Identifying high-runoff areas during peak streamflow on the Eastern Slopes of the southern Canadian Rocky Mountains

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Motivation

- In forested landscapes, vegetation can exert strong hydrological control on runoff processes and forest removal can:
  - Reduce interception and increase snow accumulation
  - Increase snowmelt rates due to less shading
- Both of these factors lead to increases in runoff, particularly during spring freshet, but it matters where the forest is removed.
- Higher elevation areas typically contribute more runoff during peak flow
  - Lower elevation areas typically receive less precipitation, and runoff also primarily occurs prior to freshet.
  - North aspects melt out slower and later than southern ones
- Disturbing these "high-runoff areas" can disproportionately affect runoff

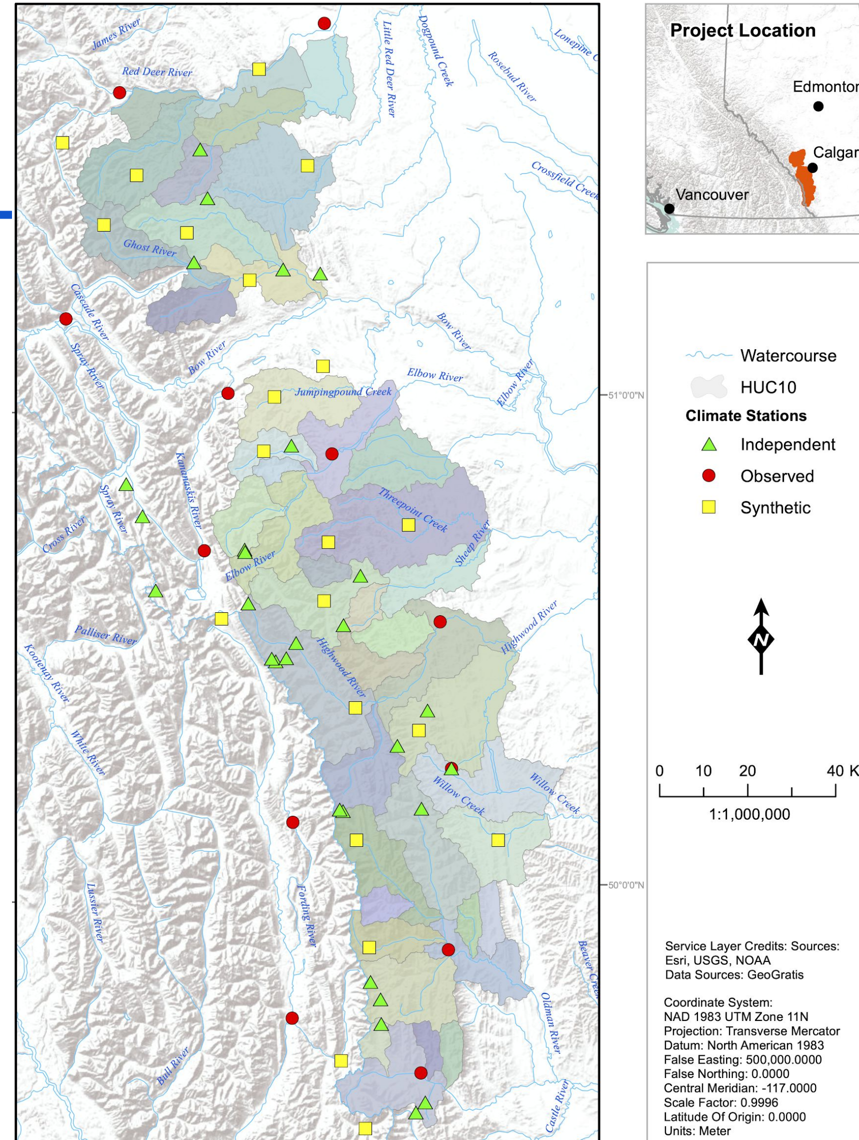
Identifying high-runoff areas

In snowmelt dominated watersheds, higher snowpack areas generally contribute more to peak flows, which in the mountains generally tends to be higher elevations.

H_{60}: the elevation above which 60% of the watershed lies

Identifying high-runoff areas

- We designed a hydrological model to simulate streamflow for Hydrologic Unit Code (HUC) 10 watersheds along the Eastern Slopes of the southern Canadian Rocky Mountains.
- We used model outputs to identify high-runoff areas, defined as areas that most actively contributed to streamflow during Peak Flow Periods.
- Simulated results under baseline and future climate change conditions.



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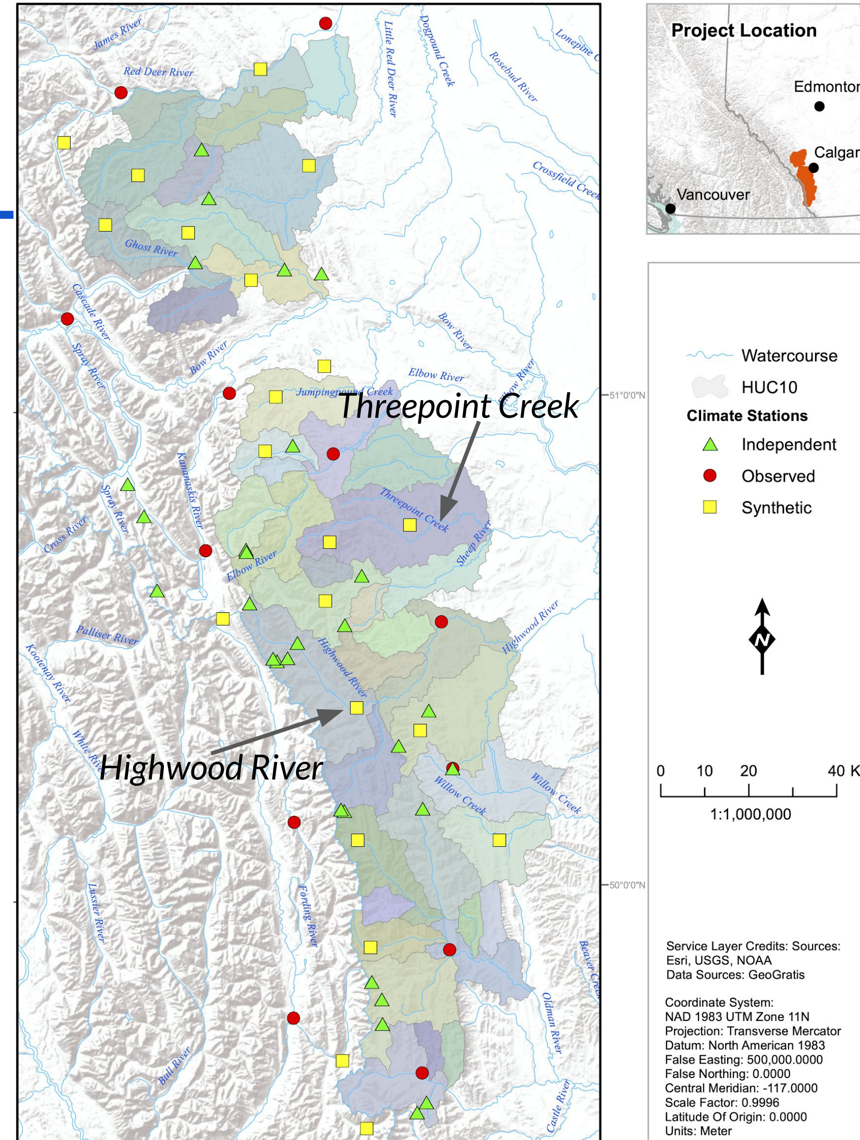

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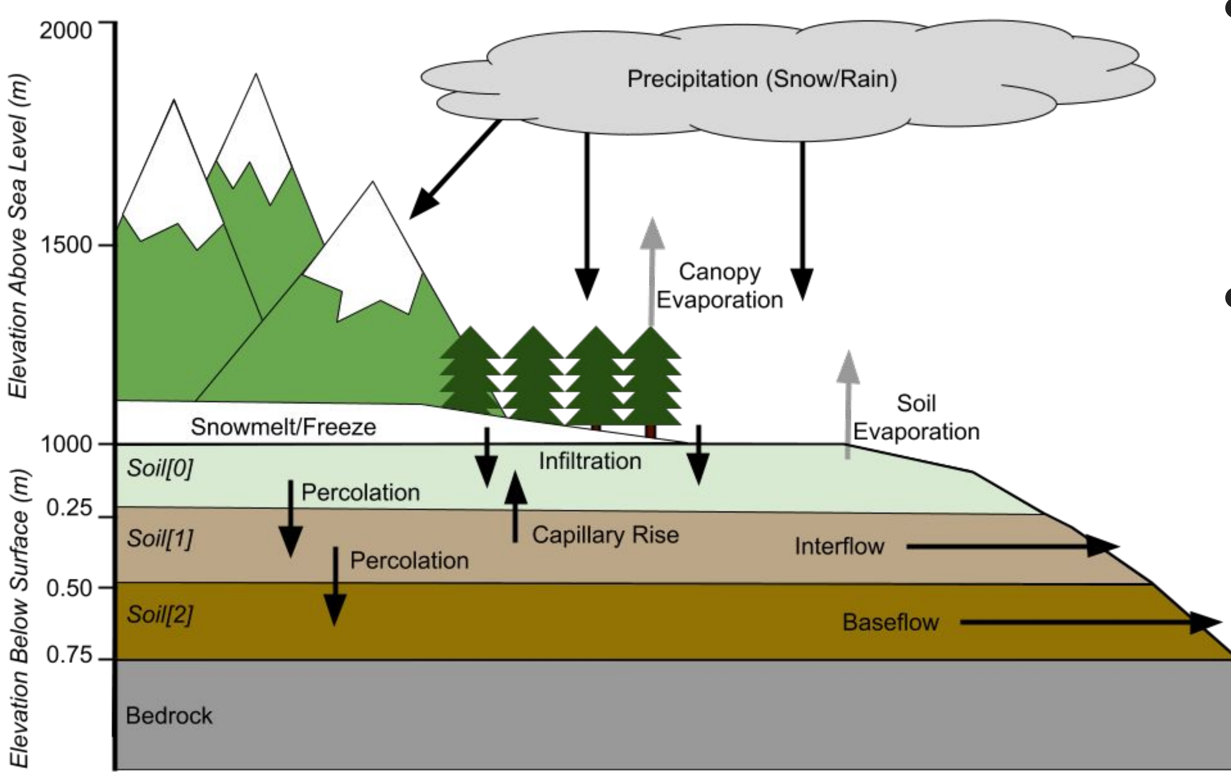
Hydrological model



- Semi-distributed HBV-EC model using Raven Hydrological Modelling Framework
- 8 major watersheds (43 sub-basins HUC10s in total) on Eastern Slopes were simulated using a relatively parsimonious model with a single parameter set

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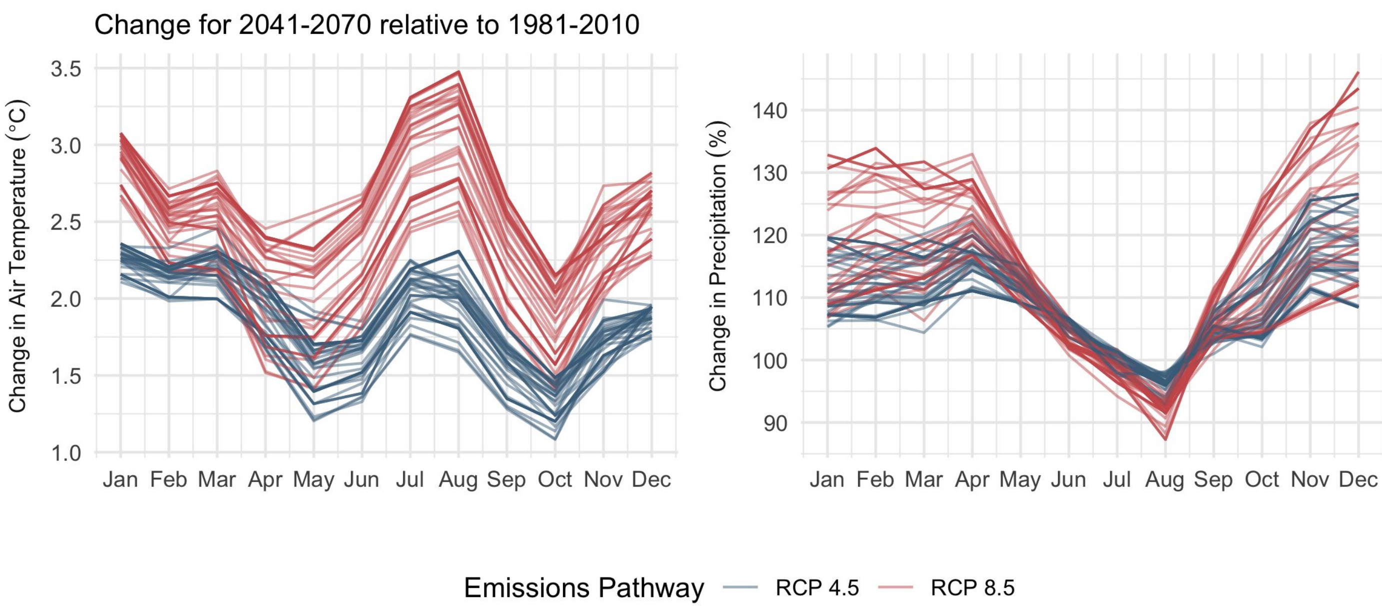
Climate Change Simulations

- Model run under baseline period (1988-2017) and future period (2041-2070)
- Median projection from Environment and Climate Change Canada's statistically downscaled climate scenarios ensemble forecast of CMIP5 29 General Circulation Models (RCP 4.5, 8.5)



Model Calibration

Model parameters (17 in total) are calibrated to fit simulations to observations

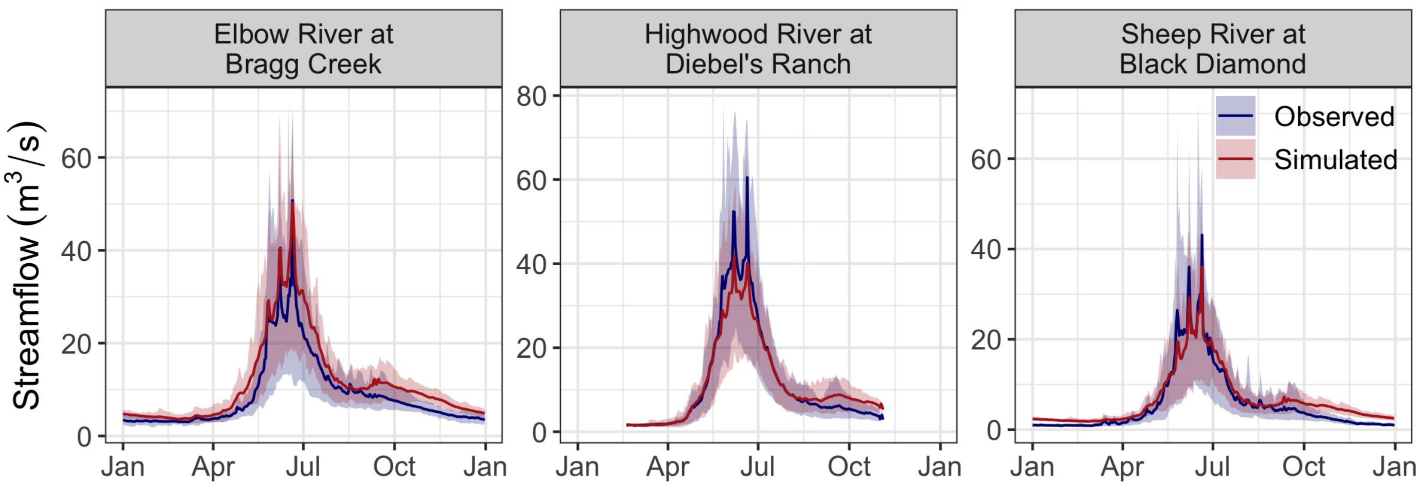
- Ensure proper process-representation (i.e. help reduce equifinality)
  - Calibrate lapse rates to temperature and precipitation observations from climate stations
  - Calibrate melt factors and lapse rates with SWE from regional snow pillow network
  - Calibrate routing and interception parameters from streamflow observations
- Calibrated model using 3 watersheds; others only used in model verification.

Guiding principle	Parameters	Criteria/objective
1) Isolate and exclude insensitive parameters	All	*CSS* < 1
2) Ensure correct air temperature and precipitation	T, P lapse rates	Maximize r^2, minimize *PBIAS* for T, P and SWE at independent climate stations
3) Ensure correct snowpack dynamics	melt factors	
4) Ensure no bias in water yield	Vegetation interception, vegetation snowmelt	Maximize NSE_Q, Minimize *PBIAS*
5) Emulate daily hydrograph shape and variability	Soil routing parameters	

Note: NSE is the Nash-Sutcliffe Efficiency coefficient, CSS is the composite scaled sensitivity, and PBIAS is the percent bias, while the subscript Q represents daily streamflow. T, P, and SWE correspond to air temperature, precipitation, and snow water equivalent.

Model Verification

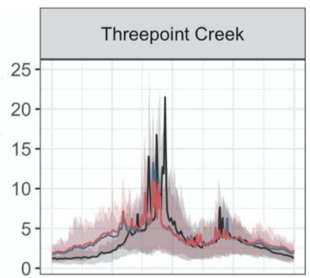
- *Compare model outputs with independent observations (i.e not used in calibration);*
  - Daily average air temperatures (r^2 = 0.93 to 0.97),
  - Daily precipitation (r^2 = 0.11 to 0.78),
  - Daily SWE (r^2 = 0.79-0.91)
- Streamflow NSE values in verification sites/periods ranged from 0.6 - 0.8 for most sites, above 0.7 for larger watershed outlets (19 total sites).

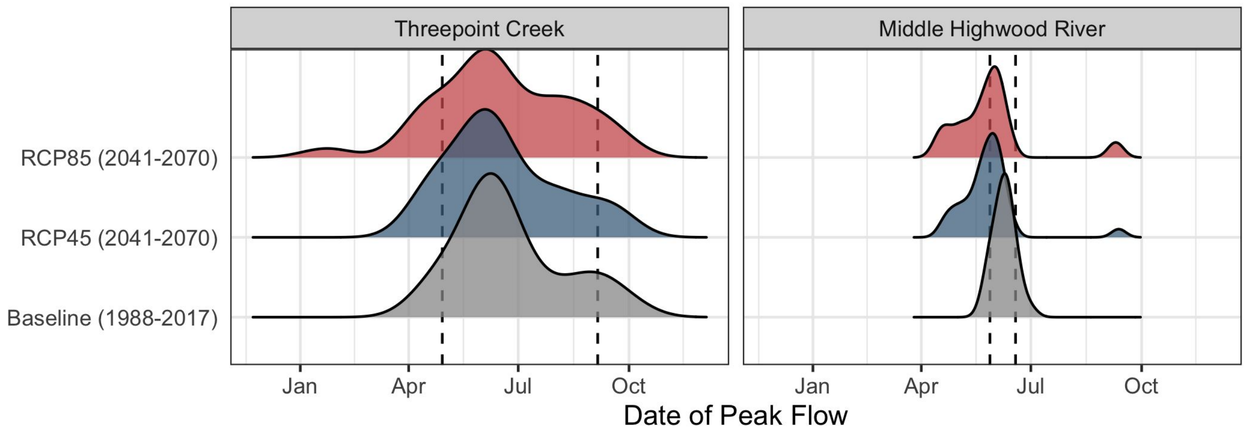


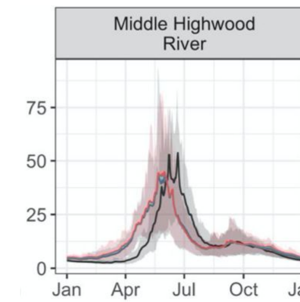
Good performance in multiple criteria; suggests model is "right for the right reasons"

Identifying the Peak Flow Period

Peak Flow Period: the 10 and 90% quantiles of the Julian Day of peak flow for each sub-basin over a 30-year period.







More variable flows, longer peak flow period that covers most of the ice-free season.

Less variable flows, shorter peak flow period that is mostly constrained to "spring" snowmelt.

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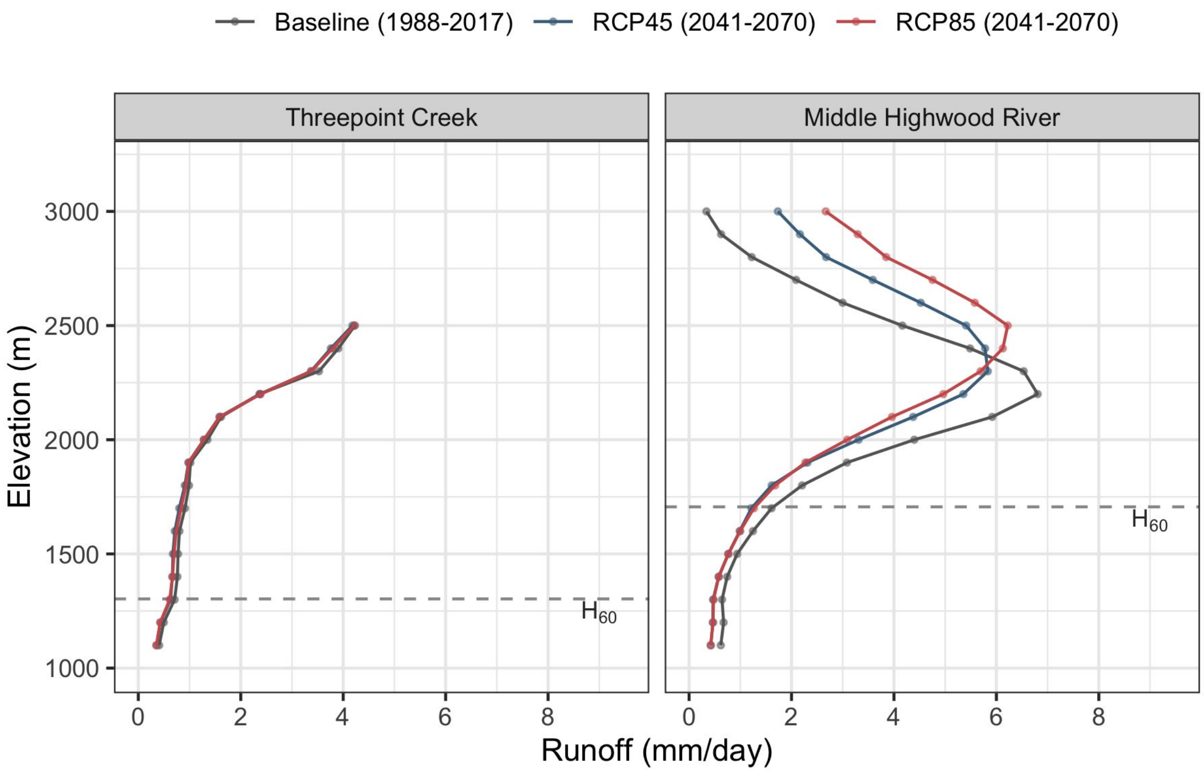
Where does Peak Flow Period runoff come from?



Areas of highest runoff during the Peak Flow Period are generally located between 2,000 m and 2,500 m in high-elevation HUC10s (i.e. Highwood River) and at the highest attainable elevations in lower-elevation HUC10s (1,800 m to 2,200 m).

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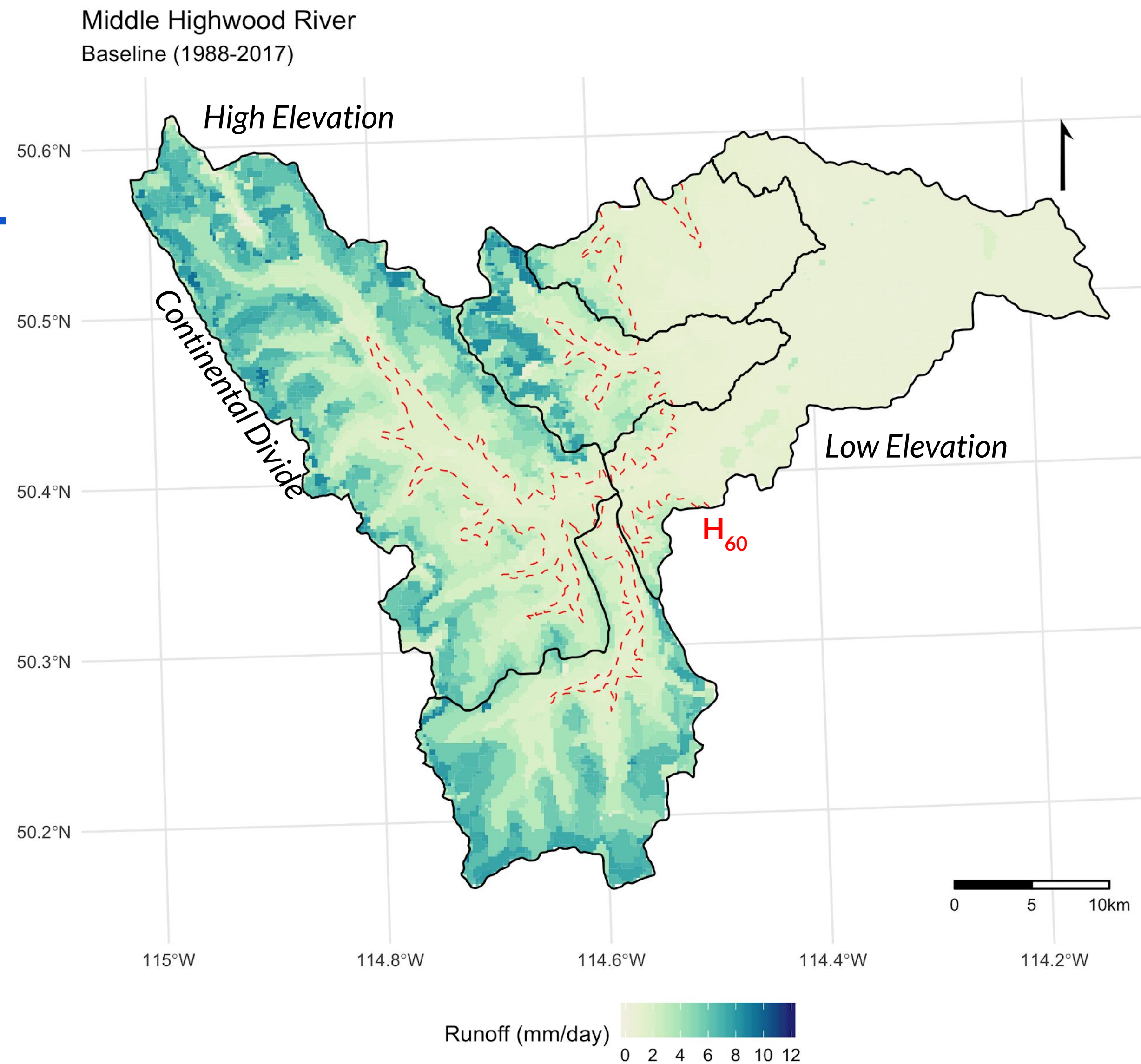
Peak Flow Runoff

Highest along more westerly portions of the study area.

Peak Flow Period driven primarily by snowmelt and covers a relatively short period (~1 month).

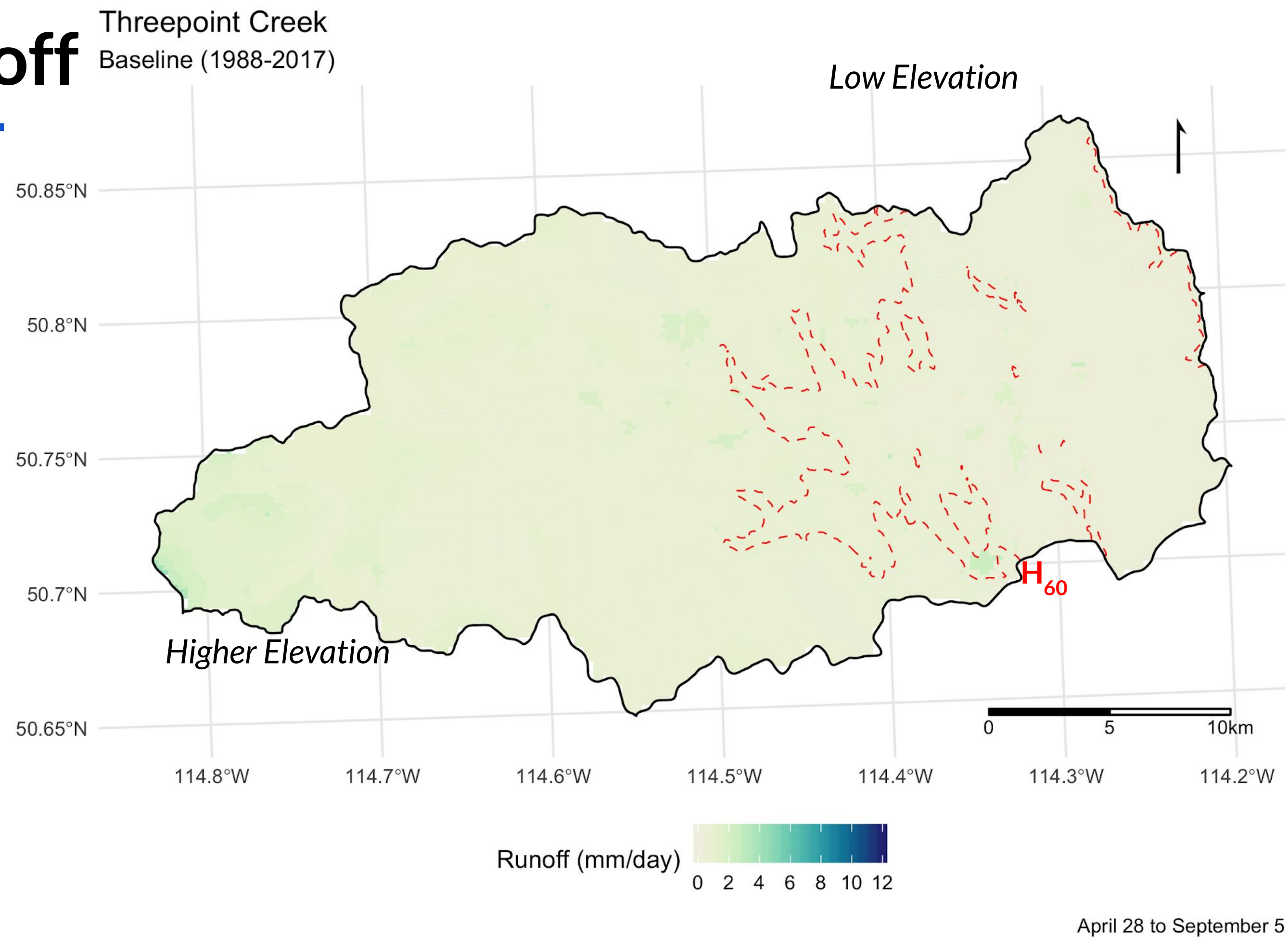


May 28 to June 18

Peak Flow Runoff

Lower elevation watersheds have a shallower snowpack and a smaller snowmelt signal.

Peak Flow Period that spanned the entire ice-free summer period (May-September).



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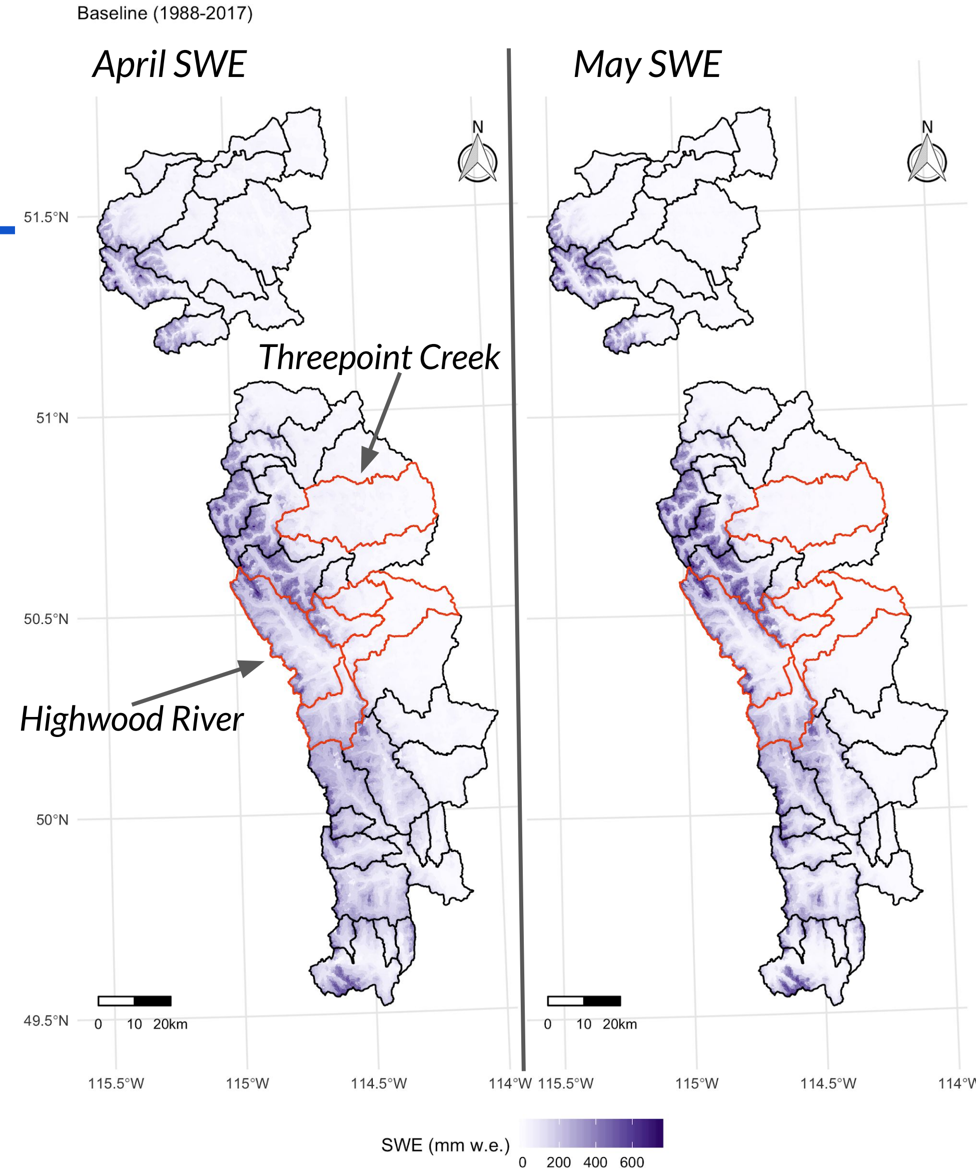
The Headwaters

Runoff during the Peak Flow Period predominantly comes from the headwaters where the snowpack is deeper and melts later in the year.



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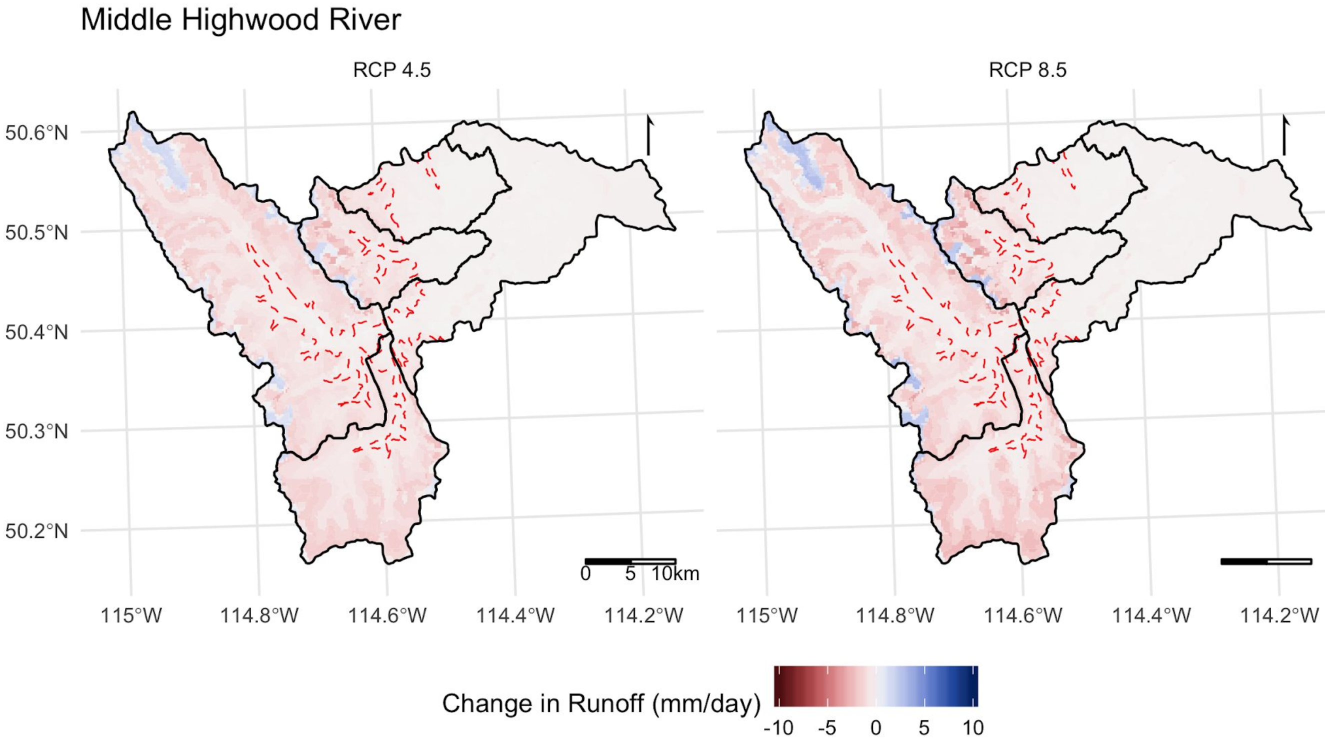
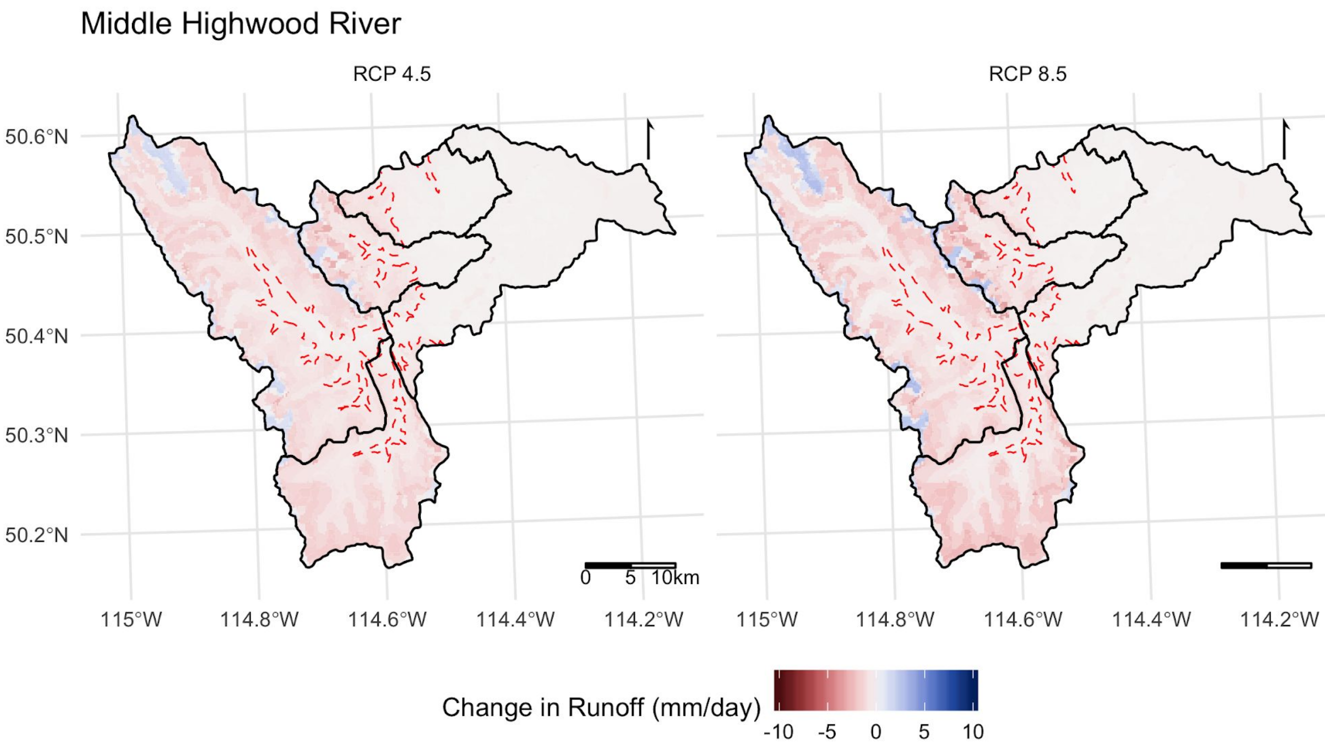
Future runoff during Peak Flow Period



Runoff (mm/day) projected to decrease at most elevations due to a longer Peak Flow Period (i.e. not less water, just spread out over longer period).

Future runoff during Peak Flow Period



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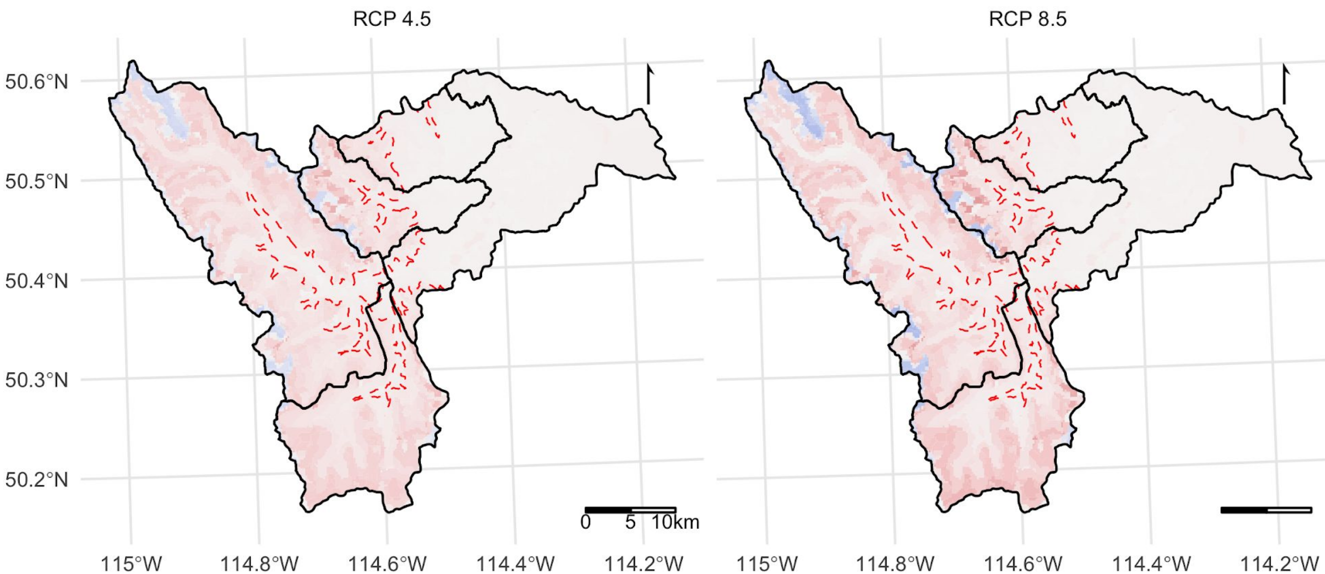
Increase is concentrated in the highest elevations with:

- *A deeper snowpack*
- *Increased precipitation under the climate change scenarios,*
- *Faster melt rates,*
- *Warmer air temperatures melting out low elevations earlier*

Future runoff during Peak Flow Period

Middle Highwood River



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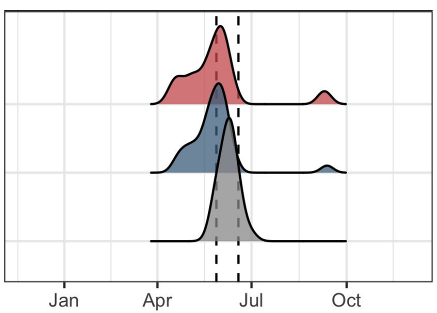

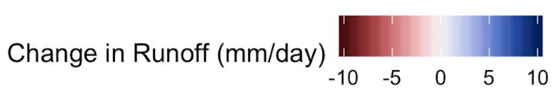

Under future scenarios Peak Flow Period is longer; Suggests more variability in flow timing, and a less snowmelt dominated freshet

Conclusions

- Results from this study generally align with the prevailing understanding of increased sensitivity of higher elevation areas to forest disturbance.
- This study highlights some of the shortcomings of hypsometric statistics, such as the H_{60}, where Peak Flow Period Runoff:
    - Follows a continuous gradient rather than a binary level,
    - Has substantial regional variability due to climate and hypsometry,
    - Is likely to change under future climate change.
- Demonstrates the applicability of a more localized approach to identifying high-runoff areas.

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Acknowledgements

- Funders:
  - A report was submitted in May 2019 and March 2020 to Forest Resource Improvement Association of Alberta (FRIAA), Alberta Agriculture and Forestry Forest Management Branch, and fRI Research as part of the FRIAA-FFI 2017 Initiative (reference number EOI FFI-17-15).

- Slides:
  - https://github.com/mchernos/CGU2020

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Upper Sheep River. Photo: M. Chernos