Rocky Mountain Water Supply Resilience and Vulnerability Evaluation Project

John Pomeroy, University of Saskatchewan
Sean Carey, McMaster University
John Diiwu, Alberta Agriculture and Forestry and Forestry
Masaki Hayashi, University of Calgary
Warren Helgason, University of Saskatchewan
Rich Petrone, University of Waterloo
Cherie Westbrook, University of Saskatchewan

www.usask.ca/hydrology
Rationale

• IPCC (2014) WG II report – “In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality”

• Mountain headwaters receive and produce a disproportionately large fraction of global precipitation and runoff including contributions to floods and water supply and drought protection for vast downstream areas.

• Snow, ice, and precipitation phase change dominate the behaviour of mountain hydrology – therefore especially sensitive to climate warming.
This Project:

Harnesses enhanced mountain observations, process hydrology advances and cold regions hydrological modelling to address water supply resiliency and vulnerability

- Forest cover and soil change
- Climate change
- Extreme hydrology – floods and droughts
The Partners

- Alberta Agriculture and Forestry (AAF)
- Alberta Environment and Parks (AEP)
- Parks Canada
- Environment and Climate Change Canada
- Natural Resources Canada
- City of Calgary
- Spray Lakes Sawmills
- Bow River Basin Council
- Fortress Mountain Resort
- Nakiska Ski Resort
- Brewster Travel Canada
- Global Water Futures Programme
Science Questions

• How do the physical characteristics (forest cover, soil type, geology, etc.) of mountain headwater basins influence runoff generation? How does this vary across the region?

• Will the hydrological systems of the Rocky Mountains enhance or dampen the effects of climate change and extreme events on downstream streamflow and water resources?

• Can forest manipulations impact the hydrological resiliency of these systems?
Approach

• Improve the understanding and description of hydrological processes governing mountain water supply,

• Demonstrate improved prediction of mountain streamflow using CRHM

• Assess historical and future mountain water resiliency in the Bow River Basin by:
  • Predicting water budgets and streamflow using CRHM, CRHO and downscaled atmospheric models,
  • Explaining how extreme events (e.g. 2015 drought, 2013 flood) have happened, and assess the vulnerability and resilience of the water supply system to extreme events.
  • Predicting concurrent impacts on water supply and hydrological extremes of:
    • Changing climate
    • Increasing weather extremes
    • Declining glacier volume
    • Managed or disturbed forest cover.
Canadian Rockies Hydrological Observatory and the Bow River Basin
Cold Regions Hydrological Modelling Platform

- **Precipitation**
- **Evapotranspiration**
- **Evaporation**
- **Surface runoff** (infiltration-excess or saturation-excess overland flow)
- **Subsurface discharge**
- **Groundwater discharge**
- **Recharge** via percolation
- **Sublimation**
- **Icemelt**

**Streams**

**Layers**
- **Soil layers**
- **Groundwater layers**
- **Icemelt**
Peyto Glacier Reconstruction of Historical Retreat and Streamflow Discharge Changes

1966: 14.4 km²
2016: 9.9 km²

New salt dilution rating curve provides 21st c. streamflow measurements
Glacier Hydrology Resilience

Runoff

Seasonal precipitation

Meltwater source

Snowfall and rainfall

Aubry-Wake and Pomeroy, in preparation
2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt
2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt

Aubry-Wake and Pomeroy, in preparation
2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt
2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt

Aubry-Wake and Pomeroy, in preparation
2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt

Aubry-Wake and Pomeroy, in preparation
Streamflow Regime – with and without glaciers

Peyto Glacier: Mean Discharge [1967-1977]

Observation
Simulation with glacier
Simulation without glacier

Daily Mean Discharge [m³/s]

Day of Year

Pradhananga and Pomeroy, in preparation
Forest Hydrology

11 August 2017 12:10
Surface temperature [°C]
- 20
- 24
- 28
- 32
- 36

Barrier Lake Clearcut and Haul Road Sites

Legend
- Barrier Clear Cut pit and MET station
- Barrier Haul Road pit and MET station
- Barrier Clear Cut - West
- Barrier Haul Road
- Barrier Clear Cut - North
- Barrier Clear Cut - East
- Barrier Clear Cut - South
- Marmot Basin
- Barrier Lake
Forest and Disturbed Soils

Barrier Forest Soil

Barrier Clearcut Soil

Barrier Haul Road Soil
Flood Simulation with Sequential Forest Canopy Removal and Soil Compaction – Marmot Creek

Fang and Pomeroy, 2016
Modelling the Bow & Elbow at Calgary with CRHM

- 2450 m of relief
- Basin area 7823.6 km²
Modelling the Bow & Elbow at Calgary with CRHM

- 2518 hydrological response units based on vegetation, soils, slope, aspect, elevation, drainage, glacier cover, water bodies
Modelling the Bow & Elbow at Calgary with CRHM

- 142 sub-basins, of which 41 have glaciers
Model test – no calibration, local meteorological data

Bow River at Banff

- Observation
- Simulation

Nash-Sutcliffe = 0.61
Model Bias = 0.18
Weather Research and Forecasting (WRF) Model, 4 km domain over Western Canada

WRF Model
Version 3.4.1

domain
2560 x 2800 km²
4 km grid spacing
37 levels

Microphysics Scheme
New Thompson et al.

No Cumulus parameterization

Planetary Boundary
Layer scheme: Yonsei University (YSU)
Long-wave and Short-wave scheme: Rapid Radiative Transfer Model relevant for GCMs (RRTMG)

Forcing Data: 6-hourly, 0.703° x 0.703° resolution ERA-Interim
WRF Comparison to Station Data in the Rockies

Rasouli et al., in preparation
WRF Comparison to Station Data in the Rockies

Rasouli et al., in preparation
Using Station Data to Correct WRF
Marmot Creek

NSE 0.57 0.22 0.36
MB  -0.03  -0.29  0.08

Marmot Creek

Obs     WRF     WRF-corrected
NSE     0.57    0.22    0.36
MB      -0.03   -0.29   0.08
1. Calculate 30-year monthly mean values of U, V, T, Qv, PSFC, Tsoil and SST of current and future climate periods from multi CMIP5 model ensemble (1976-2005 historical and 2070-2099, RCP8.5)

2. Subtract current from future to get monthly climate perturbations

3. Add time-interpolated perturbation to current reanalysis (ERA-Interim, 6-hourly) to give new WRF model initial and lateral boundary conditions
Future Change in the 21st Century

Canadian model projected conditions  RCP8.5 ‘2050’ – (1986-2005)

Temperature

Precipitation
Deliverables

- Assess the uncertainty, resilience and vulnerability of mountain water supplies in the Bow River Basin.
- Develop an integrated hydrological simulation system for the mountain headwaters of the Bow River.
- Predict climate and forest cover tipping points for hydrology,
  - explore forest management options,
  - develop future water supply scenarios and
- estimate the risk of future extreme hydrological events.
Conclusions

• Glaciers, avalanches, discontinuous forest energetics, forest evapotranspiration, wetlands, groundwater and complex terrain snow redistribution and ablation processes are better understood and are now better represented in CRHM models.

• Observations to date and historical diagnostic modelling shows remarkable resilience in Canadian Rockies hydrology for both glacierized and alpine-forested basins, despite substantial warming in winter.

• Future hydrological change has been predicted using dynamically downscaled high resolution climate model driving a physically based process hydrological model.
  • At Marmot Creek and Peyto Glacier there is loss of resiliency: more rainfall, less snowmelt, less glacier melt, less sublimation, greater evapotranspiration, drier soils, lower groundwater, earlier streamflow, more overland flow, lower low flows, greater discharge volumes
Publications

- **Pomeroy J**, (Feb 15, 2018). As a water crisis looms in Cape Town, could it happen in Canada? In *The Conversation and Maclean's*