IP3 & WC^2N Networks Joint Annual Workshop

USE OF GLACIOLOGICAL DATA FOR RUNOFF FORECASTING

Lake Louise, Alberta, Canada
17 October 2009

Frank Weber
Team Lead, Runoff Forecasting, BC Hydro
frank.weber@bchydro.bc.ca

Sean Fleming, Scott Weston & Jon Boyd

BC hydro
FOR GENERATIONS

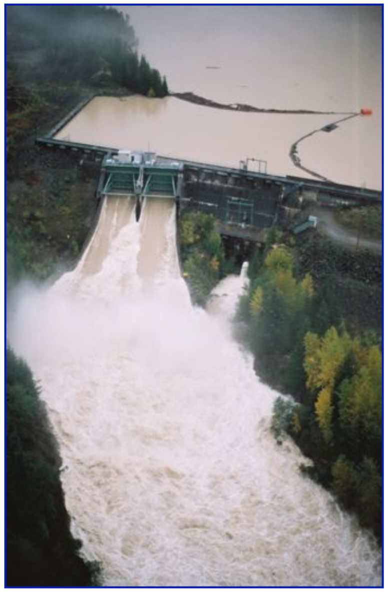
hydrology & technical services

ABSTRACT

- As a power utility with operations & revenues based largely on river flows, climate variability & change can ultimately affect every aspect of BC Hydro's business
- WC^{2}N is unique in its capabilities to model coupled glacier-streamflow responses
- The data produced by WC^{2}N has been of immense value to hydrologic modeling







BC HYDRO BACKGROUND

BC HDYRO SYSTEM

- Serving about 95% of BC's customers
- 90% from hydroelectric
  - 41 dam sites (75 dams)
  - 80 generating units
  - 30 hydroelectric facilities
- Secondarily, also thermal generation (9 units at 3 plants)
- Plus purchases: BC-sourced run-of-river & wind power IPP; market purchases

RUNOFF FORECASTING

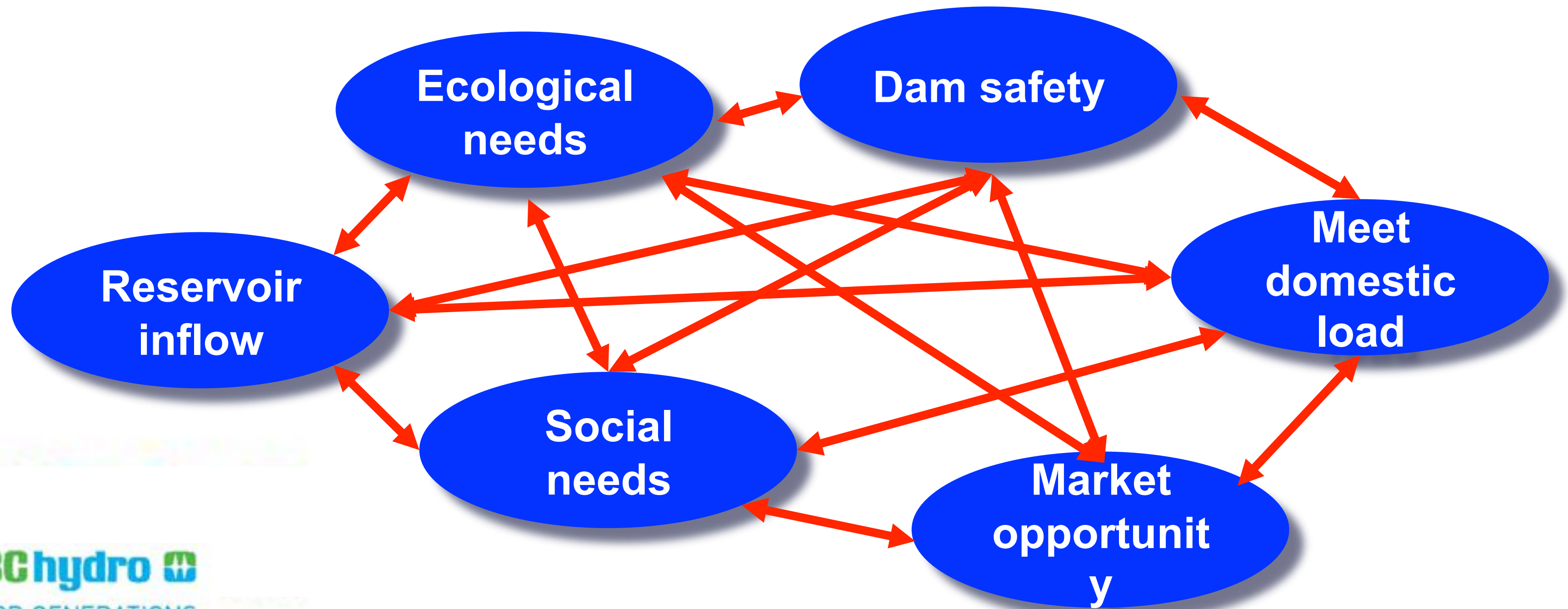
"The trouble with forecasting is that it's right too often to ignore it and wrong too often to rely on it."
Patrick Young

RESPONSIBILITY

- Provide accurate hydrologic forecasts to BC Hydro planners in a timely manner

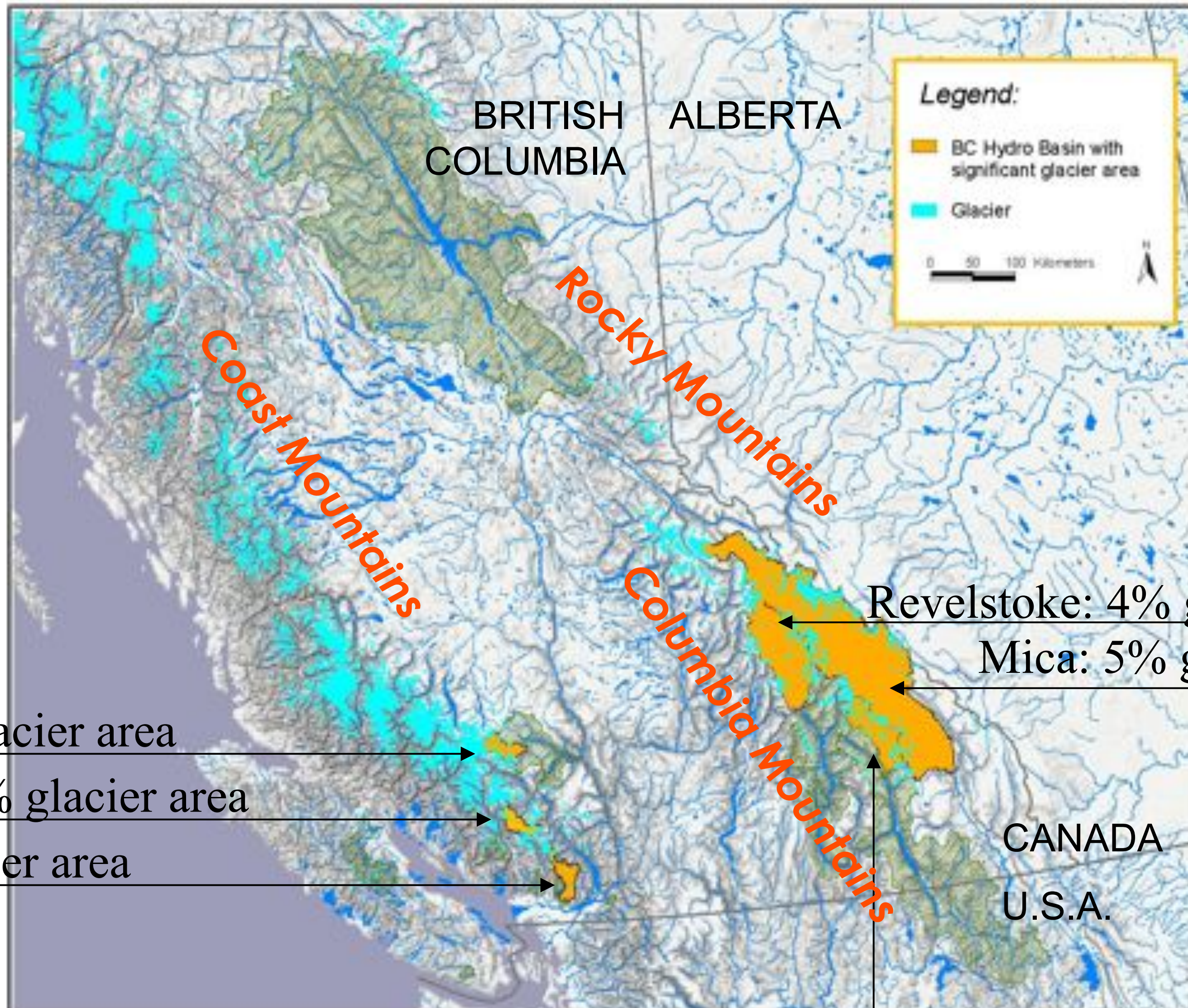
WHY FORECAST INFLOWS?

- Reservoir inflow = product supply ~ revenue... revenue forecast!
- Inflow forecast essential input to reservoir operation, which is a constrained optimization problem



BChydro FOR GENERATIONS

BC HYDRO BASINS WITH 'LARGE' GLACIERMELT CONTRIBUTION



Revelstoke: 4% glacier area

Mica: 5% glacier area

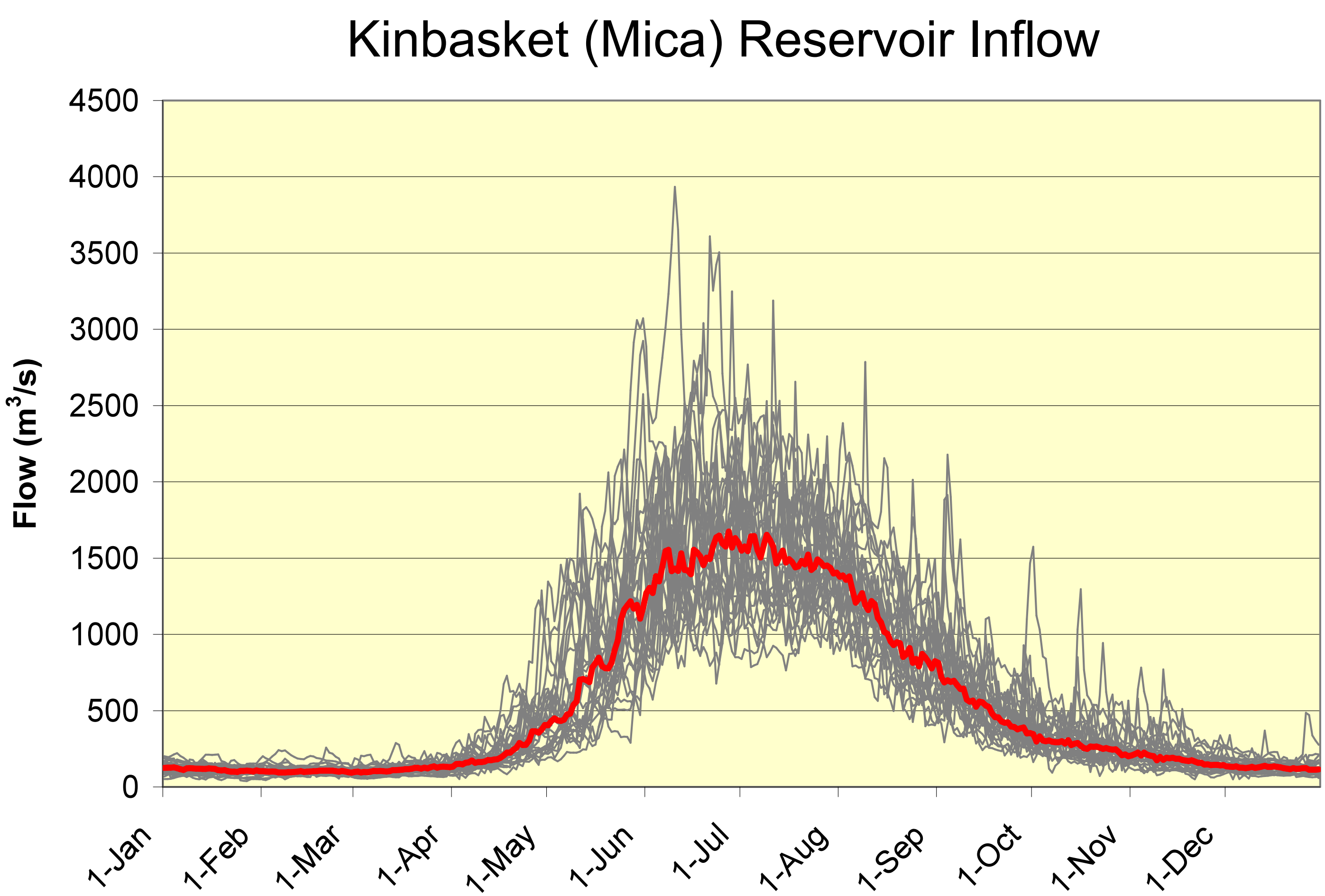
LaJoie: 19% glacier area

Cheakamus: 8% glacier area

Stave: 3% glacier area

Duncan: 6% glacier area

NIVO-GLACIAL RUNOFF REGIME



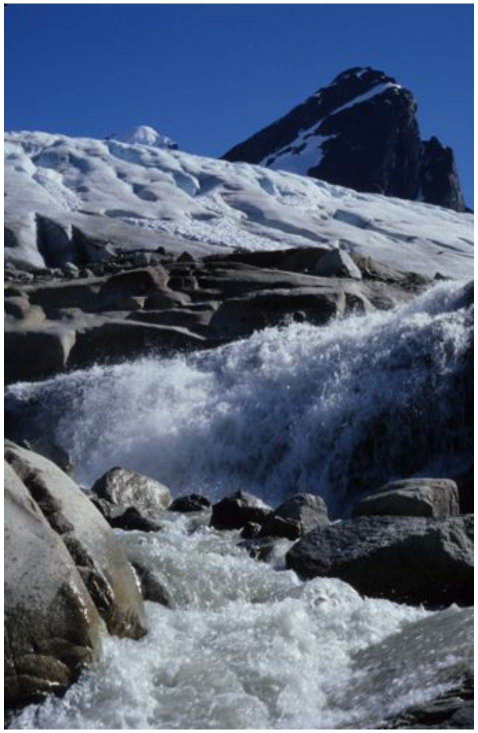
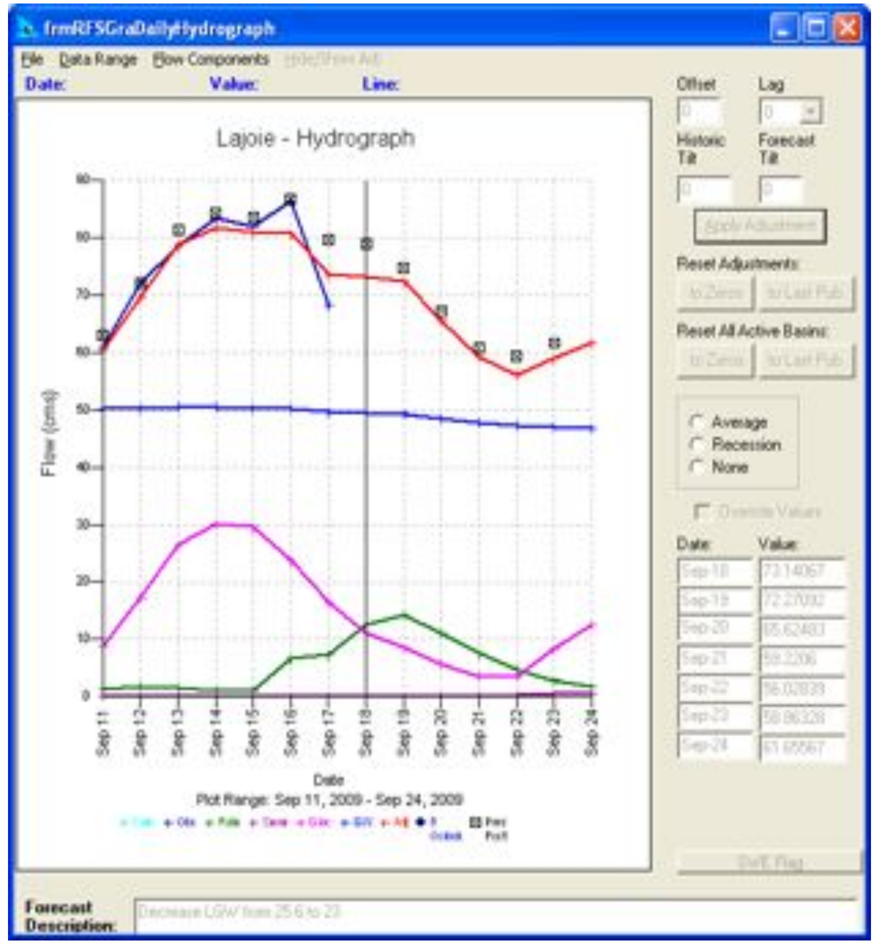


photo: D.Smith, UVIC

INFLOW FORECASTING

- For example, Lajoie inflows, September 11-18, 2009
- Glacial melt is an additional source of water (i.e., hydroelectric power, aquatic habitat, etc.)
- Most pronounced in late summer, when other runoff-generating mechanisms wane
- Buffers short-term, year-to-year climatic variations
- Modulates climate variability (e.g., ENSO) responses

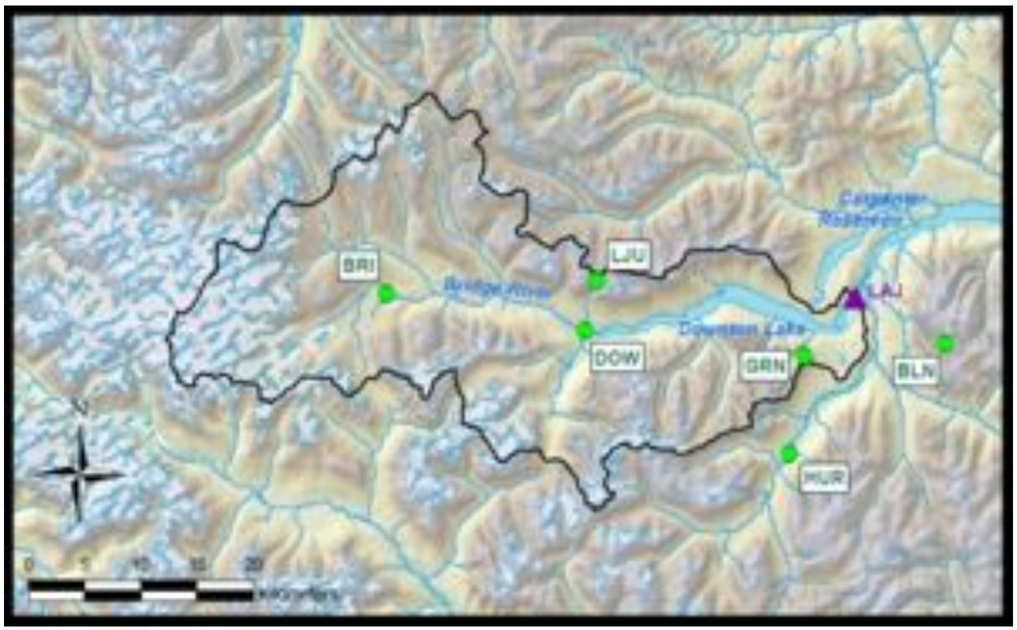


HYDROLOGIC MODELLING

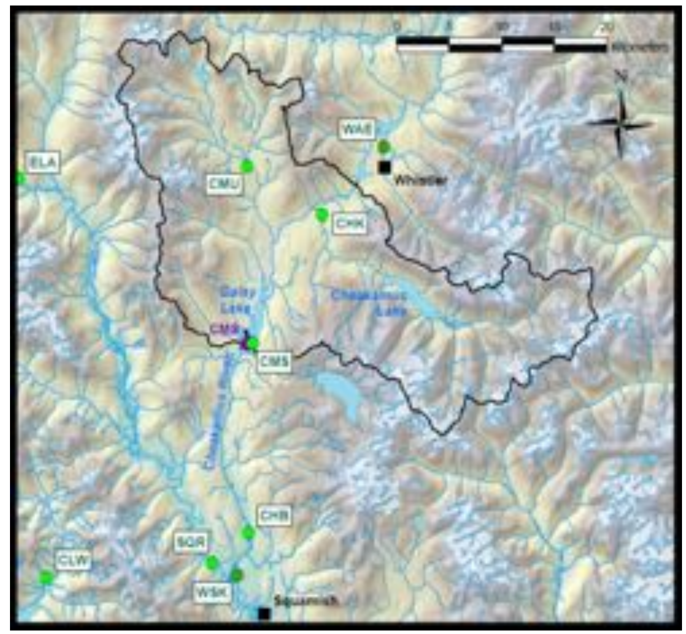
2005 GLACIER EXTENTS

- WC²N 2005 Landsat-based glacier extent: Bolch et al. 2008

Lajoie Basin, S. Coast Mountains



Cheakamus Basin, S. Coast Mountains



UBC WATERSHED MODEL CALIBRATIONS

CONSTRAINING GLACIER- & SNOWMELT SIMULATIONS

ESTIMATES OF EQUILIBRIUM LINE ALTITUDE (ELA)

- ABSYNTHE constraints
  - 1 day of the year of all years, SWE in the elevation band below the ELA band = 0 mm
  - RMSE for simulated April 1 SWE < threshold
- For example, Mica ELA estimates are based on
  - Peyto glacier ELA
  - Glacier distribution in Mica basin
  - Knowledge of local climate

- Demuth, M.N., J. Sekerka and S. Bertollo, 2009. Glacier mass balance observations for Peyto Glacier, Alberta, Canada (updated to 2007). Spatially Referenced Data Set contribution to the National Glacier-Climate Observing System, State and Evolution of Canada's Glaciers, Geological Survey of Canada.
- Demuth, M.N., J. Sekerka, S. Bertollo and J. Shea, 2009. Glacier mass balance observations for Place Glacier, British Columbia, Canada (updated to 2007). Spatially Referenced Data Set, State and Evolution of Canada's Glaciers, Geological Survey of Canada.

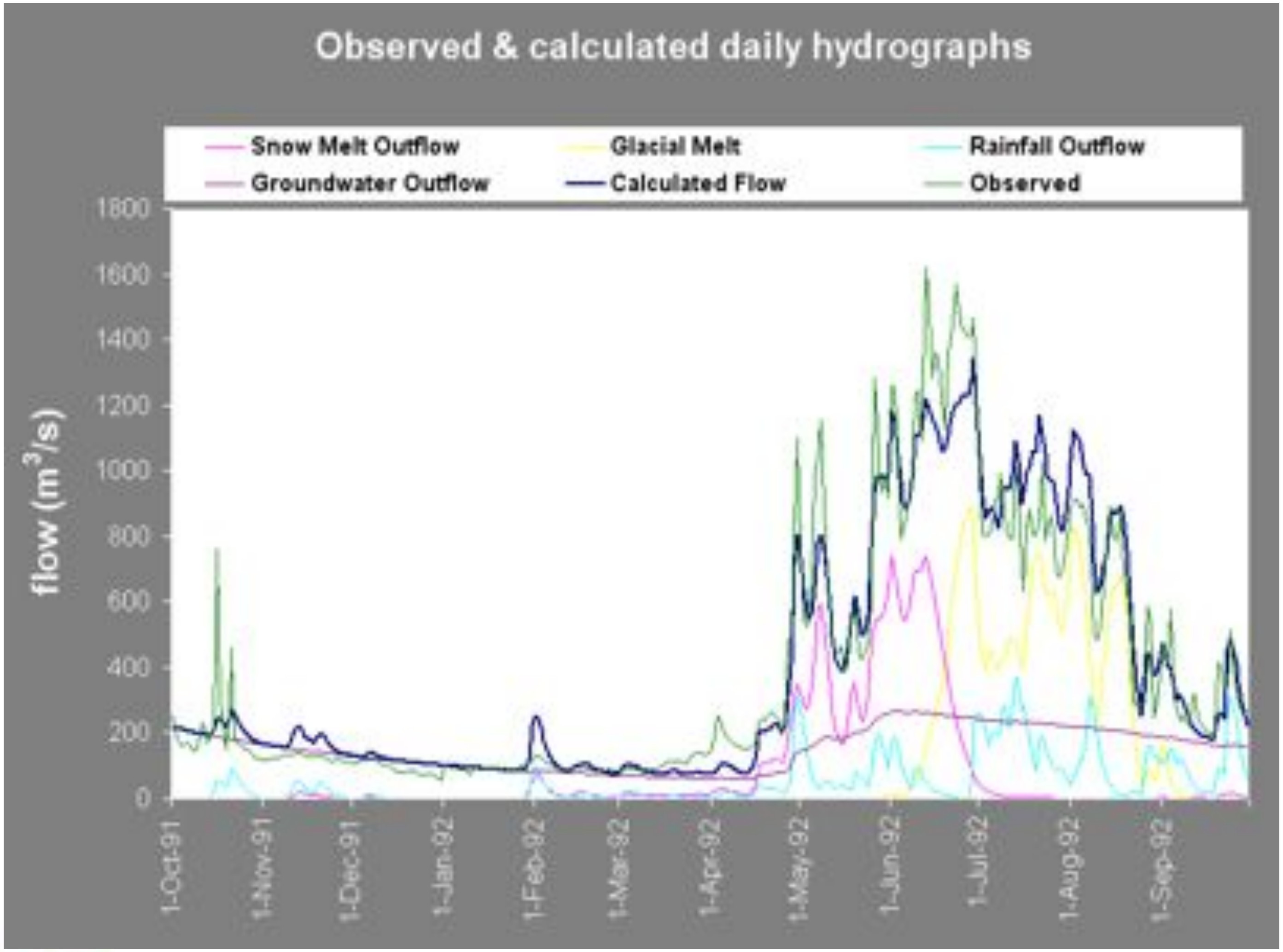
CONSTRAINING GLACIER- & SNOWMELT SIMULATIONS

ESTIMATES OF GLACIAL RUNOFF CONTRIBUTION FROM GLACIER MASS BALANCE

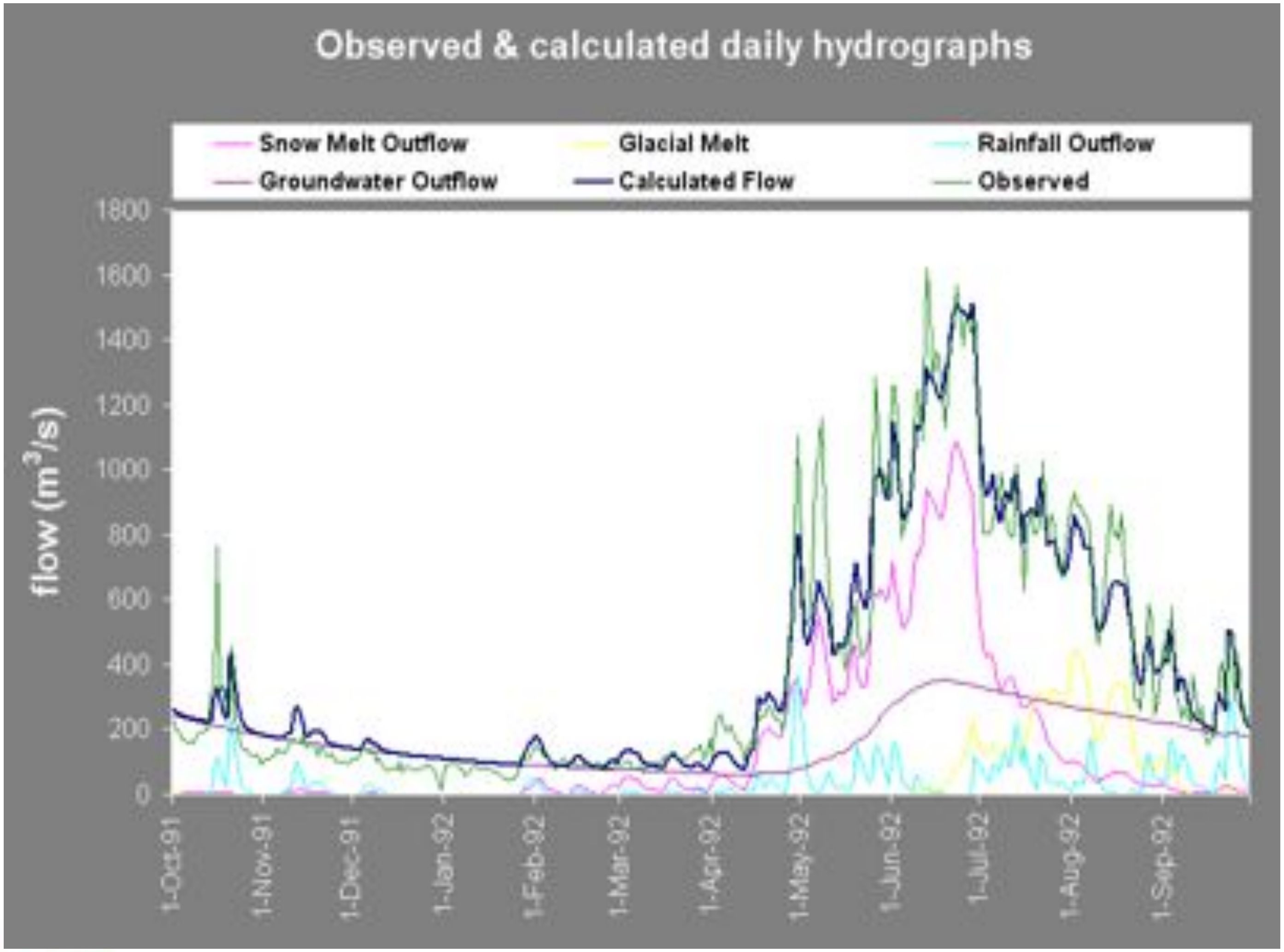
- Useful for constraining what is a ‘reasonable’ glacial melt component in the ABSYNTHE calibrations for these basins
- Back of the envelope calculation of annual total glacial runoff component, based on Peyto Glacier net annual & summer balance data

  - Mica
    - Annual glacier melt component: 49 mm/yr - 96 mm/yr
    - Q-glacier: 6% to 11% [UBCWM 8%]
  - Revelstoke
    - Annual glacier melt component: 42 mm/yr - 83 mm/yr
    - Q-glacier: 3% to 6% [UBCWM 6%]
  - Arrow
    - Annual glacier melt component: 16 mm/yr - 32 mm/yr
    - Q-glacier: 1% to 3% [UBCWM 2%]

UBC WATERSHED MODEL CALIBRATION - OLD



UBC WATERSHED MODEL CALIBRATION - NEW



GLACIER- & SNOWMELT MODELLING

- Lack of data to constrain glaciermelt in hydrologic models
- High uncertainty in glacier- and snowmelt simulations
- Inaccurate inflow forecasts from glaciated basins

SNOW COVERED AREA & SNOWLINE ELEVATION & ELA

ANALYSIS OF MODIS IMAGERY TO EXTRACT GLACIER SNOWLINES IN SUPPORT OF HYDROLOGIC MODELLING (Joe Shea 2009-2011)

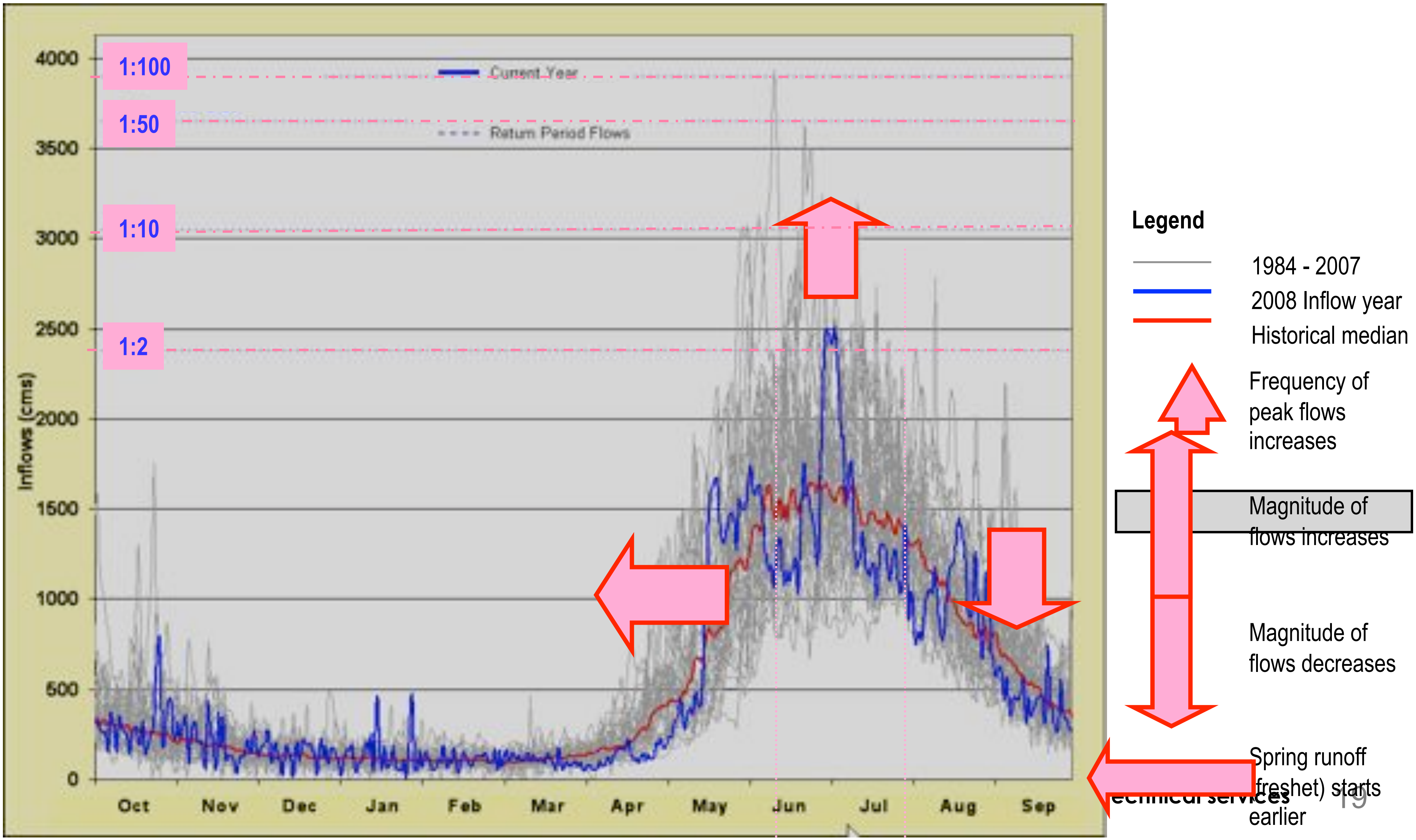
- Objectives
  - Obtain historic snowline data (2000-2009) to constrain hydrological models during calibration/validation
  - Develop a software for near real-time data extraction and processing in support of operational forecasting

- Why MODIS?
  - High repeat coverage (1-2 days)
  - Reasonably high spatial resolution in the visible spectrum (~250 m)
  - Free data

CLIMATE-GLACIER-STREAMFLOW MODELING

CURRENT MESSAGE IS QUALITATIVE

For example, potential impacts of climate-glacier changes in the Mica Basin



CLIMATE-GLACIER-STREAMFLOW MODELING

BRIDGE BASIN
COAST MOUTNAINS
BC

Observed 1986–2004 climate
Global Circulation Model (CGCM3)
Daily resolution
SRES A2, B1

Statistical Downscaling to Point Locations
- stochastic weather generator LARS-WG
- Treegen

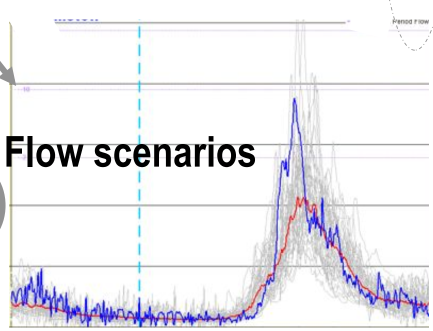
Hydrological model
HBV-EC (Hydrologiska Byråns Vattenbalansmodell – Environment Canada, Hamilton et al. 2000)
- originally Scandinavian model
- Canadian version

Simple Glaciological model

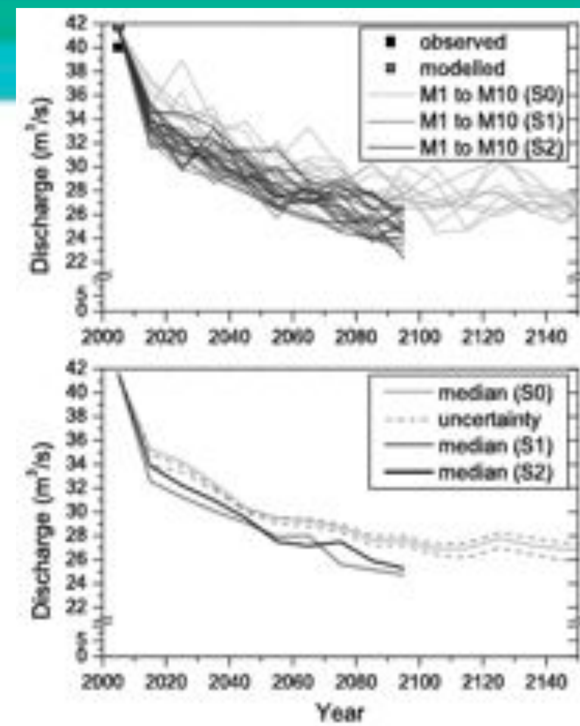
Volume-area scaling based on a decade's cumulative mass balance

WC2N

Glacier Mass Balance



Flow scenarios



August streamflow

Stahl, K., Moore, R. D., Shea, J. M., Hutchinson, D., and Cannon, A. J., 2008. Coupled modelling of glacier and streamflow response to future climate scenarios. Water Resources Research 44, W02422, doi:10.1029/2007WR005956.

WC2N
WESTERN CANADIAN CRYOSPHERIC NETWORK

CLIMATE-GLACIER-STEAMFLOW MODELING

MICA BASIN, COLUMBIA/ROCKY MOUNTAINS, BC

Global Circulation Models
Daily resolution
SRES A1B, B1

Statistical Downscaling to Point Locations
Treegen

PCIC

Interpolation to NARR-consistent Grid

WC2N

Hydrological model
HBV-EC (Hydrologiska Byråns Vattenbalansmodell – Environment Canada, Hamilton et a. 2000)
- originally Scandinavian model
- Canadian version

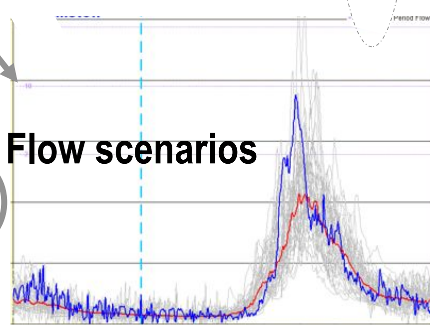
Glaciological model

Glacier Dynamics: Glacier masks and DEM's would be extracted from these outputs for a set of 10-year time slices

WC2N

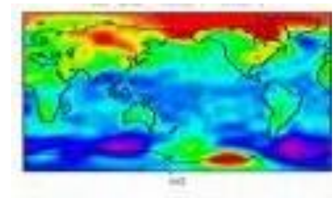
WC2N

Glacier Mass Balance

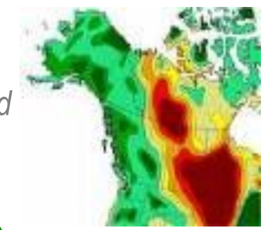


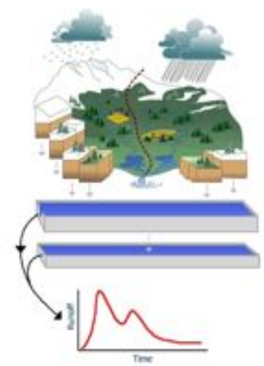
Flow scenarios

Resolution
~ 200 kilometer grids



Resolution
NARR ~ 36x29 kilometer grid





Moore, Clarke et al. 2009-2010

Pacific Climate Impacts Consortium

WC²N WESTERN CANADIAN CRYOSPHERIC NETWORK

COUPLED CLIMATE-GLACIER-STREAMFLOW CHANGE

ALL OTHER THINGS BEING EQUAL, POTENTIAL IMPLICATIONS INCLUDE:

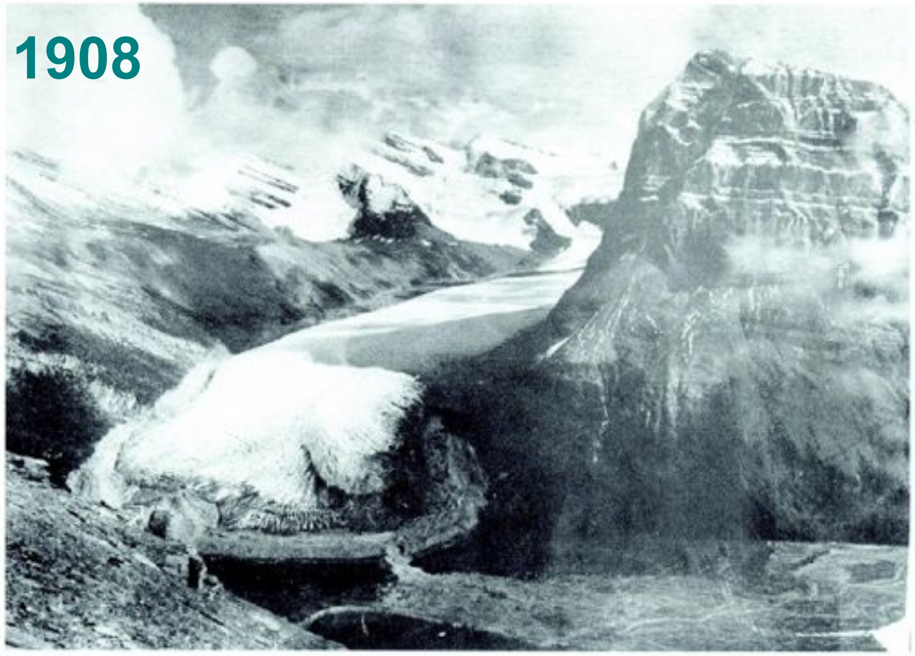
- Lower reservoir inflows
- Lower hydroelectric generation capacity, fewer $
- Lower aquatic habitat availability, esp. in late summer (can use reservoir storage from other seasons to maintain fish flows, but involves foregoing generation at those other times)
- Decreased buffering of interannual flow variability
- Potentially changed responses to ENSO & PDO
- Perhaps changes in capacity to accommodate flood regulation
- Implications for cross-border agreements

TELL A STORY!

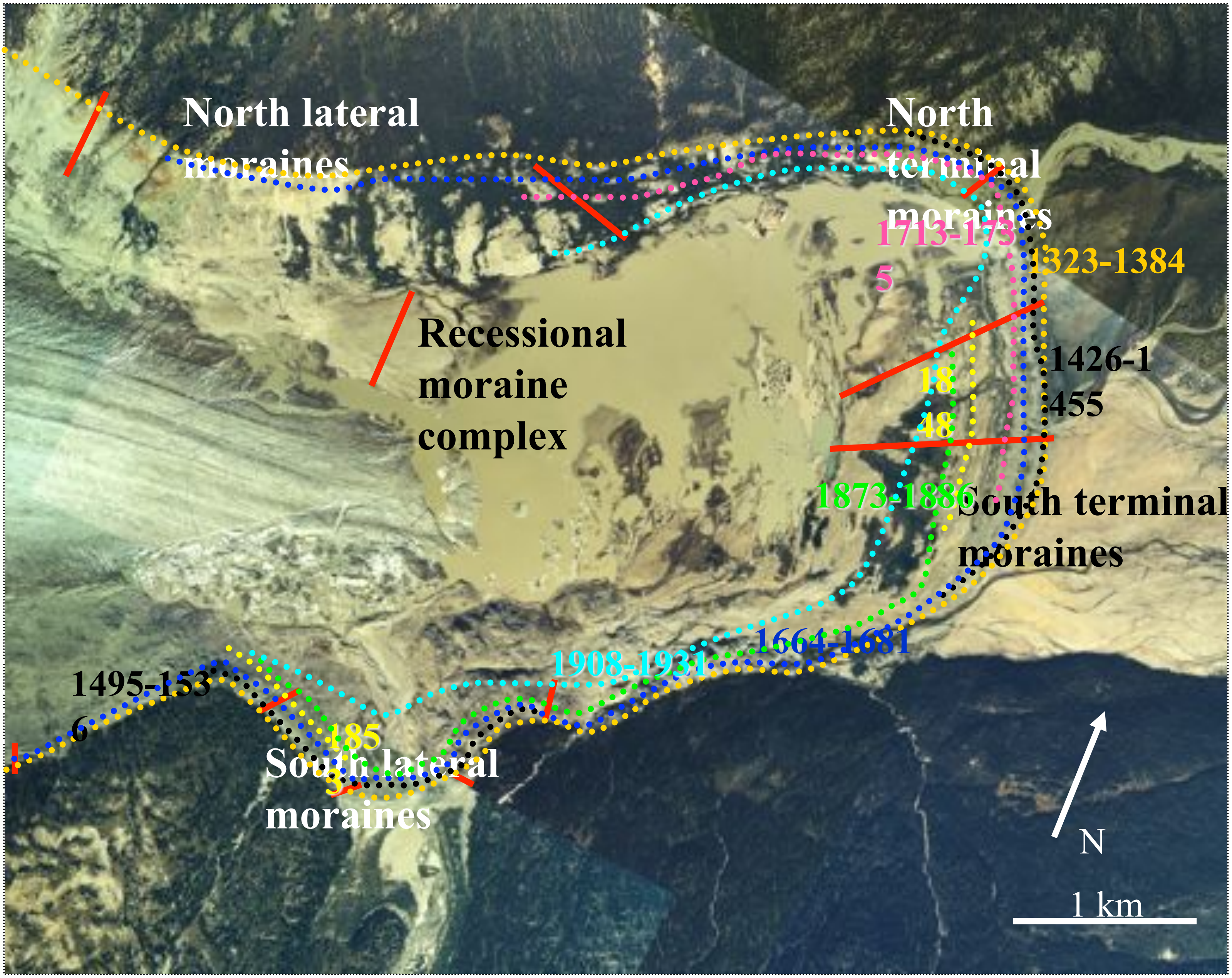
Photo Archive

Overall, mountain glaciers have receded under warming temperatures over ~last century

Robson Glacier, near Mica headwaters



from Moore et al. 2009, Hydrological Processes



BRIDGE GLACIER
COAST MOUTNAINS

D.Smith, UVIC

CORE SCIENCE QUESTIONS

CORE SCIENCE QUESTIONS

- Extraction of snow cover extent (historical & operational)
- Development of improved technologies for in-situ real-time SWE data acquisition and/or
- Development of cost-efficient techniques for remote sensing of SWE
- Ongoing monitoring of glacier extent and glacier mass balance and/or
- Ongoing modeling of glacier mass balance
- Development of hydrological models that can handle nonstationary land cover, i.e. glaciers, forests
- Improved algorithms for rain-on-snow events for flood forecasting purposes
- Quantitatively assess net reservoir inflow impacts of coupled climate & land cover changes; quantify uncertainty in the predictions

THANKS!