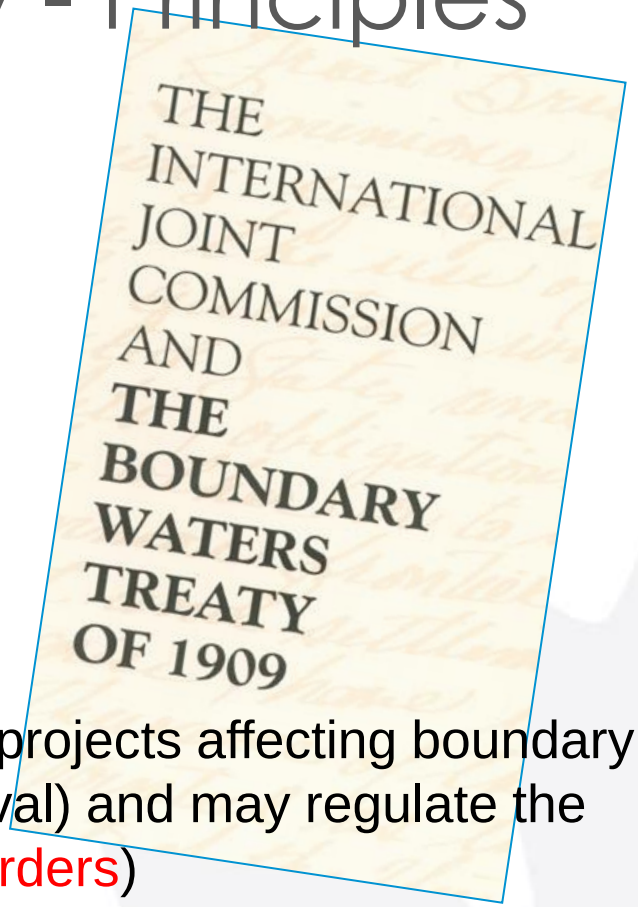
Costing arrangements



A cost-effective approach

- Bilateral, cost-shared agreements with provincial/territorial governments for water level measurement and flow estimates
  - All provinces and territories.
- Integrated program to meet combined F/P/T needs
  - hydrometric monitoring network is operated by the MSC on behalf of agreement partners
  - data collection, analysis, interpretation, dissemination, training, technology, …
- Enables consistency in approach and economies of scale
  - national standards and procedures, rigorous technical recruitment and apprenticeship, uniform quality control, etc
  - high accessibility to nationally consistent and authoritative data

Boundary Waters Treaty - Principles



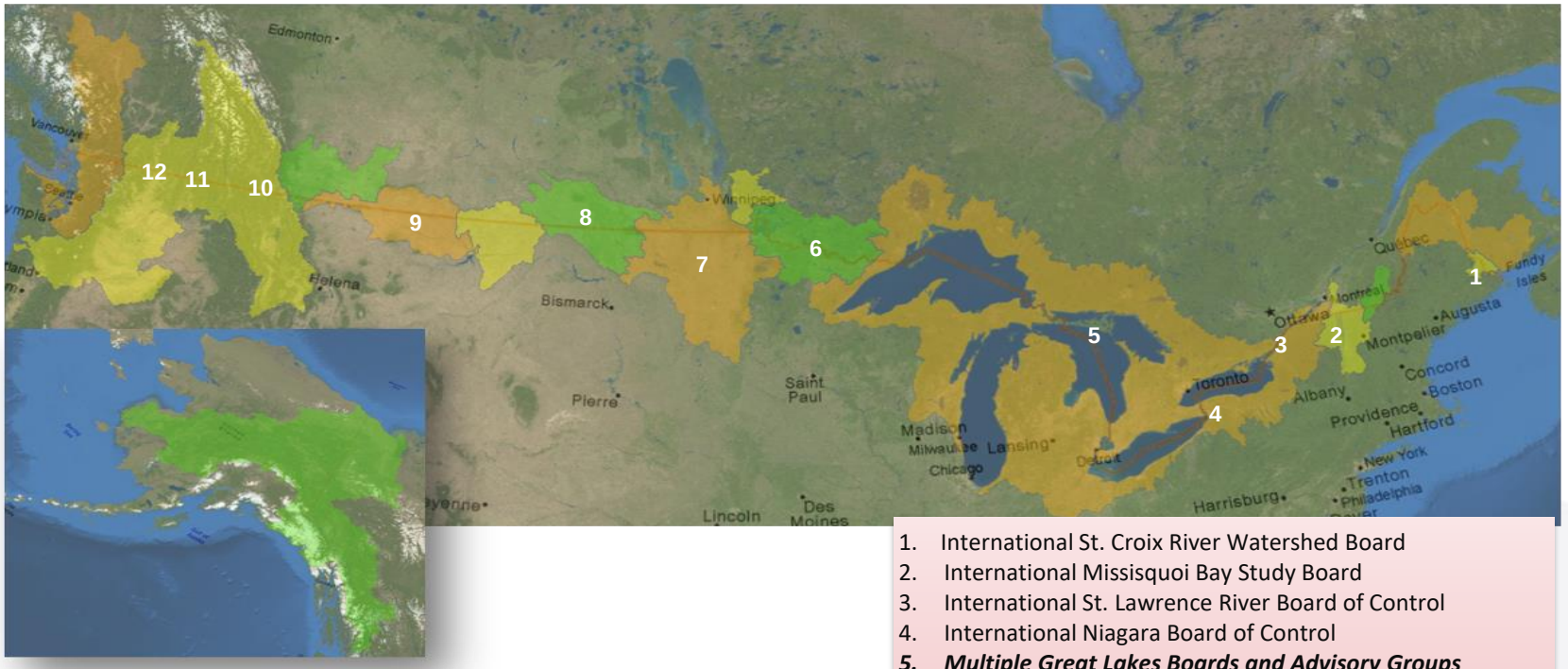
- Equal and similar rights to use of boundary waters
- Order of precedence of use – sanitary/domestic, navigation, power generation and irrigation
- Structures/diversions not to affect levels and flows on the other side
- Must not pollute water on either side to the injury of health or property on the other side
  - rules upon applications for approval of projects affecting boundary or transboundary waters (orders of approval) and may regulate the operation of these projects (review of orders)
  - investigates issues referred by governments and makes non-binding recommendations for resolution (references)
  - MSC-NHS lead agency with IJC MOU

St. Mary-Milk Rivers

Board	Origin	Officers	Duties
St. Mary's -Milk River Accredited Officer	Est by 1921 Order of the IJC respecting the St. Mary – Milk Rivers	**A.Pietroniro, ECCC - Canadian Accredited Officer)** **J Kilpatrick , USGS – US Accredited Officer**	Measurement of flow and determination of apportioned shares on a 10 day-basis.


N
Bow River
Alberta
Oldman River Basin
Oldman River
Lethbridge
Medicine Hat
Waterton River
St. Mary River
St. Mary Canal
Lake Sherburne Dam
St. Mary Diversion Dam
Milk River
Lodge Creek
Battle Creek
Shelby
Milk River
Fresno Dam
Havre
Montana

IJC Boards



15 distinct basins with some
300 lakes and rivers
water covers 43% of the 8,900 km border

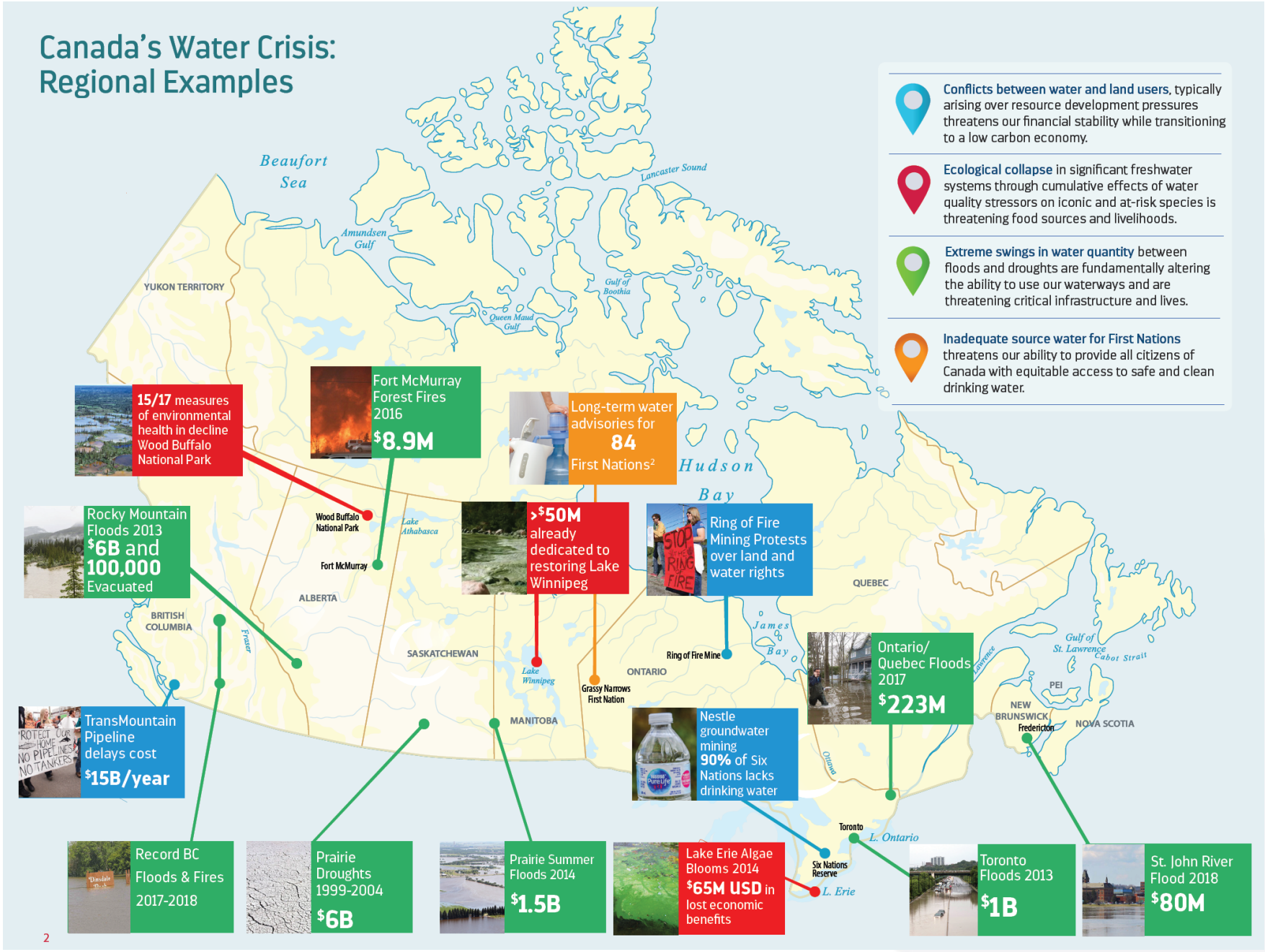
1. International St. Croix River Watershed Board
2. International Missisquoi Bay Study Board
3. International St. Lawrence River Board of Control
4. International Niagara Board of Control
5. ***Multiple Great Lakes Boards and Advisory Groups***
6. International Rainy River Pollution and Control Boards
7. International Red River Board
8. International Souris River Board
9. Accredited Officers of the St. Mary-Milk River
10. International Osoyoos Lake Board of Control
11. International Columbia River Board of Control
12. International Kootenay Lake Board of Control

Water Resources in the Meteorological Service of Canada (MSC)

- As noted ECCC has a series of mandated responsibilities for water resources and it management in Canada
- In 2018, MSC recognized the convergence of interest and capacity between MSCs national hydrometric program delivered through the Water Survey of Canada and its transboundary water management obligations.
- A National Hydrological Service was developed and is undergoing renewal as a new forward-looking vision to optimize and consolidate existing MSC program elements.

> *The impacts of climate change are felt through temperature increase and, more significantly, changes in precipitation. There are areas which becoming drier and areas where there is more flooding. This has a major socio-economic and political impact [calling for] better management of water resources…*
>
> *-- WMO Secretary-General Petteri Taalas, 2019*

Canada's Water Crisis: Regional Examples



Conflicts between water and land users, typically arising over resource development pressures threatens our financial stability while transitioning to a low carbon economy.

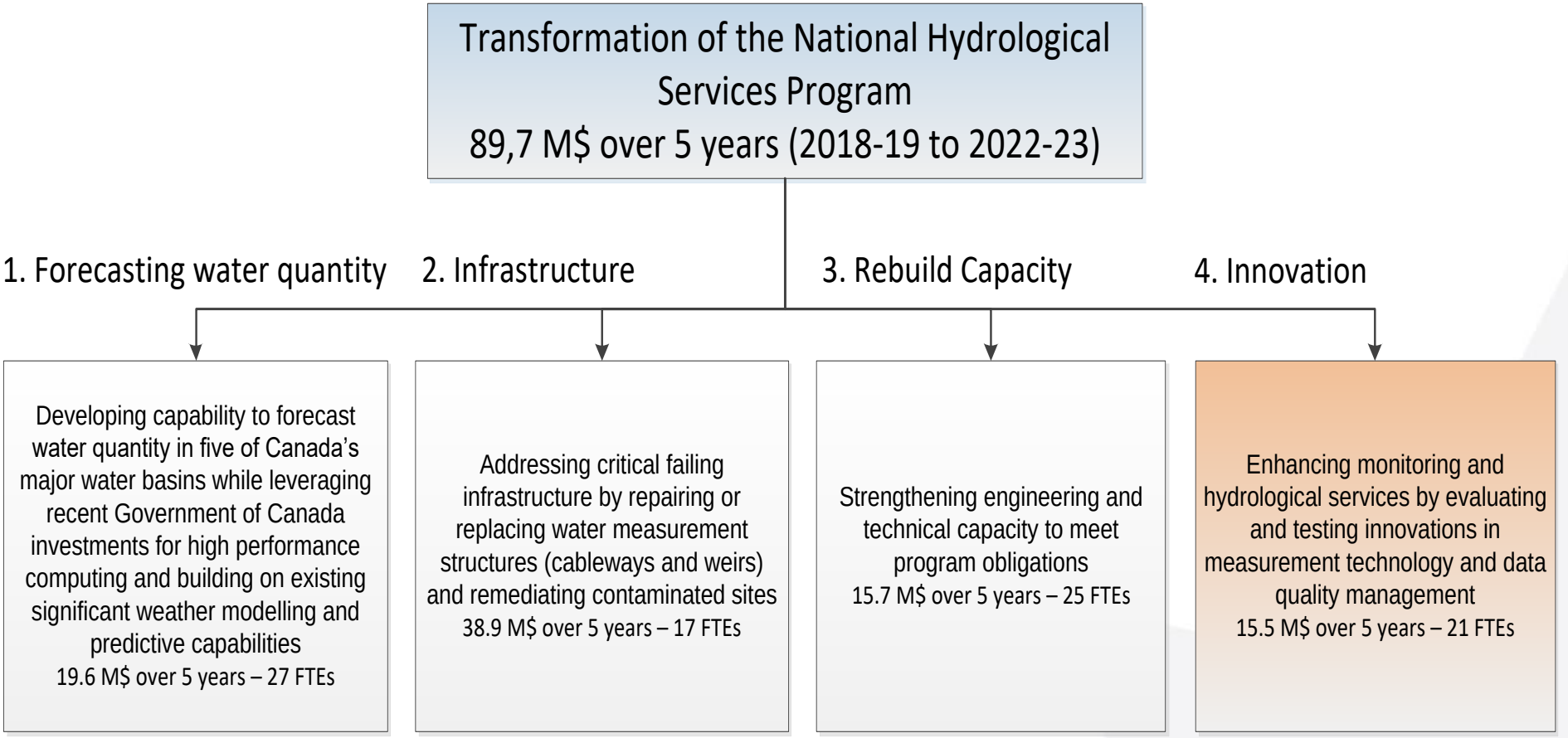
Ecological collapse in significant freshwater systems through cumulative effects of water quality stressors on iconic and at-risk species is threatening food sources and livelihoods.

Extreme swings in water quantity between floods and droughts are fundamentally altering the ability to use our waterways and are threatening critical infrastructure and lives.

Inadequate source water for First Nations threatens our ability to provide all citizens of Canada with equitable access to safe and clean drinking water.

John Pomeroy

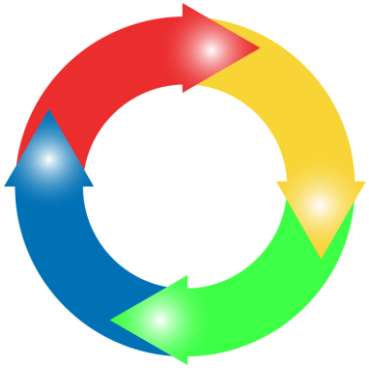
Transformation Plan



Towards a National Flow Prediction Guidance System
Collaborative R-D-O-S EFFORT

National Hydrological Services

- Provides quality-controlled hydrological data and information
- Performs studies on transboundary basins
- Contributes to the regulation of the Great Lakes and St. Lawrence Basin



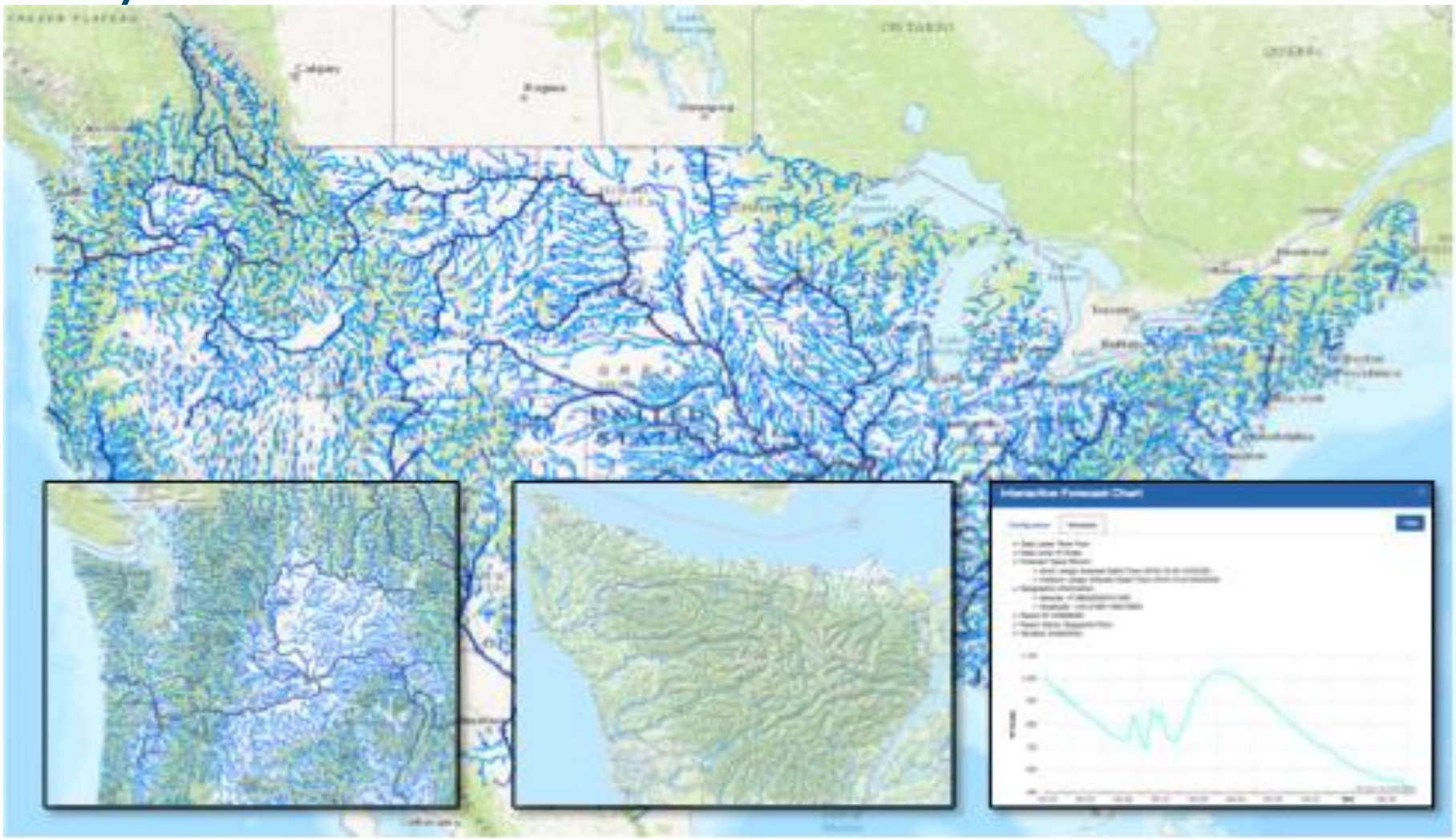
Meteorological Research Division

- Performs R&D in forecasting of environmental variables
- Proposes new or improved systems for operational implementation when they are mature

Canadian Centre for Meteorological and Environmental Prediction

- Develops and maintains operational numerical environmental prediction systems
- Delivers analyses and forecasts in real-time, with 24h/7d support

Hyper-resolution Monitoring & Prediction – National Water Mode -Martyn Clark



- 250m resol.: output for 2.7 million stream reaches, hourly timestep, deterministic
- Philosophy that higher resolution and physics reduce the need for parameter estimation
- **Hurdles**: calibration, ensembles, data assimilation, verification, longer-range forecasts

Modernizing ECCC's Water Cycle Prediction Programme

GEM-Hydro

- Integrated into MSC's operational forecasting infrastructure
  - **SVS land-surface scheme**
  - CaLDAS data assimilation
  - GEM atmospheric model
  - Two-way coupling with GEM
- Designed for regional-scale, high resolution forecasting
  - short simulation periods
  - 2.5 km resolution or better

MESH

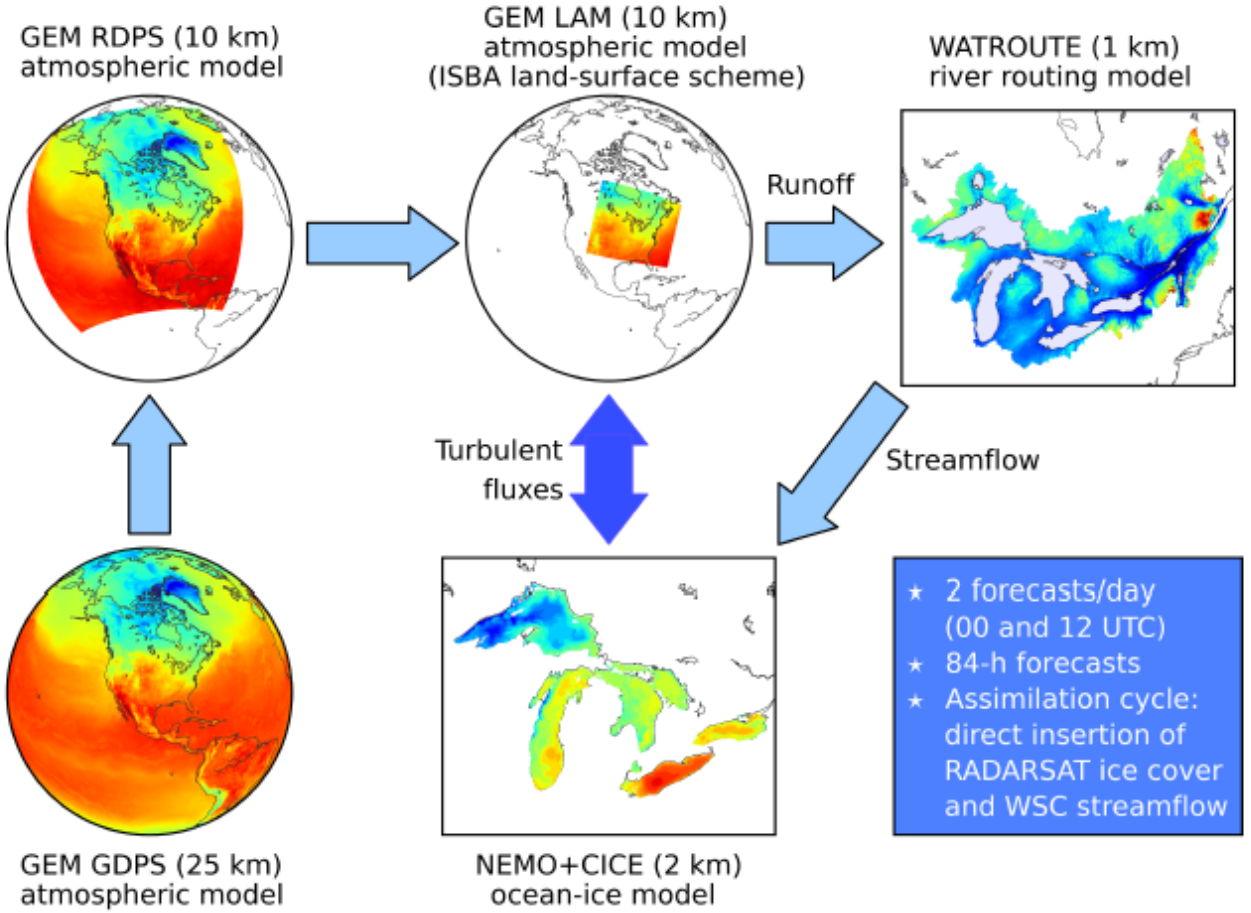
- Initially designed for R&D activities and hydroclimatic applications
  - **CLASS land-surface scheme**
- Stand-alone platform
- Community model
- Efficient system for:
  - long simulations periods
  - model calibration

External Collaborations

- **Provincial and Territorial Authorities**
  - National Administrators Table
  - Public safety
  - DOEs / Transport
  - Agriculture
  - Hydro power
- **National networks:**
  - FloodNet
  - Global Water Futures

- **Other departments/agencies:**
  - Canadian Space Agency
  - Natural Resources Canada
  - Agriculture and Agri-Food Canada
- **G&Cs**:
  - U. Laval: small-scale model evaluation
  - U. Saskatchewan: large-scale model evaluation
  - U. McMaster: early warning system
  - U. Sherbrooke: data assimilation
  - U. Waterloo: river routing
- **International collaborations**:
  - NOAA Great Lakes Environmental Research Laboratory
  - NASA Jet Propulsion Laboratory
  - Meteo-France

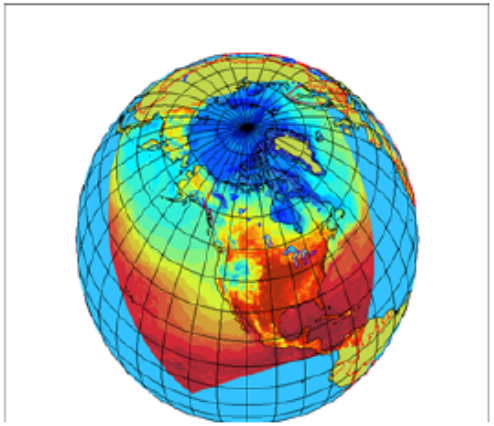
A Water Cycle Prediction System for the Great Lakes



[System described in the Bulletin of the American Meteorological Society, March 2018]

GEM Hydro – Gaborit, 2017

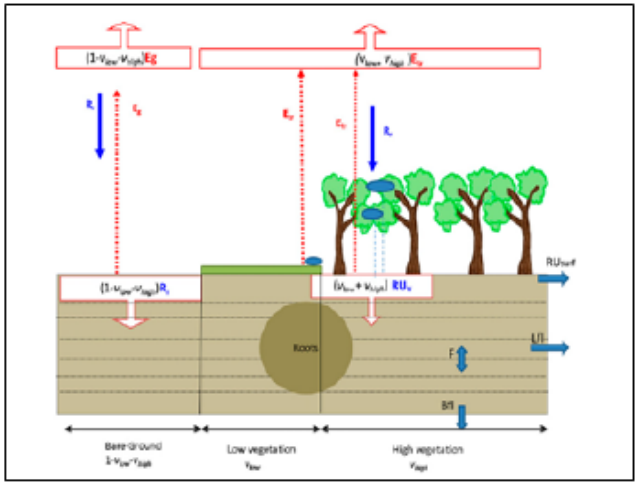
Atmospheric forcing



- Init. cond.: CaLDAS
- Forecasts from the GEM model
- Canadian Precipitation Analysis (CaPA)

Land Surface Scheme
SVS (Soil Vegetation and Snow)

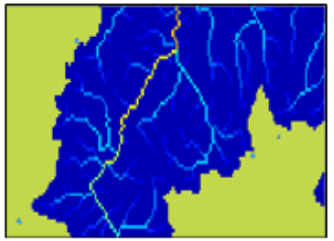
Alavi et al. (2016) Husain et al. (2016)

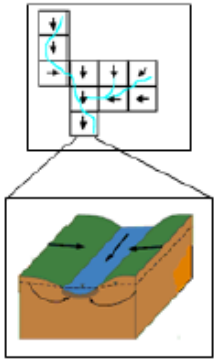


- Multiple energy budgets for bare ground, low and high vegetation
- Single layer snowpack scheme

Routing
WATROUTE

Kouwen (2010)

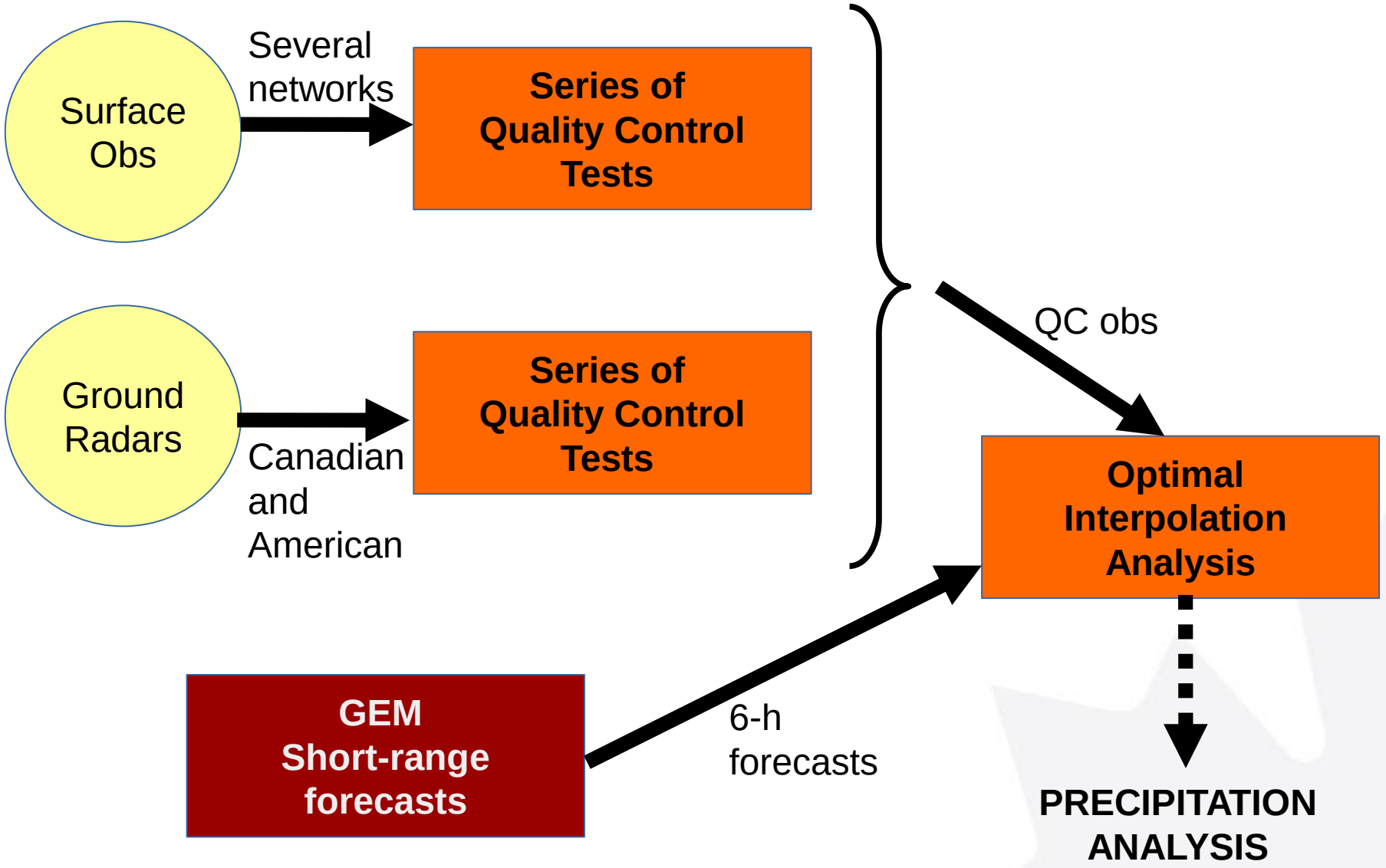




WATFLOOD
Routing scheme


Environnement et Changement climatique Canada
Environment and Climate Change Canada
Streamflow and ice cover forecast:
Zooming in on the Grand River watershed
Animation
0:00 UTC
Sunday 14 January 2018
Ice (%)
100
75
50
25
0
Debits (m³/s)
5e+02
4e+02
3e+03
2e+02
1e+02
8e+01
5e+01
2e+01
1e+01
Forecast issued on
January 10, 2018 12 UTC
© OpenStreetMap contributors

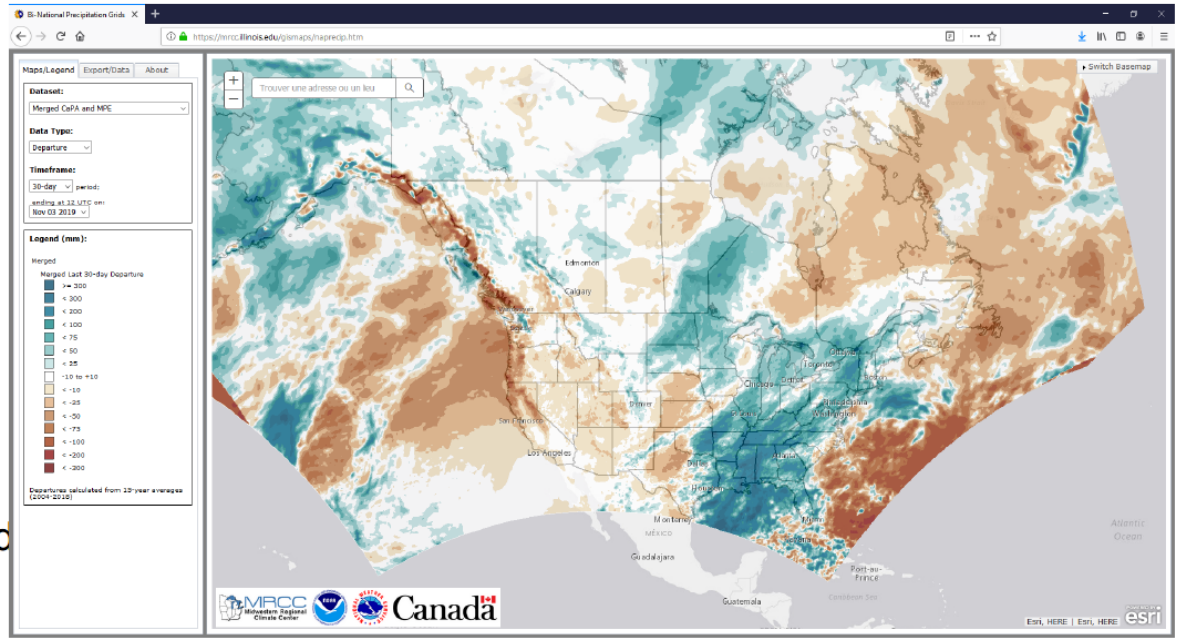
The Canadian Precipitation Analysis (CaPA)



CaPA 24 h precipitation Analysis For August 17, 2017

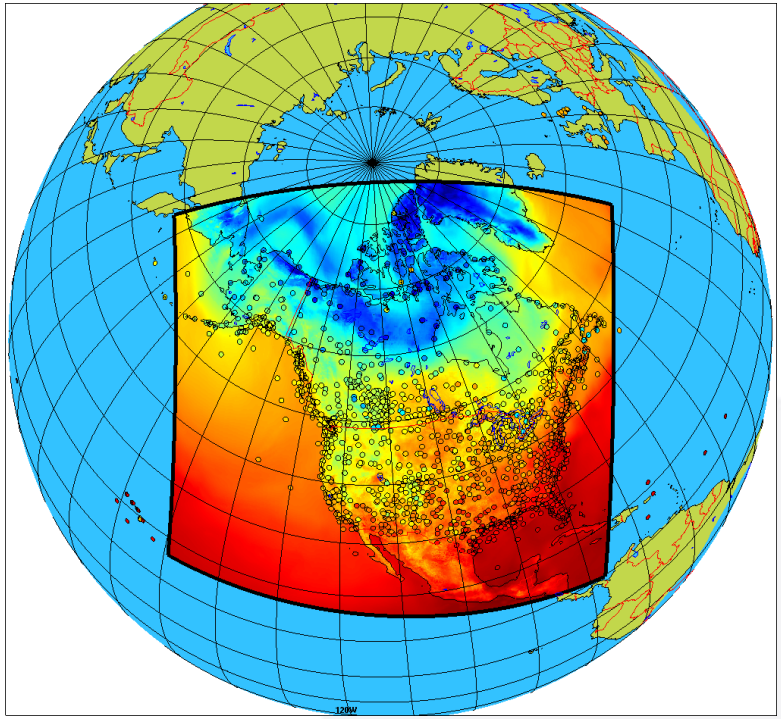
- Seamless 10-km grid covers all of Canada, USA and Mexico
- Data latency of 1h
- 2.5km product available over Canada and Northern USA
- Archive going back to 2002 available online
- Reanalysis going back to 1980 currently being processed
- Various data access options and viewing options available

Canada-US Binational Precipitation Grids (could be extended to MX)

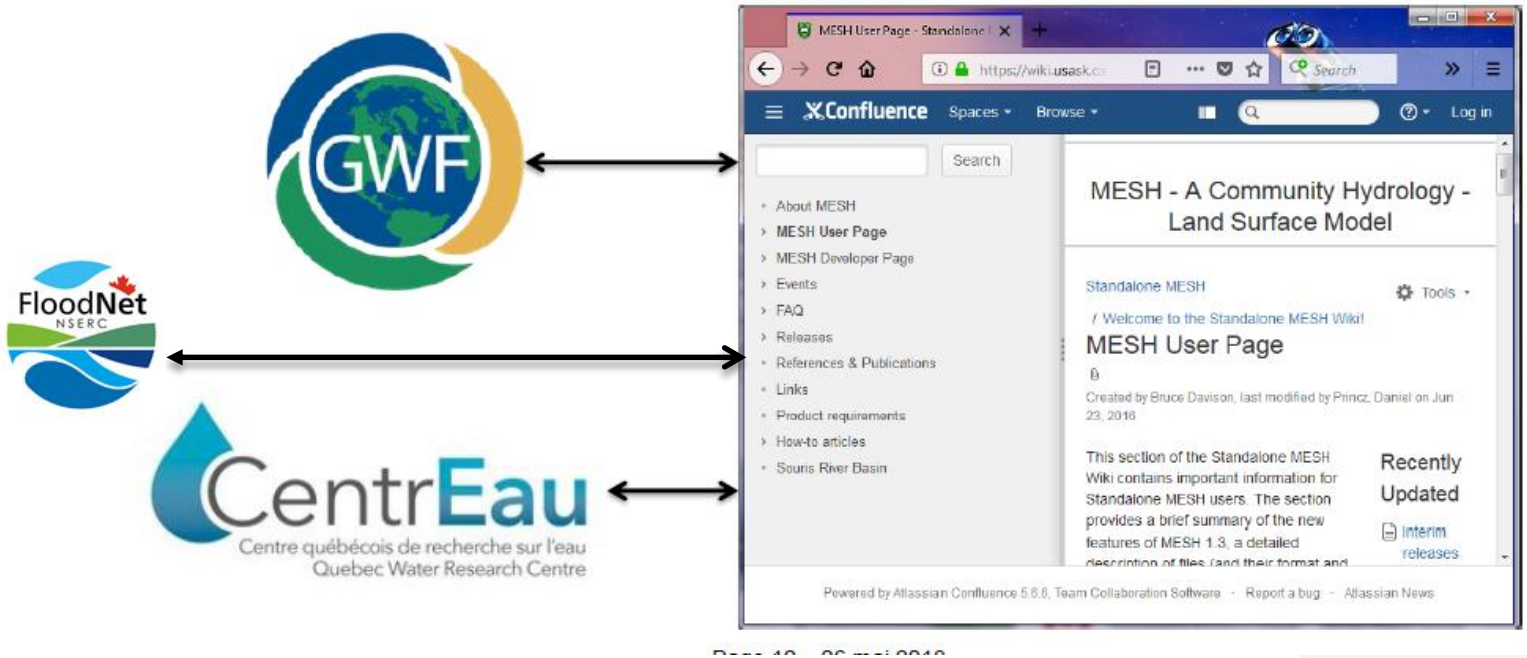


Regional Reforecast and surface Reanalysis System

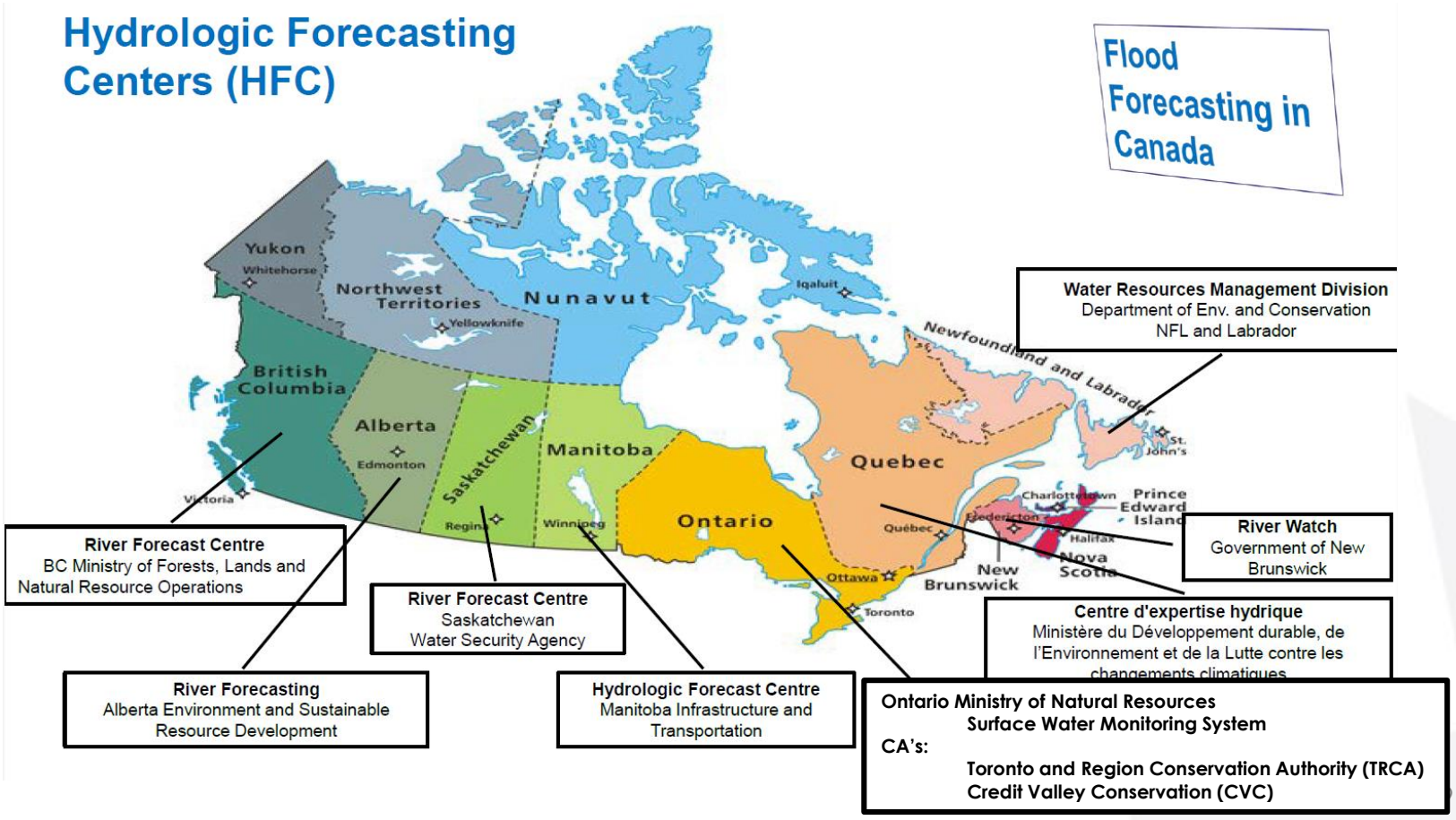
- Long-term, hi-res, continental dataset:
  - 10 km resolution, hourly outputs
  - Period covered: 1980 – present day
  - North-American domain
- Promises to improve the quality of surface meteorological variables compared to all other gridded products available for Canada
  - based on a 5-year evaluation period
- A critical output of the hydrological prediction component for internal use by NHS
- Strong demand from external users as well!



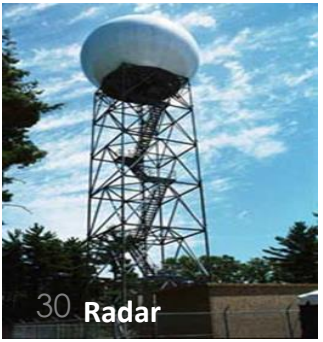
Future plans



FloodNet Partners (Coulibaly)

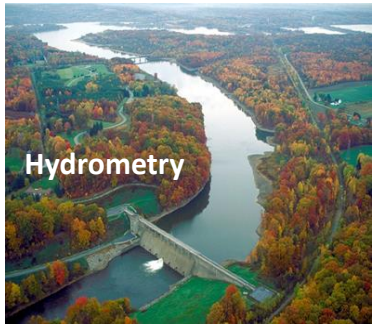


CAFFEWS: Canadian Adaptive Flood Forecasting and Early Warning System (Coulibaly)



Inputs: IDP

Inputs: Real-time



M2
Sequential Data Assimilation (SDA)

M1
Hydrologic
1 2 3 ...
1 2 3 ...
Hydraulic

M3
IUP
HUP
HUP
Dynamic Integrator Generator (DIG)
Ensemble Verification System (EVS)

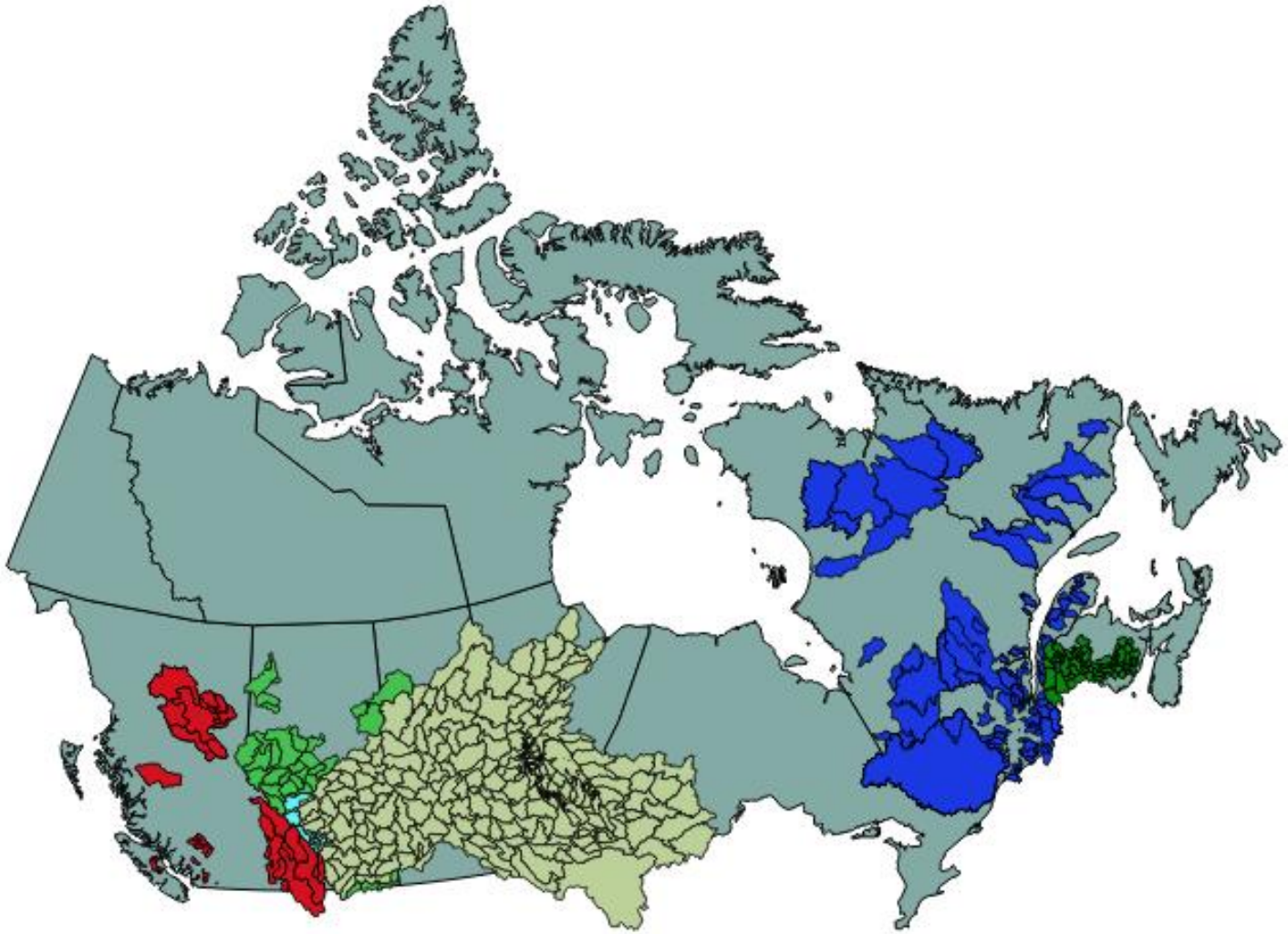
Bayesian Forecasting System (BFS)

Ensemble Post-Processor (EPP)

Deterministic & Probabilistic Flood Forecasts

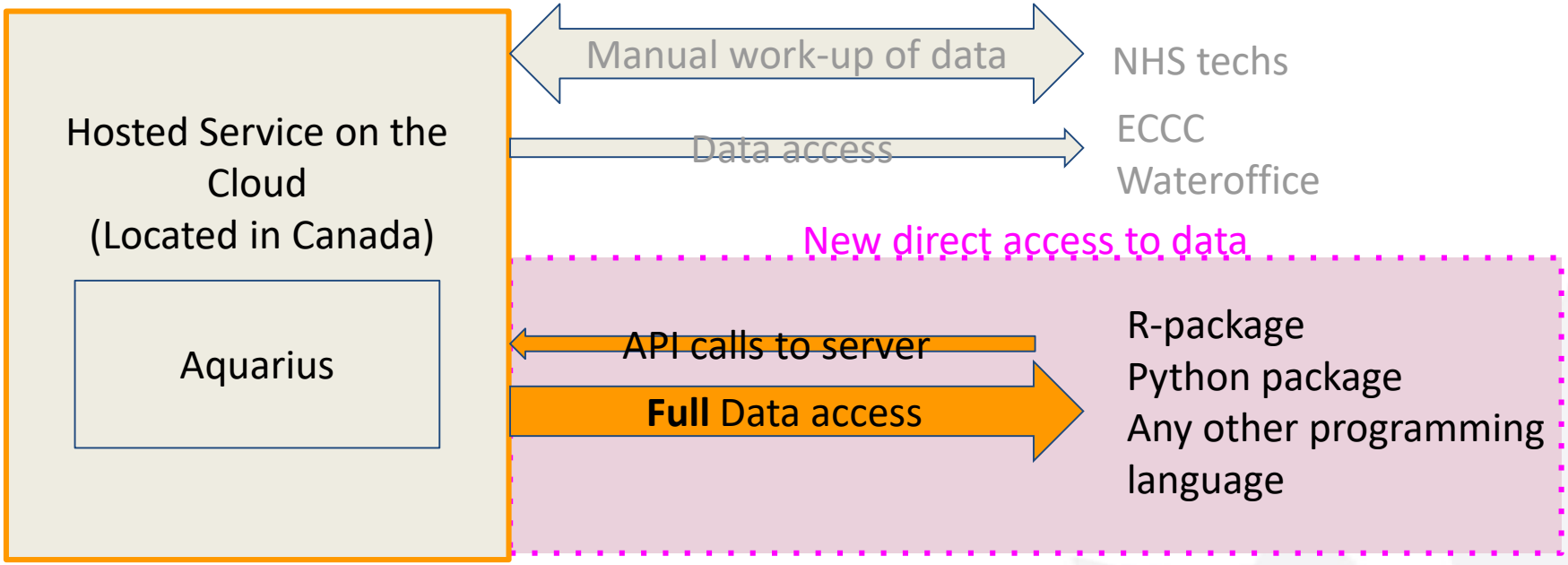
Early Warning System

Delft-FEWS in Canada



Aquarius NG and Cloud Service

Full data sharing with servers on the Cloud



Aquarius NG

- Faster framework for data processing in seconds instead of hours.
- More flexible processors for mixing and matching data and signals
- Nova Scotia and New Brunswick have been running NG end to end since June
- To be rolled out this fall/winter

Cloud Service

- Run on the cloud to allow for full database access to partners via Application Programming Interface (API)
- Full programmatic access to **all data fields**

Challenges with Gem-Hydro

- Challenging to set up and configure
- Dependent on ECCC's HPC software solution
- Needs to be tuned to ECCC's HPC hardware solution
- Incomplete documentation
- Limited support for external users

Why more research ?

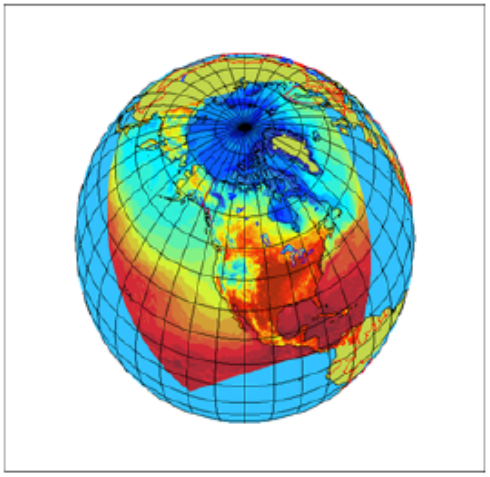
- Hydrology still not completely defined, particularly Cold Regions
  - Dealing with spares data systems, incorporating cold regions processes, basin segmentations and physics, data assimilations ….
- No systematic water quality models have been implemented
  - No In-stream quality systems e.g. (WASP)
  - No non-point pollutions models operational
  - No lake quality modelling systems
- Hydraulic models currently limited in ECCC systems
- No DSS implemented
- No water management

Current Hydrological Approaches are Limited

- Hydro-mythology : *Concepts that have been dismissed by scientific investigation but persist in hydrological model (*Pomeroy)
- Examples:
  - Radiation is difficult to estimate with normal meteorological data
    - Evapotranspiration can be estimated by temperature and wind functions
    - Temperature index melt of snow and soil thaw
  - Snowfall determines snow available for melt
    - Sublimation = 0
    - Snowfall gauge correction = snow redistribution loss
  - Soils can be represented as uniform porous media and subjected to clever mathematical manipulations
    - Macropores = 0
    - Green-Ampt or Richard's Eq. can work "as is" or are still physically based when heavily calibrated from streamflow
  - All land surfaces drain freely to streams with quick flow at overland flow velocities
    - Hortonian overland flow
    - Contributing area = 100%
  - Frozen soils behave like unfrozen soils
    - Calibration of unfrozen soil infiltration for frozen conditions

MESH (Pietroniro *et al.*, 2006)

Atmospheric forcing

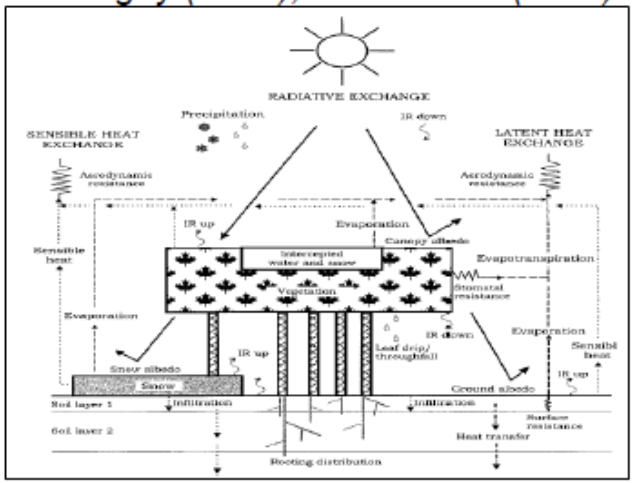


- Gridded hourly met. forcing data
- In practice, GEM and CaPA are often used

Land Surface Scheme

CLASS + WATROF/PDMROF

Verseghy (1991), Soulis et al. (2011)



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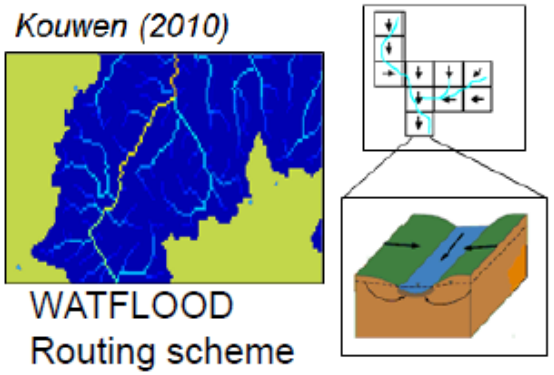
- Single layer snowpack scheme

Routing

WATROUTE

Kouwen (2010)



WATFLOOD

Routing scheme

Designed for open-loop simulations – testing and evaluating – limited assimilation capacity

Why 2 land-Surface hydrology Schemes

- CLASS (in MESH) closes the energy balance and represents more physical processes than SVS
  - Recommended for hydro-climate prediction
  - Also used by ECCC's GCMs
- SVS (in GEM-Hydro) is coupled to a land-data assimilation system (CaLDAS) that assimilates in-situ and satellite data on precipitation, soil moisture and surface temperature
  - Recommended for hydro-meteorological forecasting
  - Available for use in ECCC's NWP model GEM

The WMO calls for action to strengthen operational National Hydrological Services…

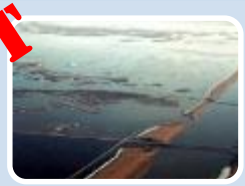
WMO Long-term ambitions for water:

1. No one is surprised by a flood
2. Everyone is prepared for drought
3. Hydro-climate and meteorological data support the food security agenda
4. High-quality data supports science
5. Science provides a sound basis for operational hydrology
6. We have a thorough knowledge of water resources
7. Sustainable development is supported by information covering the full hydrological cycle
8. Water quality is known

…and its ambitions can serve as guideposts for the evolution of Canada's National Hydrological Service

Water Vision 2023: No one is surprised by a flood, everyone is prepared for drought…

DRAFT





	Flood Management	Water Security	Sustainable Water Use	Water Governance	Hydrometric Network Optimization
Why?	• To address critical issue associated with climate change through an Integrated approach	• To undertake world-class research that enables sustainable use and protection of water resources	• To understand how water is being used in Canada, by whom and what opportunities exist	• To consider indigenous interests with respect to domestic water boards, legislation and a coordinated approach to water management	• To maintain modern and innovative technological solutions to water management
Partners	• Natural Resources Canada, Public Safety, SSC • Provinces/Territories	• University of Sask. • Université du Québec à Montréal (UQAM) • Provinces/Territories	• Statistics Canada • Provinces/Territories • Municipalities	• First Nations • Water Boards • International Joint Commission (IJC) • USGS and NOAA • WMO, GEO	• Provinces/Territories
Outcomes	• Floodplain mapping • Smart floodplain development • Standardized National Flood predication	• National Water Security Centre(s) • Opportunities for Fed-Industry-Academia partnerships	• Understanding water balance and quantity basin-by-basin • Water census to understand use	• Updated Federal and ECCC governance bodies • Modernized legislation / regulations (e.g. CWA)	• Hydrometric data on water quantity and quality are made available in coherent and modern way • Leading edge technologies (e.g. EO, IoT, AI …)
Out-puts	• National floodplain maps • Updated landuse plans	• Strategic research plan • Centre of excellence for water sustainability	• Water balance • State of the water in Canada report card • Sustainability practices	• Renewed CWA and updated board legislation • Water strategy	• Modernized network action plan

…and sustainable development is supported by information covering the full hydrological cycle