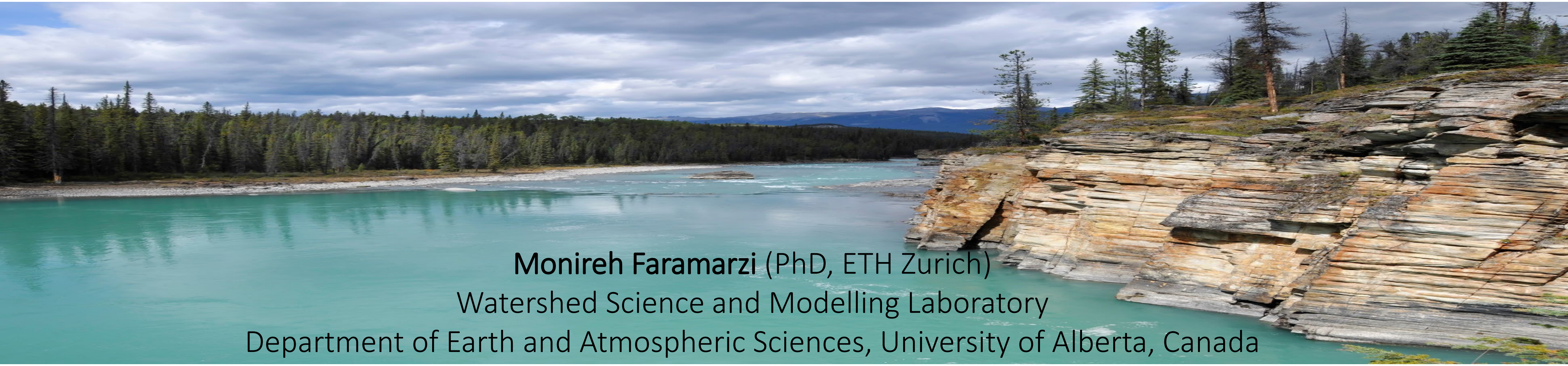
Response of geographically isolated wetlands to climate change and their effects on nutrient cycling in agricultural watersheds of Canadian Prairies

Quan Cui, Mohammed Ammar, Saeid Vaghefi, Timm Doebert, Pouya Khalili, Badrul Masud, Xinzhong Du, Danielle Loiselle



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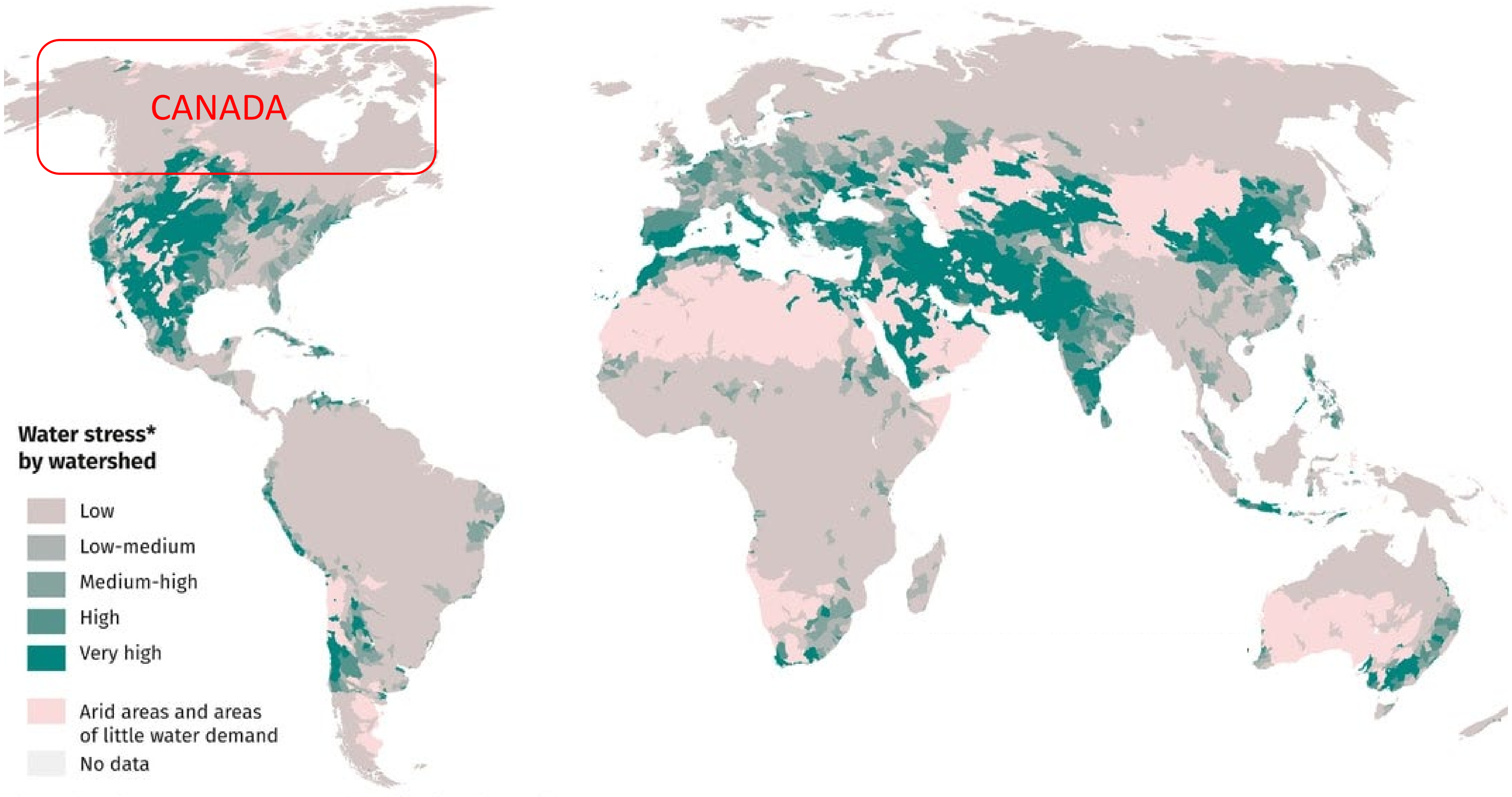
UNIVERSITY OF ALBERTA

2023 SWAT Conference, Aarhus University, Demark, 26-30 June 2023

Soil & Water Assessment Tool SWAT

Water Resources in Canada

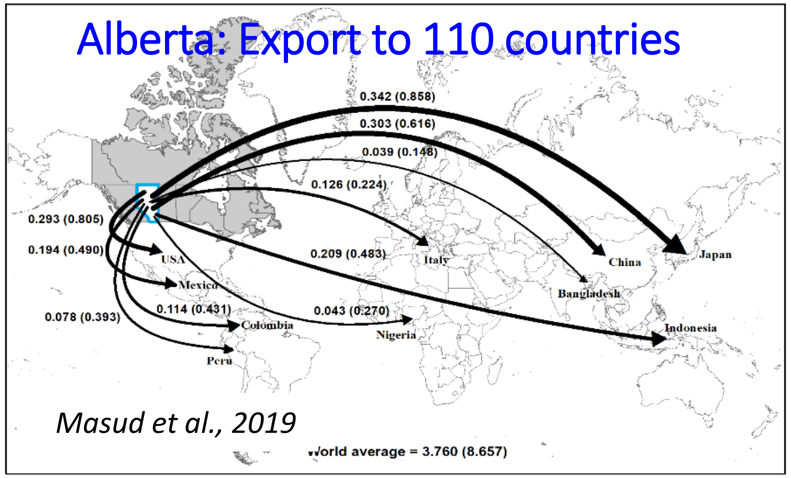
- 20% of world's freshwater supply
- 7% renewable; 13% fossil

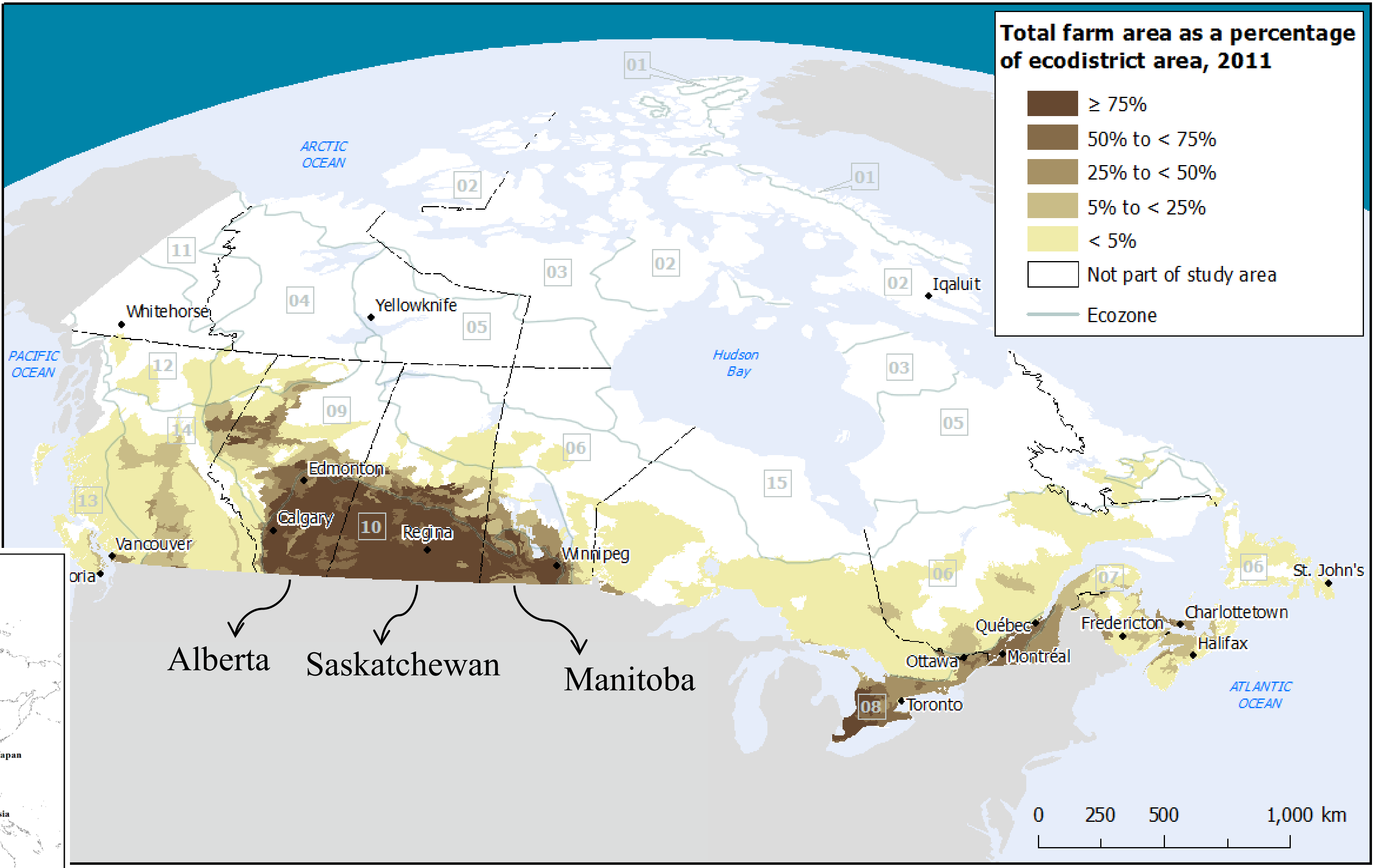


https://espace-mondial-atlas.sciencespo.fr/en/topic-resources/map-5C33-EN-projected-water-stress-in-2040.html

Agricultural Production and Export in Canada

- ~ 70 million ha; 7.3% total land area in Canada) *(Statistics Canada, 2016)*
- $ 44.1 billion to national GDP
- Export to over 170 countries
- Export of ~ 40 million tonnes of wheat and canola (~ 60 bcm VWT)

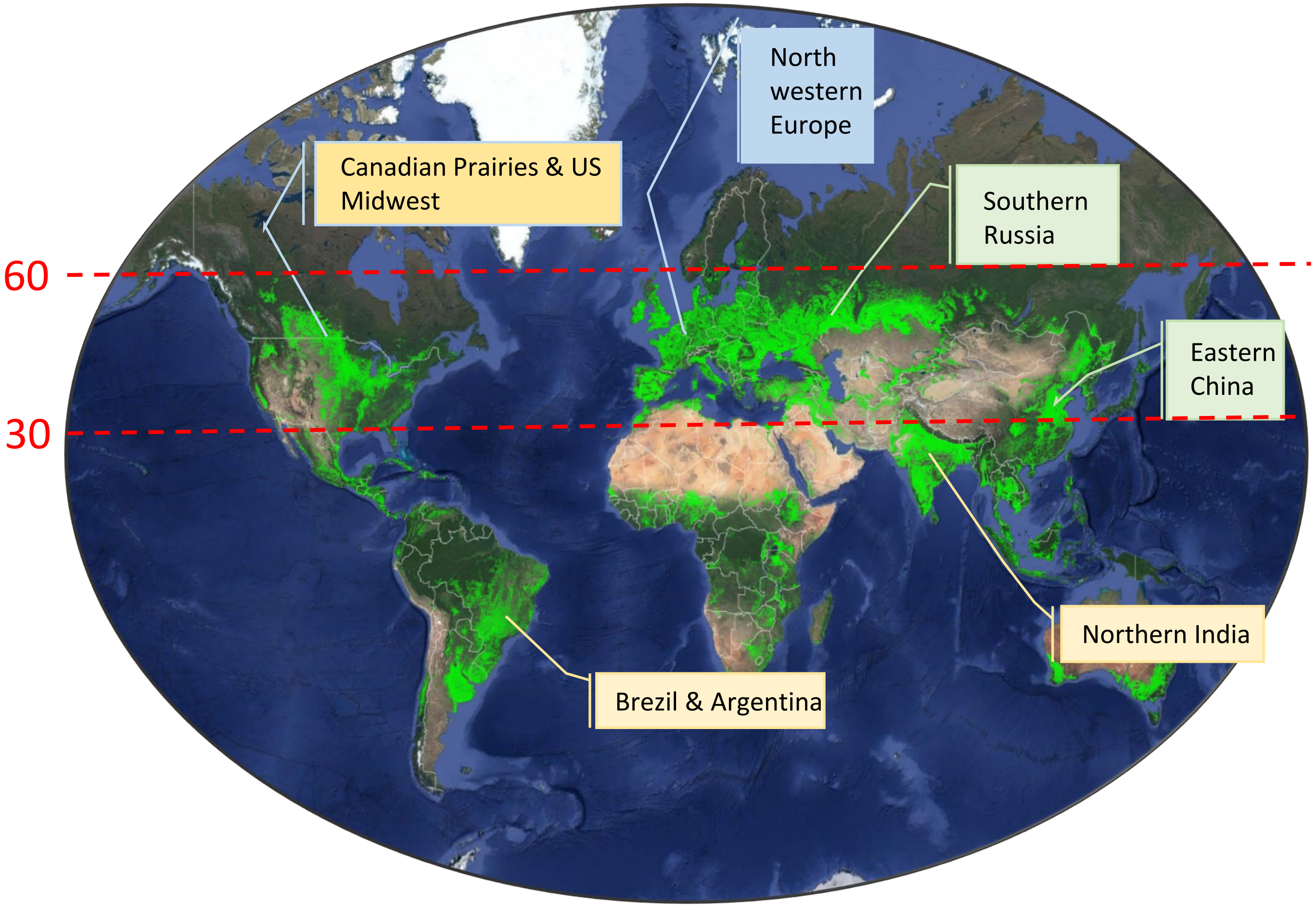




https://www150.statcan.gc.ca/n1/daily-quotidien/141113/dq141113a-eng.htm

Most global breadbaskets are in mid-to-high latitude regions

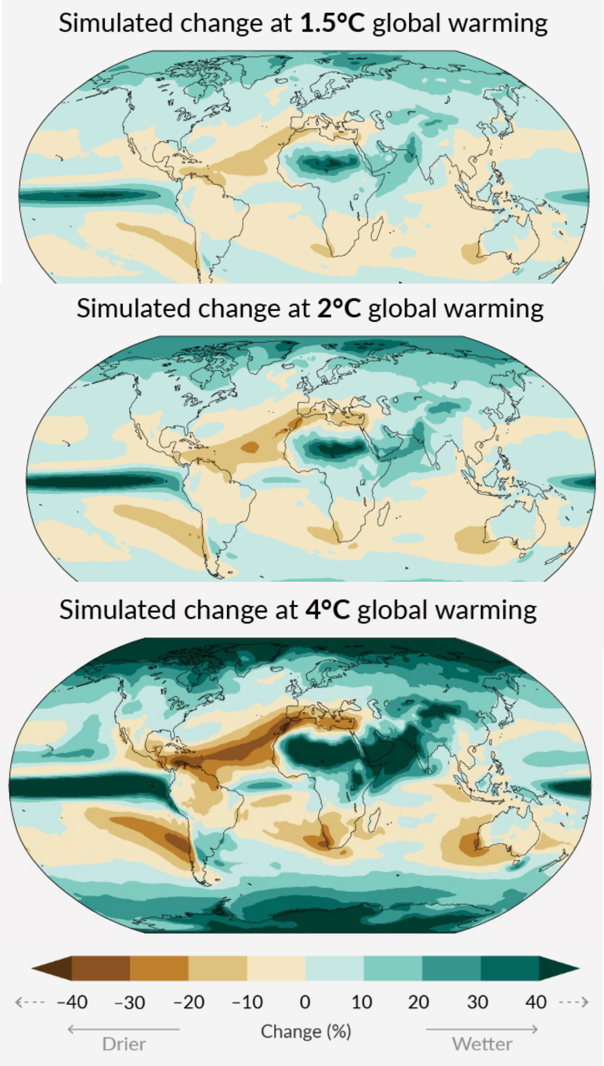
- The unfolding **climate change** crisis poses a growing challenge to water and food security
- Yet the reliability of the **global breadbaskets** and their relation with water resources in the future is poorly understood.
- The global breadbaskets are defined as **key production regions** for food grains and recognized for their vital contribution to global food security.



Map of World Croplands: USGS, 2015

Most global breadbaskets are located in mid-to-high latitude regions

Annual mean precipitation change (%)
relative to 1850-1900



- Increased precipitation
- Improved crop yields

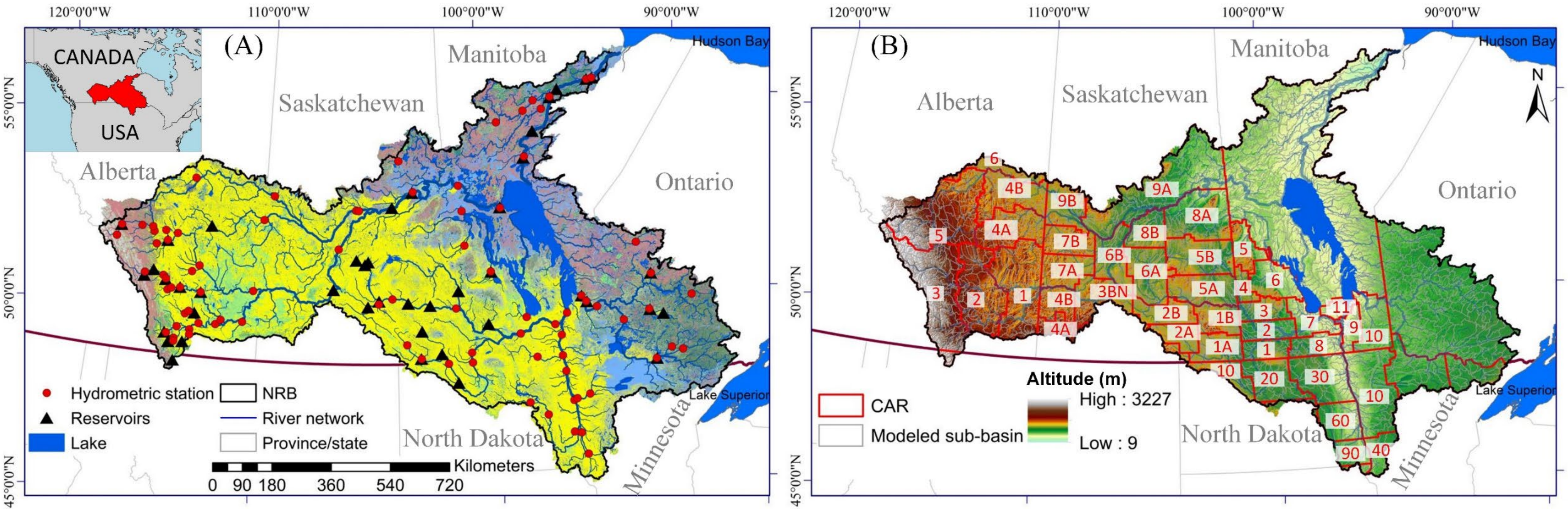
Perceived as beneficial to crop production and export potentials in the future

Gap:

Extreme warm-dry events, and watershed hydrology and **water quality**

IPCC Assessment report 6
https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers/figure-spm-5

Study Region: Nelson River Basin (1.1 million km^2)



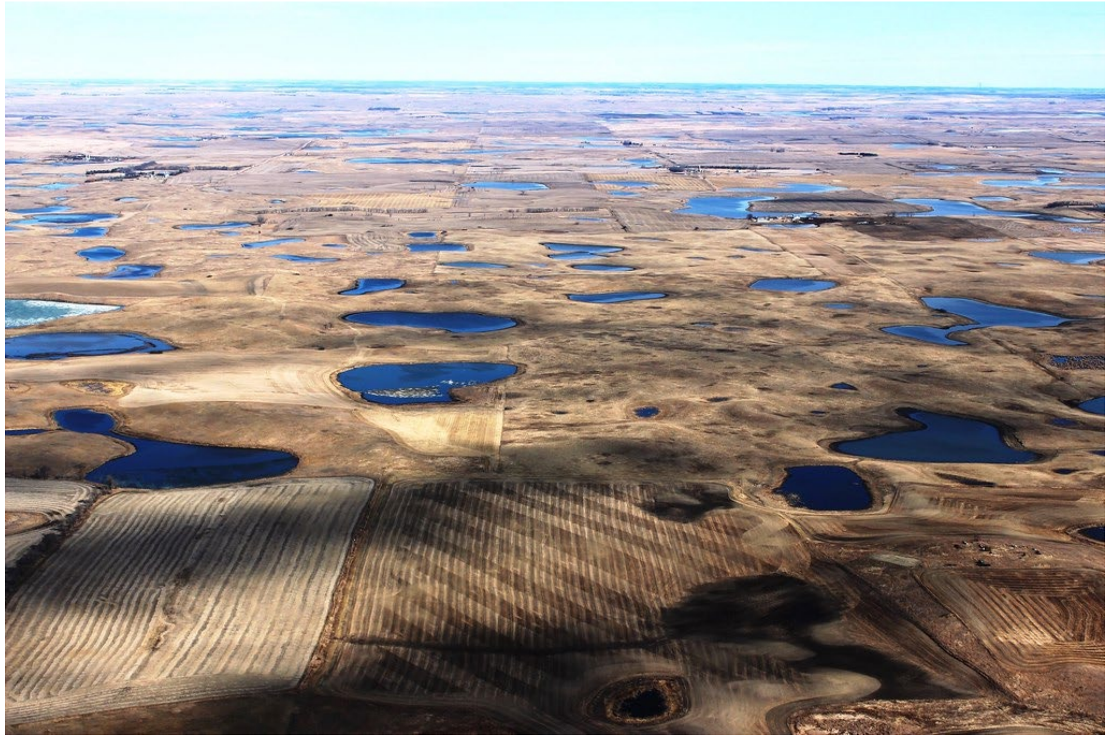
Water-food-climate nexus: assessing their role in watershed hydrology and nutrient cycling under extreme climatic events.

Characteristics of Agricultural Watersheds in Canada

Unique agro-hydrological conditions

- Long non-growing seasons
- Freeze–thaw cycles: release of nutrients
- Temperature and biogeochemical reactions
- Snowmelt runoff and variability
- Droughts and floods

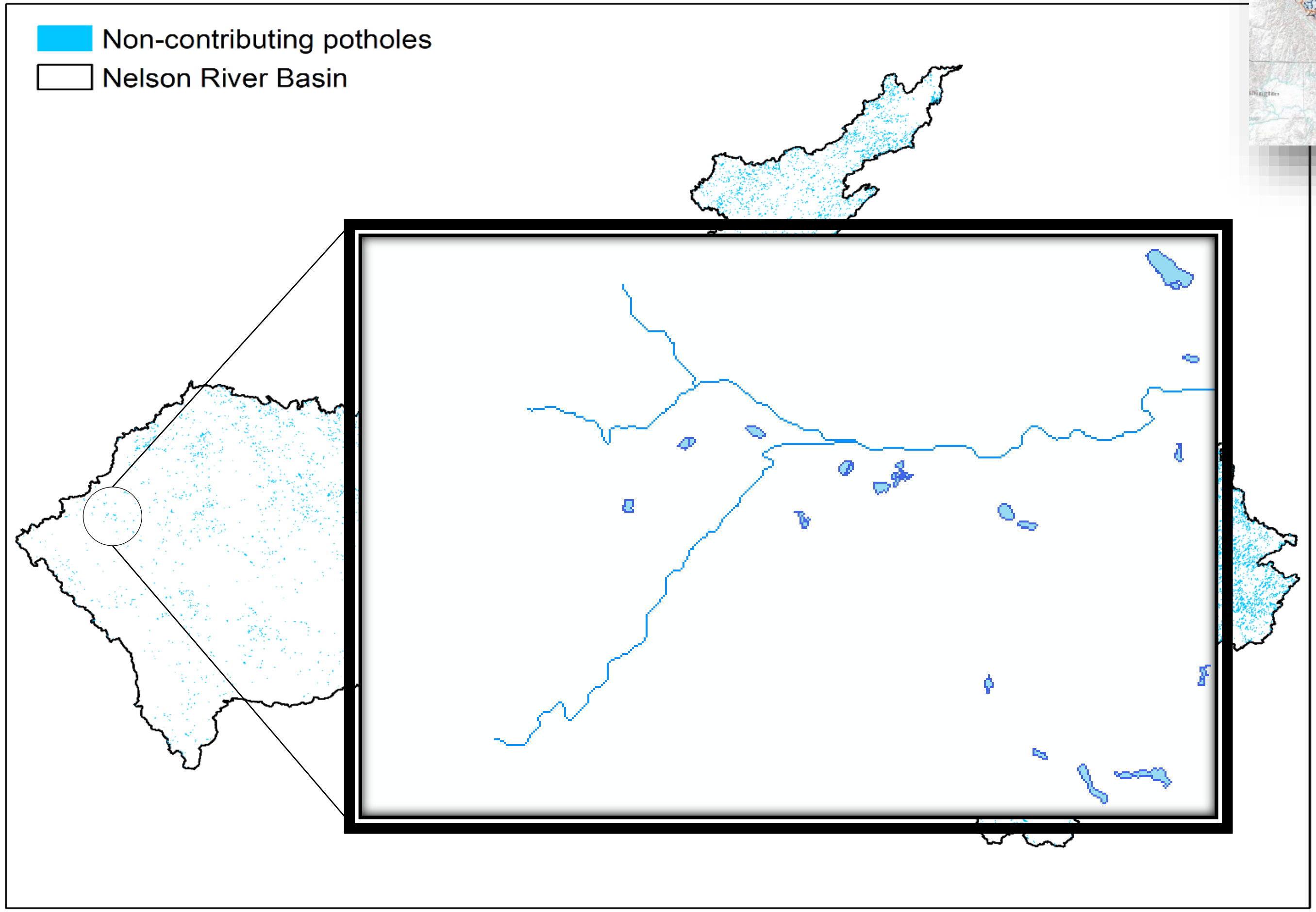
The geographically isolated wetlands (GIWs), known as Prairie Potholes

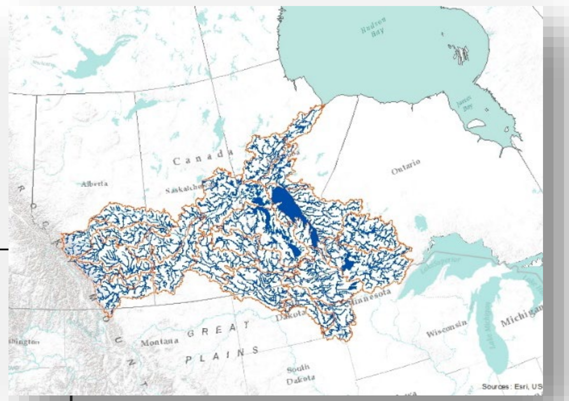


https://www.flickr.com/photos/usfwsmtnprairie/16826406199

Crucial in regulating water and nutrient cycling in these watersheds

Role of wetlands in regulating water quantity and quality





Influence of future climate on GIWs

ABMI Alberta Biodiversity Monitoring Institute

SWAT model:

- WSV of GIWs as input
- Assumes a hypothetical GIW in each sub-basin
- Dose not simulate seasonal connectivity of GIWs
- Does not simulate GW contribution to the WSV
- Water quality processes

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

ELSEVIER

Regional wetland water storage changes: The influence of future climate on geographically isolated wetlands

Check for updates

Quan Cui [a], Mohamed E. Ammar [a,b], Majid Iravani [c], Jahan Kariyeva [c], Monireh Faramarzi [a,*]

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ARTICLE INFO

Keywords:
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Hydrologic modelling
Machine Learning
Wetland geographic features
Wetland monitoring indicator

ABSTRACT

Geographically Isolated Wetlands (GIWs) are essential ecological and ecosystem entities that are vulnerable to climate change. The water storage volume (WSV) of GIWs is an important indicator to monitor their health and ecosystem services. Therefore, the projection of changes in future WSV of GIWs is crucial for conservation policies that are typically set at the regional scale. A limiting factor for the extended spatial projection of WSV of GIWs is the lack of data on their geometry, bathymetry, and the complexity of hydrologic relation to the sur-

2020 — Cui, Q., Ammar, M.E., Iravani, M., Kariyeva, J., Faramarzi, M. Regional wetland water storage changes: The influence of future climate on geographically isolated wetlands. Ecological Indicators. DOI: https://doi.org/10.1016/j.ecolind.2020.106941

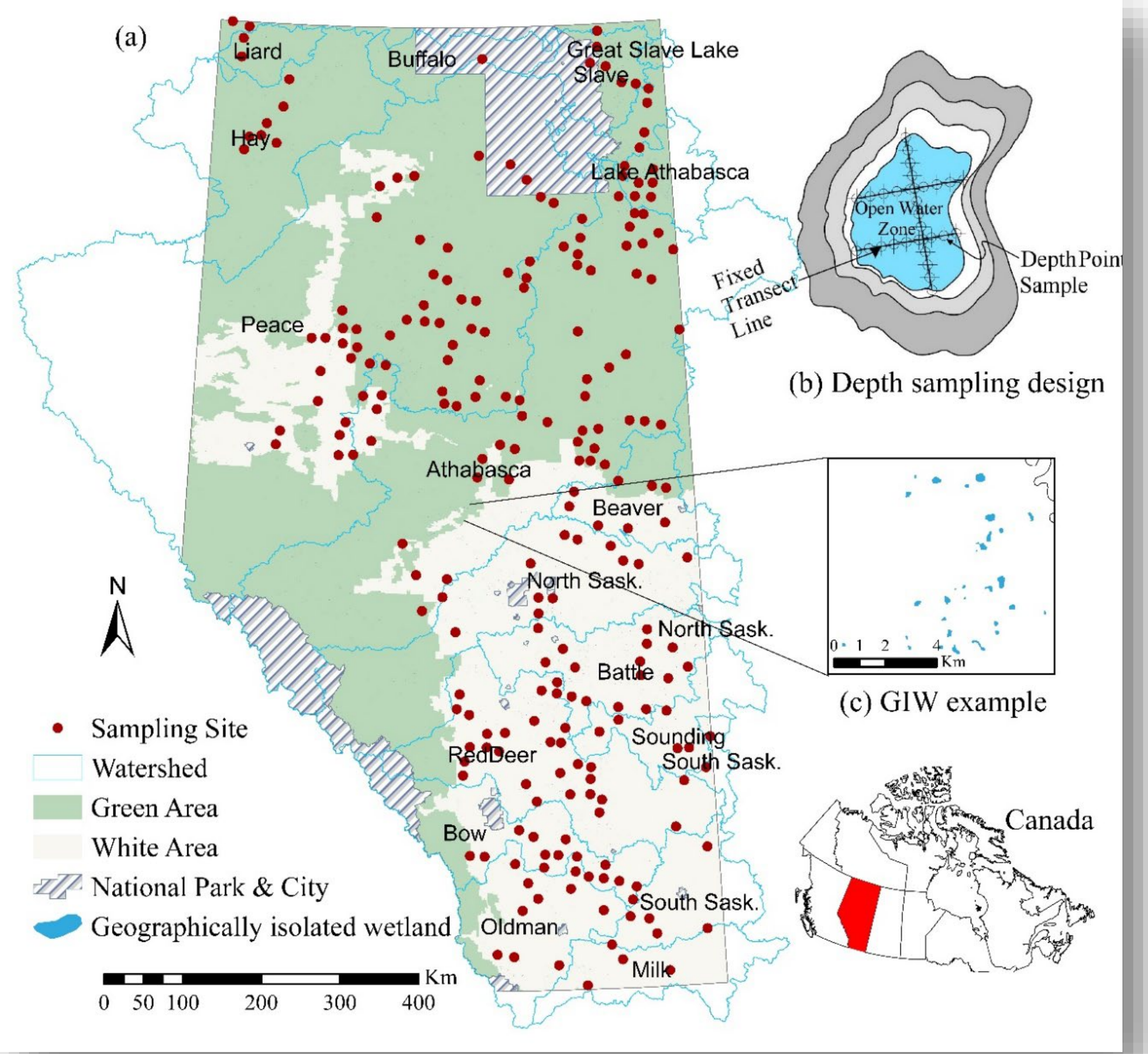
Influence of future climate on GIWs (100,000 GIWs)

ABMI Alberta Biodiversity Monitoring Institute

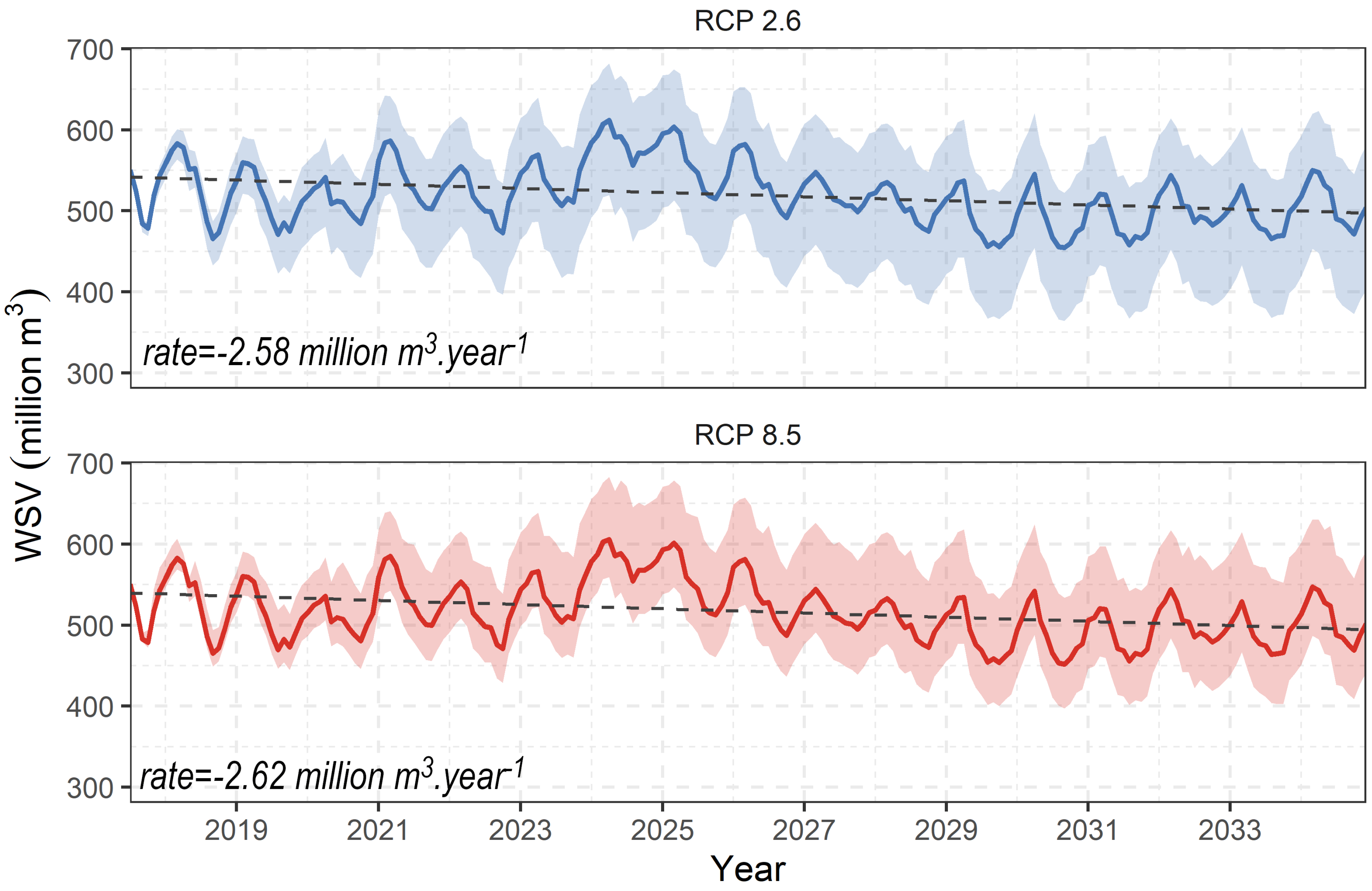
A three-step procedure:

1) ML models to estimate the WSV of GIWs (234 monitored GIWs, baseline)
2) SWAT modelling for future water balance (2018-2034): 9 downscaled GCMs
3) SWAT model outputs and RS data: mass balance of each individual GIWs

Integration for future projection of WSV

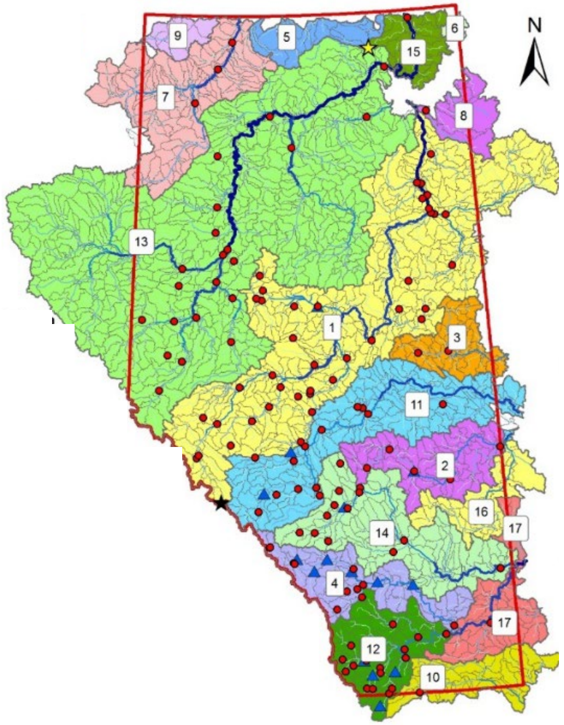


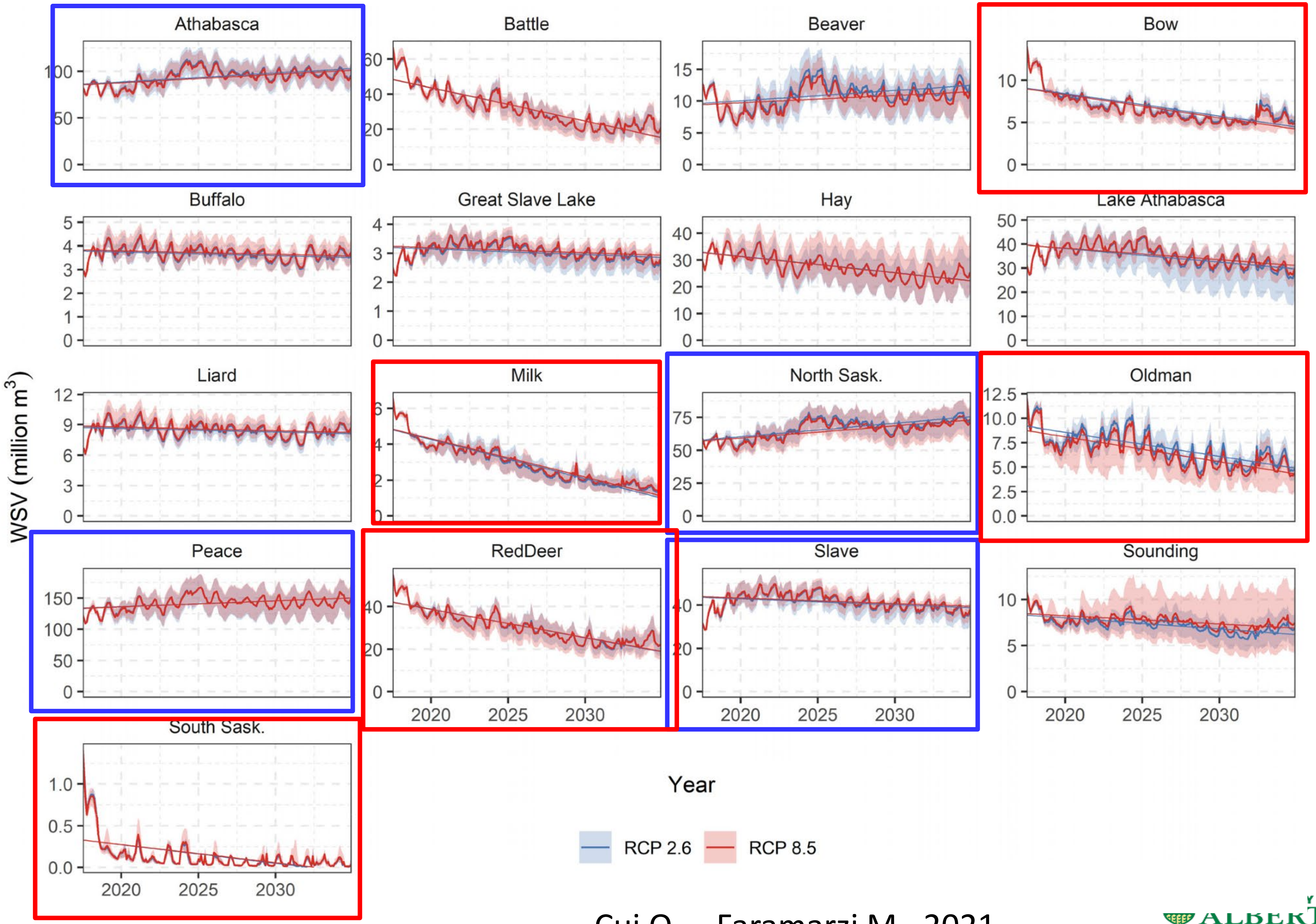
2020 — Cui, Q., Ammar, M.E., Iravani, M., Kariyeva, J., Faramarzi, M. Regional wetland water storage changes: The influence of future climate on geographically isolated wetlands. Ecological Indicators. DOI: https://doi.org/10.1016/j.ecolind.2020.106941



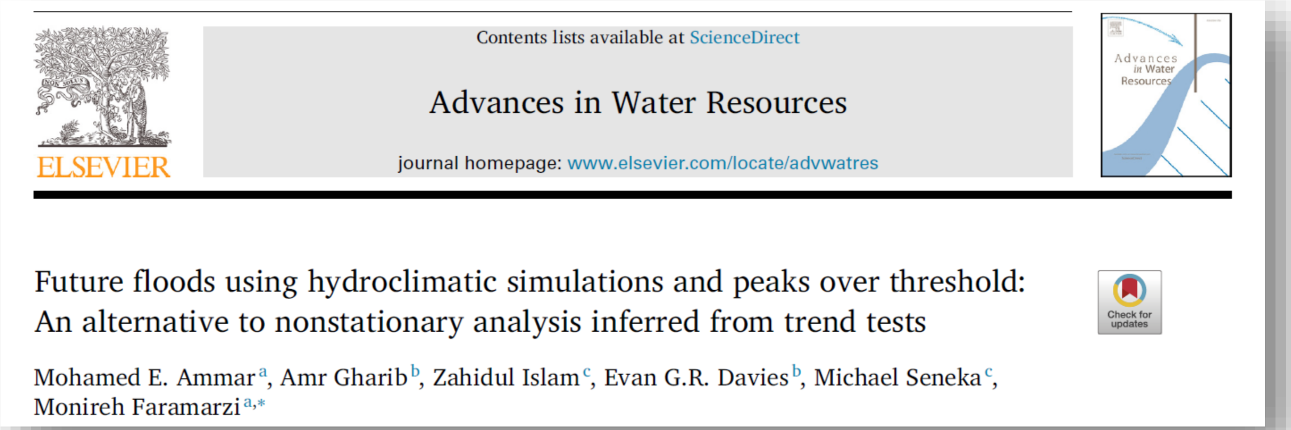
2020 — Cui, Q., Ammar, M.E., Iravani, M., Kariyeva, J., Faramarzi, M. Regional wetland water storage changes: The influence of future climate on geographically isolated wetlands. Ecological Indicators. DOI: https://doi.org/10.1016/j.ecolind.2020.106941

Area: 700,000 km^2





Cui Q., , Faramarzi M., 2021



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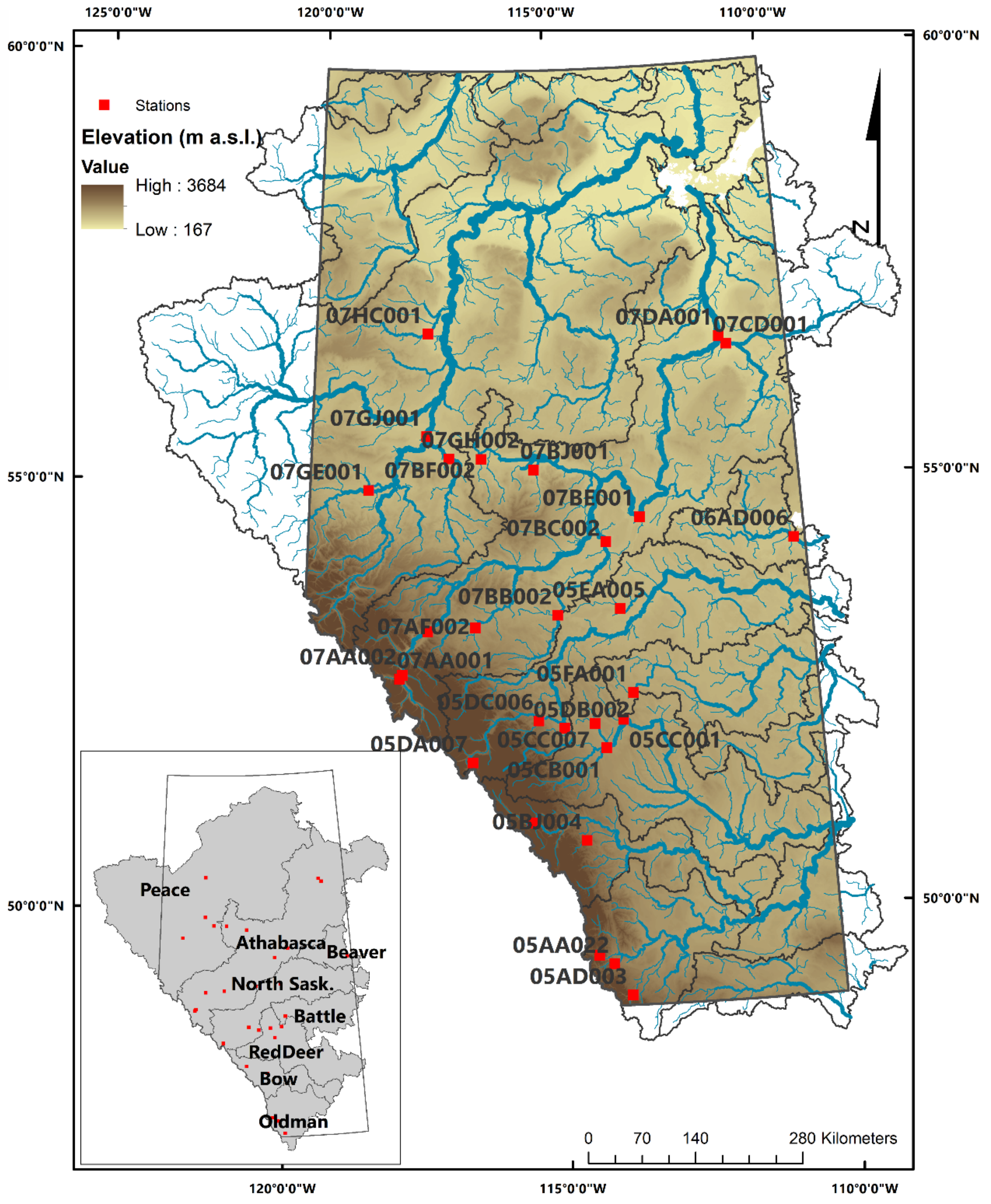
Advances in Water Resources

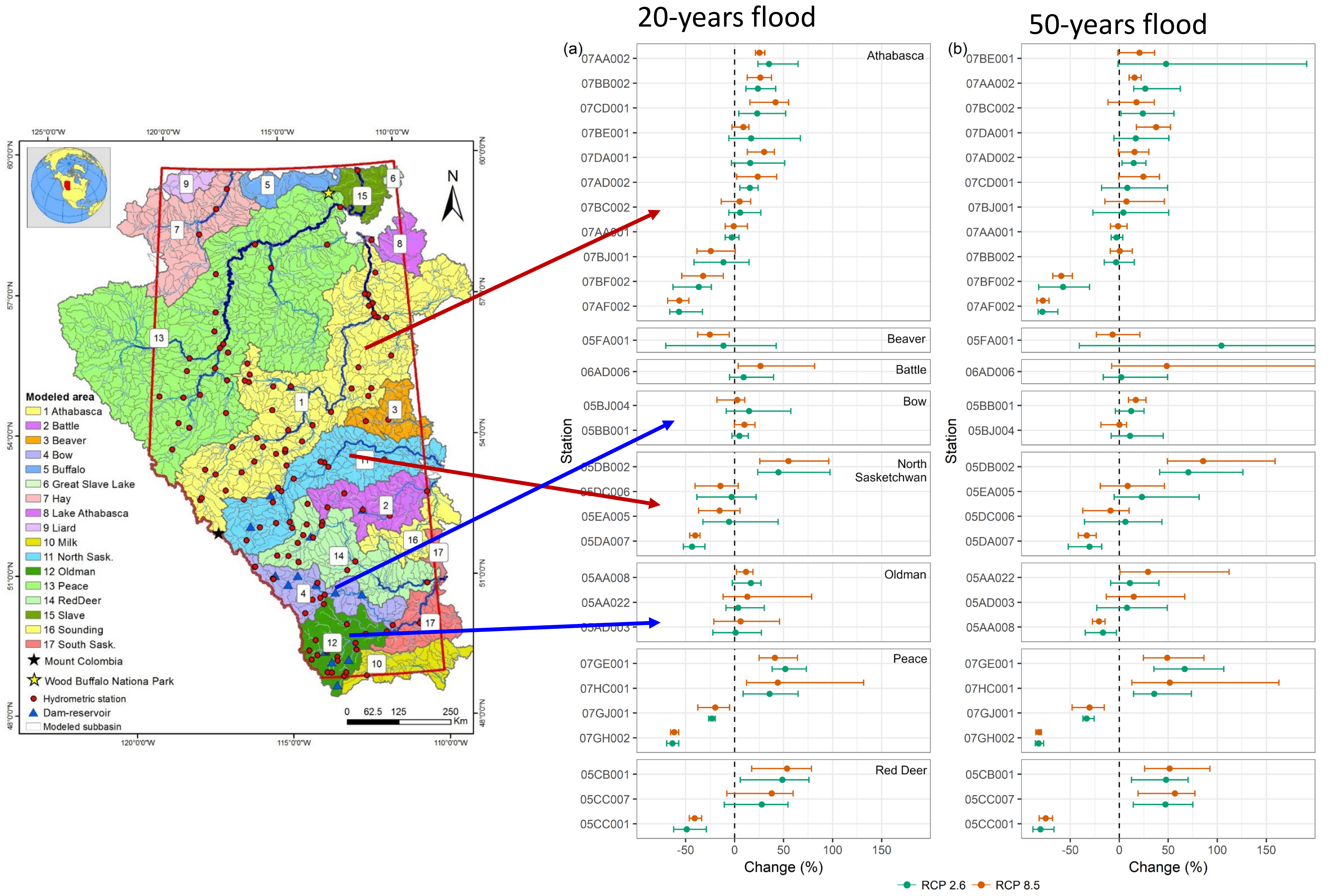
journal homepage: www.elsevier.com/locate/advwatres

Future floods using hydroclimatic simulations and peaks over threshold: An alternative to nonstationary analysis inferred from trend tests

Mohamed E. Ammar[a], Amr Gharib[b], Zahidul Islam[c], Evan G.R. Davies[b], Michael Seneka[c], Monireh Faramarzi[a,*]

- SWAT model was verified for daily POT
- 29 station data were used for comparison
- A GPD was fit
- 20-years and 50-years flood was projected for past and future
- Flood attributes were projected for future
  - Timing
  - Duration
  - Regularity
  - Magnitude




20-years flood
50-years flood
(a)
(b)
Athabasca
Beaver
Battle
Bow
North Saskatchwan
Oldman
Peace
Red Deer
07AA002
07BB002
07CD001
07BE001
07DA001
07AD002
07BC002
07AA001
07BJ001
07BF002
07AF002
05FA001
06AD006
05BJ004
05BB001
05DB002
05DC006
05EA005
05DA007
05AA008
05AA022
05AD003
07GE001
07HC001
07GJ001
07GH002
05CB001
05CC007
05CC001
Station
Change (%)
RCP 2.6
RCP 8.5
Modeled area
1 Athabasca
2 Battle
3 Beaver
4 Bow
5 Buffalo
6 Great Slave Lake
7 Hay
8 Lake Athabasca
9 Liard
10 Milk
11 North Sask.
12 Oldman
13 Peace
14 RedDeer
15 Slave
16 Sounding
17 South Sask.
Mount Colombia
Wood Buffalo Nationa Park
Hydrometric station
Dam-reservoir
Modeled subbasin
N
Km

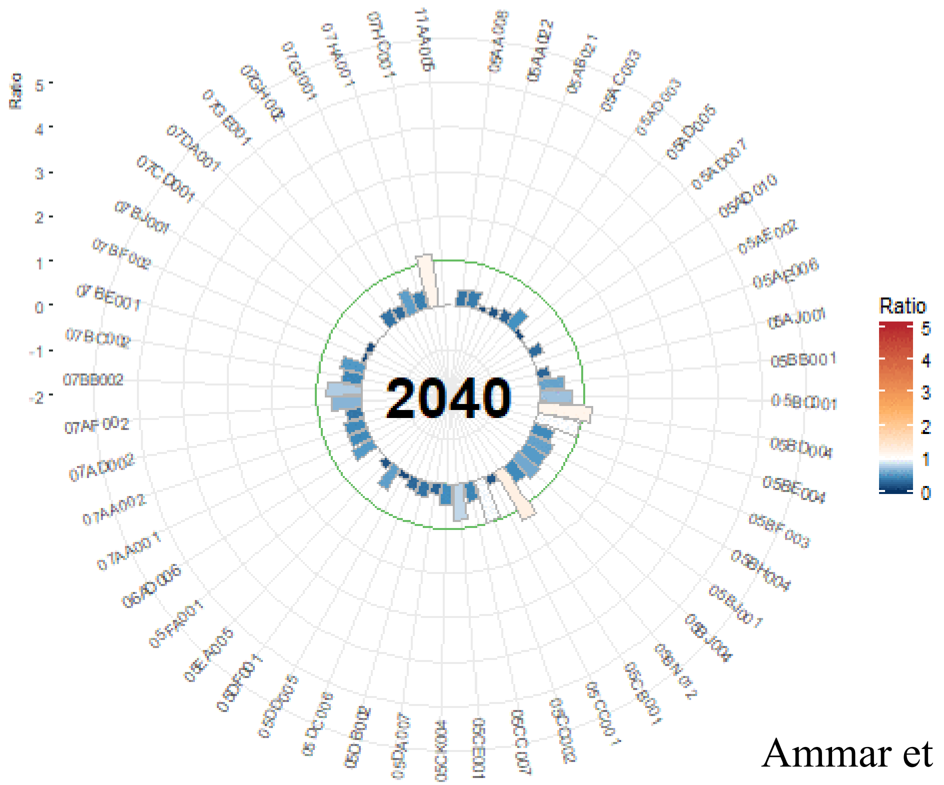
Flood projections (2040-2064 period)

WSML Watershed Science & Modelling Laboratory

Maximum future peak flow change with time compared to the largest historic peak flow occurred

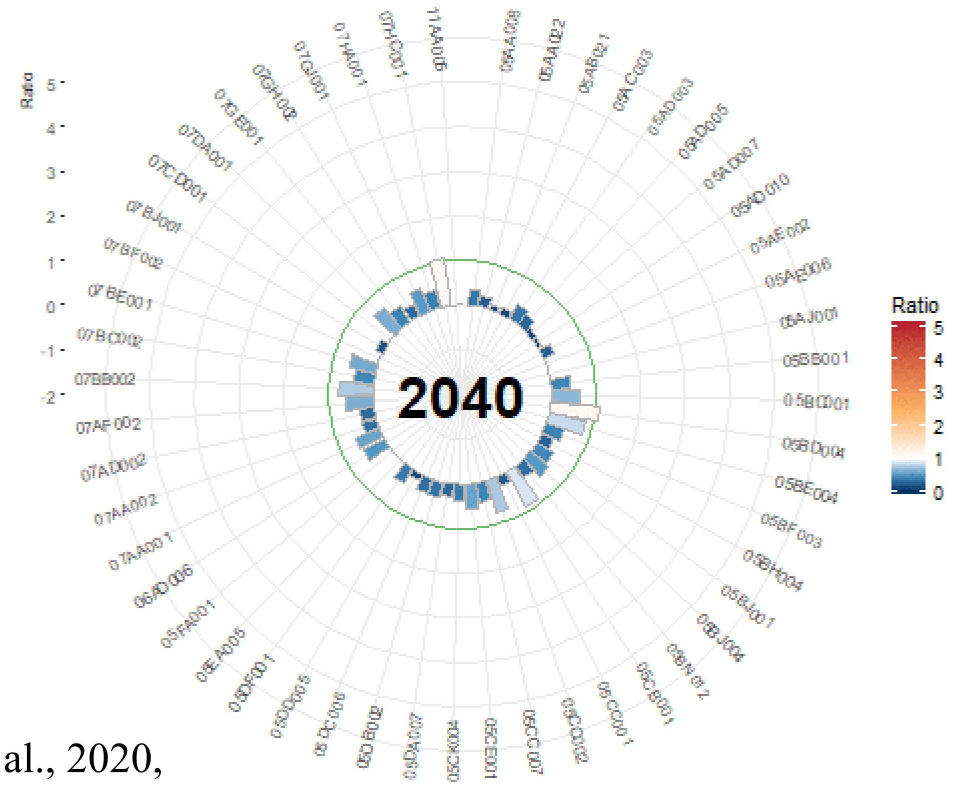
$$\frac{PF_{future\ maximum\ annual}}{PF_{historic\ maximum}}$$

No preference in the arrangement of the stations
Blue represents a smaller peak flow compared to the largest historic peak flow
Red represents a higher peak flow compared to the largest historic peak flow occurred
Some stations show an increase equals to 5 times the largest occurred historic peak flow



RCP 2.6

Ammar et al., 2020, Advances in Water Resources



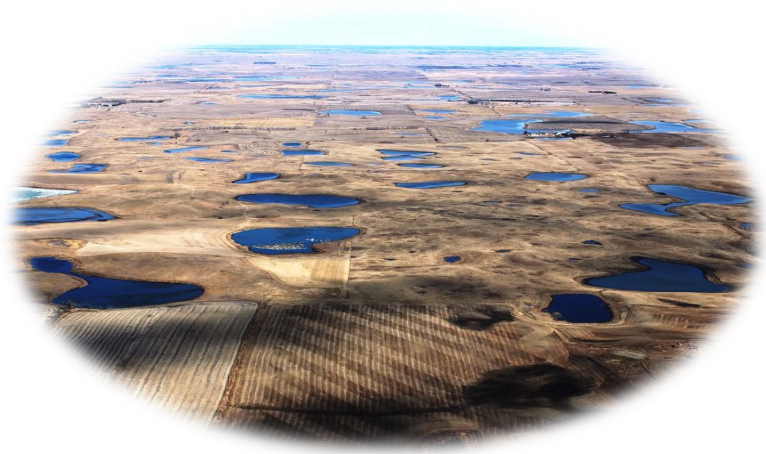
RCP 8.5

Implications:

Studies showed that the loss of approximately 4 million ha of GIWs in the Prairie Pothole Region of North America has resulted:

- Increase of 5–140 teragrams (Tg) per year of sediment entering surface waters and
- Decreases of 0.84–13 Tg per year carbon sequestration
- Decrease of 0.00040–0.20 Tg per year phosphorous storage
- Decrease of 0.032–0.21 Tg per year denitrification potential

Question:



1) Would crop production be sustainable In Canada and in global breadbaskets of northern latitudes?

2) How to simulate nutrient cycling in the soil and throughout the watershed by considering cold region hydrological processes?

Conclusion and future directions:

1) SWAT is a powerful tool that facilities integration of disciplines

2) Model improvements for regional assessment of water-food relation:

   - Cold region process: (freeze-thaw, soil temperature, water temperature)
   - Soil carbon integration with in-stream processes
   - Seasonal connectivity of potholes
   - Water quality processes in potholes
   - GW contribution

WSML Watershed Science & Modelling Laboratory

UNIVERSITY OF ALBERTA

Thank you!

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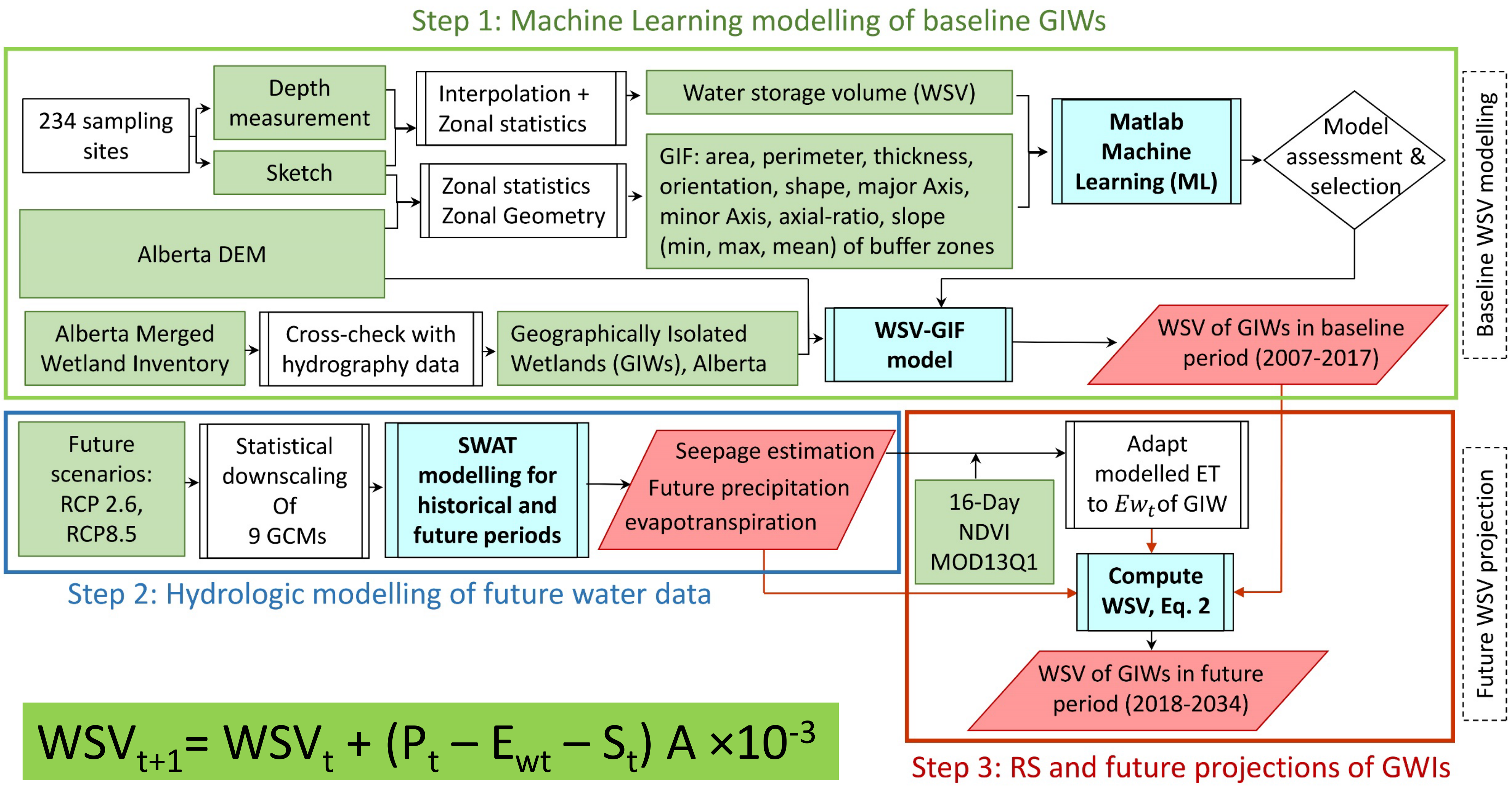
Watershed Science and Modelling Laboratory-WSML

https://cms.eas.ualberta.ca/faramarzilab/key-publications/



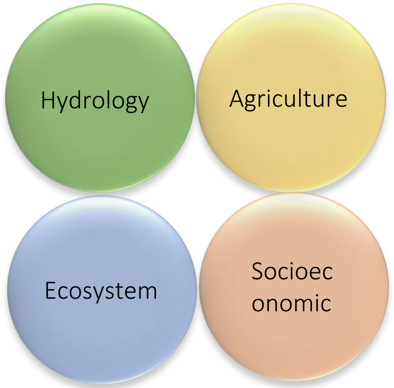
$$WSV_{t+1} = WSV_t + (P_t - E_{wt} - S_t)\, A \times 10^{-3}$$

Water-food security needs collaboration between different disciplines

Hydrology, agronomy, ecology, geology, aquatic ecosystem science, socioeconomic

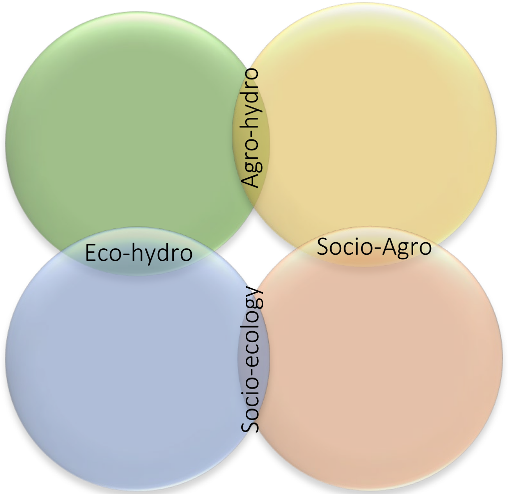
Multi-disciplinary

- No collaboration
- Fixed philosophy
- Work in isolation
- **Little innovation**



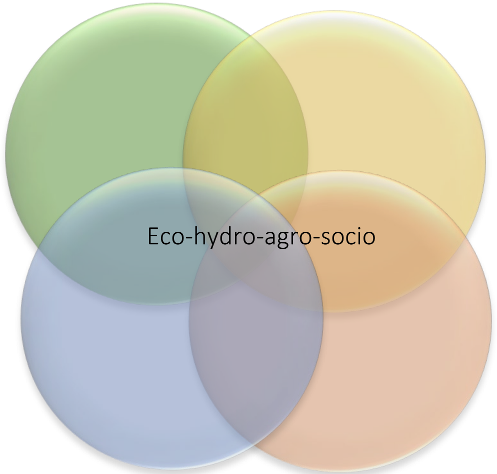
Inter-disciplinary

- Some collaboration
- Flexible philosophy
- Work with others
- **Some innovation**



Trans-disciplinary

- A lot of collaboration
- Open philosophy
- Work transformed by other disciplines
- Improved theories, novel methods
- Novel synergy of system
- **Al lot of co-creative innovation**

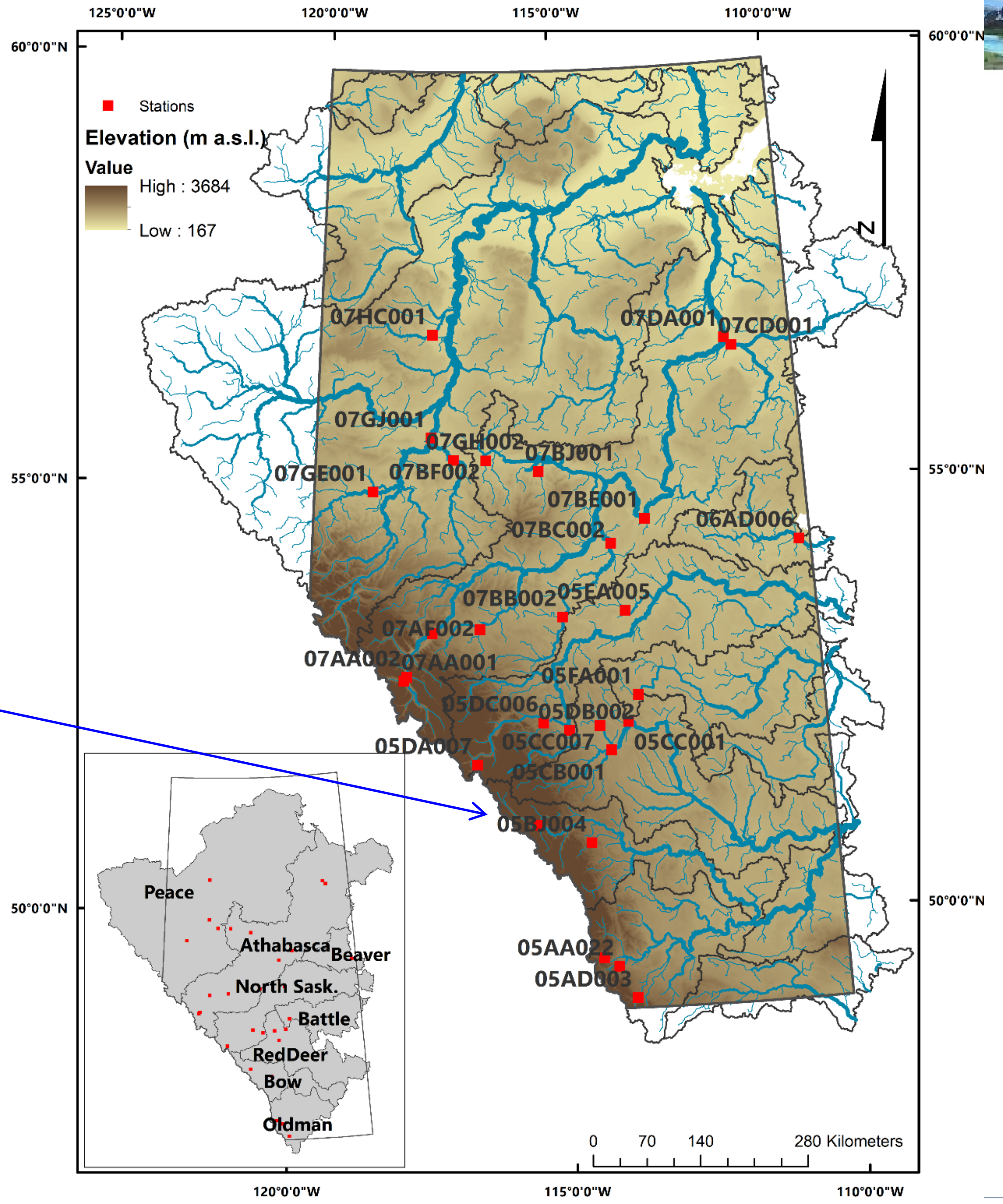


Folke, C., et al., and J. Rockström. 2016. Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society* 21(3):41.
Blöschl, G., et al., Promoting interdisciplinary education-the Vienna Doctoral Programme on Water Resource Systems, *Hydrol. Earth Syst. Sci.*, 16: 457-472.

Watershed Science & Modelling Laboratory

Provincial study:
Calibrated and validated SWAT hydrologic model in combination with climate projection of 9 GCMs under RCP 2.6 and RCP 8.5

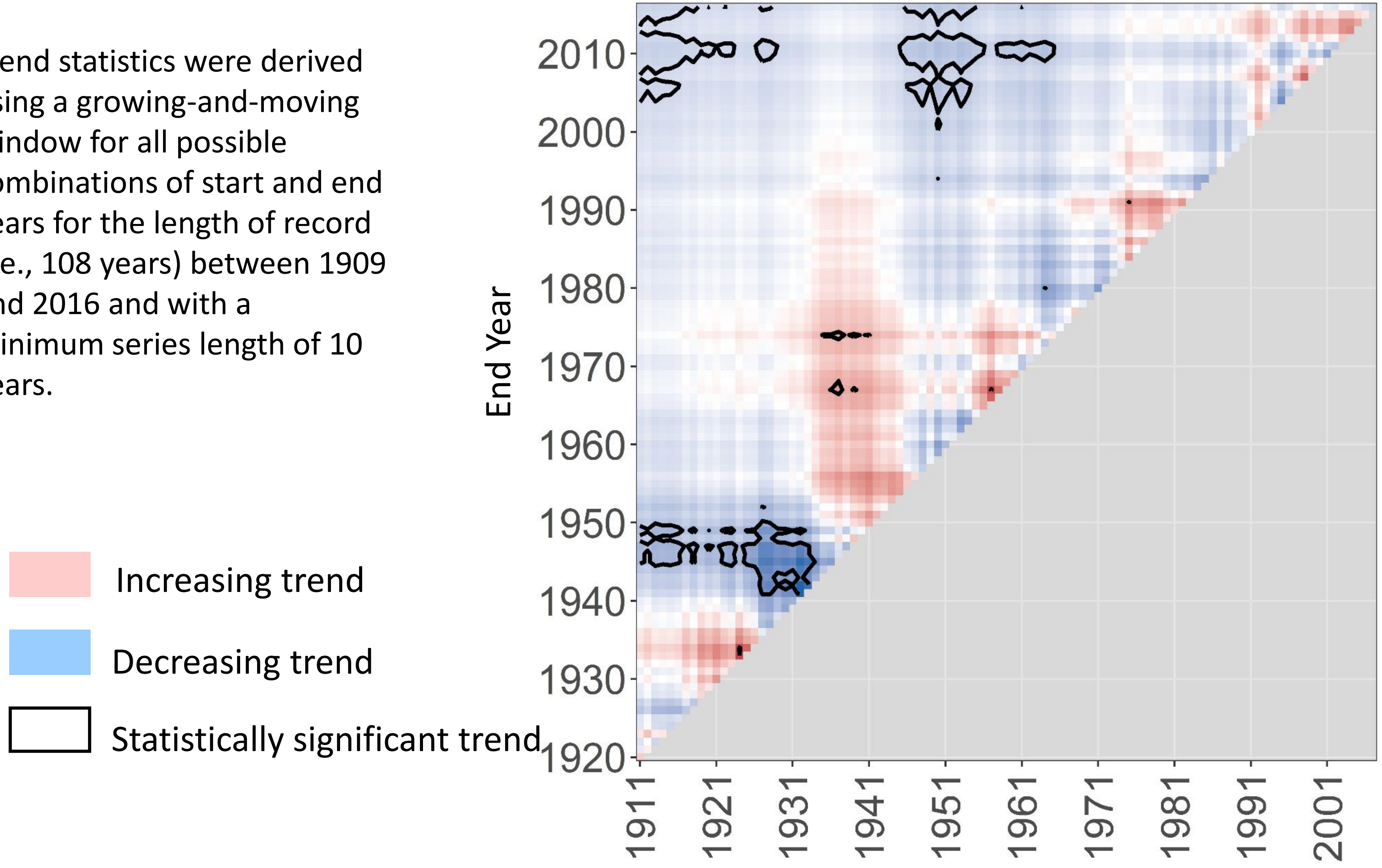
Bow River at Banff, 05BC001 station, with the longest record of 108 years of observed streamflow data



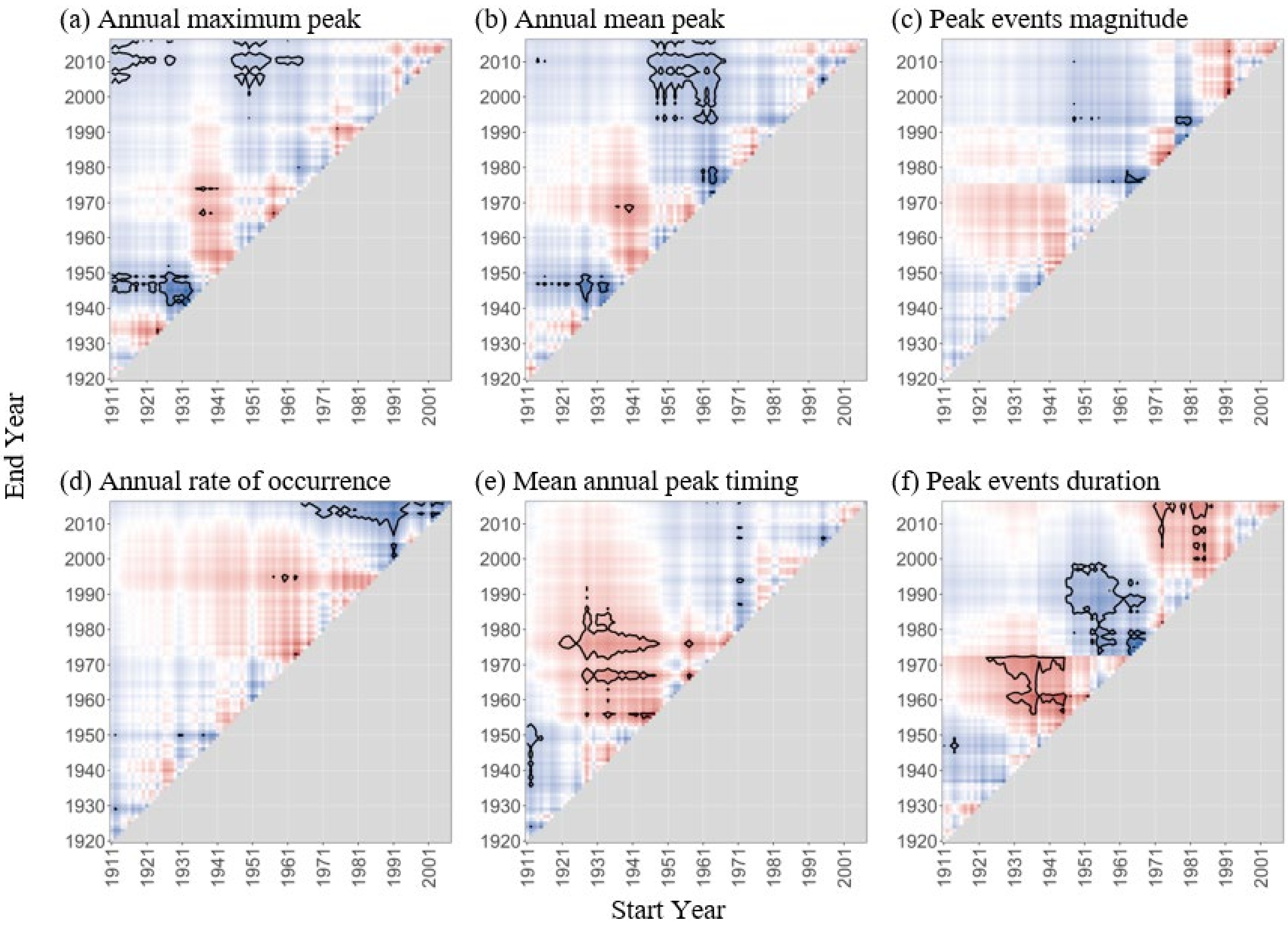
Future floods using hydroclimatic simulations and peaks over threshold: An alternative to nonstationary analysis inferred from trend tests: *Ammar et al., Advances in Water Resources, 2020*

Trend statistics were derived using a growing-and-moving window for all possible combinations of start and end years for the length of record (i.e., 108 years) between 1909 and 2016 and with a minimum series length of 10 years.

Annual maximum peak



Ammar et al., 2020


(a) Annual maximum peak
(b) Annual mean peak
(c) Peak events magnitude
(d) Annual rate of occurrence
(e) Mean annual peak timing
(f) Peak events duration
End Year
Start Year
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
1911
1921
1931
1941
1951
1961
1971
1981
1991
2001

In agreement with Whitfield and Pomeroy (2016):
They found significantly negative trend in floods over the past 100 years for Bow River at Banff, but when separating the events based on their generating processes, neither snowmelt floods or rain-over-snow floods showed any trends over time.

Depending on the individual processes of interest the trends may show different pattern. In fact our water systems are a result of interactions of multiple processes that are dynamic.

Key message:

Inference of non-stationarity from trend tests might be misleading, simply because processes and their evolution are not quantified. This requires simulation of processes governing our water systems.

Hydro-climate simulations: key for understanding cause-and-effect processes underlying GW-SW interactions and their dynamics for future projections

Climate change impacts on crop yields

2021 — Khalili, P., Masud, B., Qian, B., Mezbahuddin, S., Dyck, M., Faramarzi, M. Non-stationary response of rain-fed spring wheat yield to future climate change in northern latitudes. *Science of the Total Environment*. DOI: https://doi.org/10.1016/j.scitotenv.2021.145474

2019 — Masud, M.B., Wada, Y., Goss, G., Faramarzi, M., Global implications of regional grain production through virtual water trade, *Science of the total environment* 659: 807-820. DOI: 10.1016/j.scitotenv.2018.12.392.

2018 — Masud, M.B., McAllister, T., Cordeiro, M.R.C., Faramarzi, M., Modeling future water footprint of barley production in Alberta, Canada: Implications for water use and yields to 2064, *Science of the Total Environment* 616-617: 208-222.
DOI: 10.1016/j.scitotenv.2017.11.004.

Climate change impacts on crop yields

Direct impacts:

- Increased heat stress *(Yang et al., 2017a, 2017b)*
- Frequent extreme temperatures *(Zhang et al., 2016)*
- Intermittent heavy rainfall and waterlogging of soils *(Li et al., 2019)*
- Changes in atmospheric composition and CO2 *(Swann et al., 2016)*

Indirect impacts:

- Changes in ice and snowmelt dynamics
- Hydrologic cycle *(Wang et al., 2017)*
- Pests and diseases *(Jabran et al., 2020)*

Climate change impacts on crop yields

<u>Magnitude of impacts:</u>

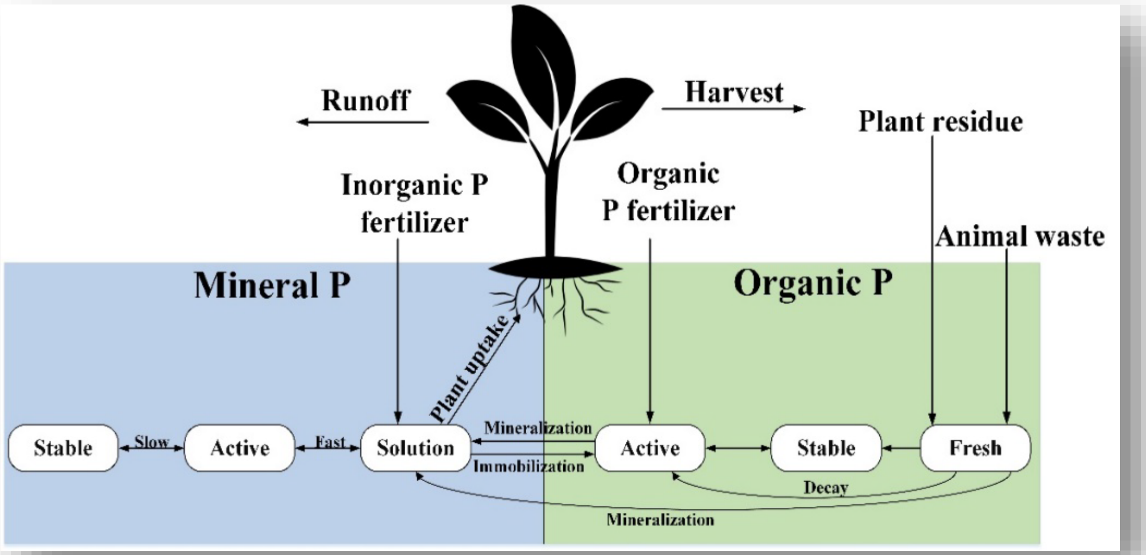
- Crop type
- Stage of growing season
- Geographic location

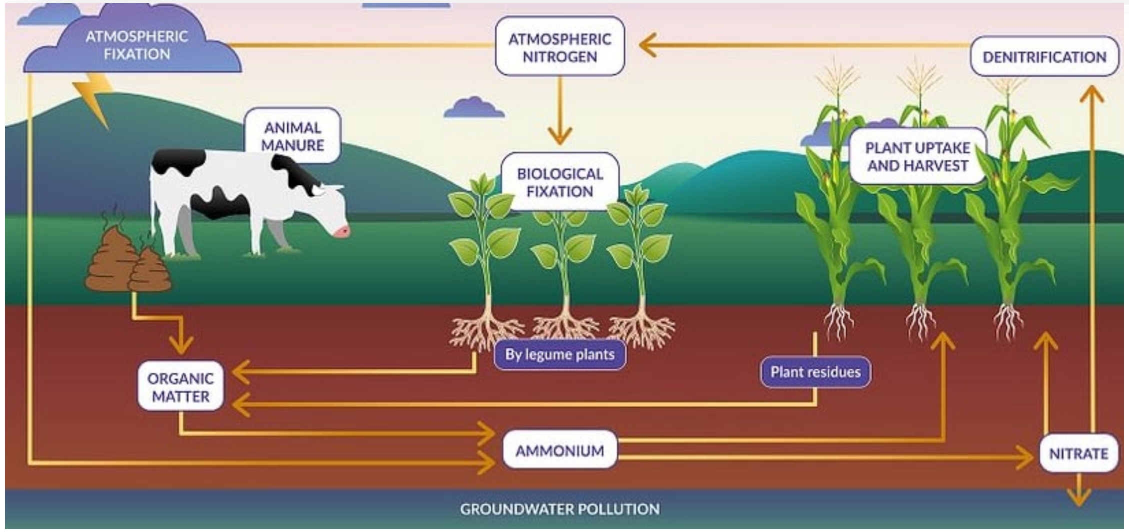
- Numerous biogeochemical and hydro-climate factors
- Spatiotemporal variability

Question: is crop response to changes in future climate change stationary?

Nutrient cycle

- Nutrient supplement by **fertilizer** or **manure** application to the cropping systems may form insoluble minerals and may be transported out from lands and loaded into water bodies *(Hansen et al., 2001)*.





https://www.cimmyt.org/news/nitrogen-in-agriculture/

Nutrient cycle and transport in Canadian Prairies

- Runoff-soil interface is primarily affected by frozen soil and the amount and rate of snowmelt → erosion and export of nutrients

Processes involved:

- Long non-growing seasons,
- Release of nutrients from soils and crop residue after freeze–thaw cycles
- Slower biogeochemical reaction rates by low temperature
- Snowmelt runoff and variability
- Restricted nutrient retention and infiltration to the frozen soil

https://goodineverygrain.ca/2021/12/06/facts-for-teachers-winter-and-farming/

https://www.producer.com/news/weather-network-predicts-abrupt-mid-march-shift-into-spring/