Welcome to this week's presentation & conversation hosted by the **Canadian Association for the Club of Rome**, a Club dedicated to intelligent debate & action on global issues.

The Status and Future of Freshwater Supply in Canada.

Our speaker today is Dr. John Pomeroy, Director of the Global Water Futures Programme. At U Saskatchewan, he is the Canada Research Chair in Water Resources & Climate Change. He is also UNESCO Chair in Mountain Water Sustainability, Distinguished Professor of Geography, Director of the Centre for Hydrology, & Director of the Coldwater Lab. He is a Fellow of the Royal Society of Canada, American Geophysical Union, & Royal Geographical Society, & Institute Professor of the Biogeoscience Institute of the U Calgary & Adjunct Professor at U Waterloo & Wilfrid Laurier U. For the World Climate Research Programme, he leads the Int'l Network for Alpine Research Catchment Hydrology. He received the Walter Langbein Lecture Award for hydrology from AGU, the Miroslaw Romanowski Medal for environmental science from RSC, & the Tuzo Wilson Medal for geophysics from CGU. He was the founder & President of the Int'l Commission on Snow & Ice Hydrology, Chair of the Int'l Decade for Predictions in Ungauged Basins, President of the Canadian Geophysical Union, the first Professor of Hydrology at the U Wales, Research Scientist with Environment Canada & US Forest Service, & NATO Science Fellow at U East Anglia. He has developed several hydrological models & a network of hydrological research basins, a written > 400 research articles & reports & several books, with > 25,000 citations.

DESCRIPTION: Climate change, land cover change, water management are altering the supply of freshwater in Canada such that it is no longer reliable in some places There are implications for hydrology of changes to climate, land cover, & water management, & some regions where there will be great water stress. Changes to water supplies in the Mackenzie, Saskatchewan, & Okanagan basins will be reviewed. The impacts of deglaciation, permafrost thaw & reduced snow-cover, & loss of forest cover will be discussed, plus adaptation & management across Canada.

The presentation will be followed by a conversation, questions, & observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, & Inuit in Canada) and their descendants.

Website: canadiancor.com
Twitter: @cacor1968
YouTube: Canadian Association for the Club of Rome
2024 Mar 06 Zoom #187

The Status and Future of Freshwater Supply in Canada

John Pomeroy, Alain Pietroniro+, Chris DeBeer,
Mohamed Elshamy, Zelalem Tesemma, Fuad Yassin

Centre for Hydrology, University of Saskatchewan

+Dept of Civil Engineering, University of Calgary

GLOBAL WATER FUTURES

SOLUTIONS TO WATER THREATS
IN AN ERA OF GLOBAL CHANGE

Urgent Need for Global Water Sustainability

85% of the human population live in arid areas. By 2030, half of the population will be living in areas of high water stress.

6-8 million human beings are killed each year from water-related disasters and diseases.

750 million people lack access to safe water, while nearly 2.5 billion people lack access to adequate sanitation.

*Inventoried by UNESCO-IHP

Canada's Water Crisis in the 21st Century

Rapid Glacier Loss

Retreating glaciers creating hazards, loss of water storage. Disappearance of Slims River and loss of inflow to Kluane Lake, YT.

Snowmelt Flooding July 2021

Unprecedented flooding in Whitehorse and Southern Lakes area.

Ice-Jam Flooding May 2022

Unprecedented ice jams and flooding, Hay River, NT.

Water Shortage August 2022

City of Iqaluit declares emergency due to water shortage caused by lack of rainfall.

Drinking Water Advisories

As of 2022 there are 31 long-term advisories in 27 Indigenous communities

Fort McMurray Wildfire May 2016

Direct and indirect damages totaled almost **$10 Billion**. 88,000 people evacuated.

Rainfall-Driven and Rain-on-Snow Flooding

Devastating and unprecedented flooding cost $ Billions and affects:

- Eastern Prairies (2011, 14)
- Southern Ontario and Quebec (2017)
- New Brunswick (2018, 19)
- Nova Scotia and Newfoundland (2021)

Increasing Wildfires

Series of recent record-breaking fire seasons in central and western Canada, increasing costs and area burned.

Greater Toronto Area Flooding July 2013

Toronto flood caused almost **$1 Billion** in damage and is the costliest flood disaster in Ontario history.

B.C. Lower Mainland Flooding November 2021

Cost of rebuilding estimated at nearly **$9 Billion**.

Southern Alberta Flood June 2013

City of Calgary and surrounding communities sustained over **$5 Billion** in damages. 100,000 people evacuated.

Severe Drought 2000–2002

Prairie drought at turn of century cost **$5.8 Billion**. Drought recurrence since has cost many billions more. Crop insurance payout of **$2.4 Billion** in SK, 2021.

Large and Sustained Algal Blooms

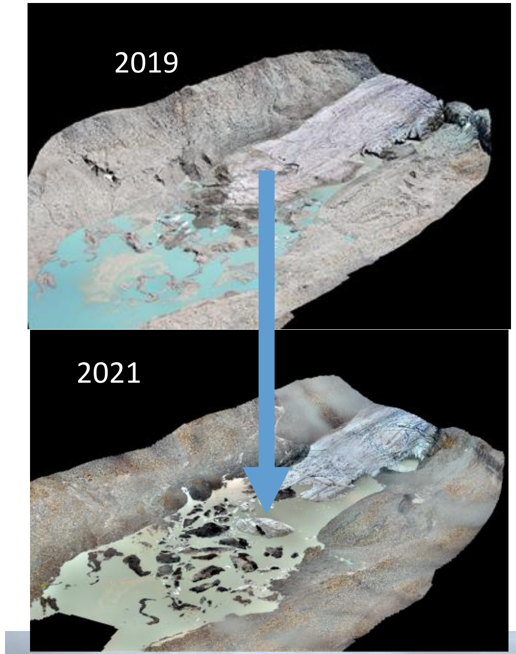
Increasing frequency and severity of algal blooms in Lake Winnipeg.

Threats to Great Lakes Ecosystems

Economic costs of eutrophication estimated at **$270 Million per year** for the Canadian side of Lake Erie.

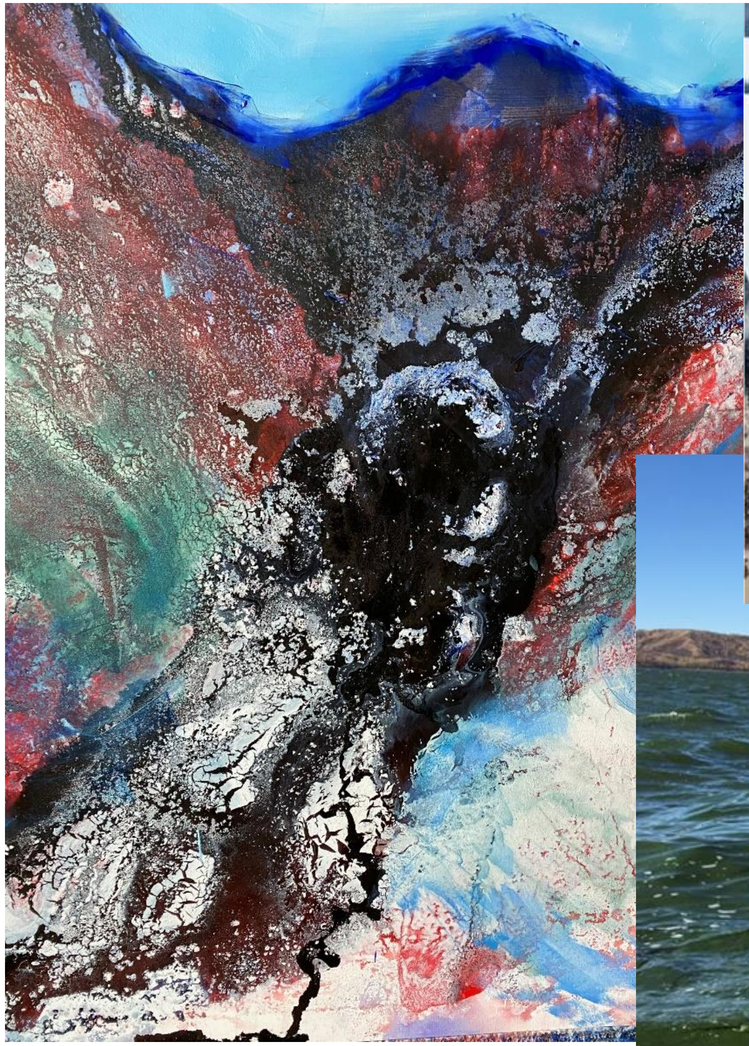
Recent Canadian Water Disasters

Flooding, drought, wildfire, deforestation, deglaciation, permafrost thaw, declining snowpacks, water quality degradation, toxic algae, microplastics, endocrine disrupters, invasive species.



Canada's water crisis needs solutions and an early warning system to help manage and prepare for water disasters that increasingly afflict Canada.

Inadequate Water Management Magnifies Disasters



Gennadiy Ivanov, GWF Artist in Residence

Global Water Futures:
Solutions to Water Threats in an Era of Global Change

GWF

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

University of Saskatchewan | University of Waterloo | McMaster University | Laurier *Inspiring Lives.*

University of Guelph

University of British Columbia

University of Northern British Columbia

University of Calgary

Université Laval

McGill University

Université du Québec à Montréal

University of Alberta

University de Montreal

University of Manitoba

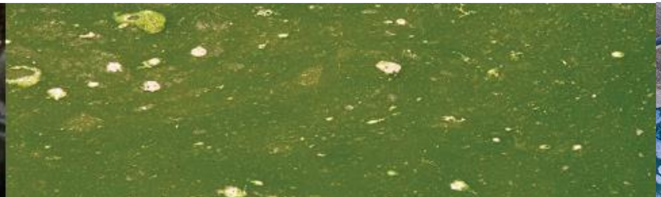
University of Victoria

Brock University

Canadian Rivers Institute (University of New Brunswick & University of Prince Edward Island)

Yukon University






Global Water Futures Aims:

a) to **place Canada as a global leader in water science for cold regions**,

b) to **address the strategic needs of the Canadian economy** in adapting to change and managing the risks of uncertain water futures and extreme events.

Global Water Futures Mission

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Global Water Futures
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- **Improve capability for water-related disaster warning**
- **Diagnosing and predicting water futures and future impacts on society and ecosystems**
- **Develop new models, tools and approaches for managing water-related risks**
  - a) adaptation to change
  - b) risk management.

Global Water Futures Observatories 2023-2029

INNOVATION
Canada Foundation for Innovation
Fondation canadienne pour l'innovation

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CANADA FIRST RESEARCH EXCELLENCE FUND
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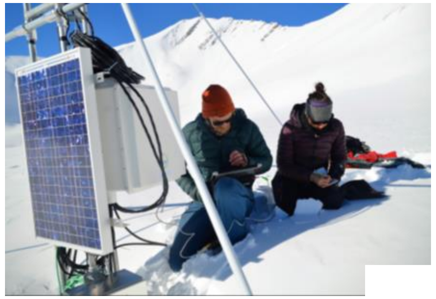
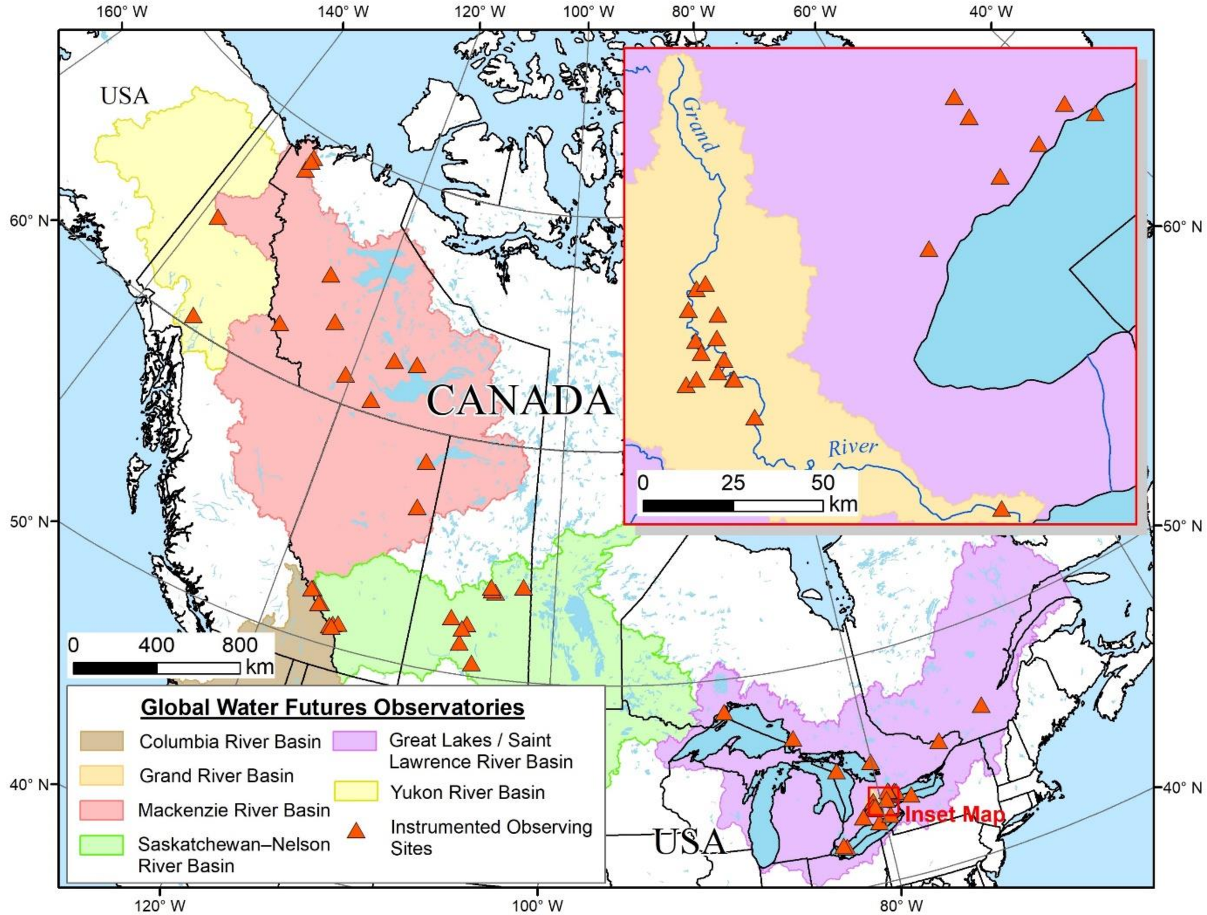
University of Saskatchewan
University of Waterloo
McMaster University
Laurier Inspiring Lives.
Carleton University
University of Toronto Scarborough
Trent University
Western University · Canada
University of Windsor

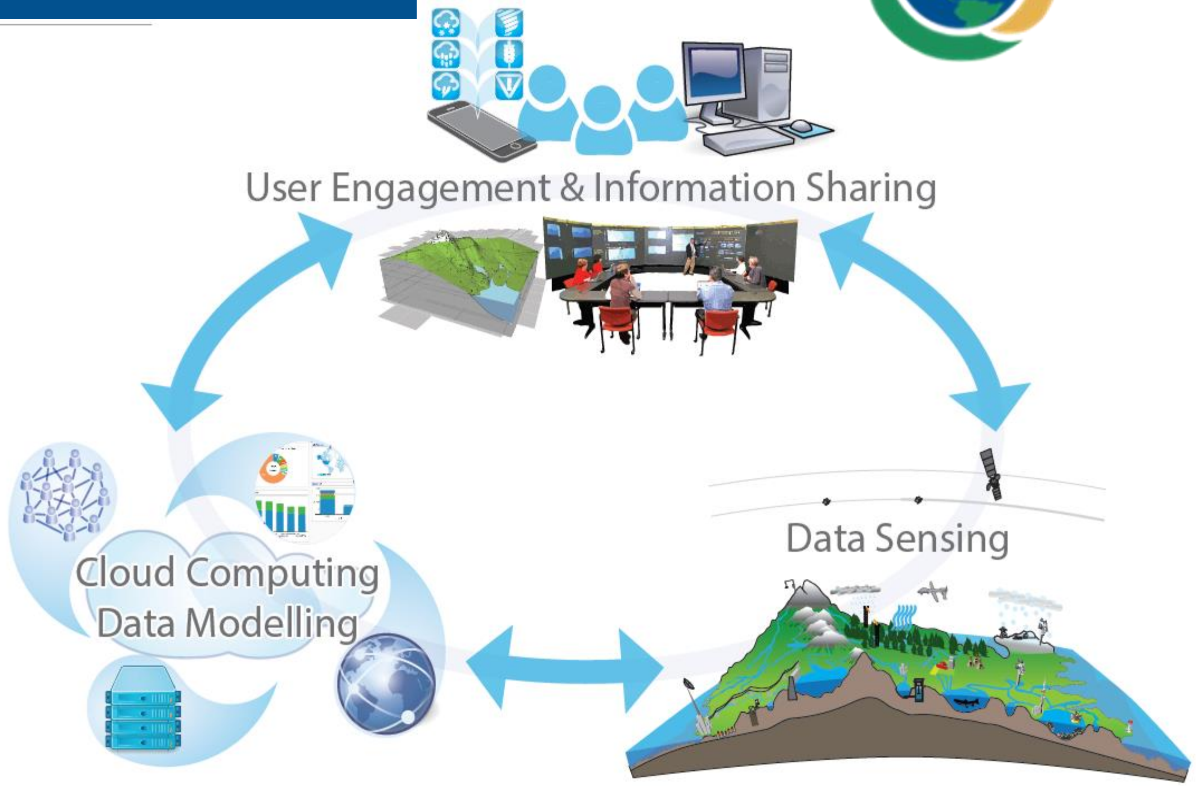
GLOBAL WATER FUTURES OBSERVATORIES

Canada's freshwater early warning system





Global Water Future's coupled water observation, data management, water prediction, and knowledge mobilization strategy



5 Million km^2

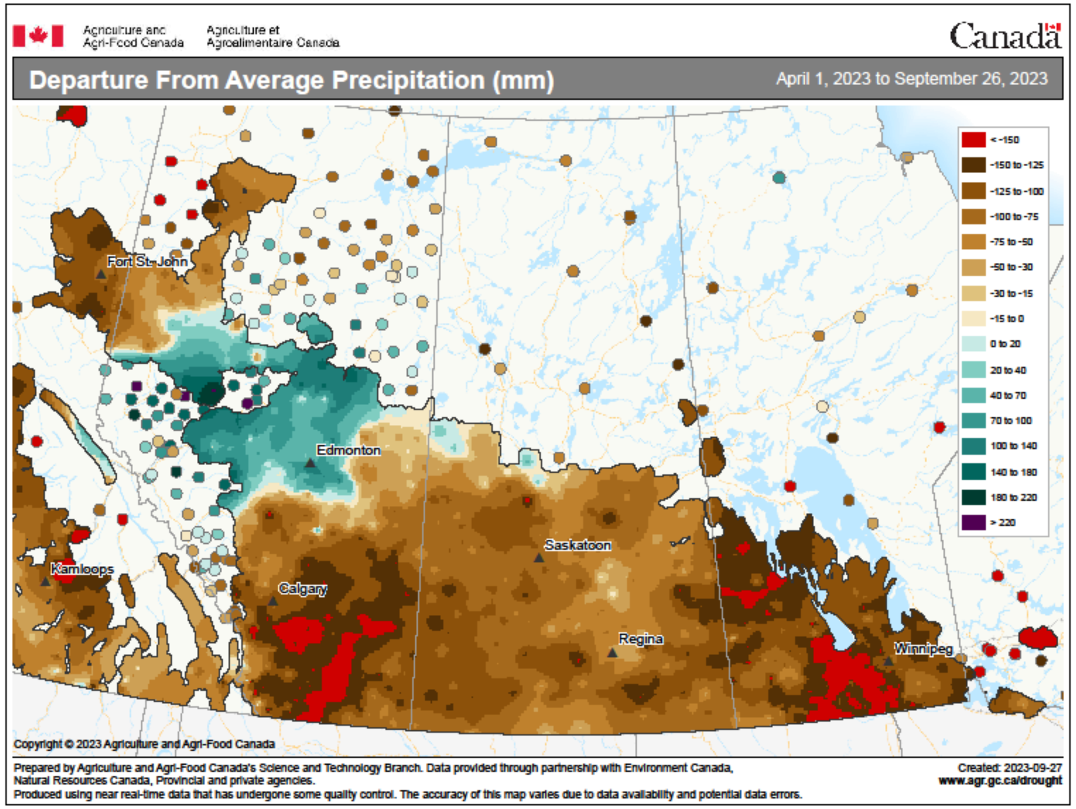
7 major river basins

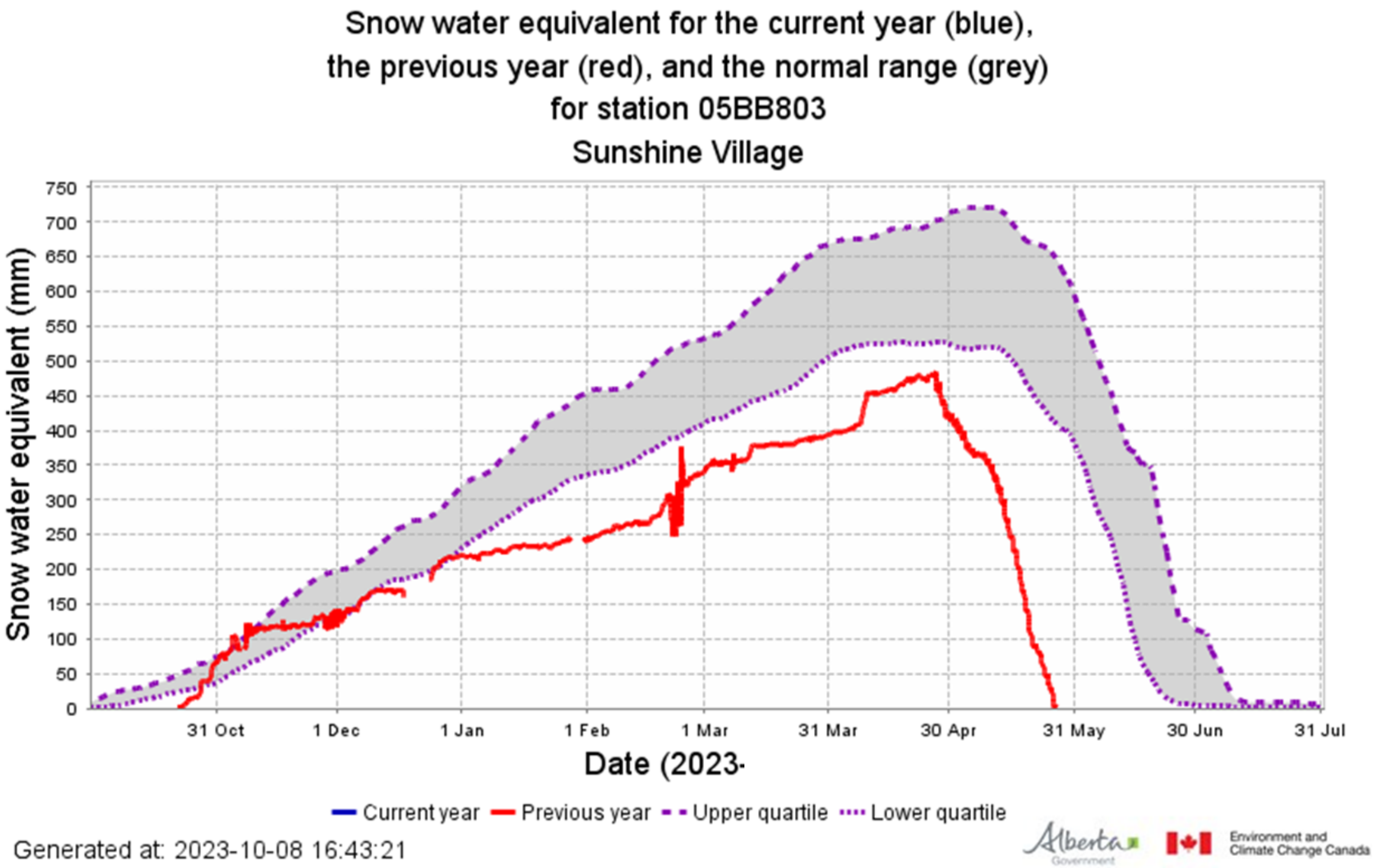
64 water observatories
Global Water Futures Observatories

Canadian Snow Drought of 2023

Snowpacks 150 mm below normal
Melt one month earlier than normal

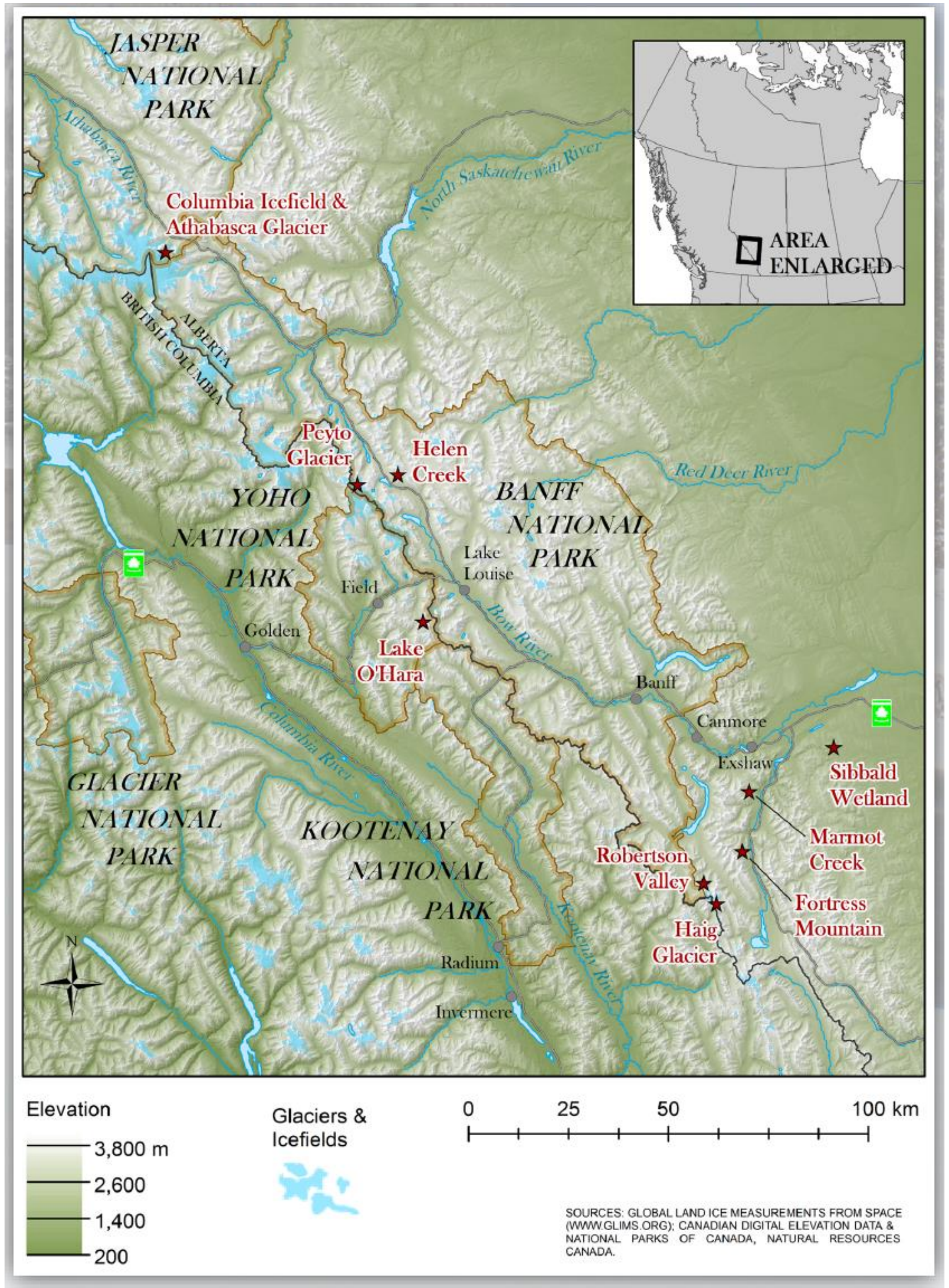
Spring, summer precipitation ~100 mm below normal





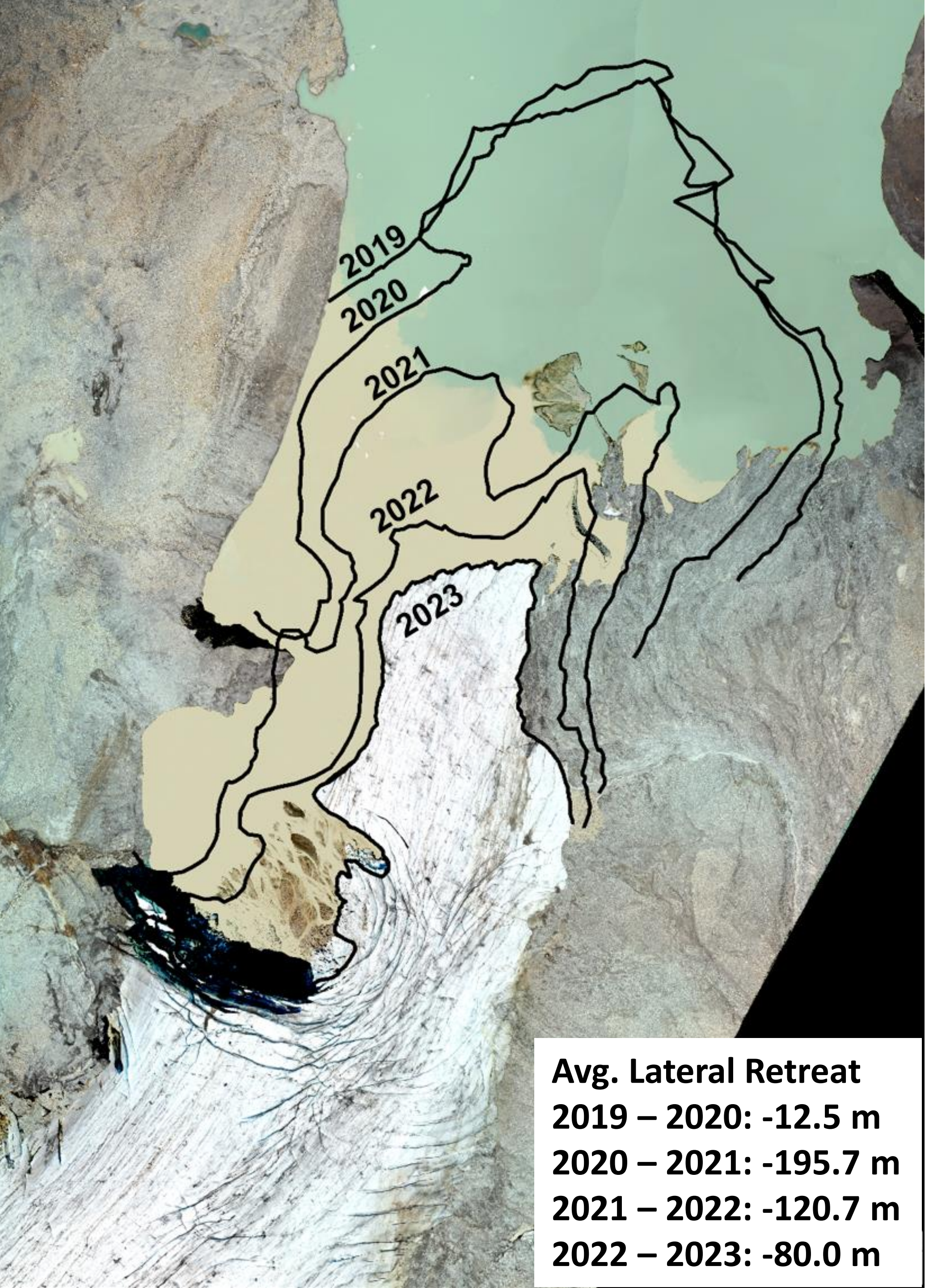
Snowpacks depleted in GWFO research basins in mid-May
Glacier melt started in early May at low elevations.

Canadian Rockies Hydrological Observatory

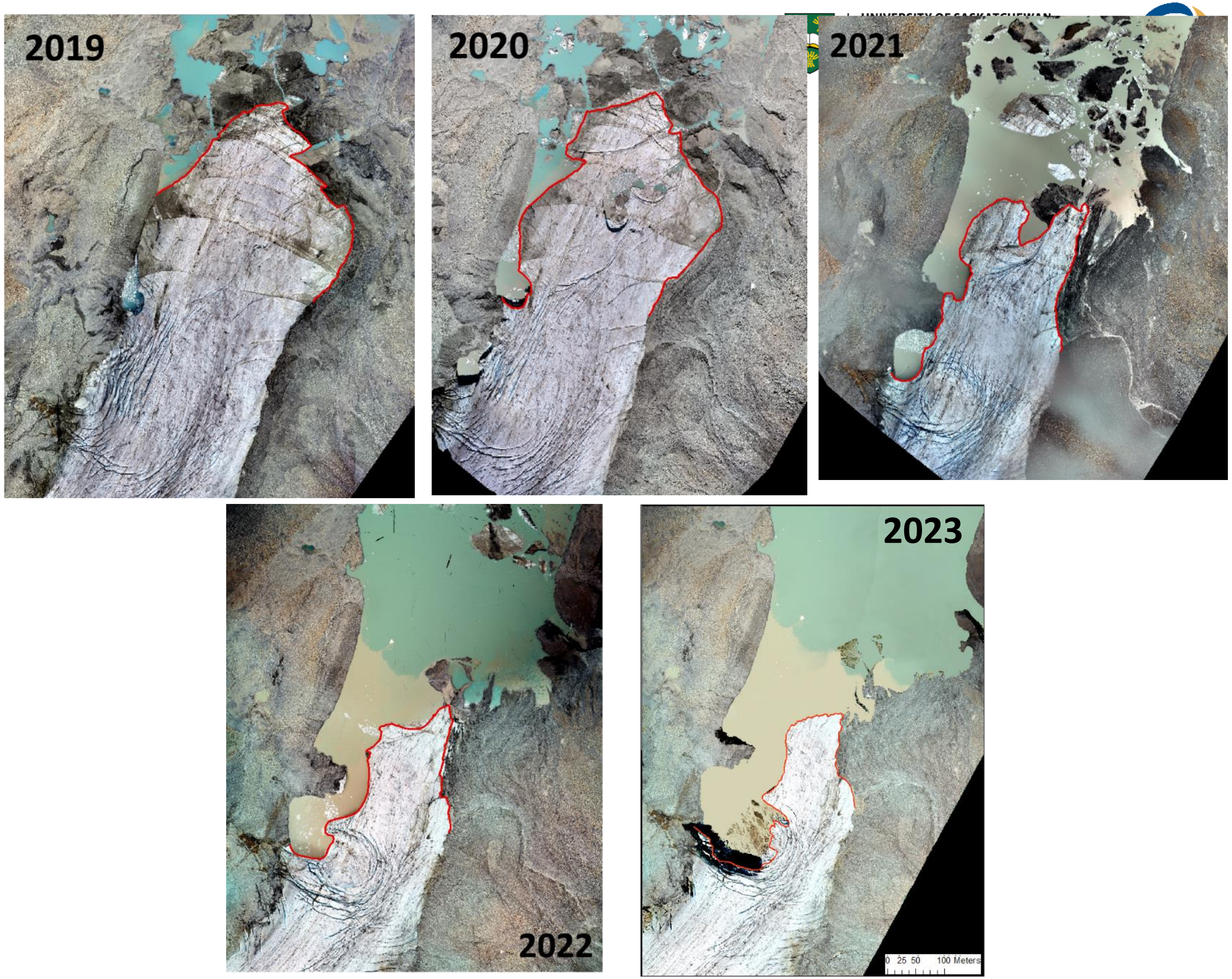


GWFO GLOBAL WATER FUTURES OBSERVATORIES

Glacier Monitoring – Global Water Futures Observatories

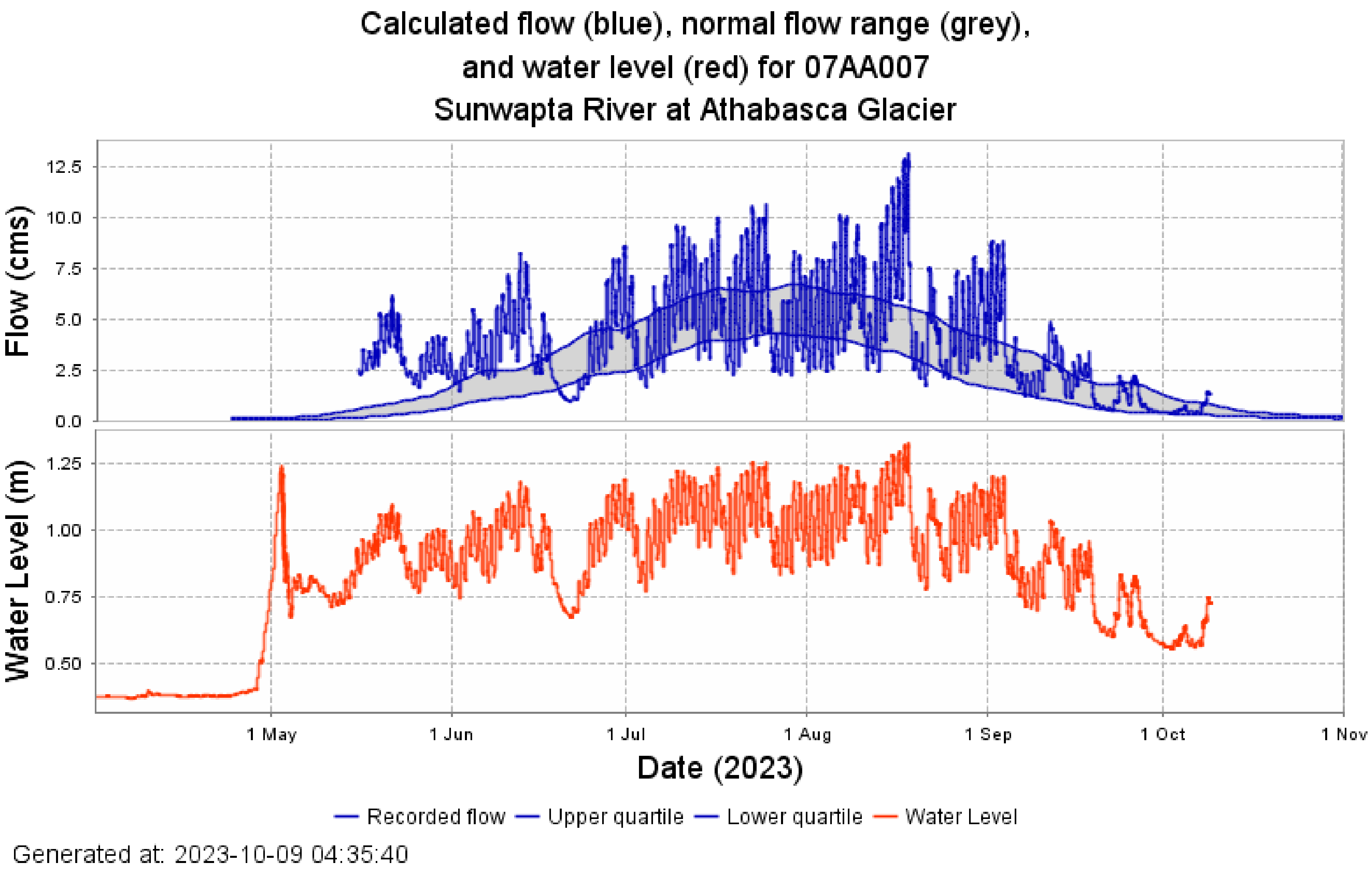


Extent of Peyto glacier toe from 2019 – 2023, overlain over aerial photography of Peyto taken in 2023

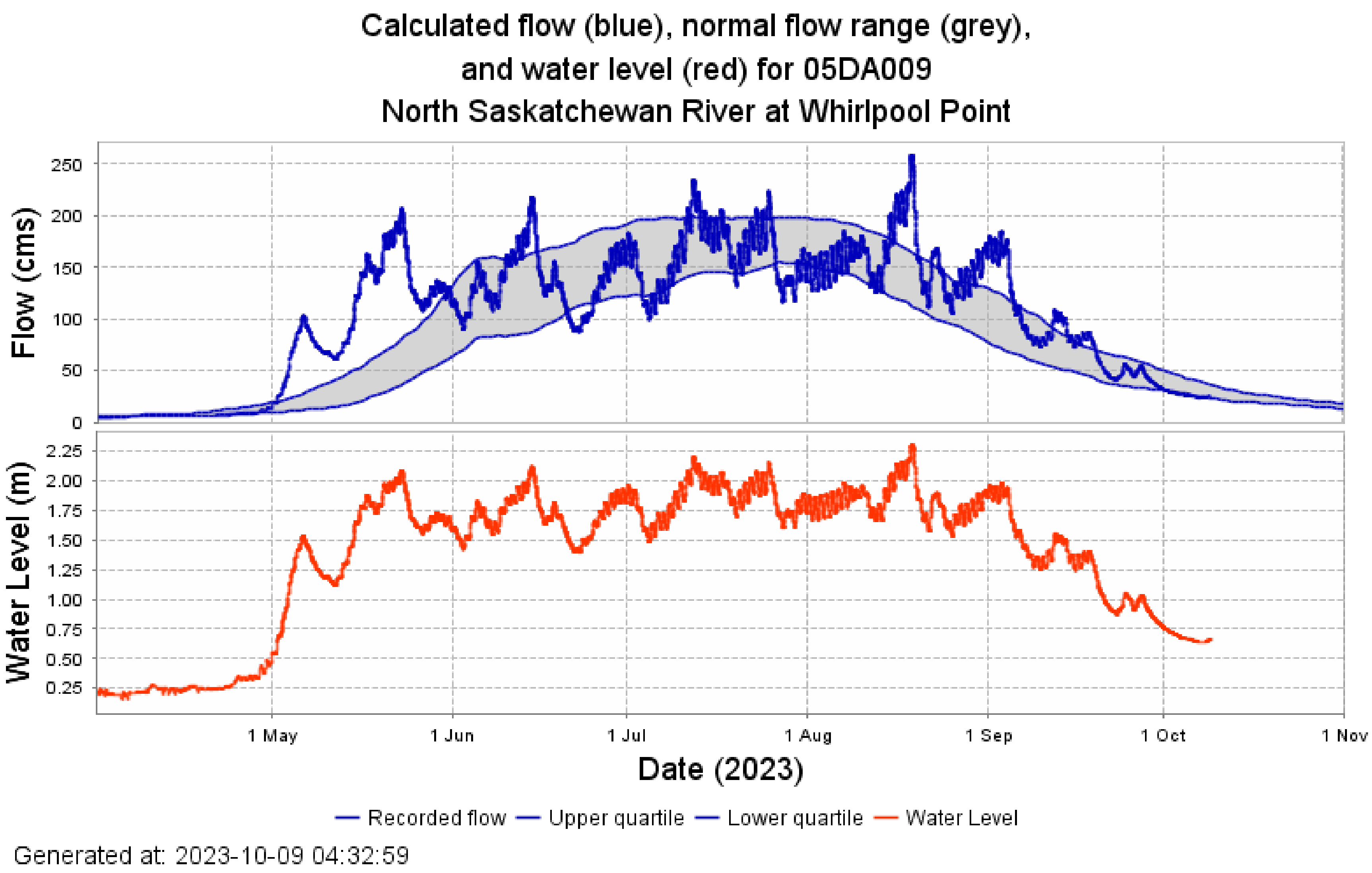


Definition of Peyto glacier toe for each year from 2019 - 2023

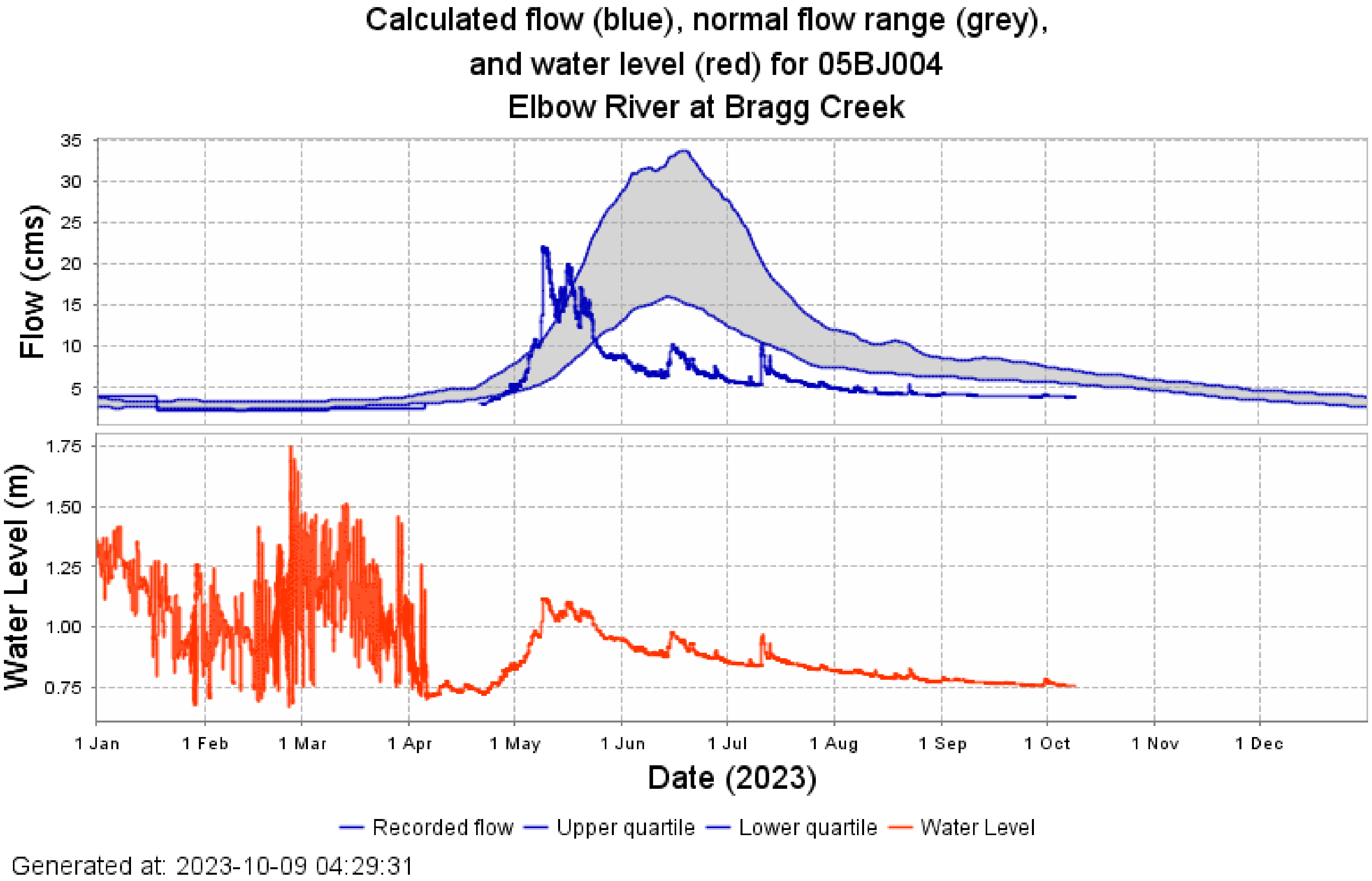
Glacier Streamflow Regime in Drought



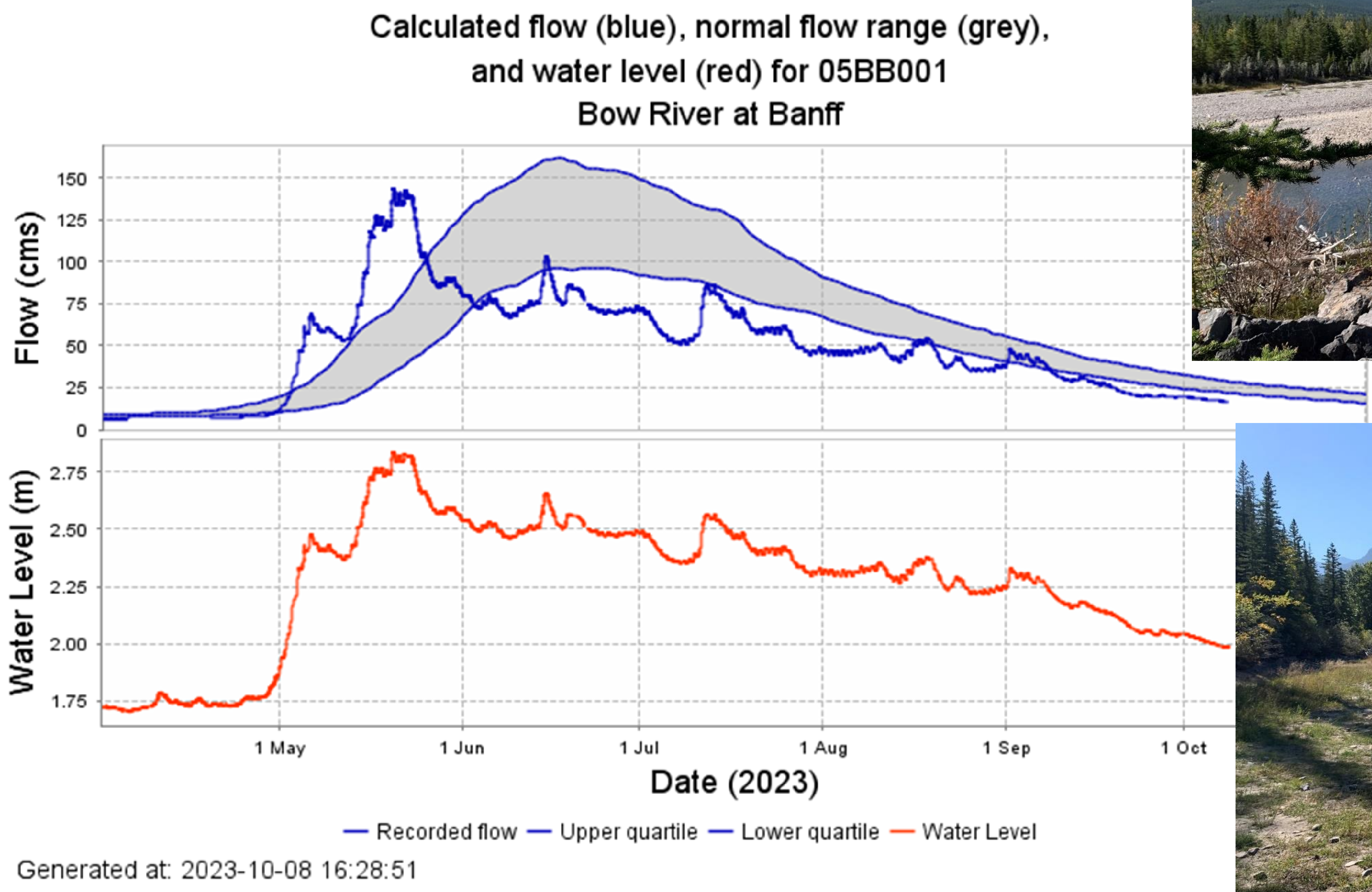
Glacier Influenced Streamflow Regime in Drought



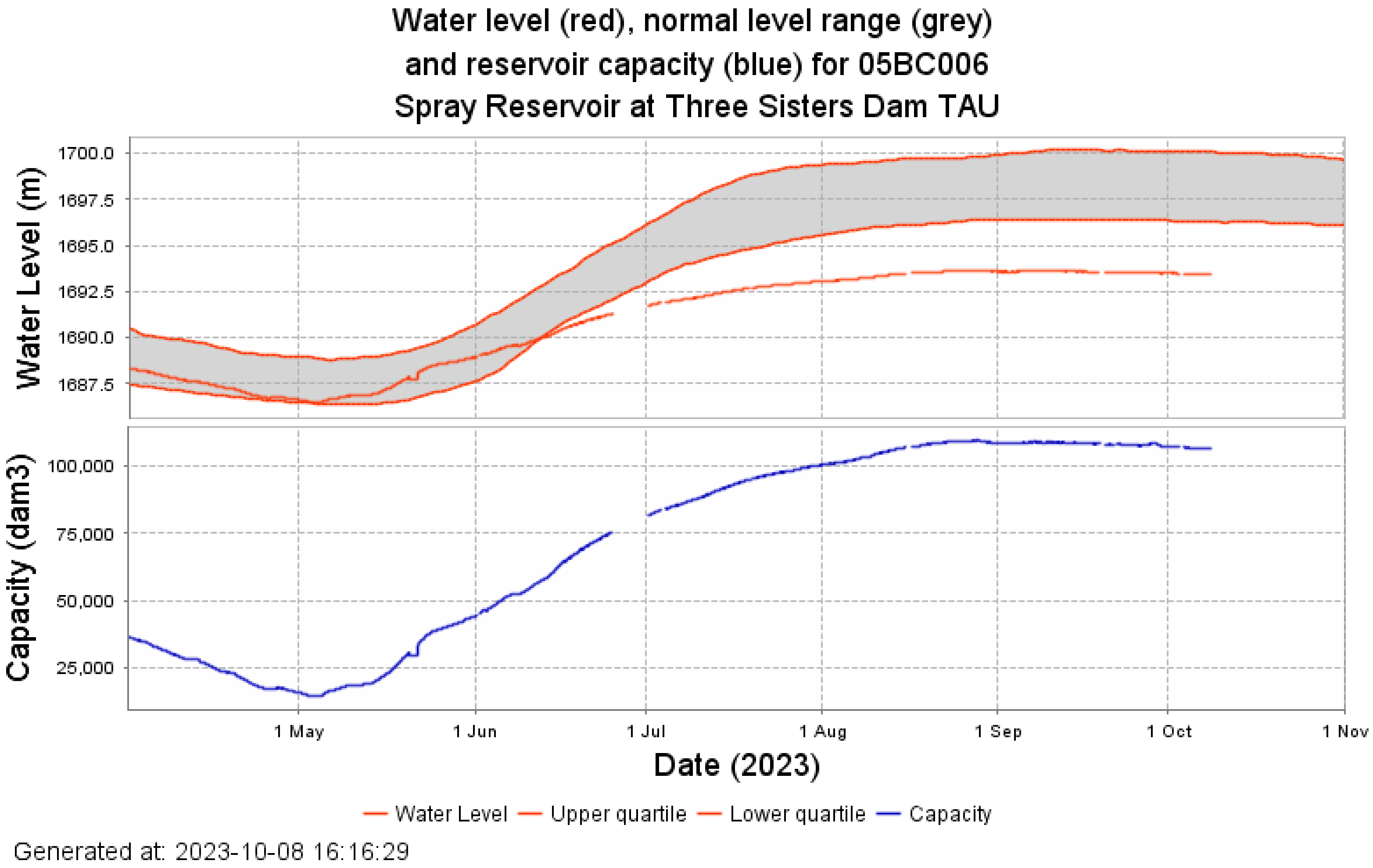
Snowmelt Streamflow Regime in Drought



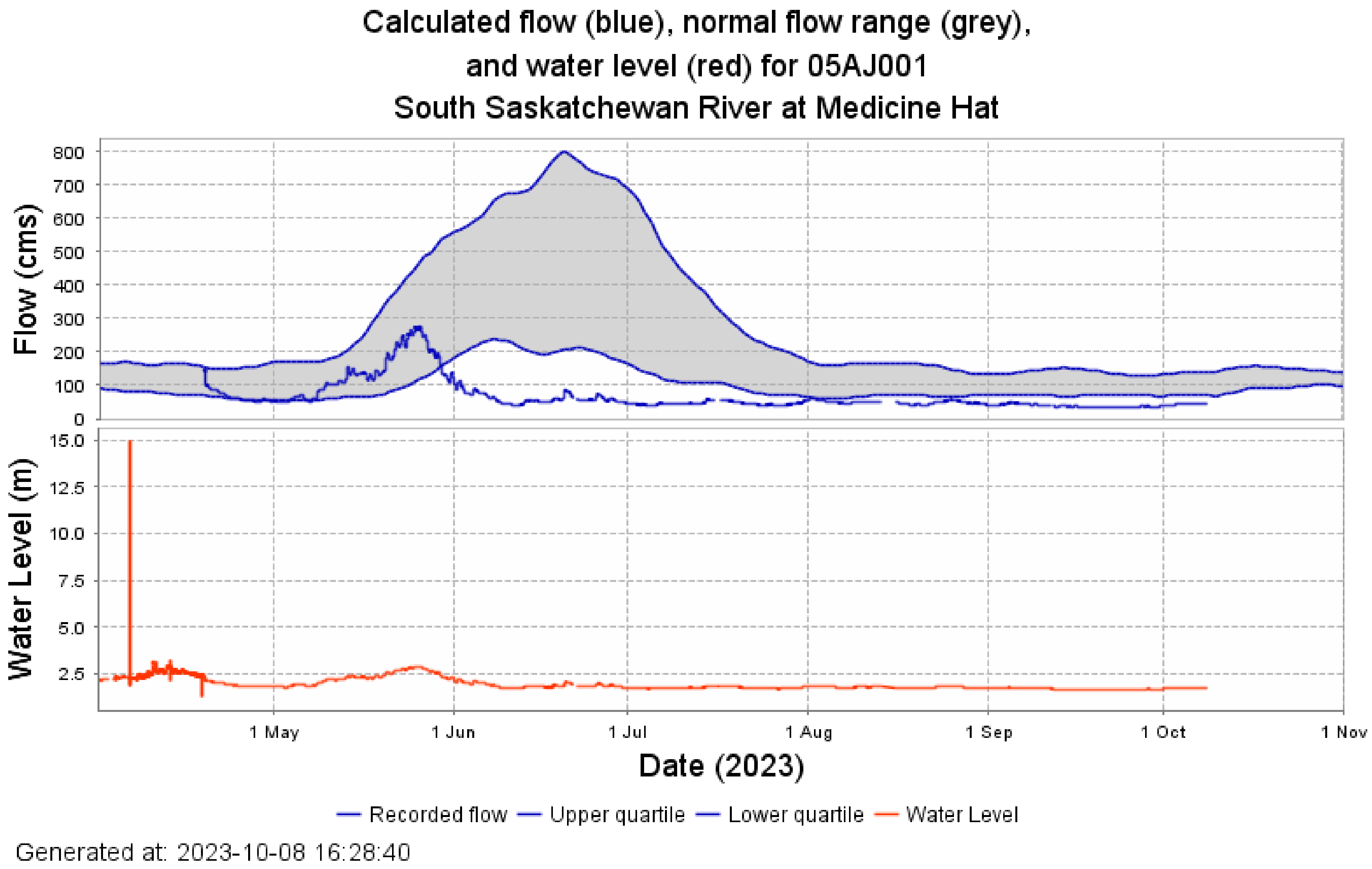
Hydrological Drought - Rivers



Hydrological Storage - Drought



Hydrological Drought - Downstream

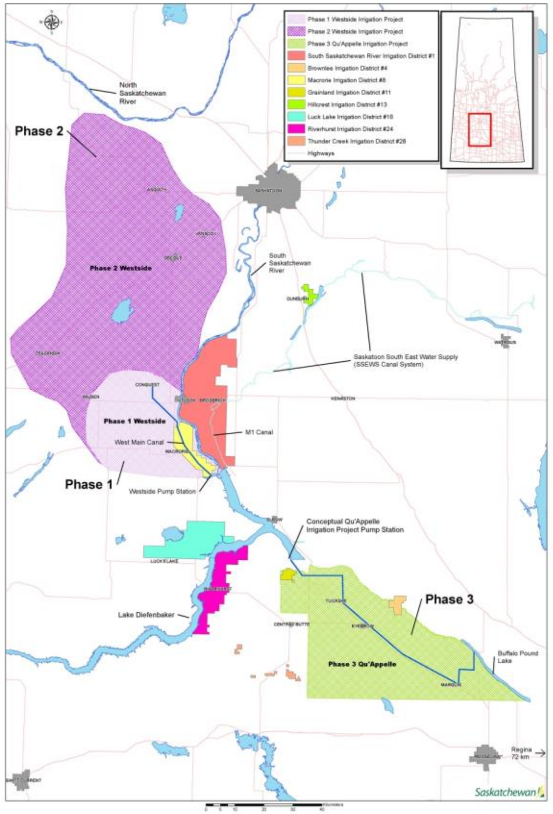


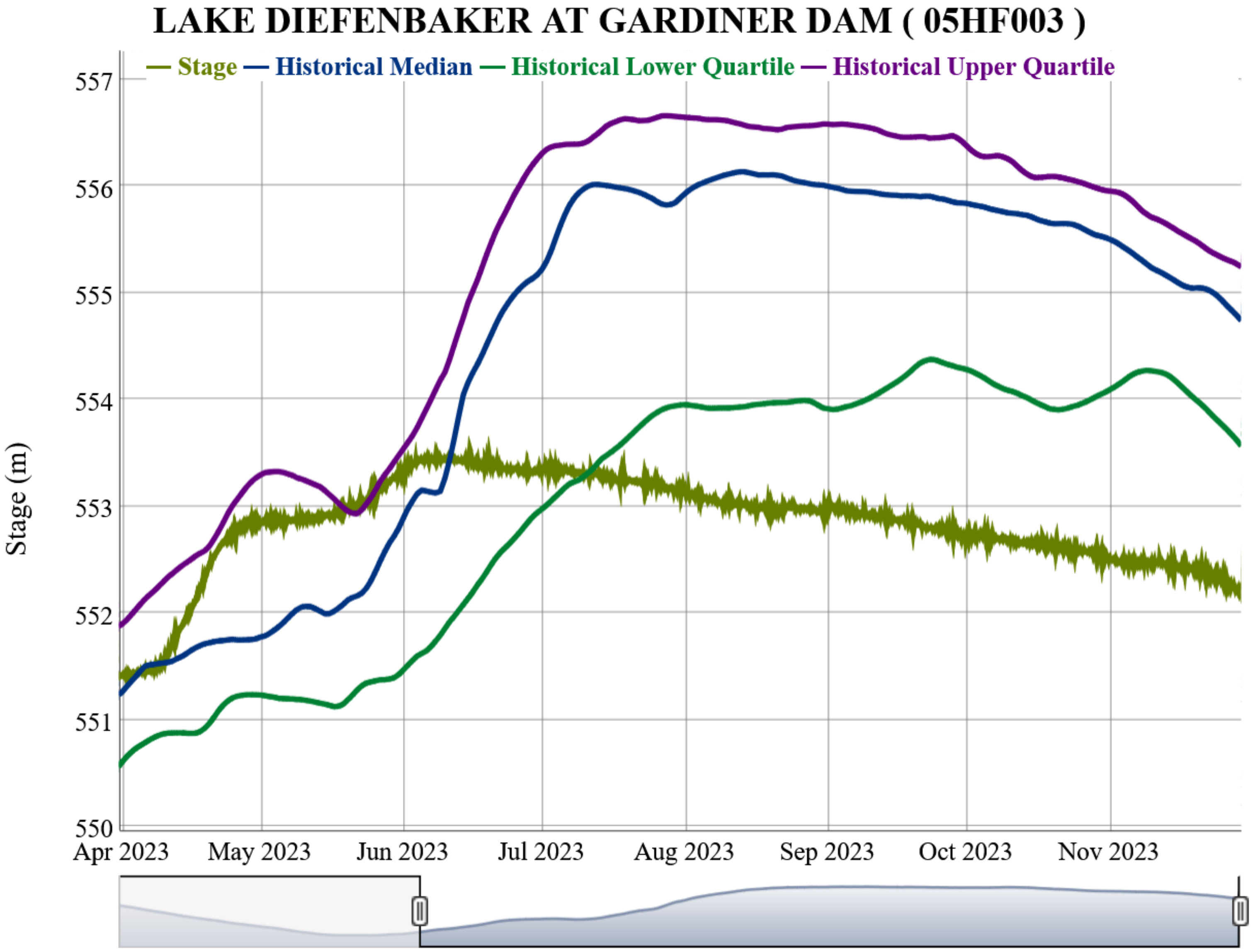
SE Alberta, August 2023

Downstream Impacts

Lake Diefenbaker supplies 70% of Saskatchewan's population and most of its industry with freshwater and supports the provinces largest irrigation district – proposed to expand by 380,000 acres

Lake Diefenbaker Development Area





Saskatchewan River Delta

Largest inland freshwater delta in North America
one of Canada's richest regions for abundance and diversity of wildlife

Saskatchewan

Cumberland House, Sask., declares state of emergency due to low water supply

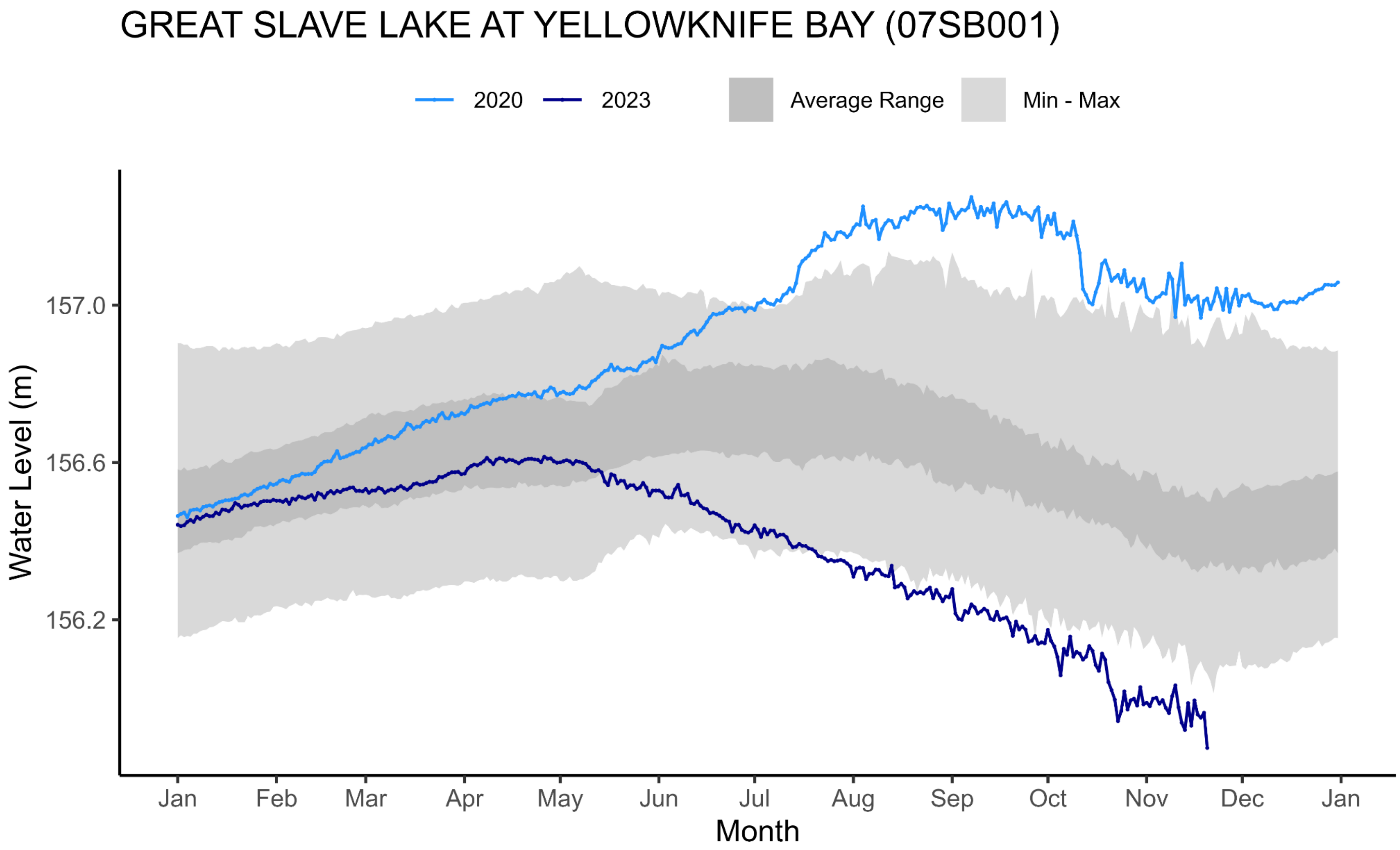
Local reservoir the only source of water for about 2,000 people

Louise BigEagle · CBC News · Posted: Oct 20, 2023 4:27 PM MDT | Last Updated: October 20, 2023

An aerial view shows the community of Cumberland House. The population of the village and adjoining reserves is about 2,000. (Cumberland House)

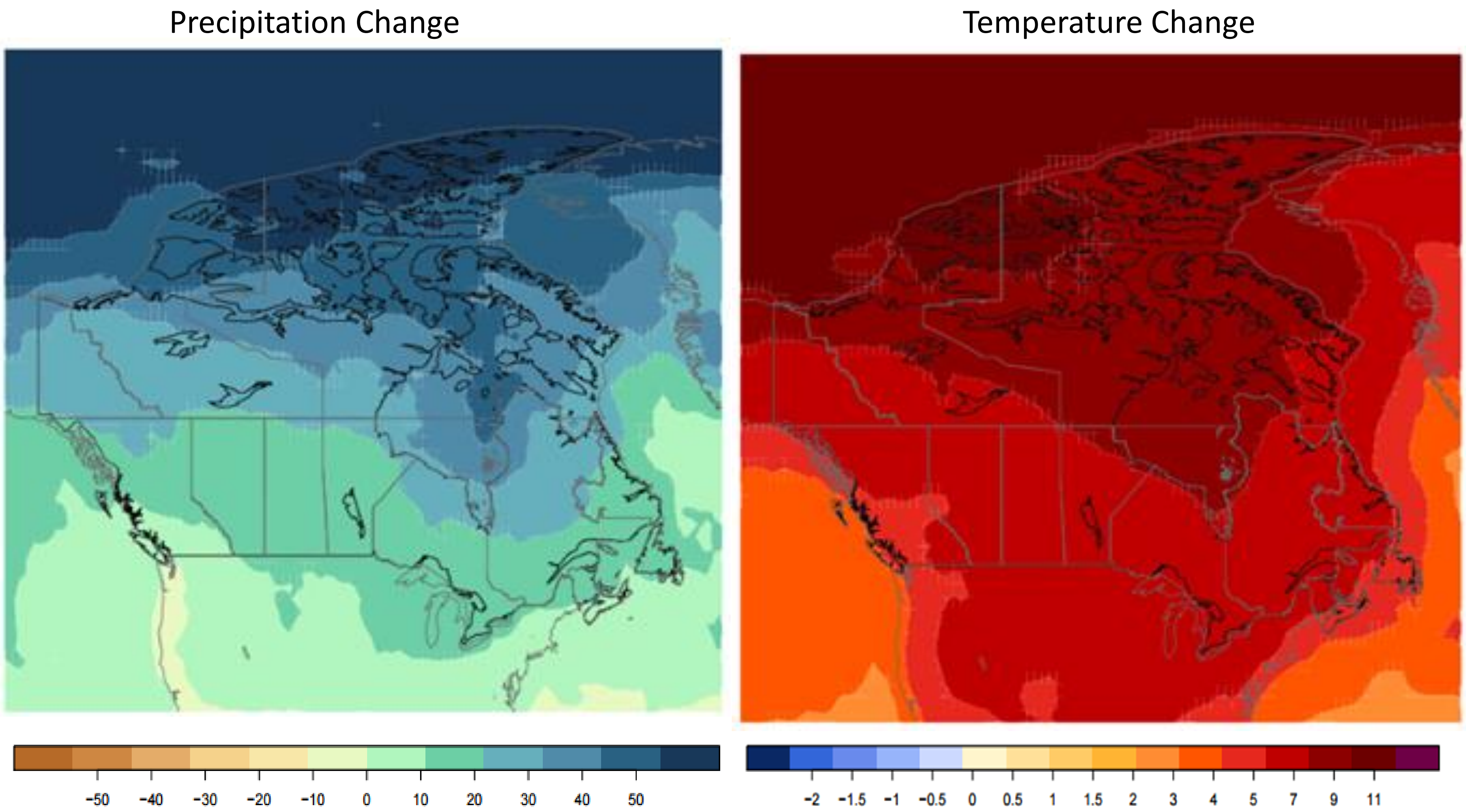
Leaders in Cumberland House, Sask., have declared a statement of emergency because the community has only four weeks worth of water left in its reservoir — a worrying scenario as winter approaches.

Great Slave Lake Water Levels – record lows



Courtesy Ryan Connon, GNWT

Climate Warming and Wetting



RCP 8.5 Canadian Climate Data and Scenarios
www.ccds-dscc.ec.gc.ca

Predicted change from present to 2085-2100

More Intense Precipitation in a Warming World

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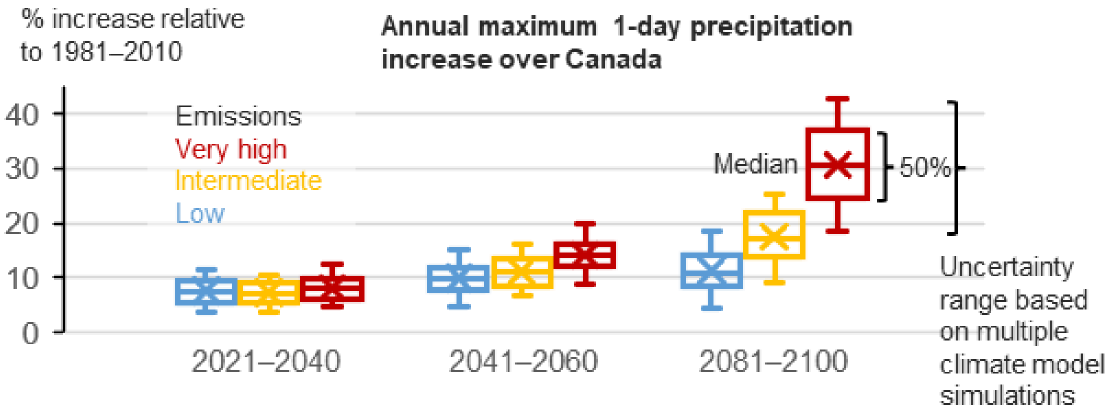
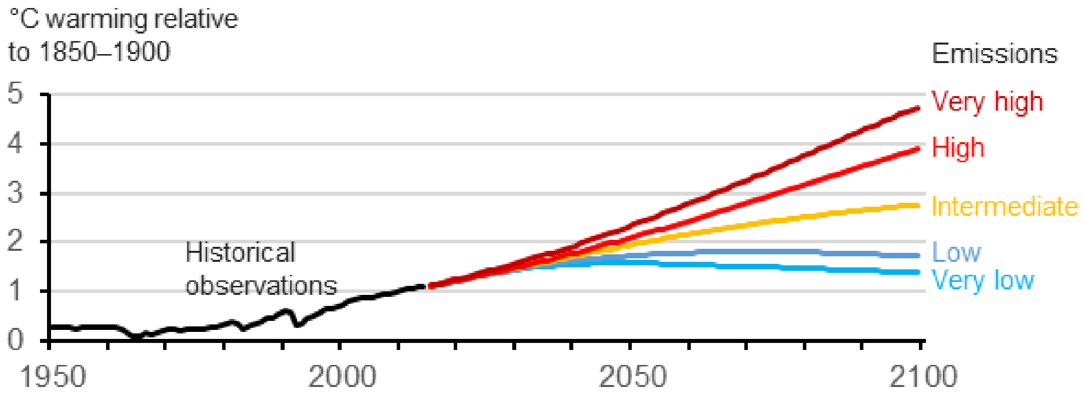
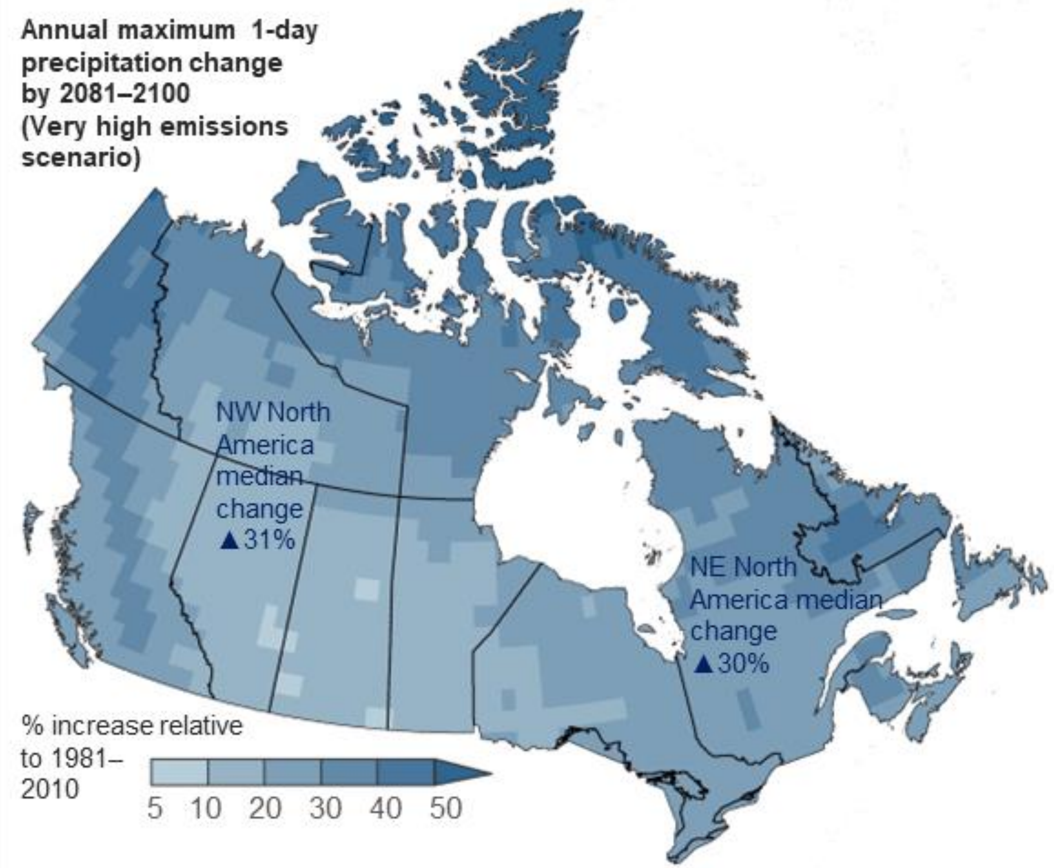
- IPCC scenarios show up to 5°C of global warming is possible by the late-21st century—far more in high latitudes such as Canada.
- Extreme precipitation has intensified since the 1950's at the rate of 6.6% per °C of observed global warming.
- Annual maximum 1-day precipitation could increase by 30% or more over Canada by the late-21st century.







Francis Zwiers, Univ Victoria

Future Hydrology from Climate Models

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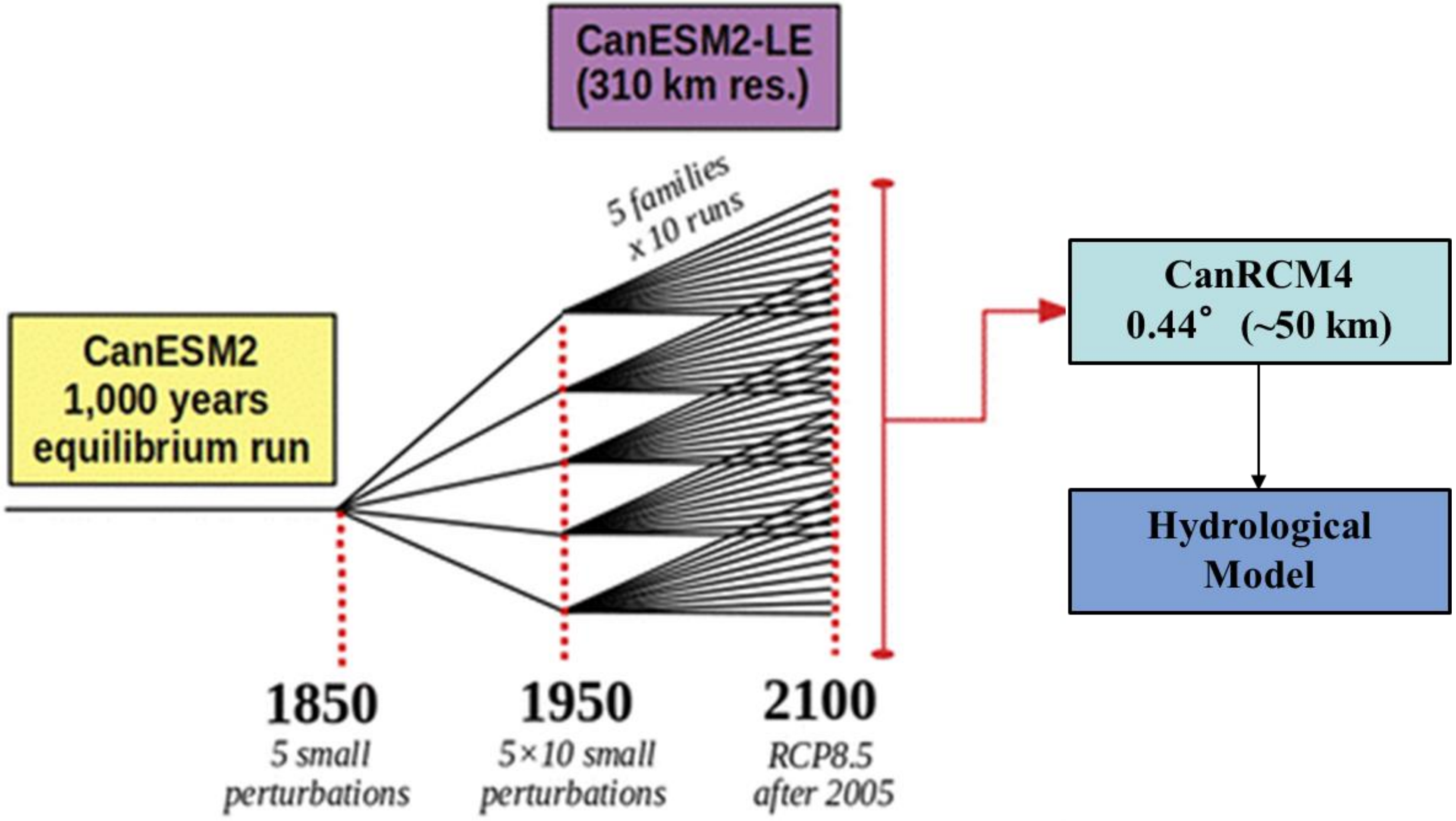
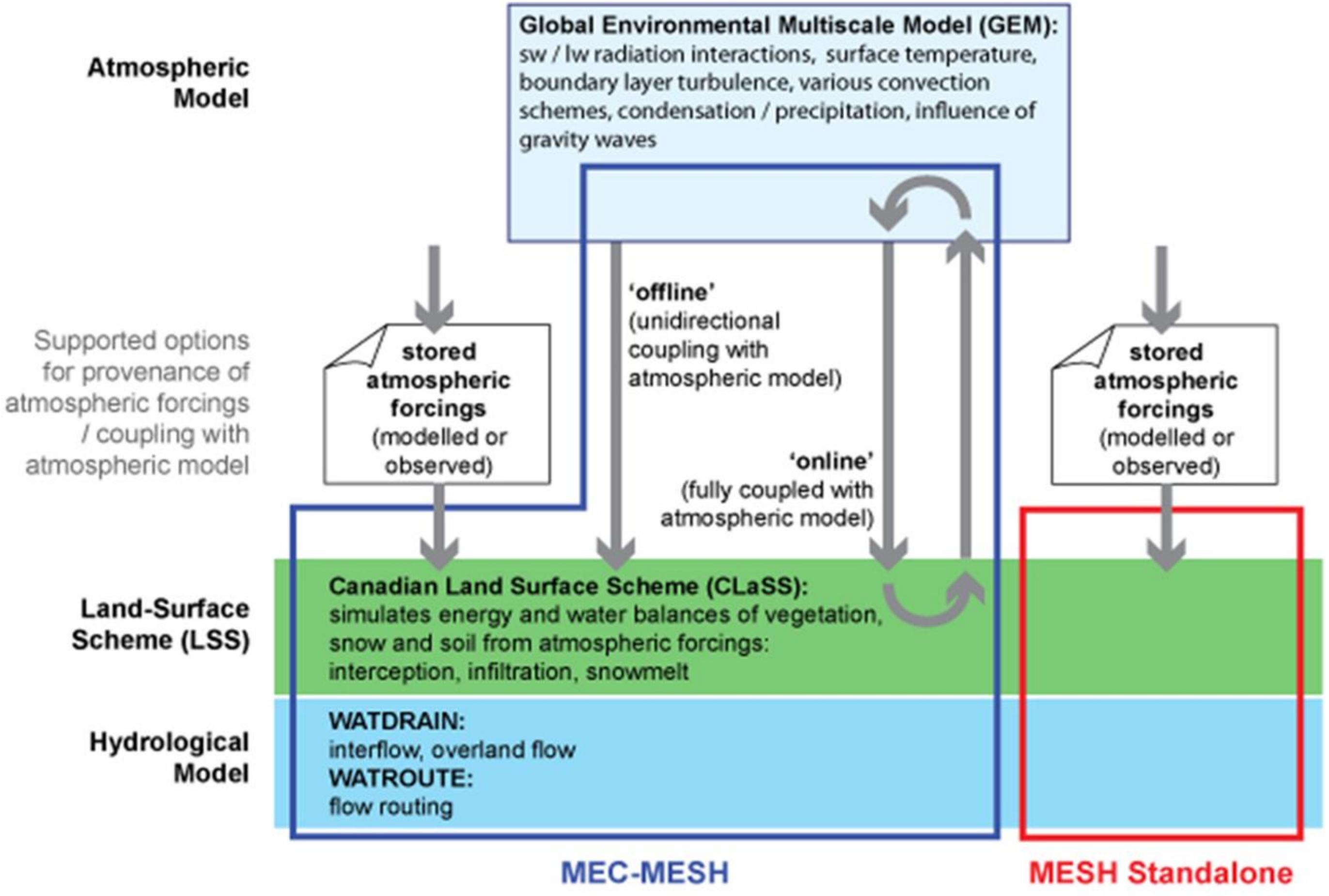


- CanESM2: Canadian Earth System Model 2 global climate model
- CanRCM4: Canadian Regional Climate Model 4

(Scinocca et al., 2015; Leduc et al., 2019)

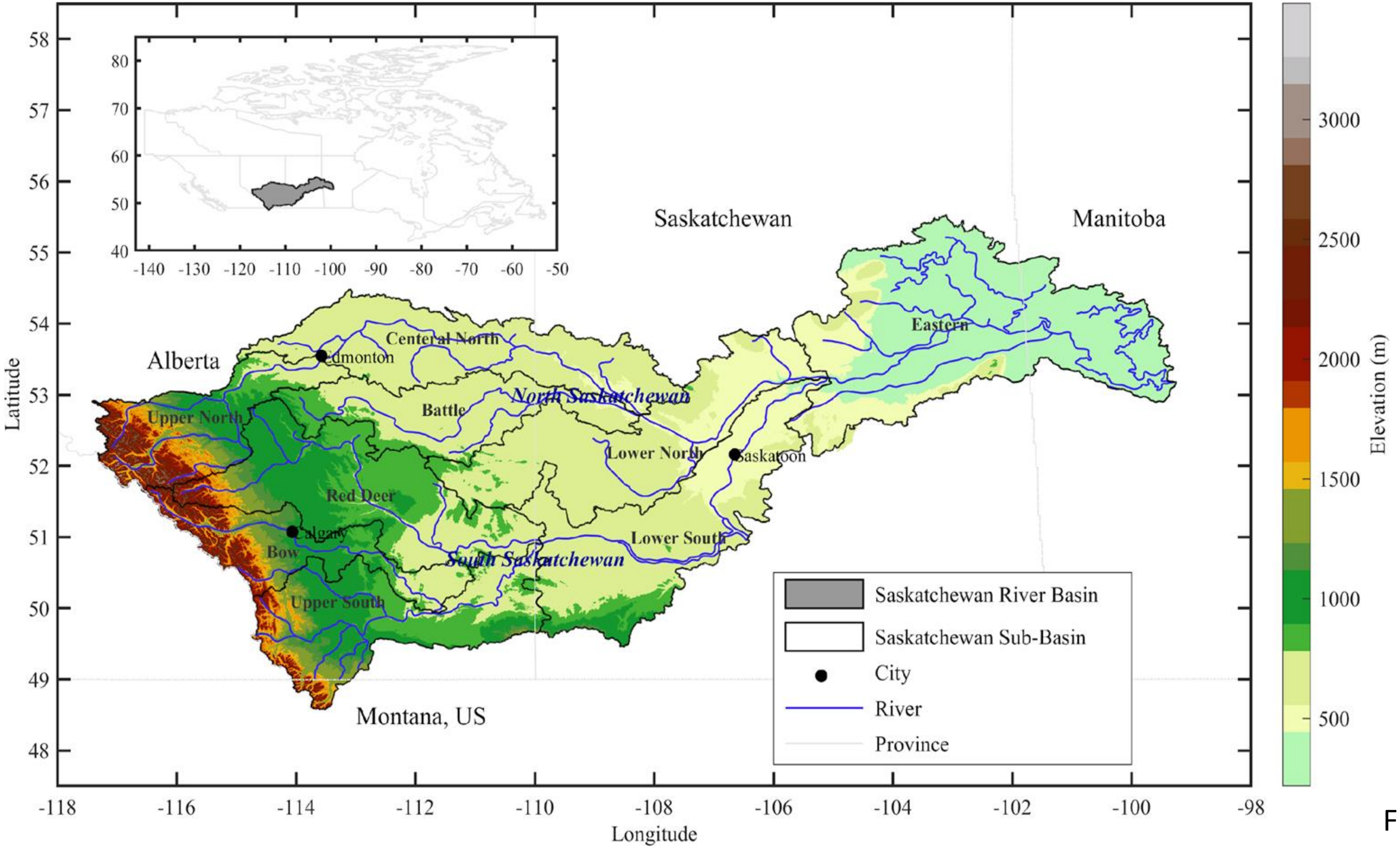
Modélisation Environnementale Communautaire - Surface & Hydrology, The MESH Hydrological Model

- Hydrological land surface scheme developed by ECCC and GWF
- **CLASS**, Canadian Land Surface Scheme & WATFLOOD hydrological model & new modules
- **Physically based model** – restricted parameter calibration
- **Cold Regions Processes** : Glaciers, blowing snow, sublimation, frozen soil infiltration, slope/aspect irradiance, energy balance snowmelt, lapse rates for T and P, physically based precipitation phase
- Includes **water management** processes
- **Suitable for large, cold regions river basins**



Pietroniro et al, 2007; Wheater et al., 2022

Saskatchewan River Basin (SRB)



Fuad Yassin

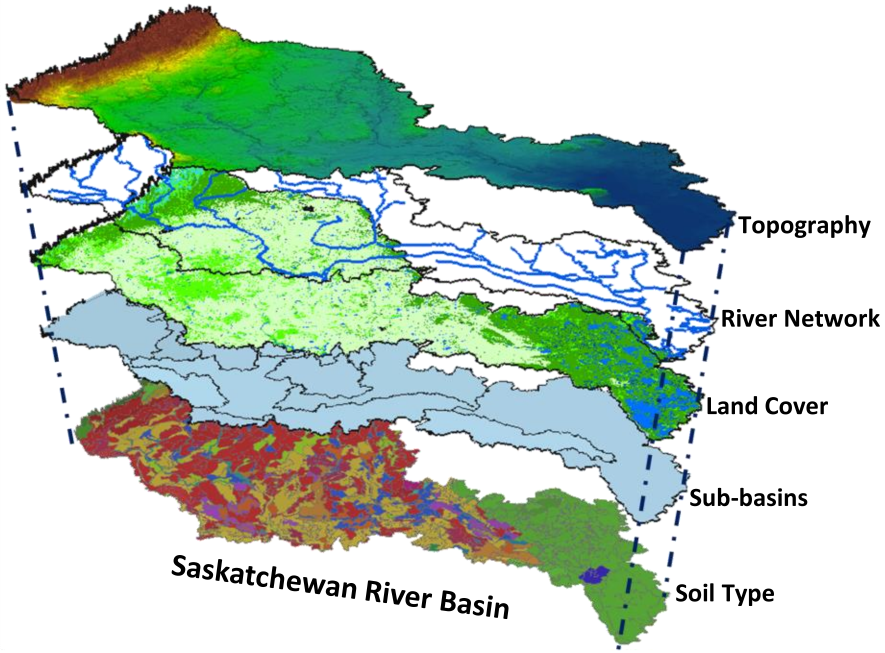
MESH model Saskatchewan River Basin

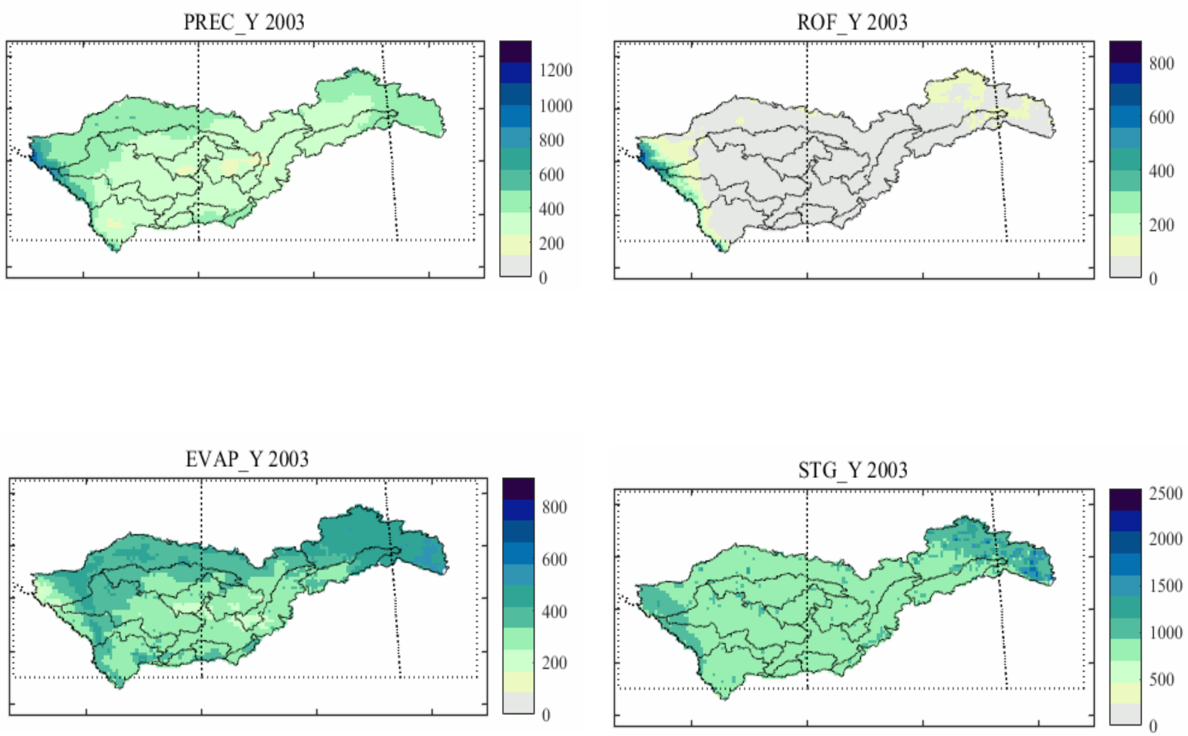
- How much streamflow is generated in the mountains, prairie and boreal forests of the Saskatchewan River Basin?
- How much streamflow is generated by glacier melt, snowmelt, rain-on-snow, and rainfall-runoff processes?
- How did the water budget components respond to the drought and the very wet years?
- How much irrigation water consumption is occurring in the basin and how does this vary over time and space?

Important Processes added to MESH

- Glaciers, Blowing Snow Transport and Sublimation, Reservoir Operation, Irrigation, Non-contributing Area Dynamics.

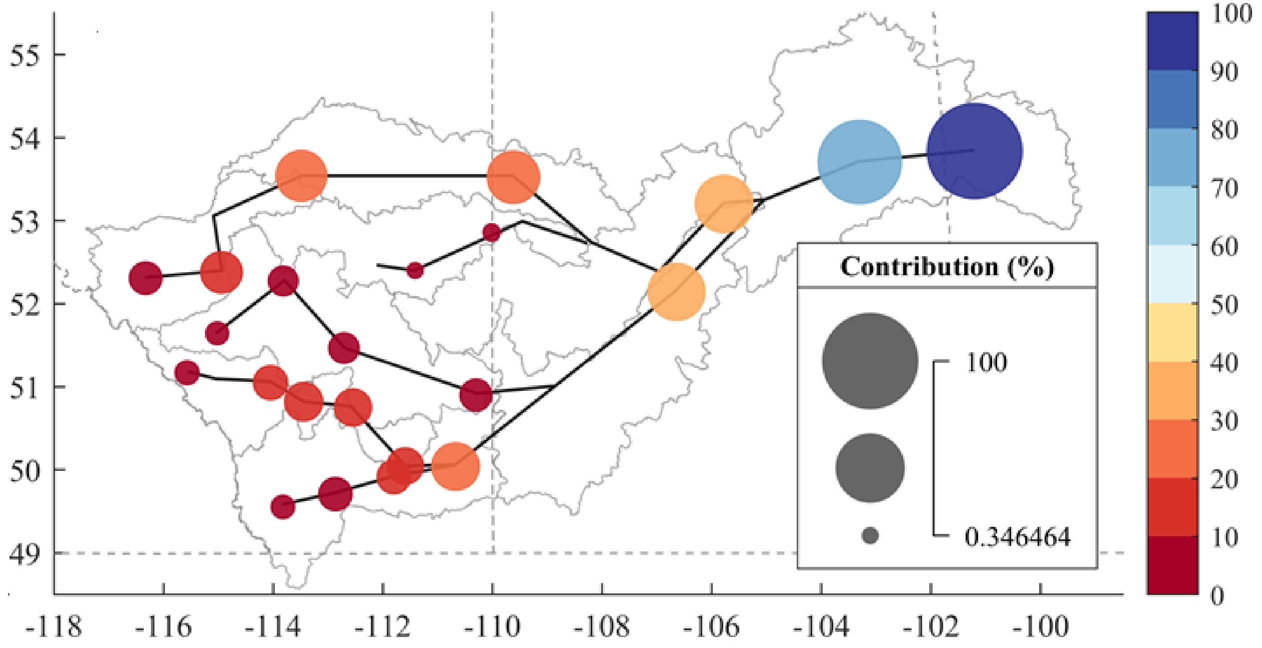
MESH configured at 10 x 10 km grid cell and driven by GEM-CaPA over 2004-2016



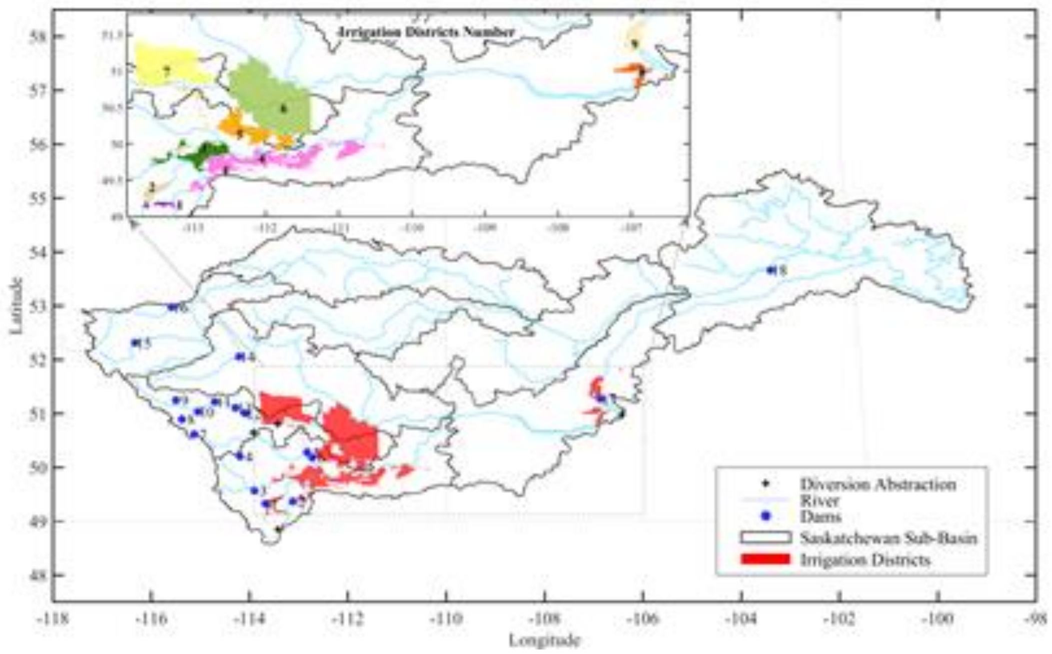


Saskatchewan River Basin Prediction - MESH

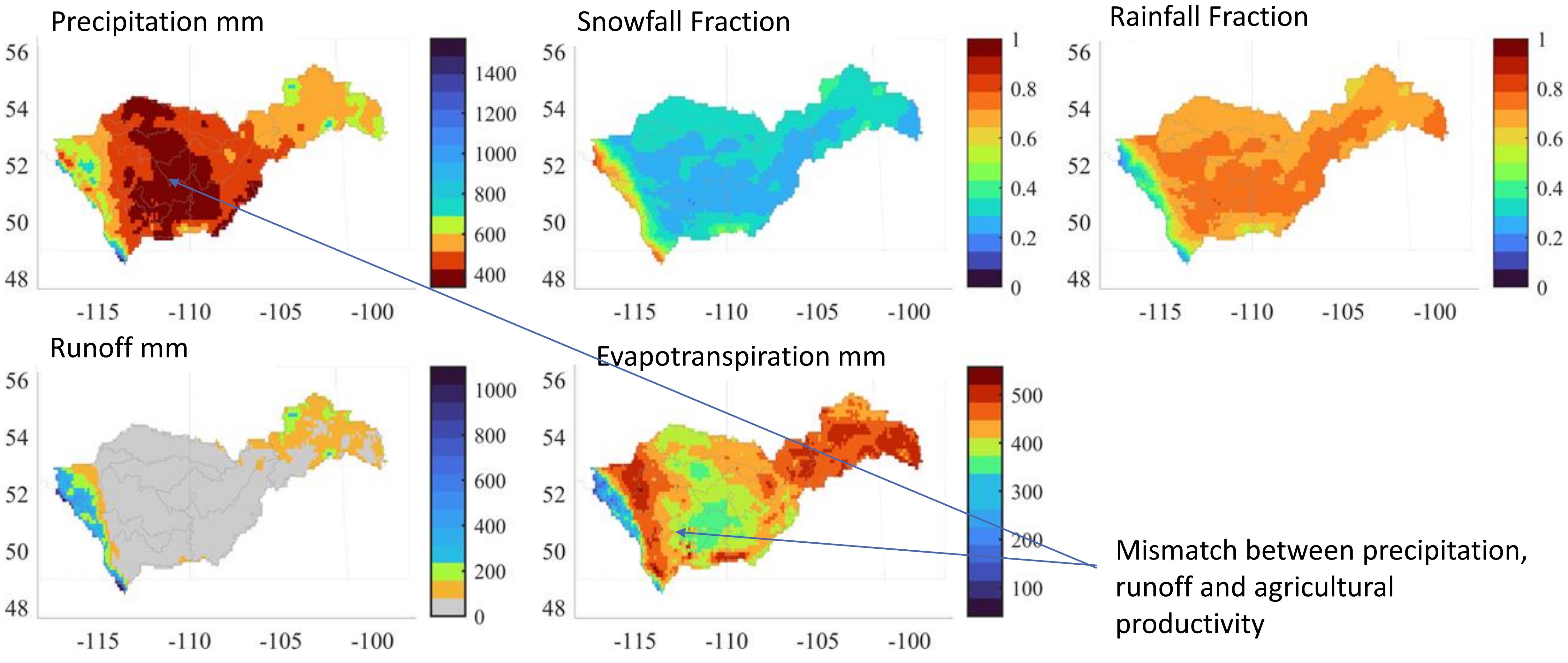
Cumulative Streamflow Volume and River Network



Irrigation Districts and Area Modelled



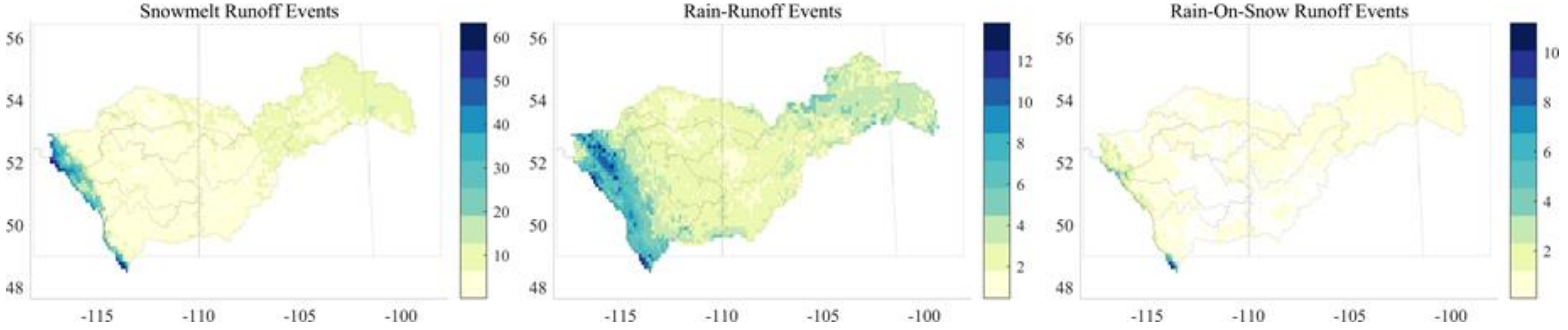
Saskatchewan River Basin Current Water Balance

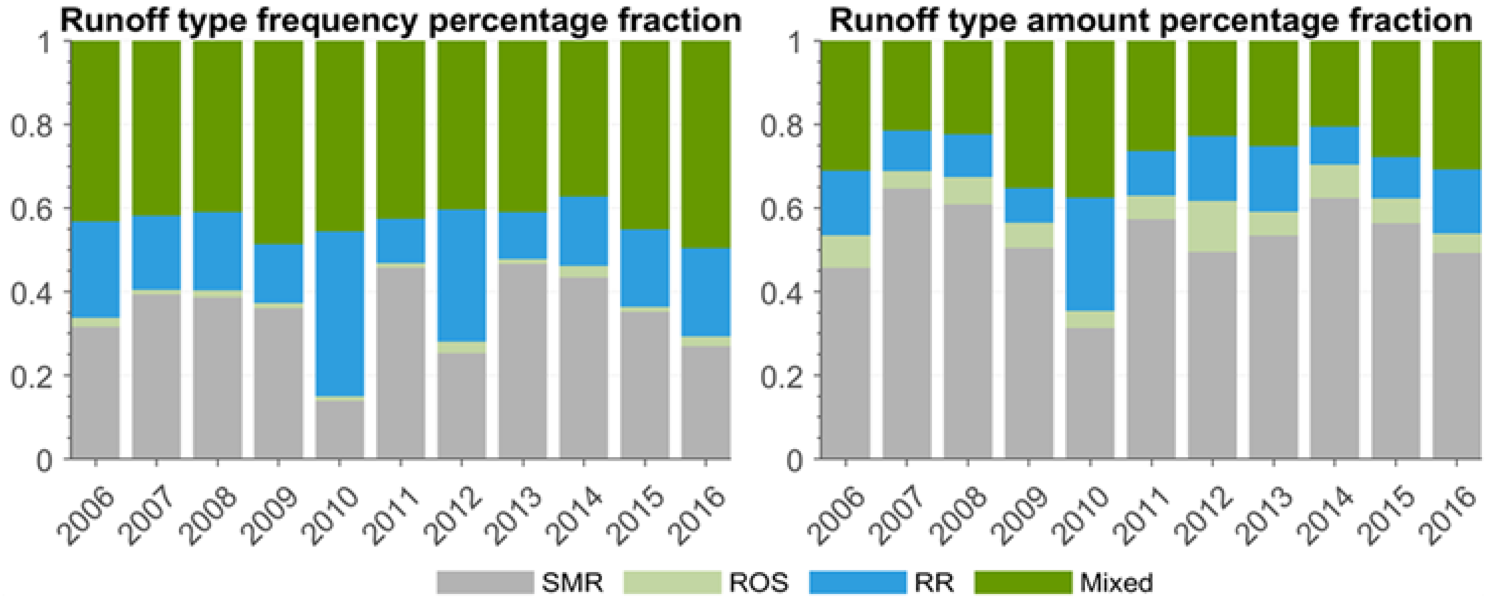


2006-2016 model diagnostic runs (MESH) Fuad Yassin

Runoff Generation Primarily Snowmelt from the Canadian Rockies

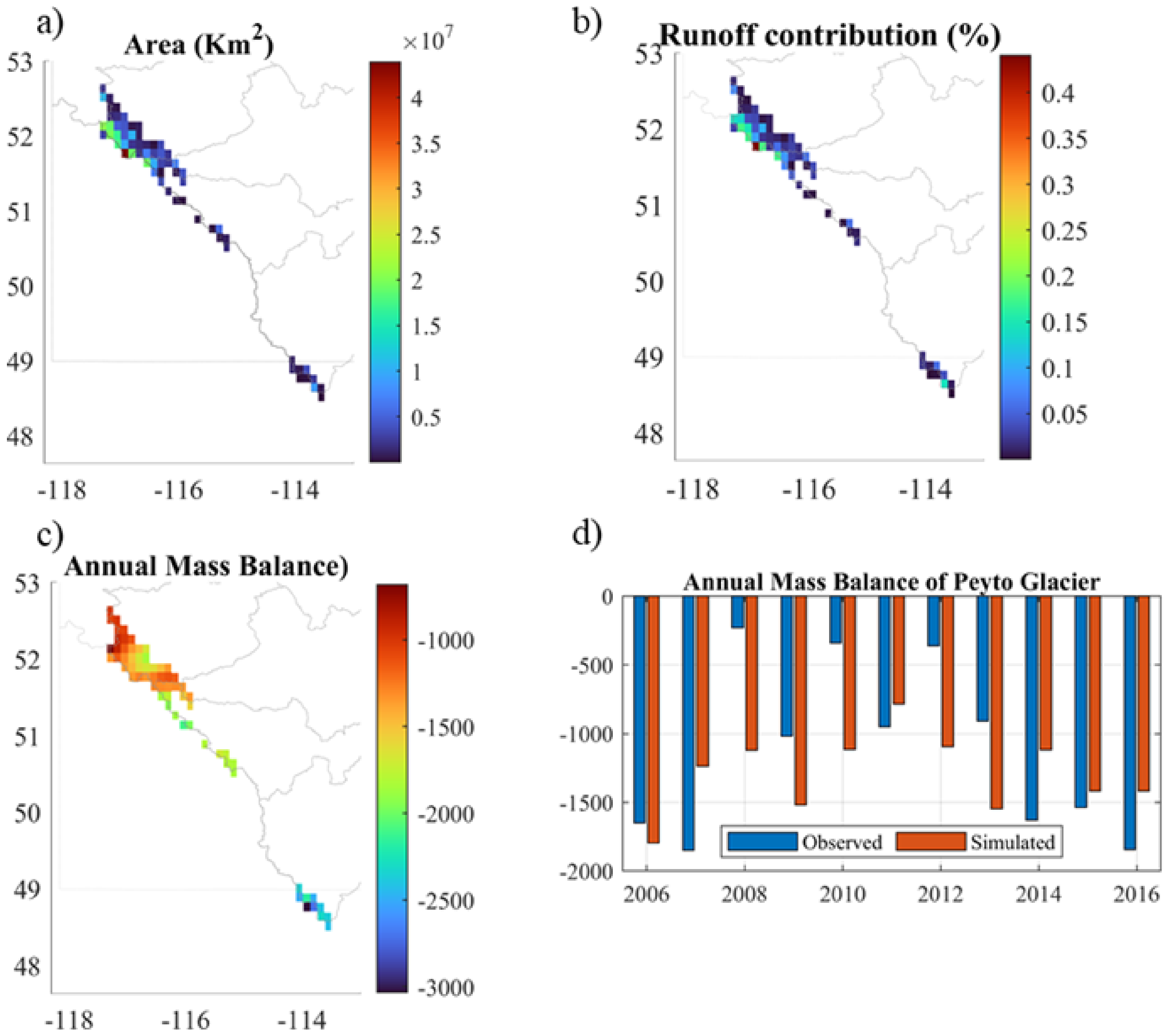
Substantial runoff events over 10 years (2006-2016)





Annual fraction of runoff type
SMR – snowmelt
ROS – rain on snow
RR – rainfall runoff

Glacier Contributions to Streamflow

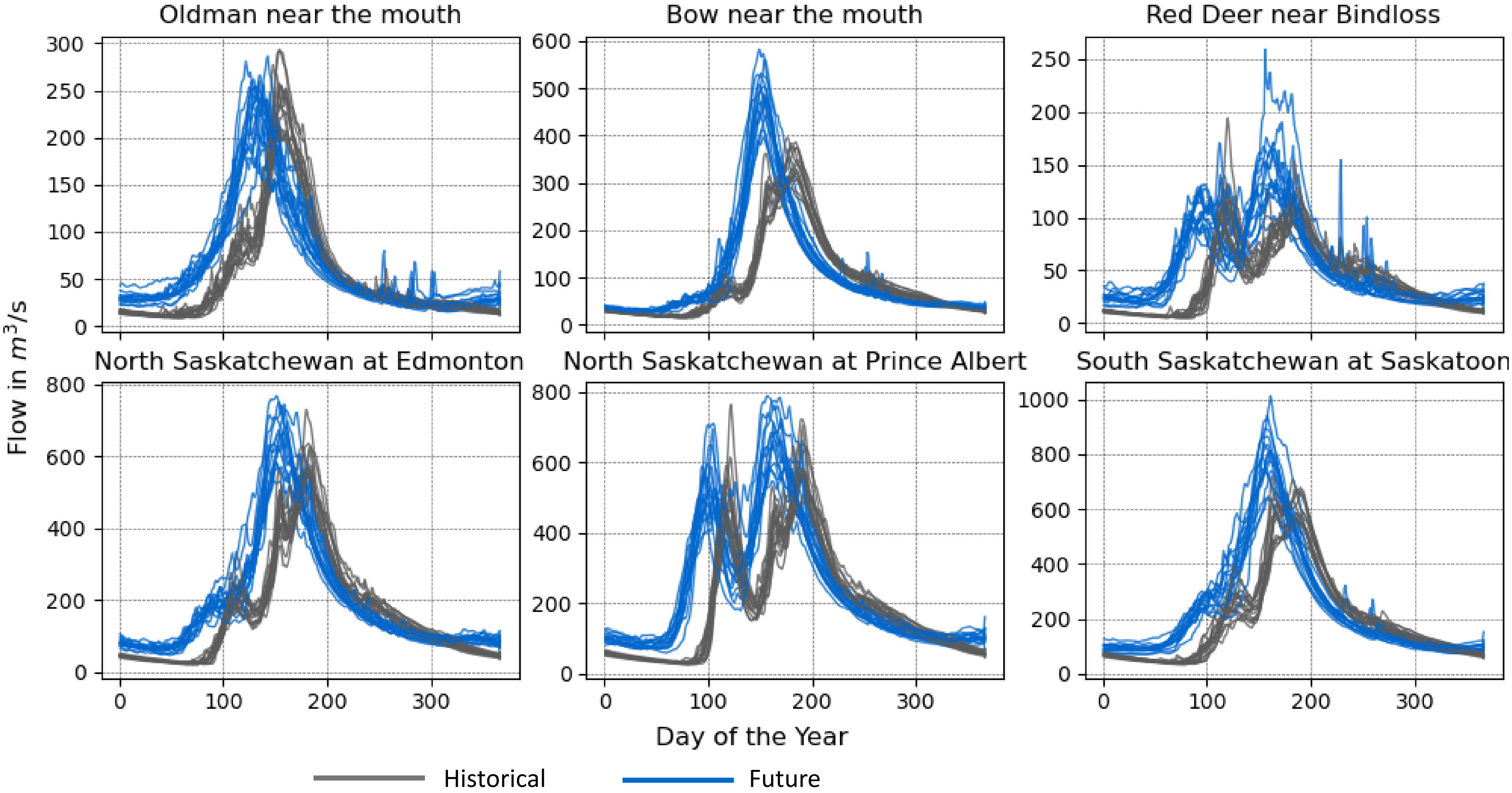


All glaciers have a negative mass balance (receding) which contributes extra water to streamflow discharge.

Glacier runoff contributions limited in size and area.

Current glacier wastage contribution to the Saskatchewan River Basin annual discharge is 3.2%, mostly from runoff in the North Saskatchewan River basin with smaller contributions elsewhere.

Saskatchewan River Basin - Streamflow change

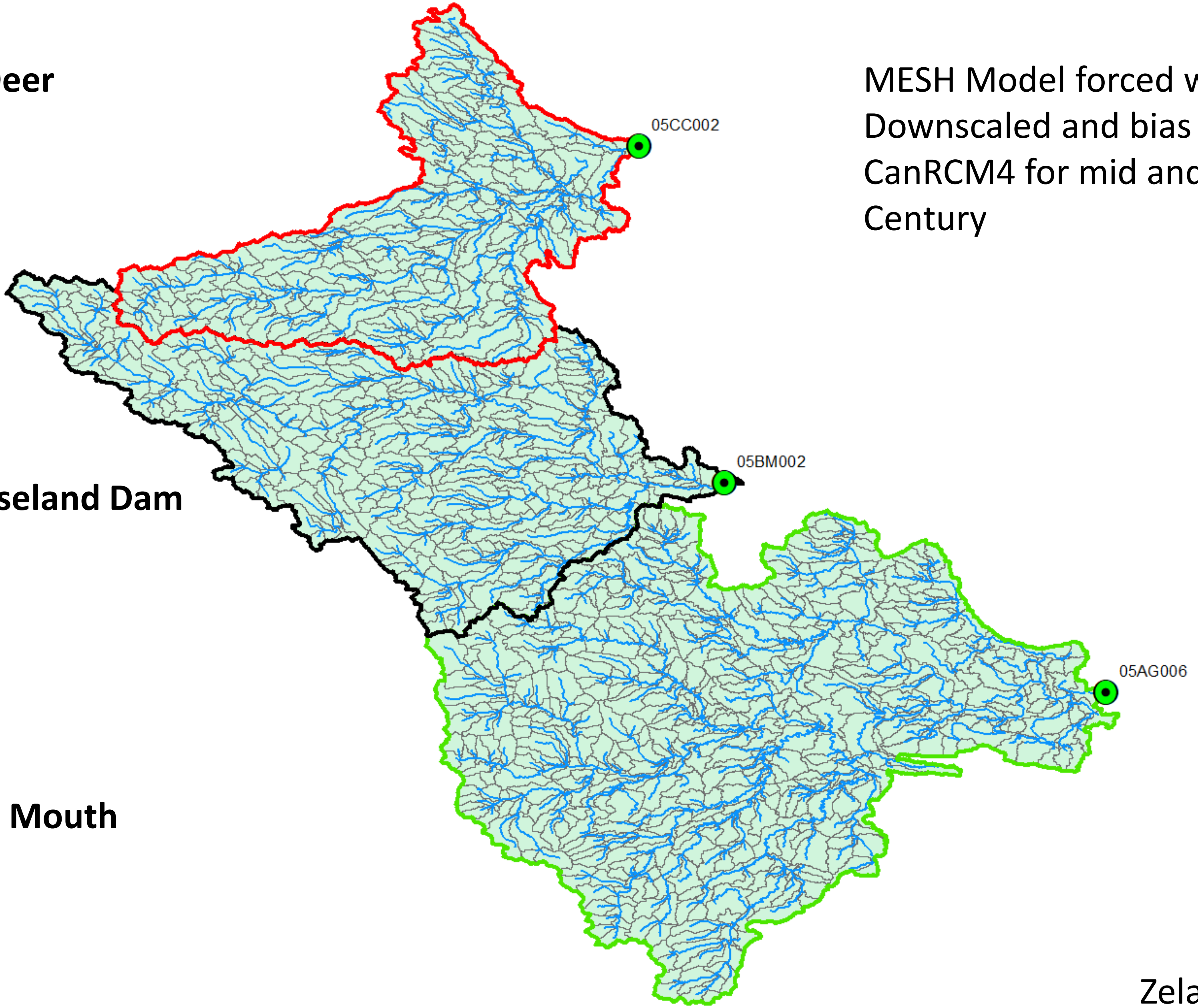


South Saskatchewan Headwater River Basins

Red Deer at Red Deer
237 Subbasins

Bow River below Carseland Dam
335 Subbasins

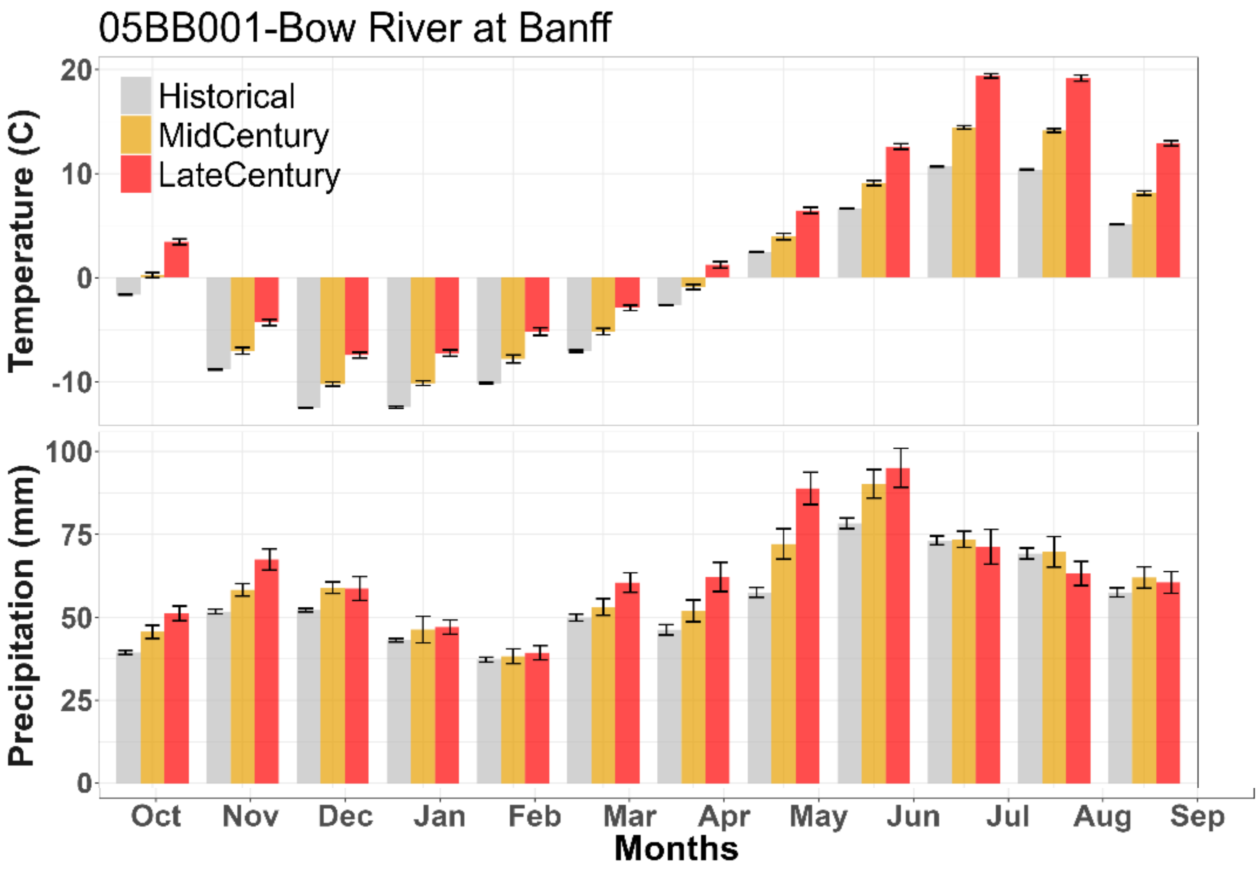
Oldman River near Mouth
570 Subbasins

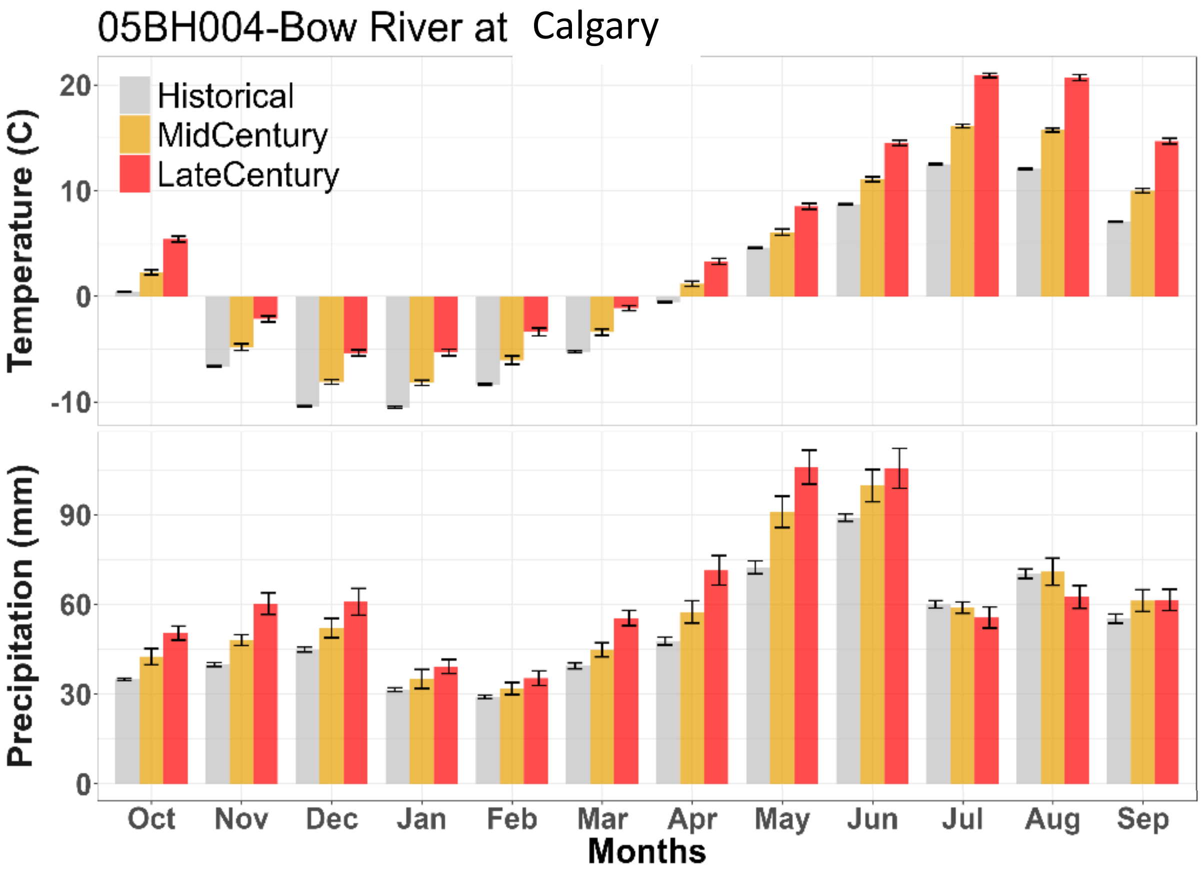


MESH Model forced with Downscaled and bias corrected CanRCM4 for mid and late 21st Century

Zelalem Tessema

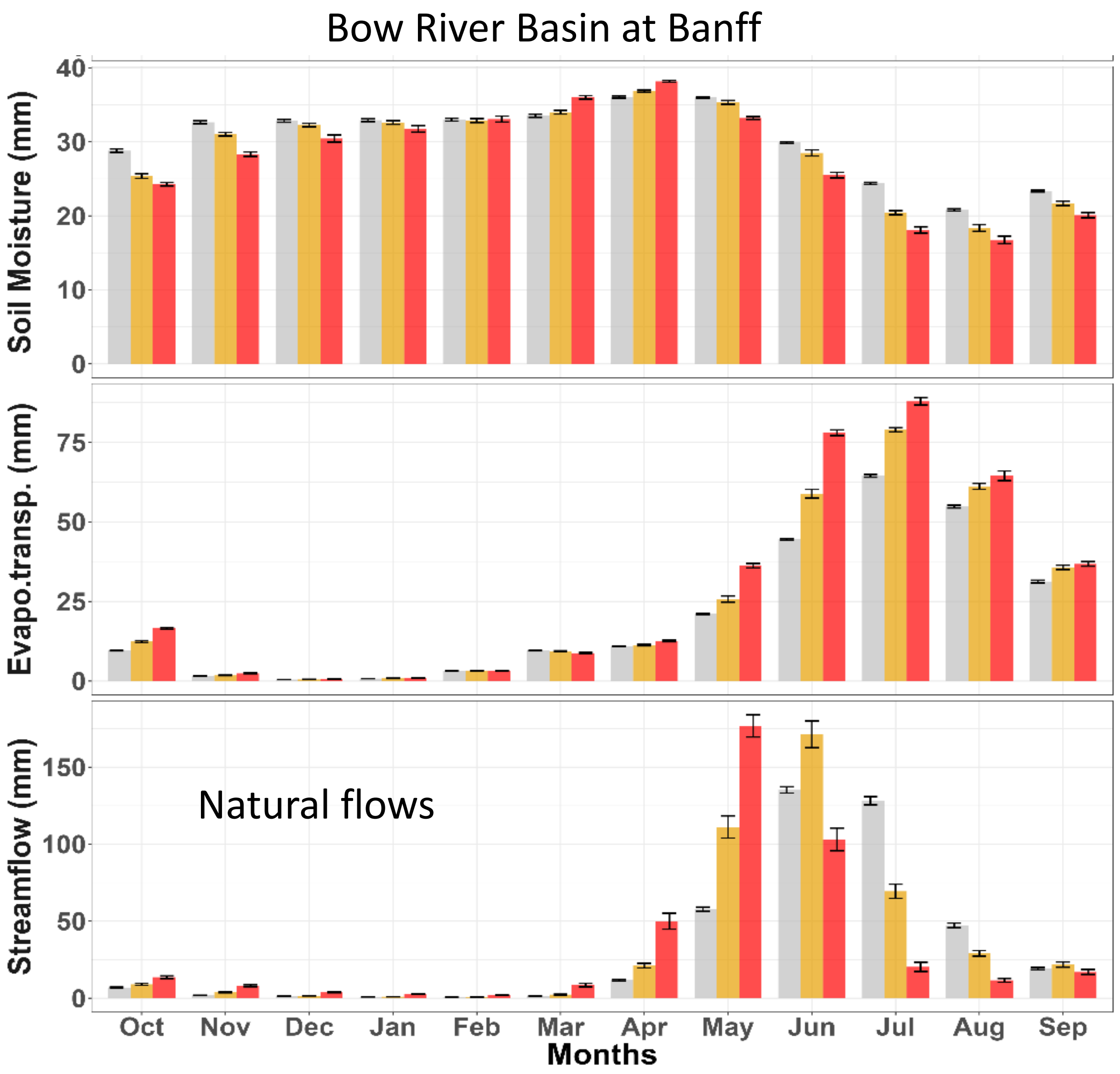
Climate Change in Bow River Basin

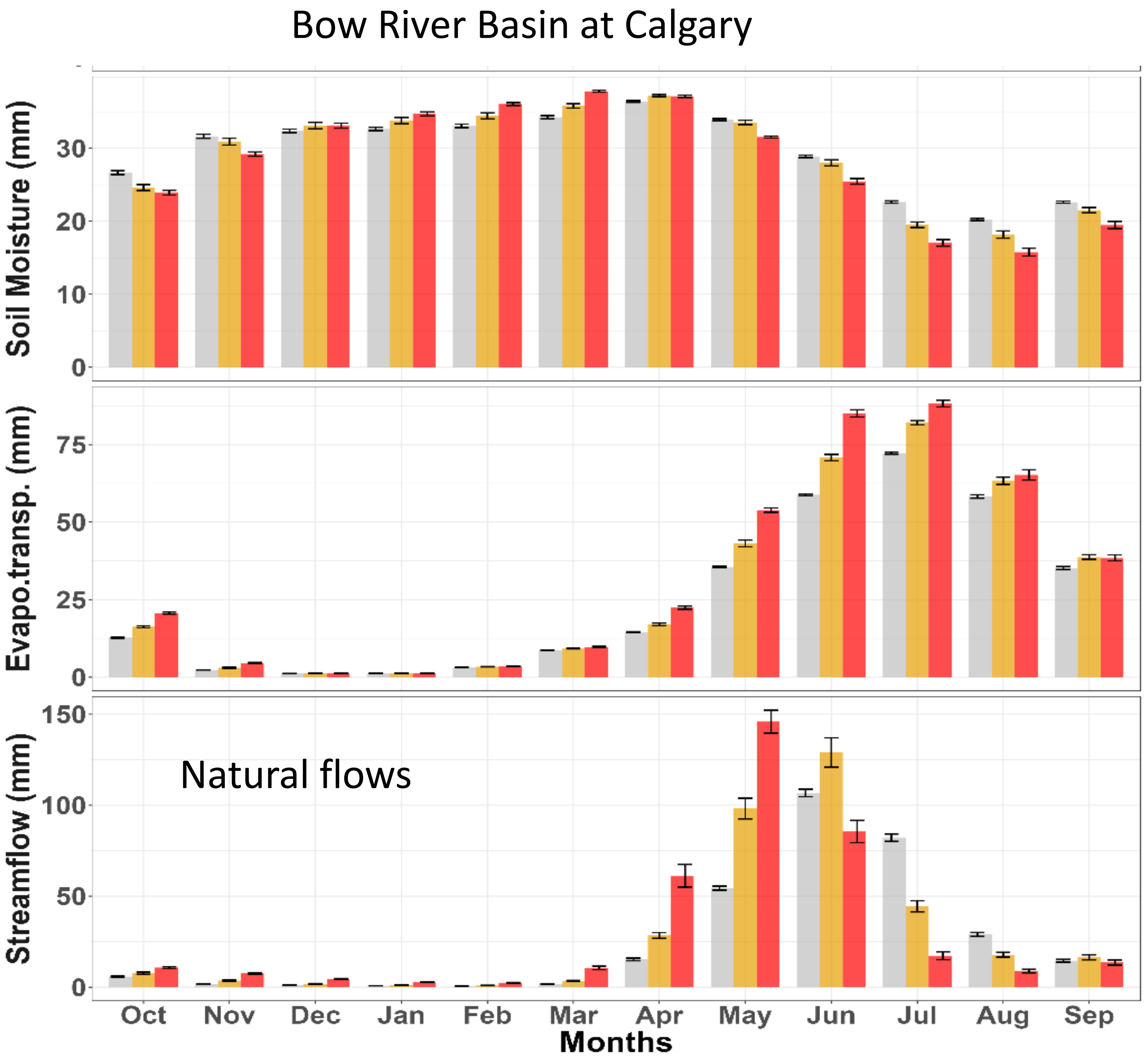




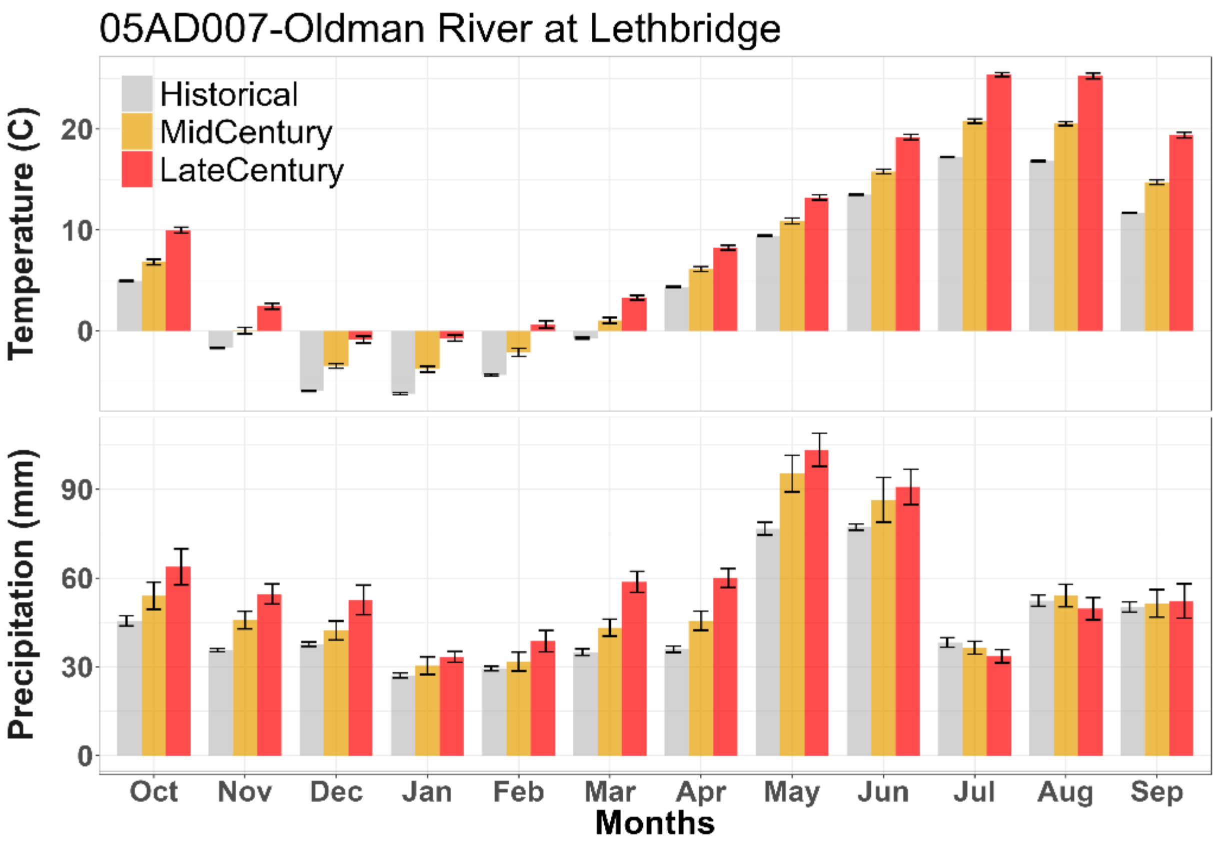
Historical is 1980-2010

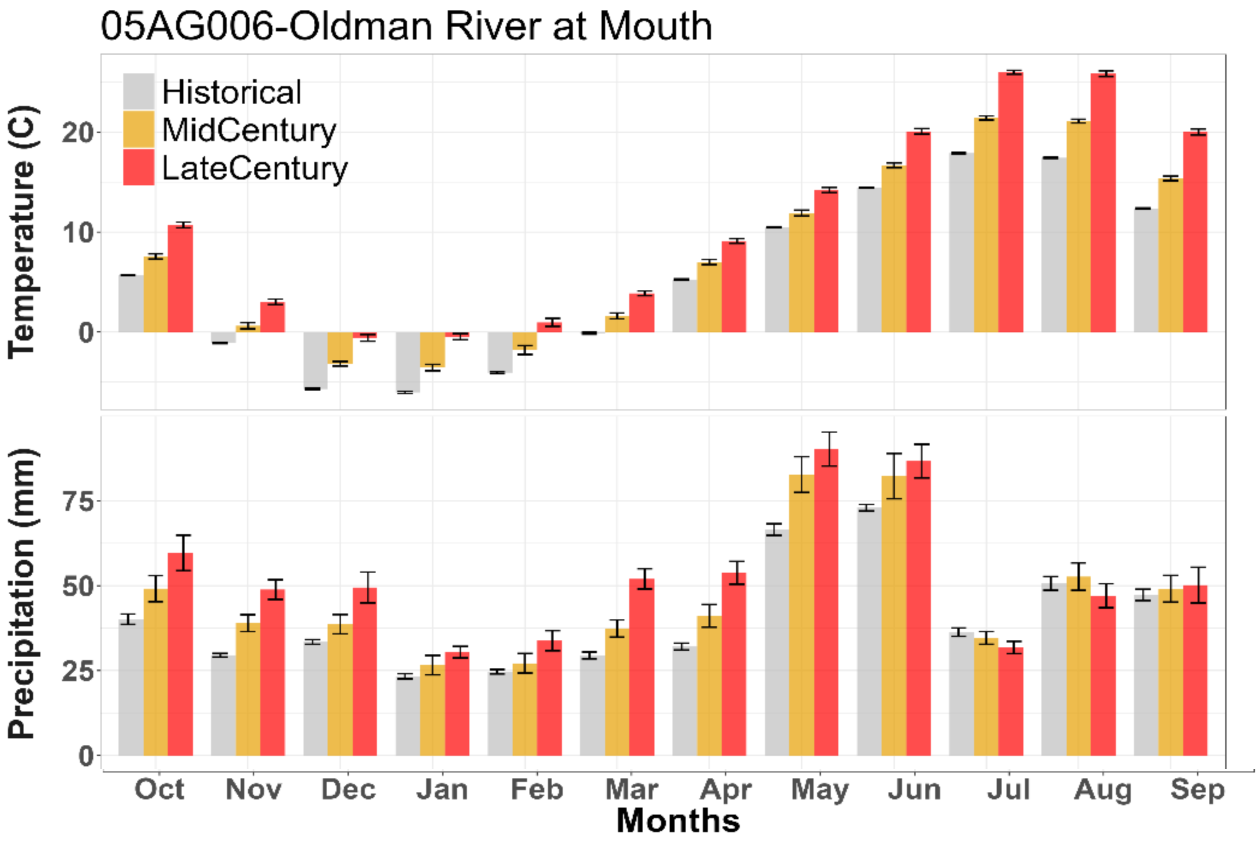
Hydrological Change in Bow River Basin





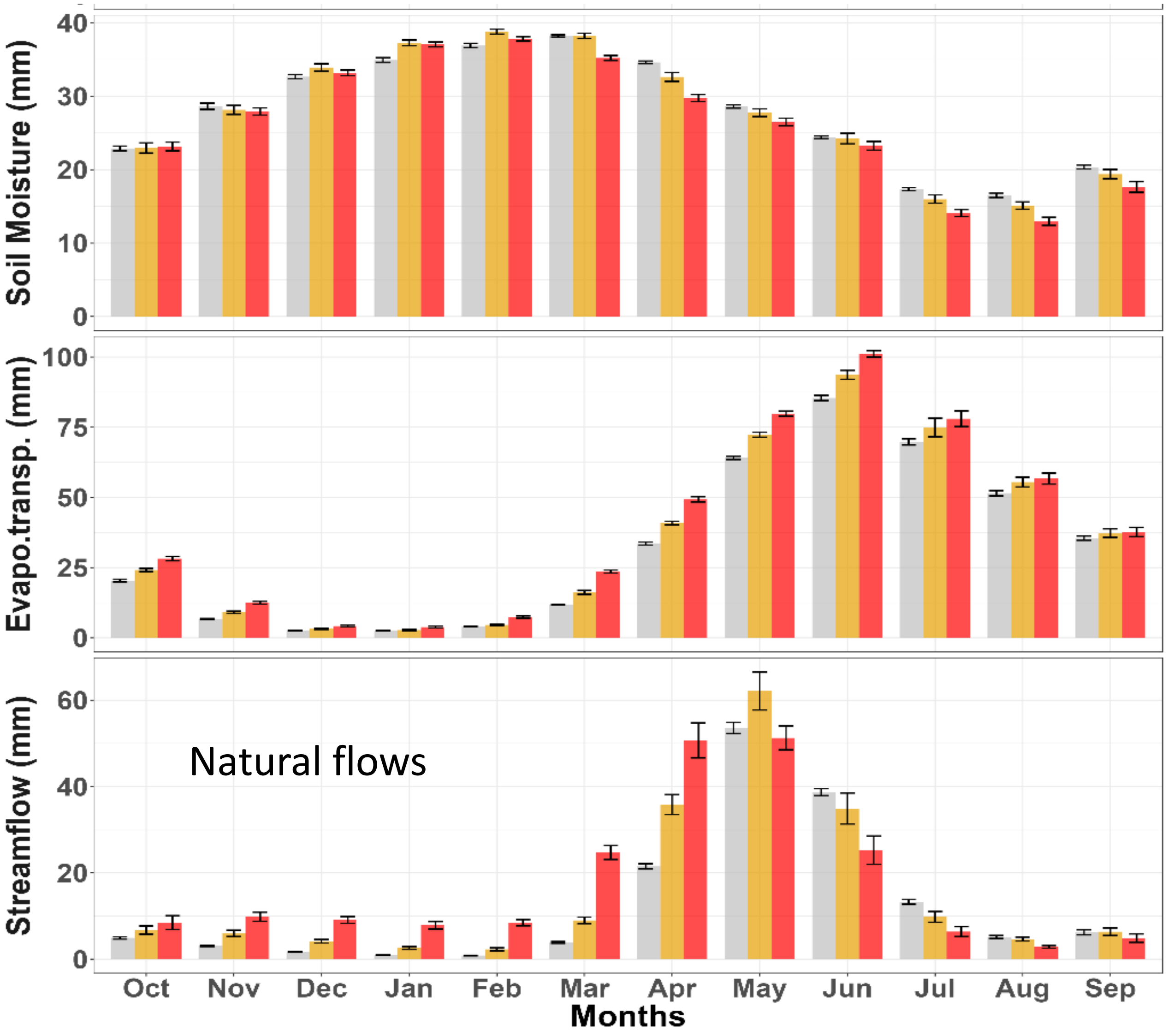
Climate Change in the Oldman River Basin



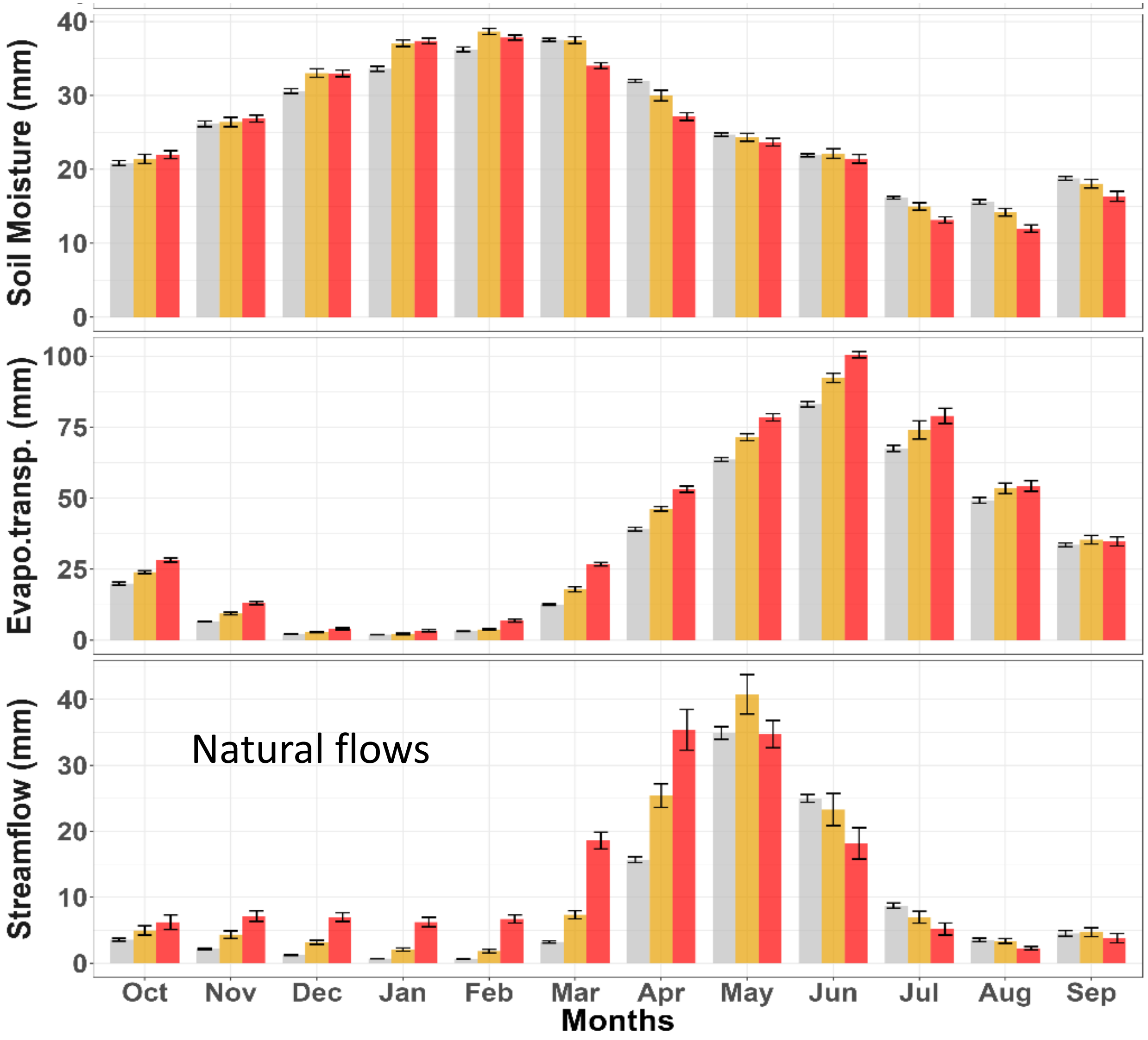


Hydrological Change in the Oldman River Basin

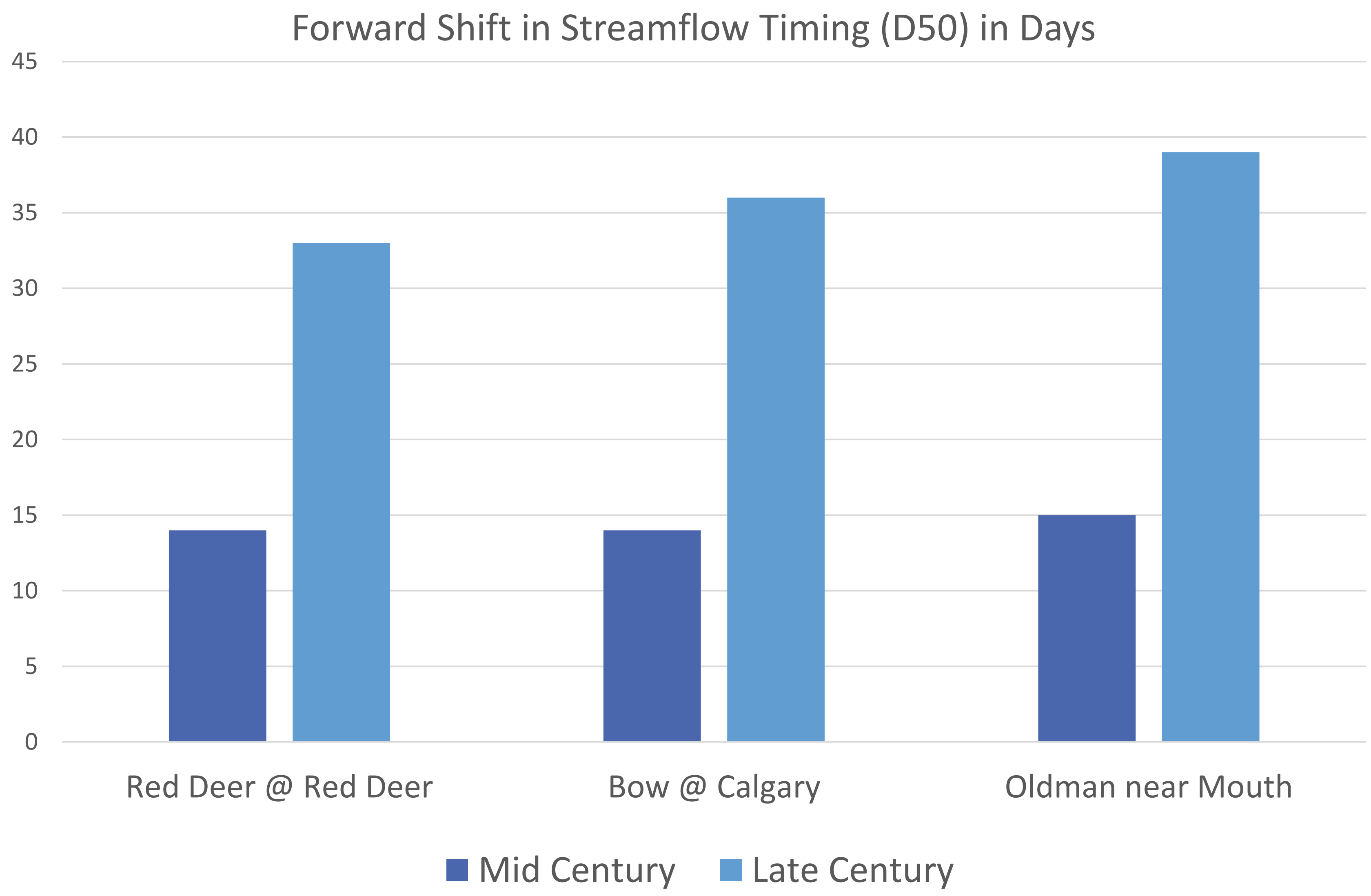
Oldman River @ Lethbridge



Oldman River @ The Mouth

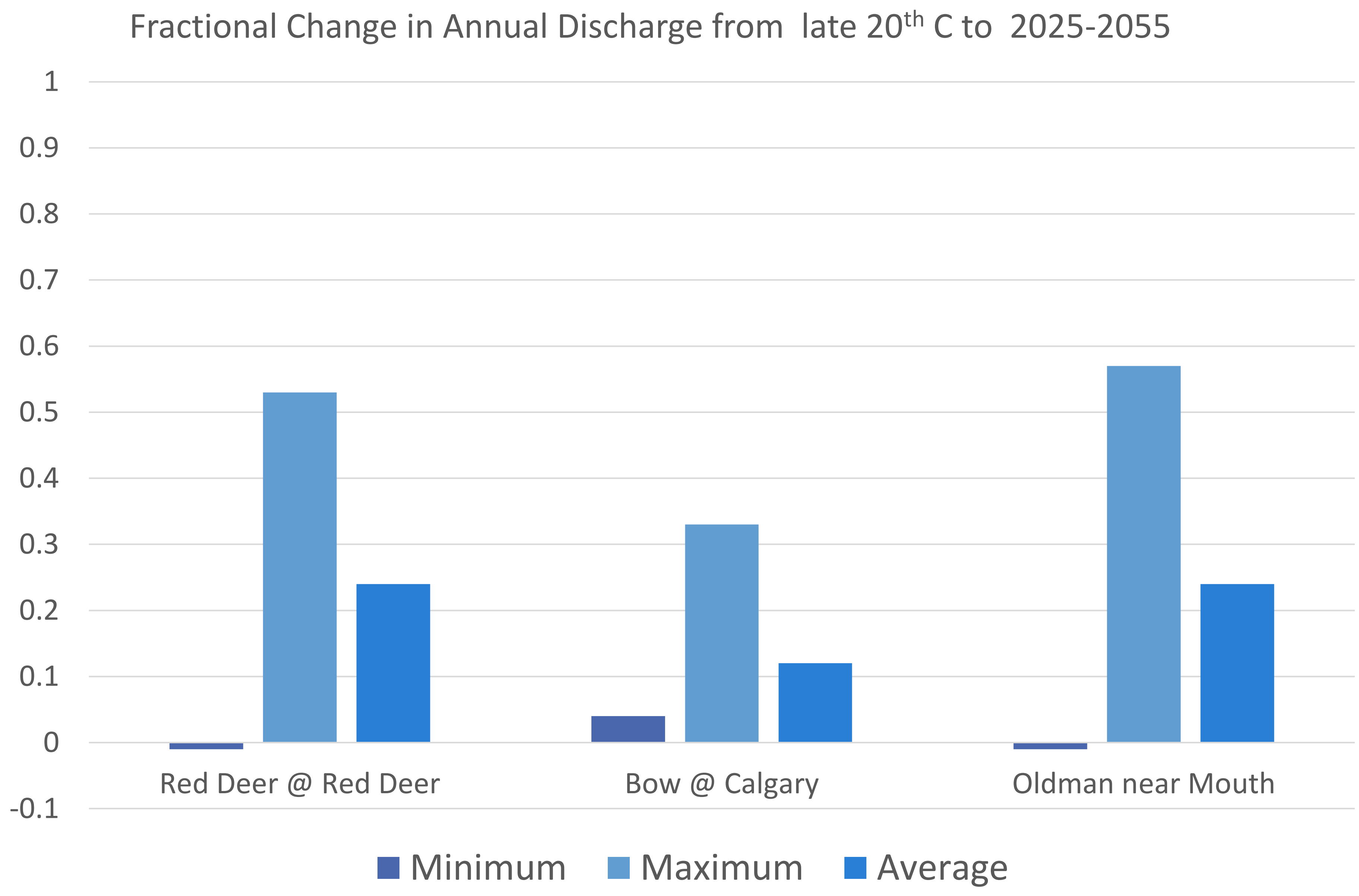


Changing in River Flow Timing

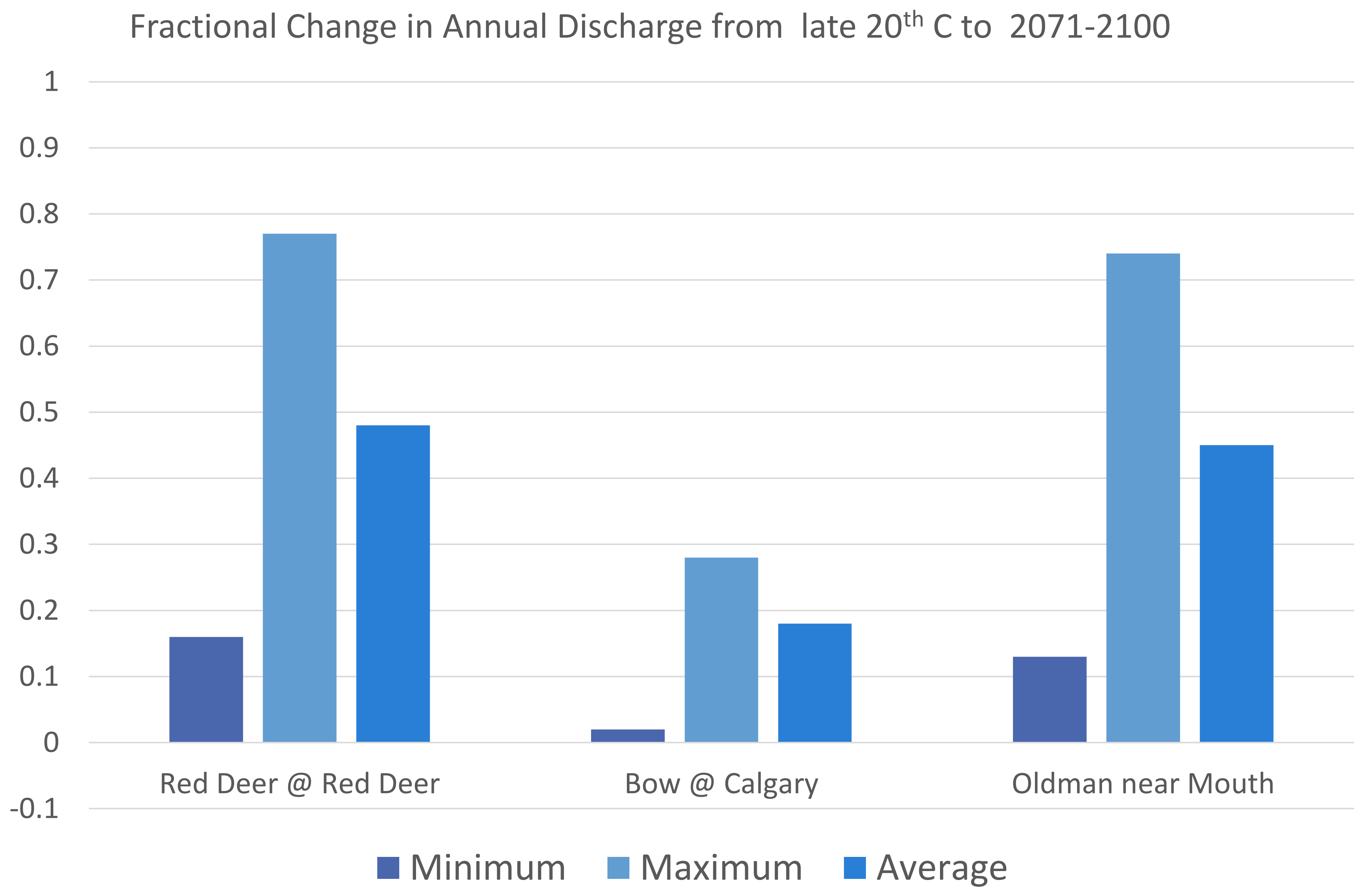


D50 is the Centre of Mass of Streamflow, the timing is the day of the year in which this occurs

Changes in Annual Water Supply by Early Mid Century



Changes in Annual Water Supply by Late Century

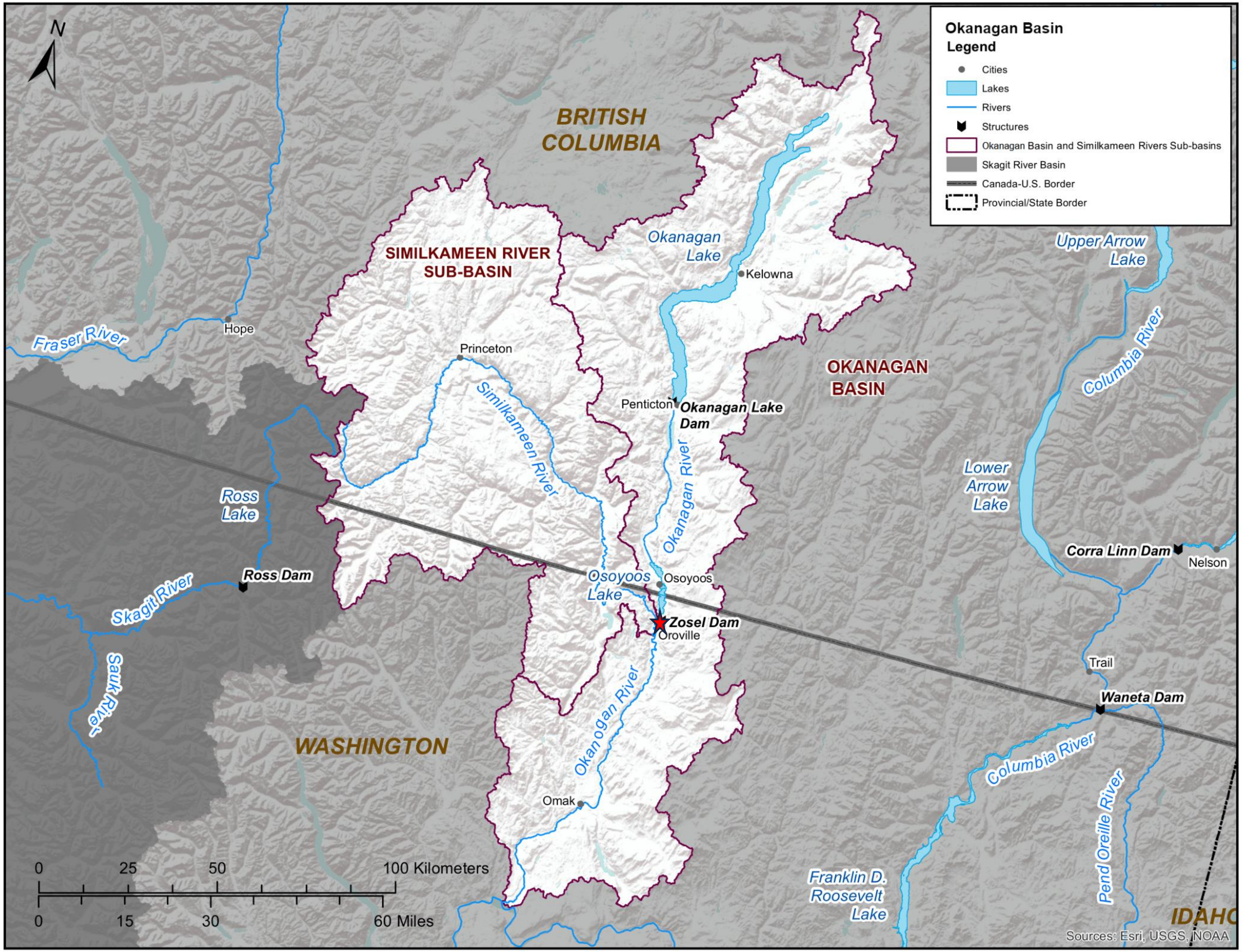


Okanagan Basin MESH Modelling

Natural flow calculations without reservoir storage, river diversion or extraction for irrigation

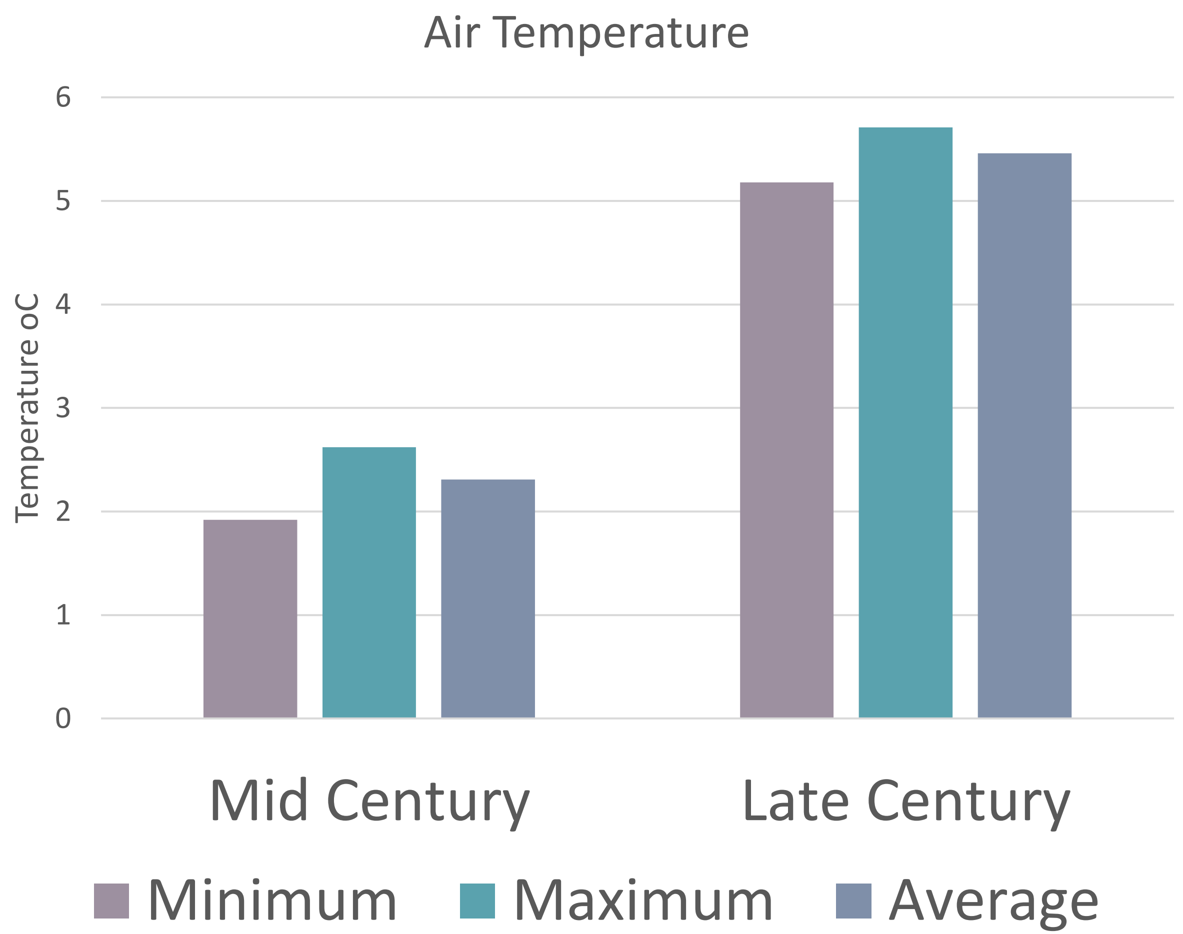
Mountain MESH – accounts for effects of slope, aspect, forests, elevation on solar and thermal radiation, wind, pressure and precipitation, including blowing snow and snow interception redistribution

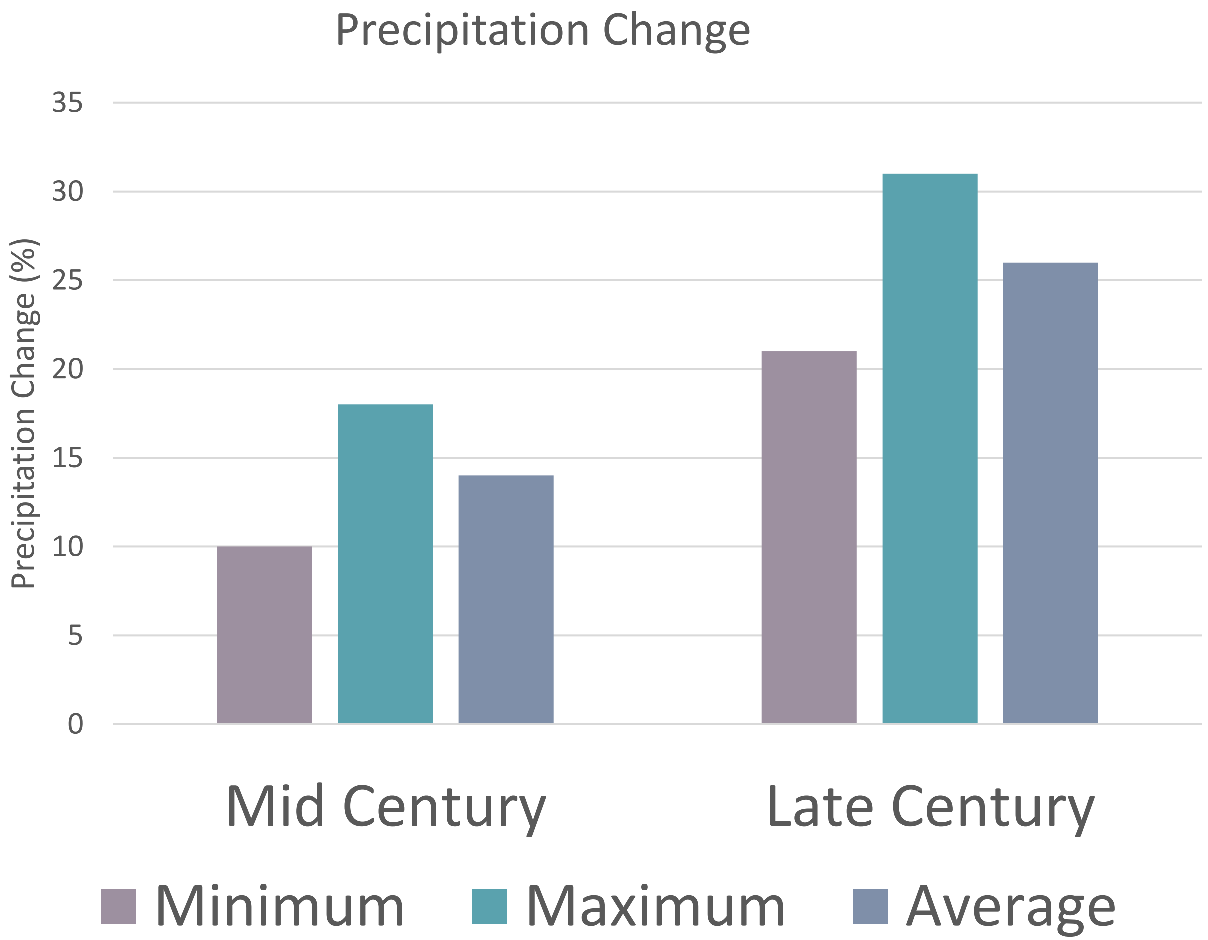
Zelalem Tessema



Climate Change – Okanagan Basin (to Oliver)

RCP 8.5

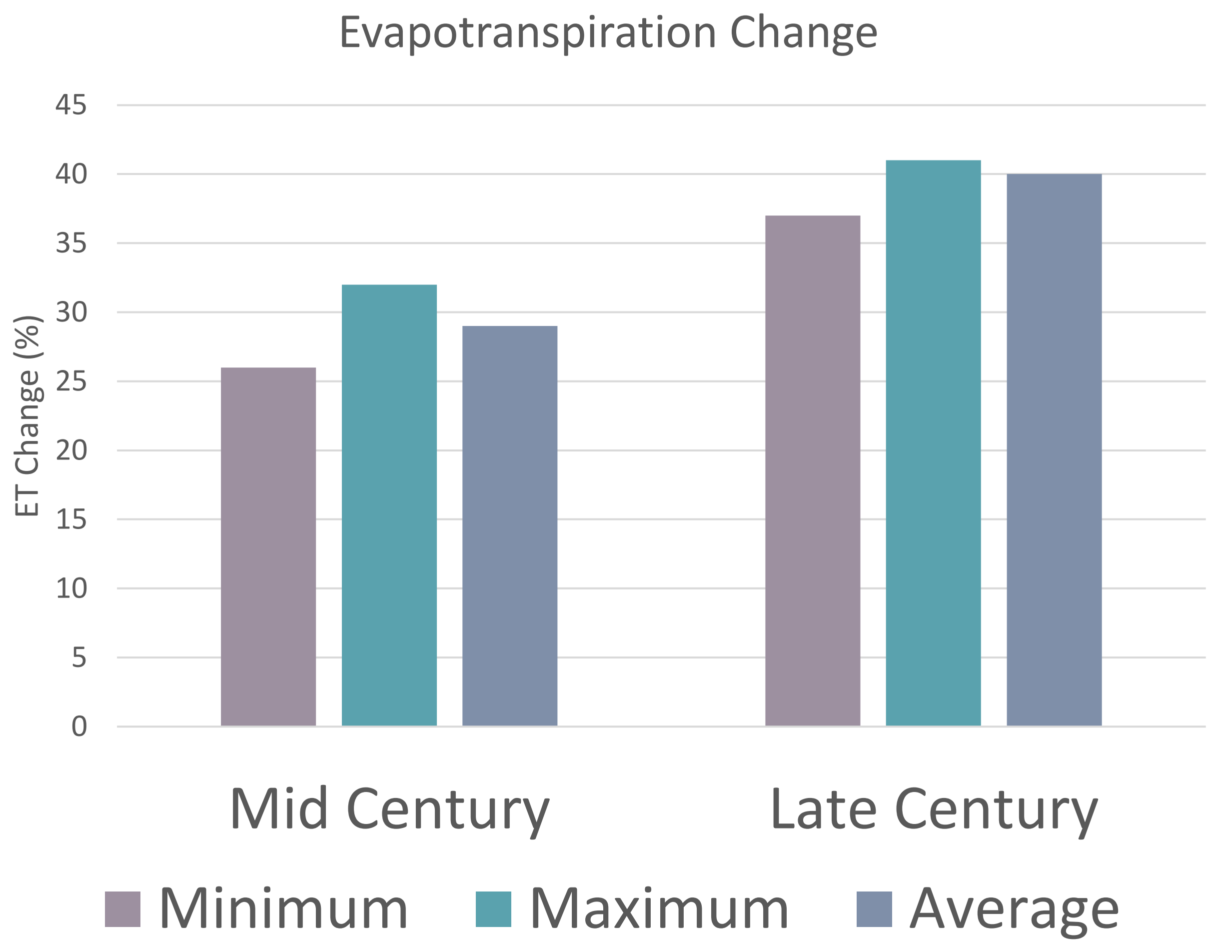


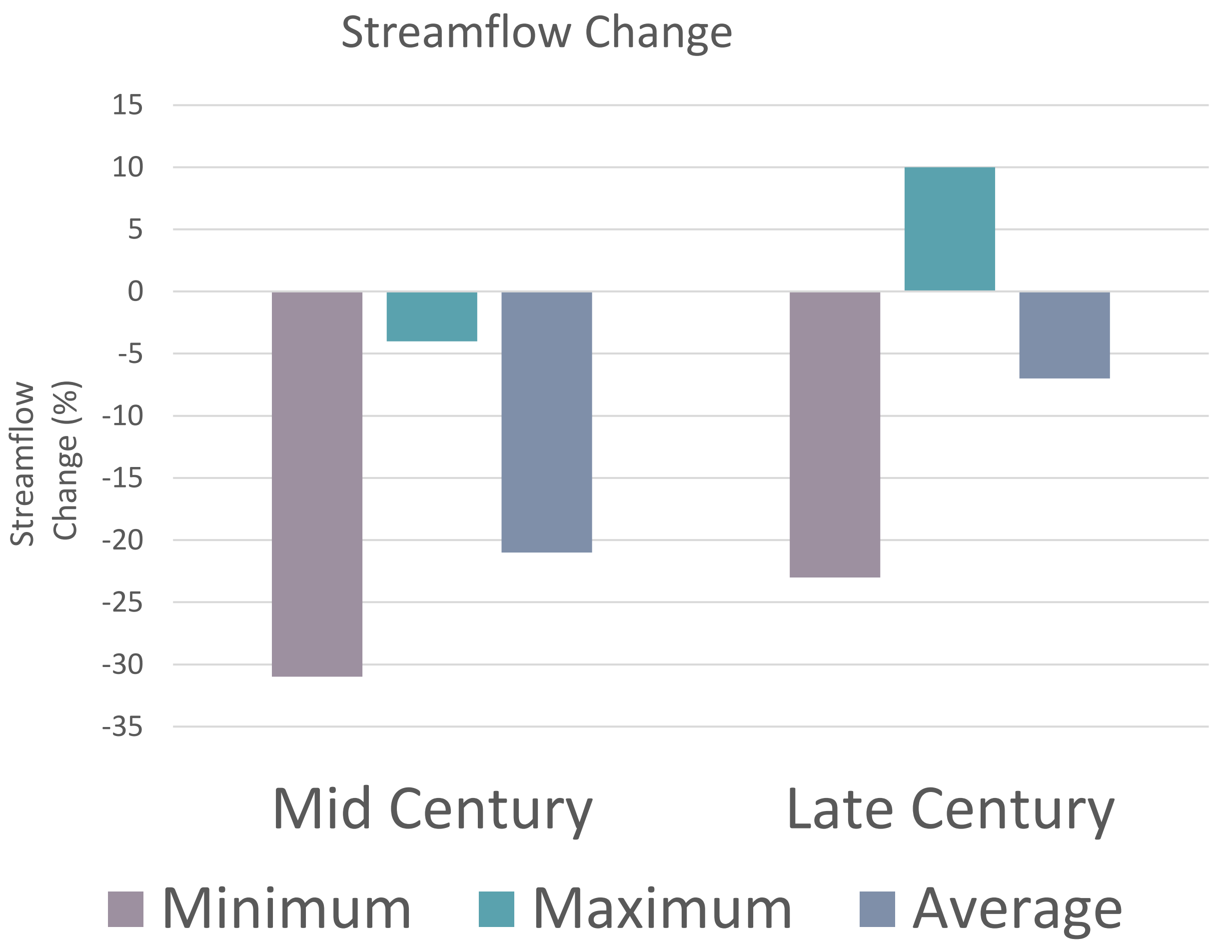


Current: 1980-2010 Early Mid-century: 2025-2055 Late-century: 2070-2100

Hydrological Response to Climate Change – Okanagan Basin (to Oliver)

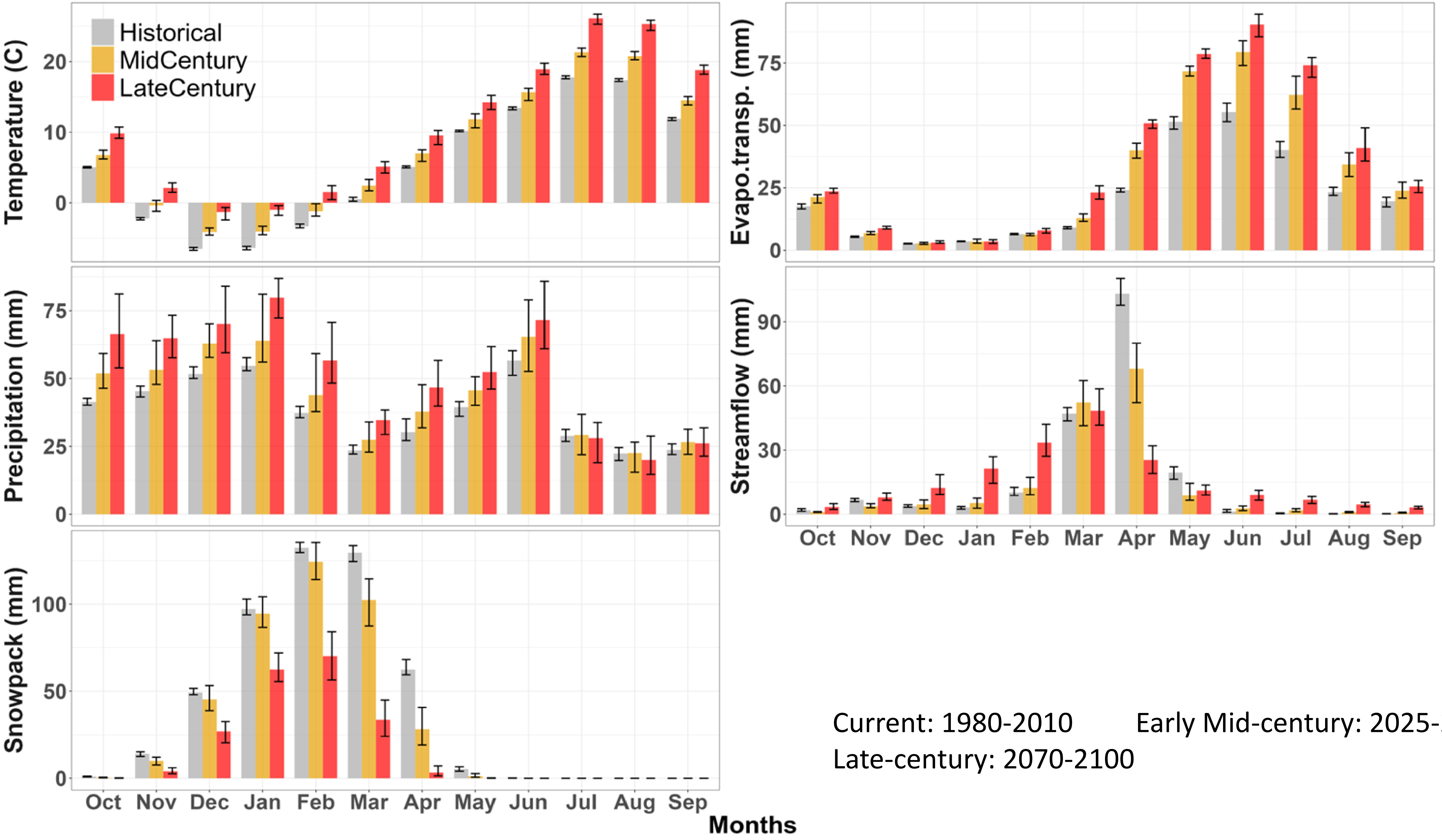
RCP 8.5





Current: 1980-2010 Early Mid-century: 2025-2055 Late-century: 2070-2100

08NM085-OKANAGAN RIVER NEAR OLIVER

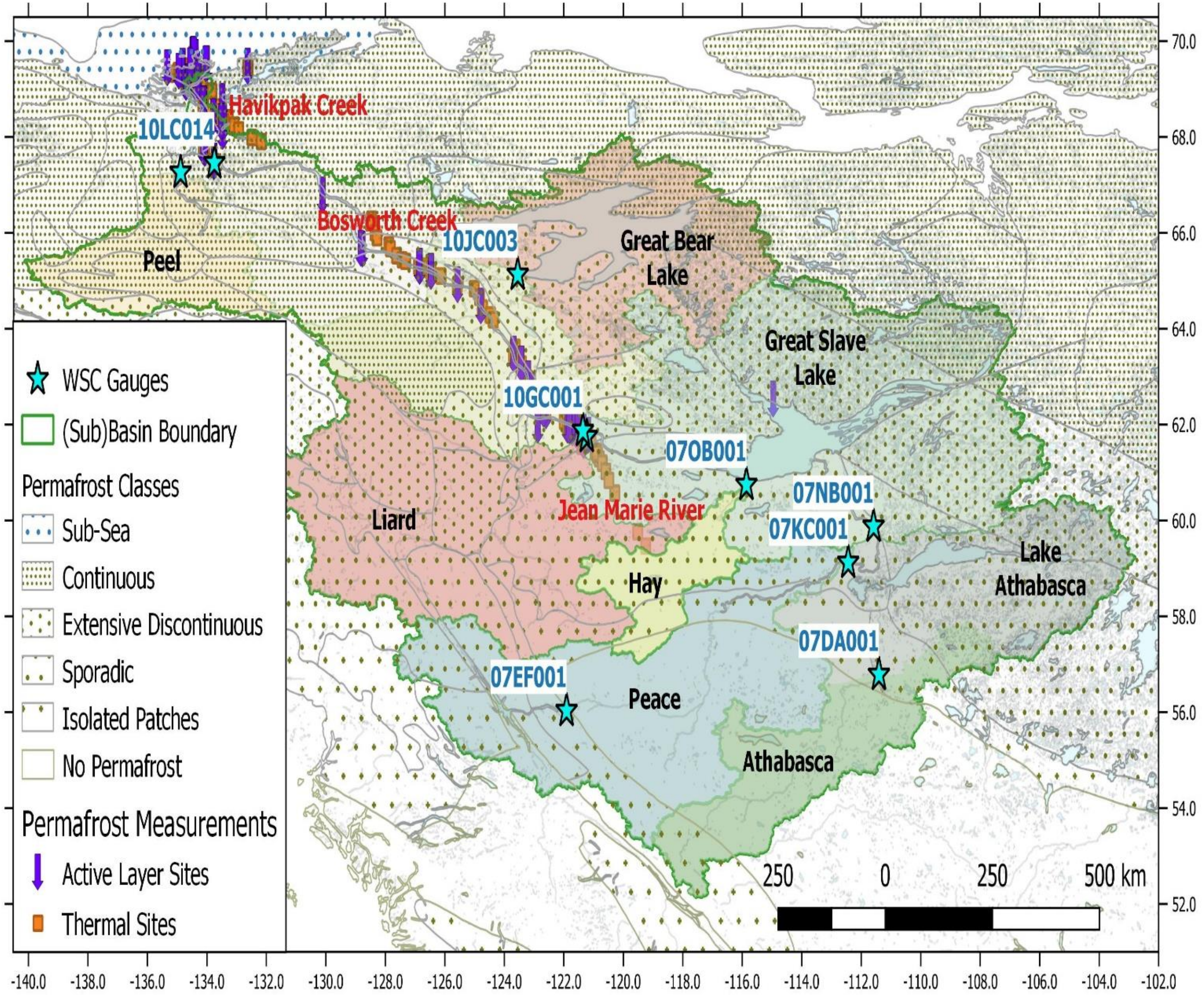


Current: 1980-2010 Early Mid-century: 2025-2055

Late-century: 2070-2100

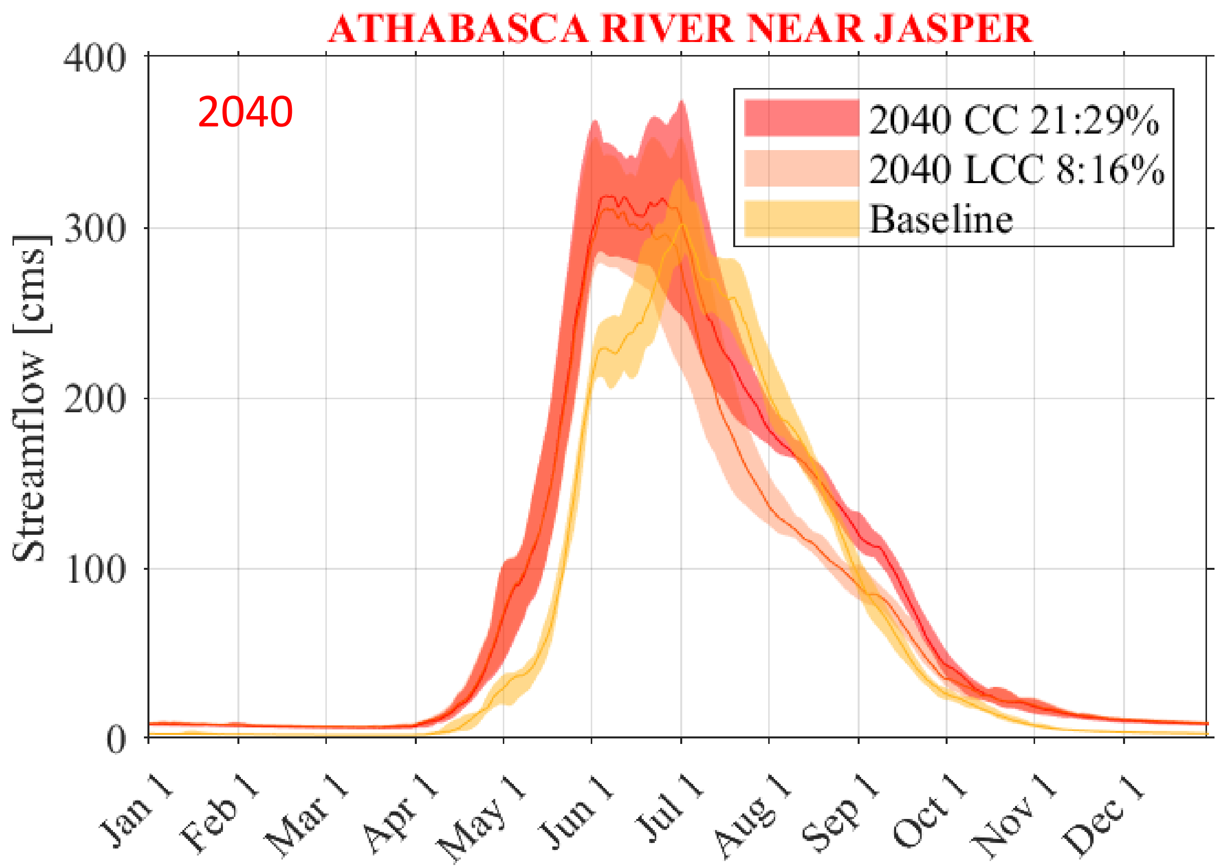
Mackenzie River Basin (MRB)

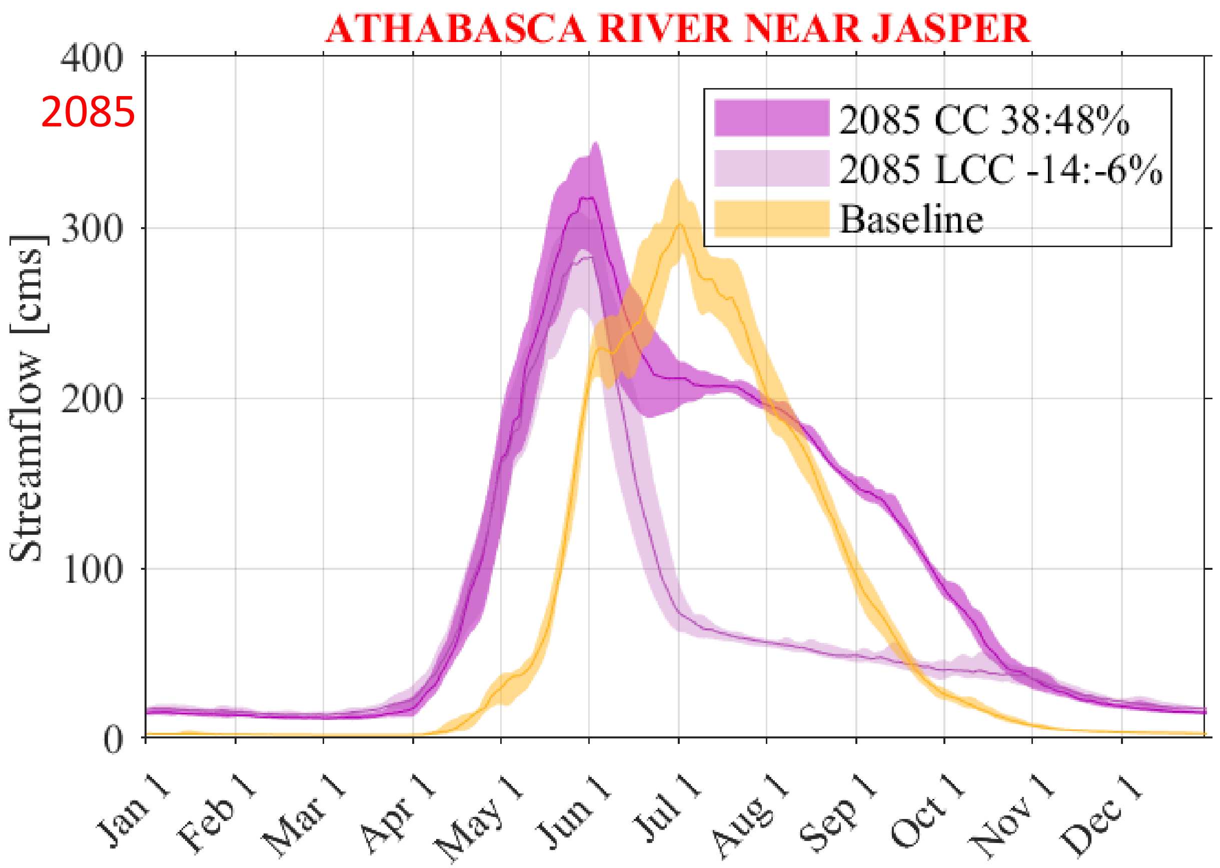
UNIVERSITY OF SASKATCHEWAN
Global Water Futures
GWF.USASK.CA



Mohamed Elshamy

Future Athabasca River Streamflow Regimes – CanRCM-MESH





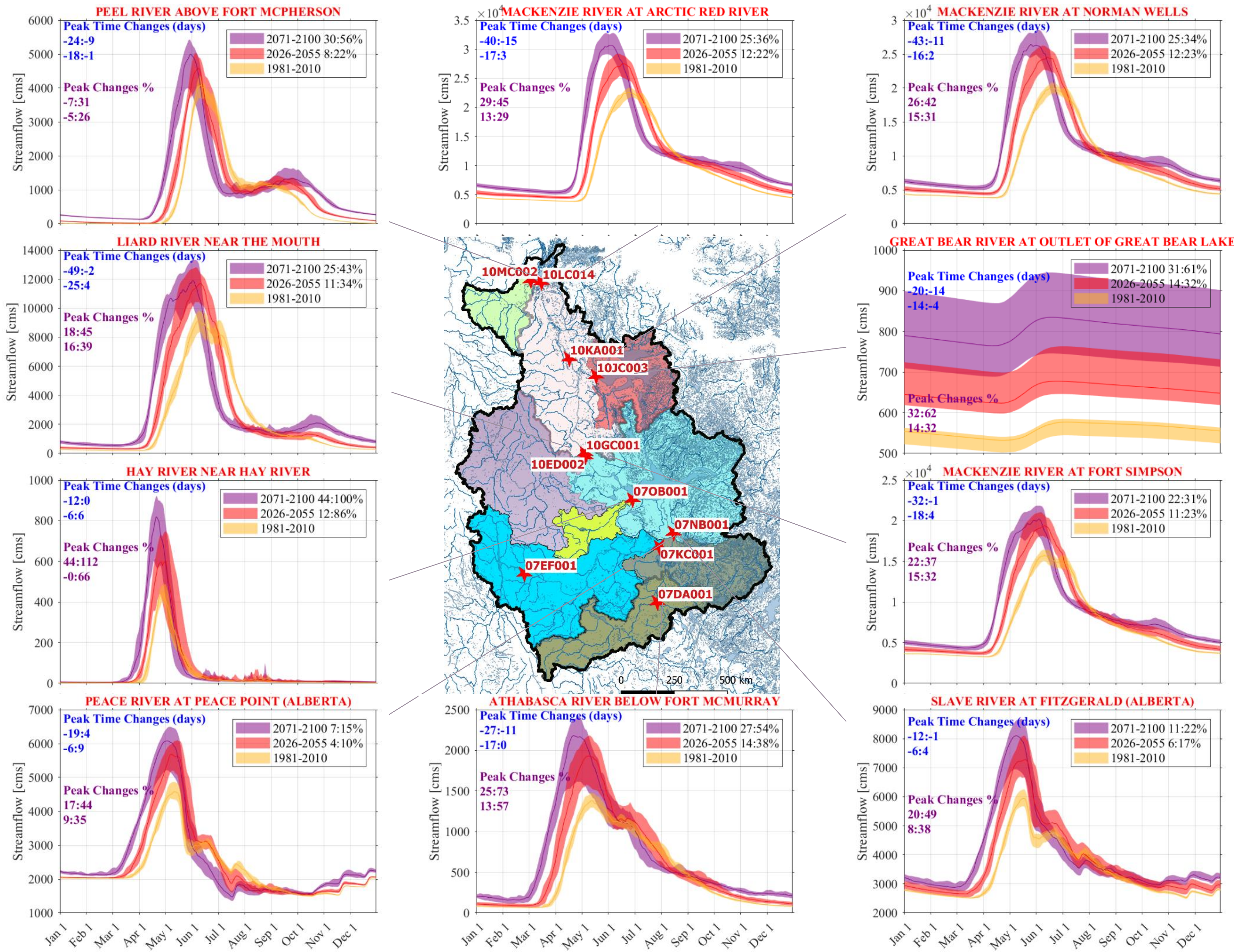
CC – climate change impacts alone with glaciers and land cover held constant (RCP 8.5)

LCC – glacier retreat, land cover change and climate change impacts combined (RCP 8.5)

These are 30-year means from 15 ensemble members. The shading shows the spread across the ensemble
The legend shows the changes in total mean volume compared to the baseline (1981-2010);
range (min:max) shown across the ensemble (inter-annual variability not shown)

Elshamy et al., in preparation

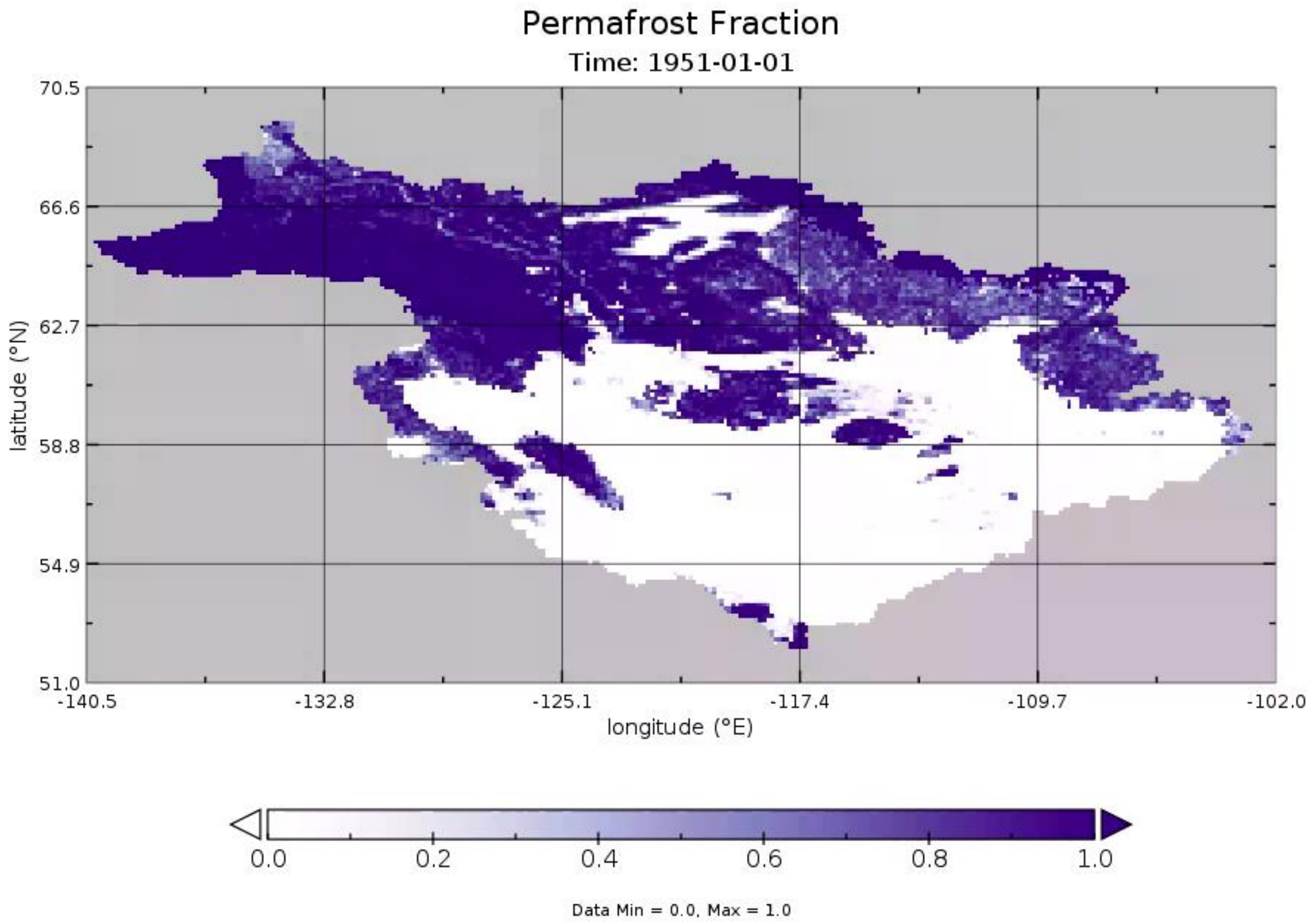
Future Projections - Streamflow

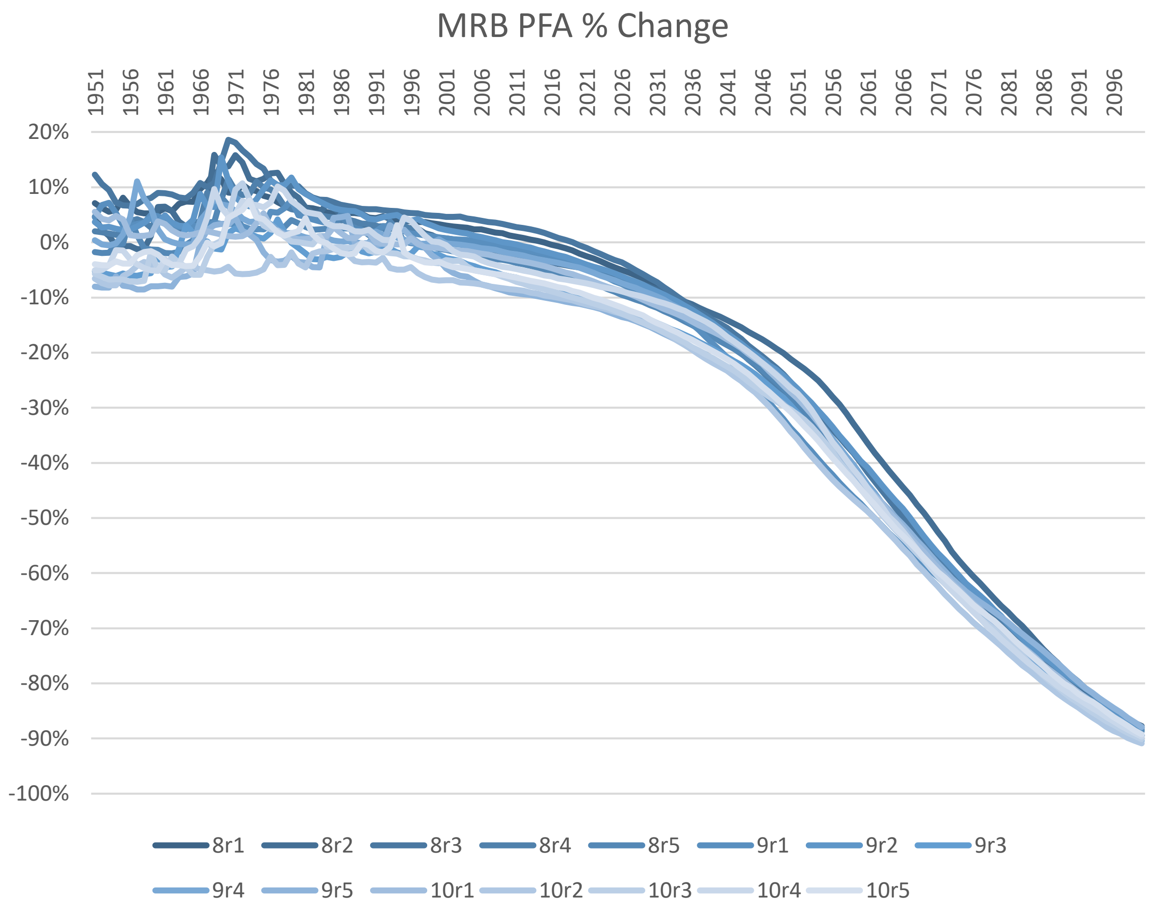


Land cover, glacier, and permafrost change included

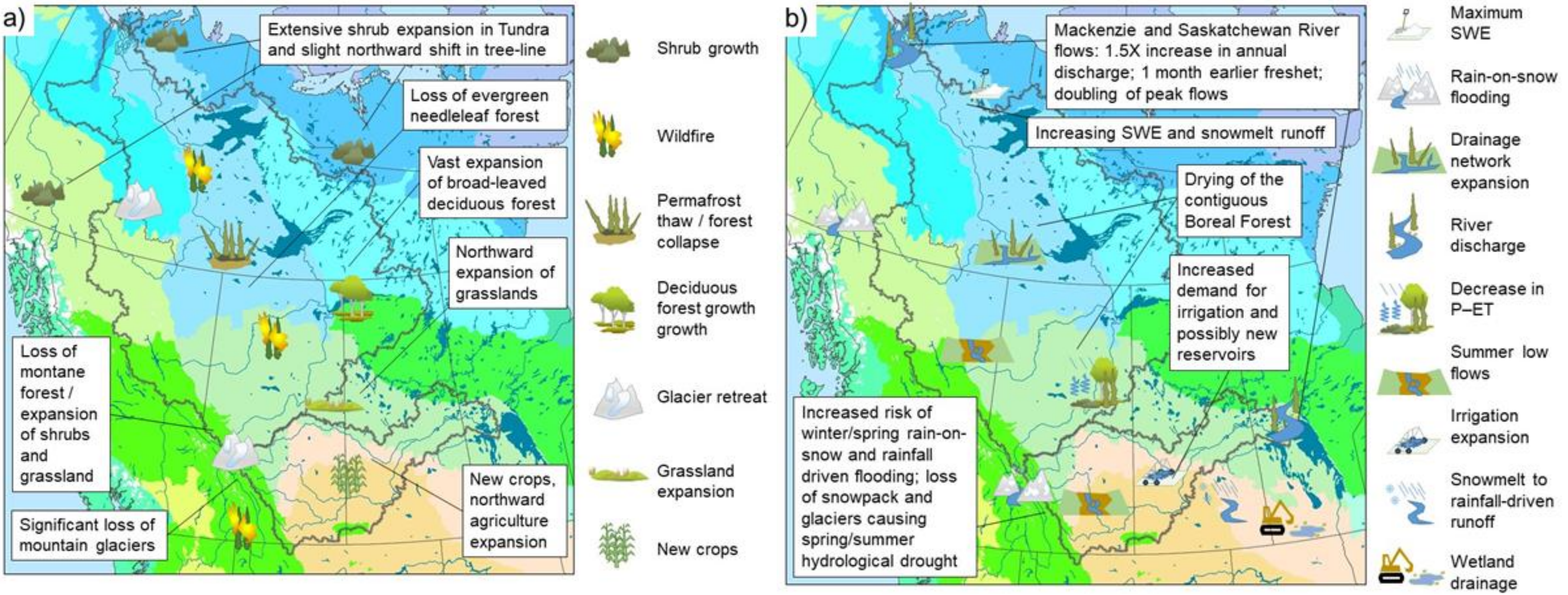
Changes are given as min:max range across the ensemble members, relative to the 1981-2010 period for each future period

Future Permafrost – Mackenzie River Basin





Western Canada's Water Future – late 21st C



DeBeer, Wheater, Pomeroy, et al., 2021

Major Findings

- Drought of 2023 had similar temperatures and lower precipitation to the worst-case climate change scenarios for 75 years in the future.
- Acceleration in timing and reduction in volume of snowmelt runoff from the Canadian Rockies in 2023 was similar to expected future climates.
- Glacier retreat and melt is accelerating – glacier contributions to water in the irrigated districts of Alberta are declining and will be negligible in a few decades, glacier contributions to streamflow are still increasing in BC and northern Alberta
- Detailed hydrological-water resources model coupled to bias corrected and downscaled climate model provides possible future impacts of climate change on water supplies – rising temperatures and rising winter/spring rainfall but declining summer rainfall.
- Okanagan air temperatures will rise by **2 ºC in early mid-century** and **5 ºC by late-century**. Precipitation will increase about **10%** by early mid-century and by **25%** by late-century, with a large shift to rainfall at all elevations and seasons. Peak snowpacks will decline by **50%** by late-century and peak snowmelt freshet will occur **one month earlier**.
- Okanagan streamflow will decline by about **20%** in early mid-century and **7%** in late century with April streamflow dropping by **75%** by late-century – this is due to large declines in mountain snowpacks and large increases in spring and early summer evapotranspiration. Late summer evapotranspiration will not increase as much as plants will not have sufficient soil moisture to support increased transpiration and growth.
- Shift of the Okanagan Basin to a more Mediterranean climate will come with climate extremes of temperature, rainfall, and drought that will challenge current water resources management, municipal and agricultural practices and require substantial adaptation based on improved predictions and forecasting and adaptive management of water use and crops.
- Timing of Saskatchewan River Basin headwater river discharges will be accelerated by **15 days mid-century** and by **one month late century**
- Annual discharges of Saskatchewan River Basin headwater rivers might **decrease slightly or increase by up to half** of current flows by **mid-century**
- Annual discharges of Saskatchewan River Basin headwater rivers might **not change or increase by up to ¾** of current flows by **late century**
- **Drop in June-July-August Saskatchewan River Basin headwater river flows** in most scenarios, sometimes to 50% of current flows.
- For the Mackenzie River Basin - Large increases in baseflow, peak daily streamflow higher (30-50% by 2100) and earlier (2-6 weeks by 2100) at most sub-basin outlets → This leads to higher annual streamflow volumes (20-35% by 2100) depending on the basin. Lower flows in upper Athabasca River in Jasper Park.
- Mackenzie River Basin permafrost degrades quickly – only 10% of the basin remains underlain by permafrost by 2100

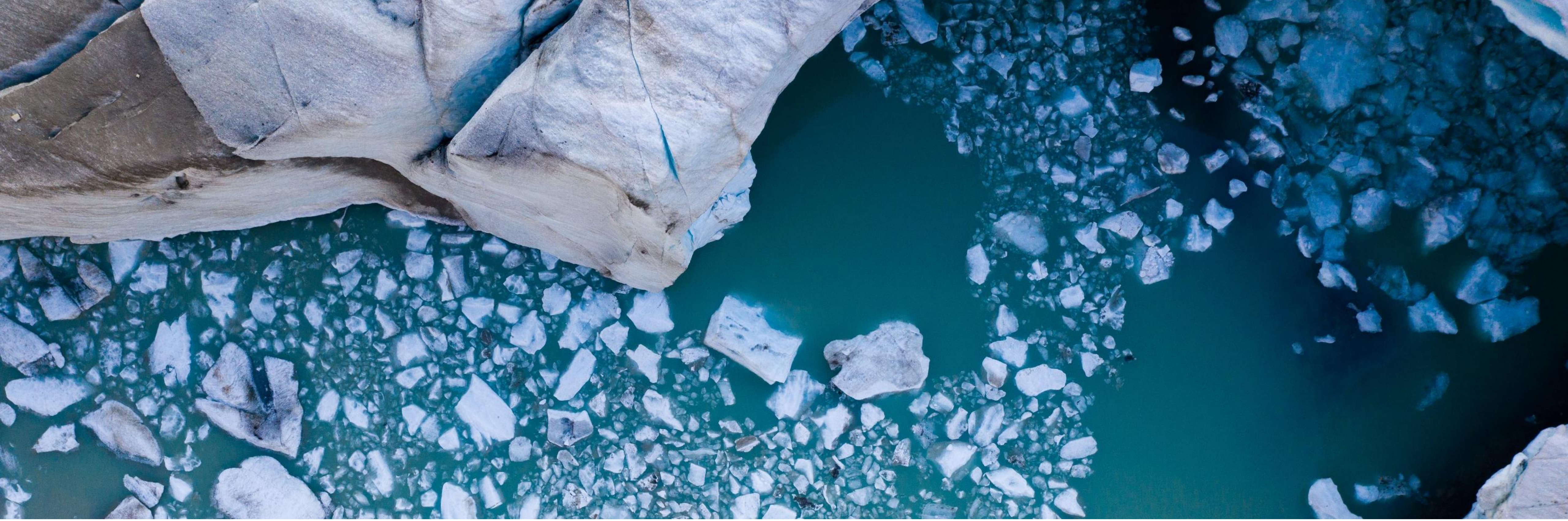
Conclusions

- 5 ^{o}C or more of warming is possible by the end of the century with increased rainfall likely, except in summer which may be drier. Warming and rainfall may increase more in the North.
- Okanagan Basin flows will decline by mid-century and increase by late century as the basin snowmelt declines and rainfalls increase. Increased temperature will drive greater evaporation in early summer, exhausting soil moisture reserves.
- The Saskatchewan River Basin water supply is sourced primarily from the Canadian Rockies snowmelt and annual flow volumes may increase by 15-30% this century as rainfall increases along with temperature.
- Saskatchewan River Basin streamflows will rise months earlier, with larger winter/spring peaks and lower summer flows as the climate changes. Reliability may decrease in summertime as flows become more rainfall dependent.
- The Mackenzie River Basin streamflows will rise earlier in the spring and increase substantially with climate change by the end of the century. 90% of MRB permafrost is expected to thaw by the end of the century with potential for substantial forest and road/community infrastructure disturbance. Wildfires will magnify these impacts
- We **cannot continue to manage freshwater as we have in the past**

Solutions

- Water Monitoring and Prediction
  - Enhance provincial/territorial, federal, university (Global Water Futures Observatories) and related community weather and water observations
  - Development of cutting-edge, open-source hydrological forecasting and prediction of snow, glaciers, reservoirs, groundwater soil moisture, irrigation withdrawals, urban water use, river flows and associated wildfire risk, drought, crop yields, irrigation scheduling, water quality and water apportionment
- Community-based to provincial to national river basin adaptation
  - Solutions developed with communities/districts/basins and implemented by communities/districts/basins for greater resiliency to water-based impacts of climate change and development on source waters, water for food, water for energy and key ecosystem waters
    - Change in timing of flows
    - Higher overall flows
    - Lower summer flows
    - Greater flow variability
  - Safer, more reliable, more resilient and more efficient infrastructure for water storage, irrigation, industrial use, community use and for flood protection
  - Integrated river basin management to address competing needs for water allocations from agriculture, industry, ecosystems, and urban, rural and Indigenous communities. Everyone must be at this table.

www.usask.ca/hydrology



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