Hydrologic Observations and Modeling in the Rain-Snow Transition Zone

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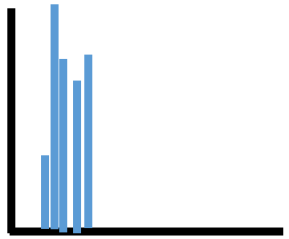
Catchment Hydrology: Thinking Inside the Box



Receive

Rain and Snow

Q = f(P, S, T)

Store

Transmit

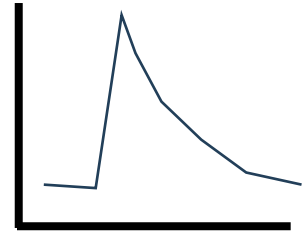
Partition

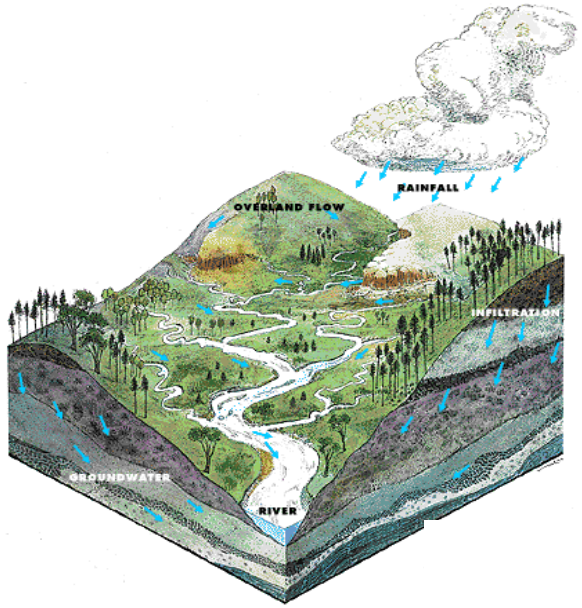
Release

Streamflow

Evapotranspiration

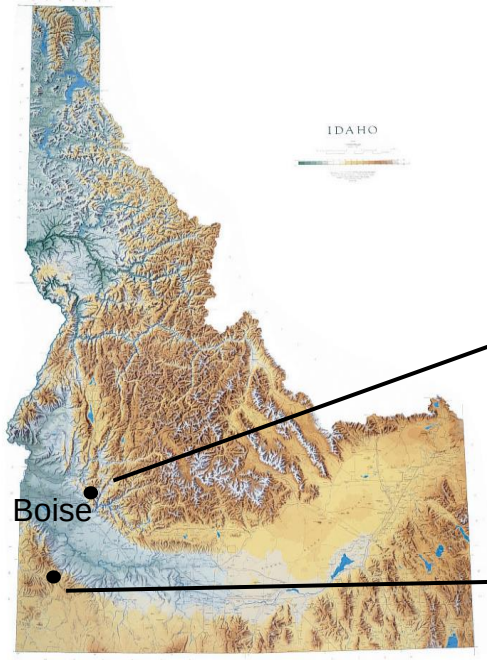
Deep Infiltration





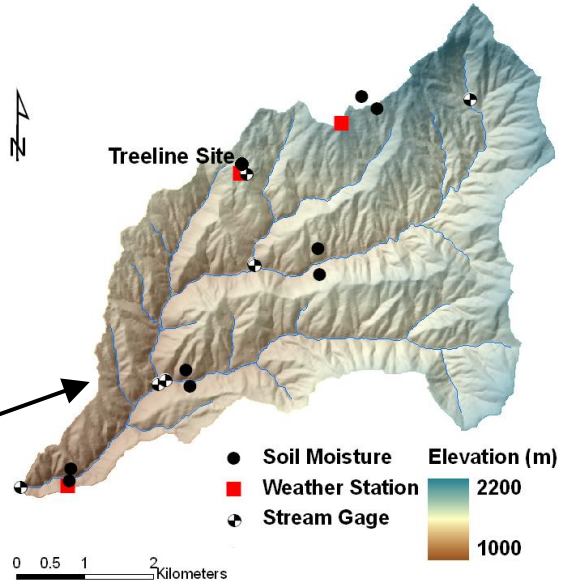
We look inside the box to seek process understanding

Reynolds Creek and Dry Creek



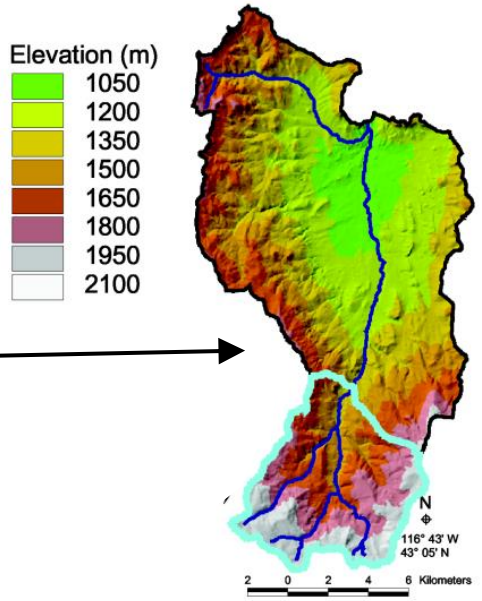
Since 1998

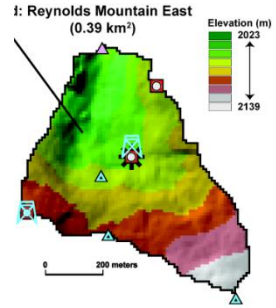
Dry Creek Experimental Watershed

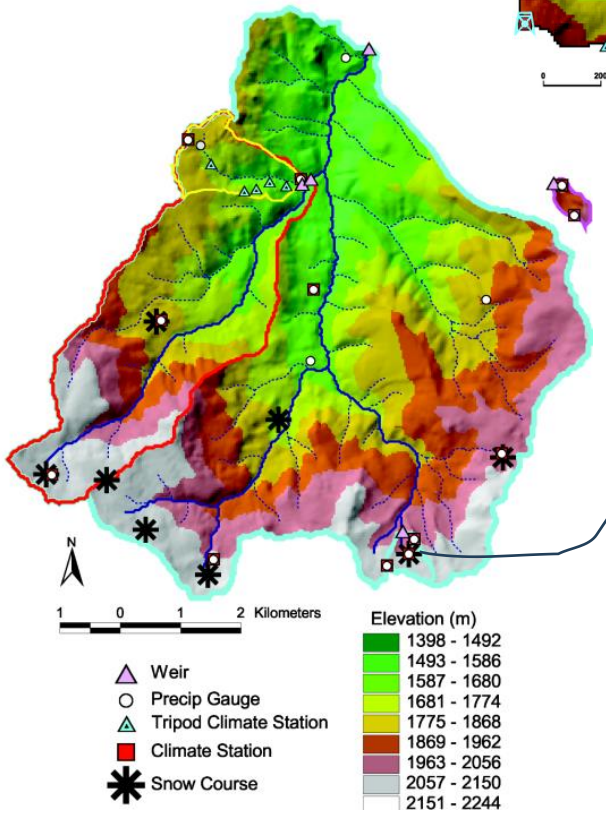


Since 1965

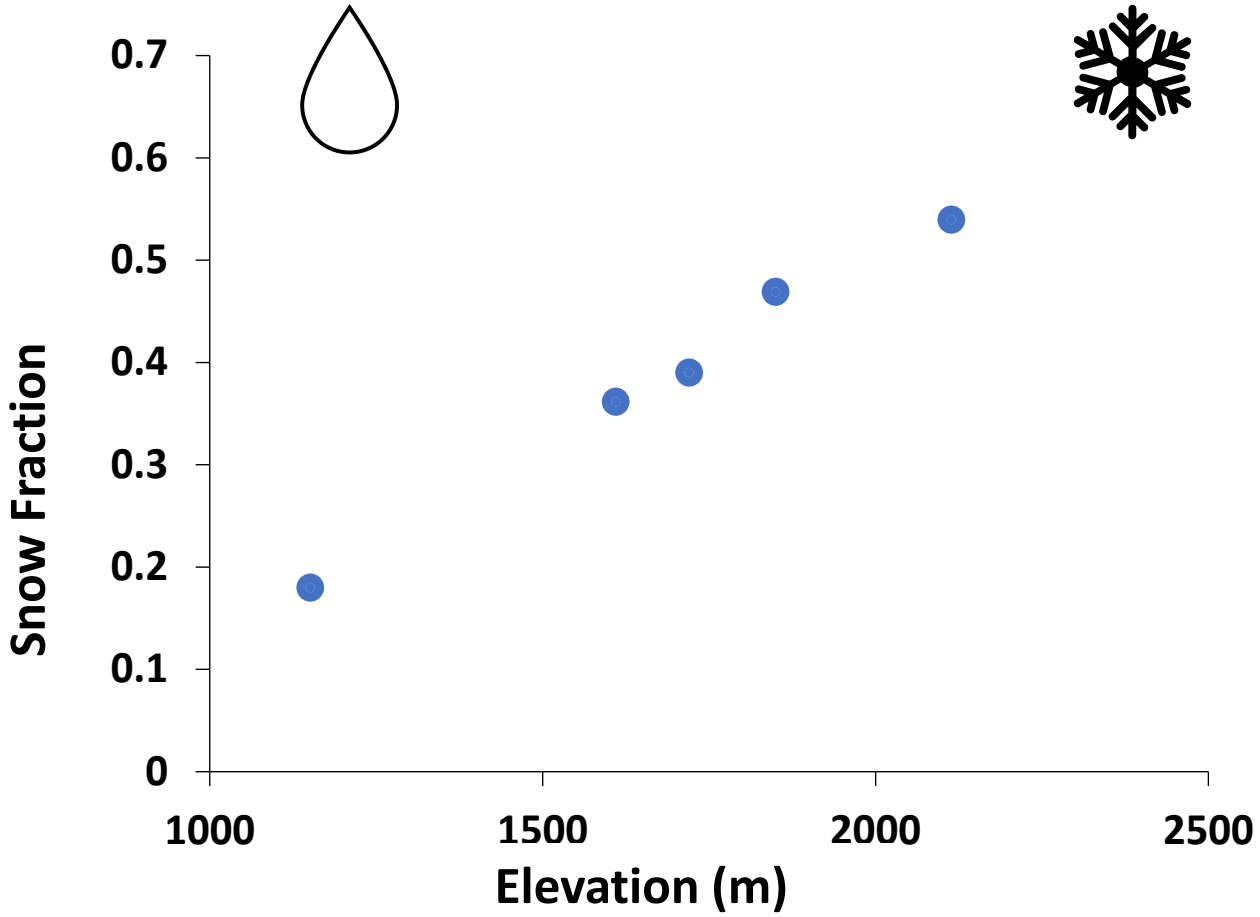
Reynolds Creek Expimental Watershed (239 km²) and Tollgate sub-basin (55 km²)





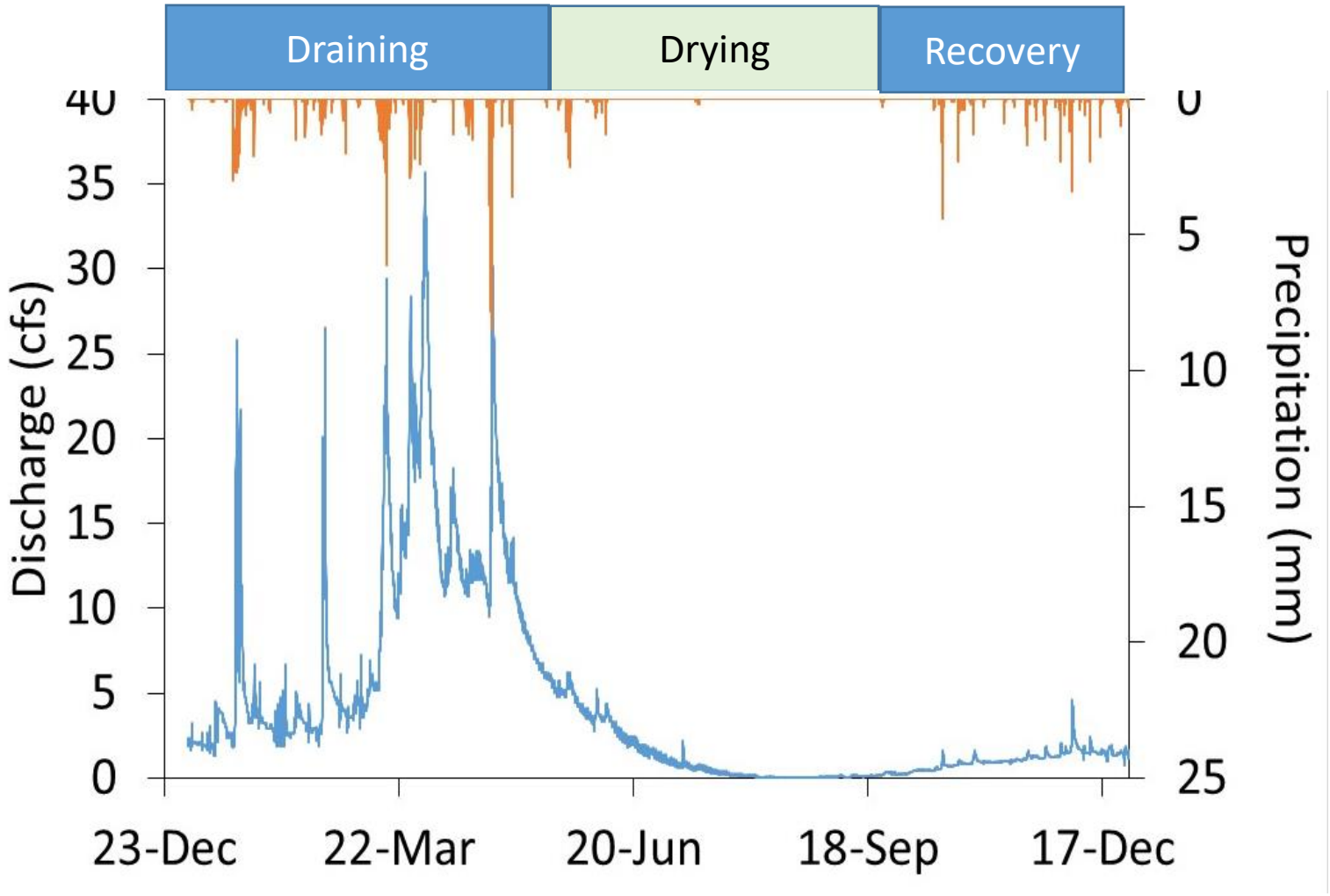


Rain to Snow



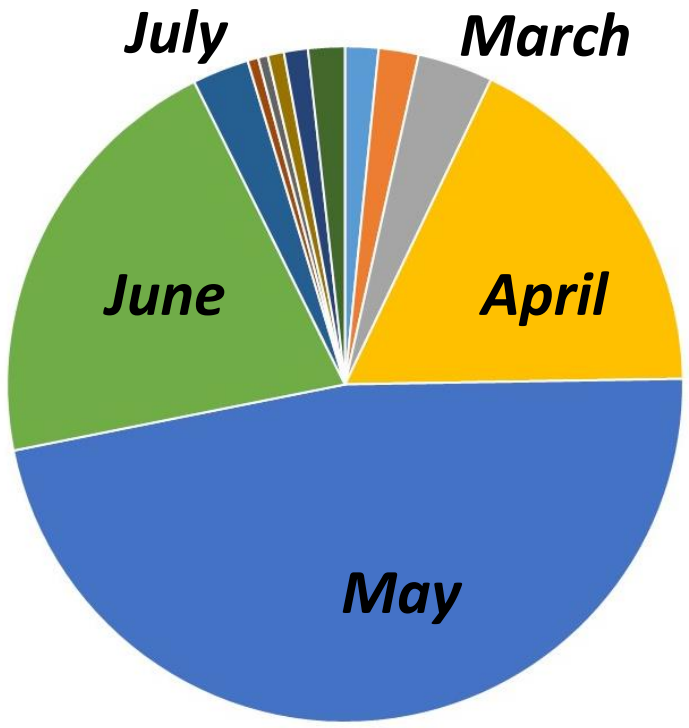
Morell (2024)

Dry Creek Experimental Watershed

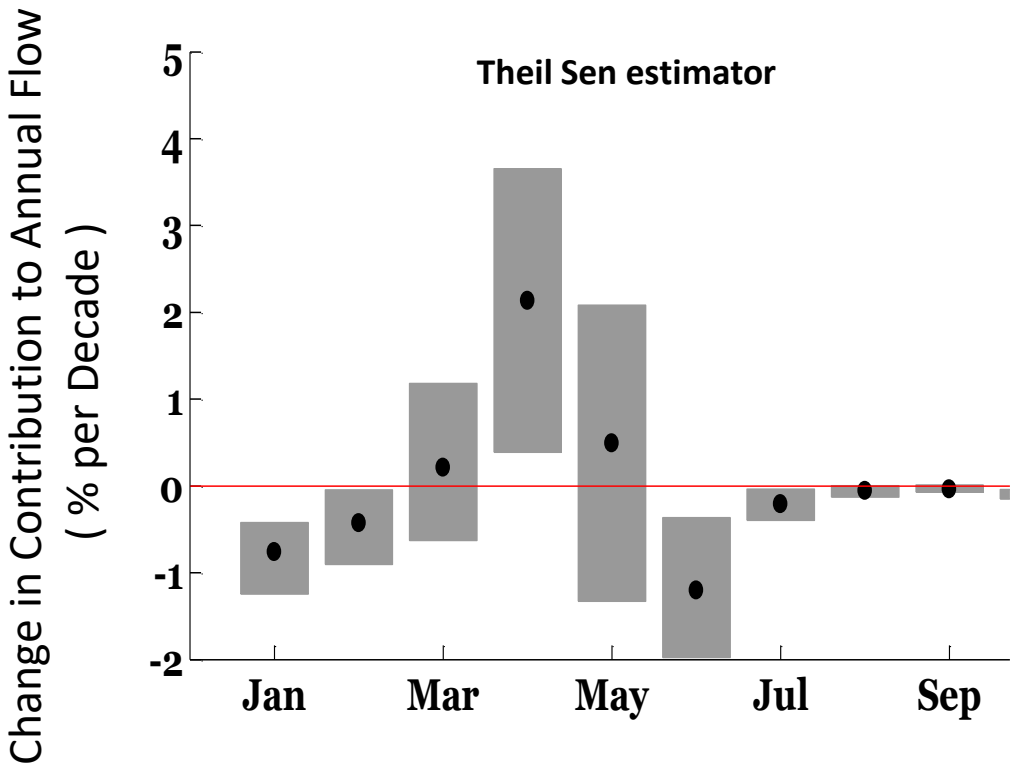


Spring is taking water from summer

Average
Proportion of Annual Flow



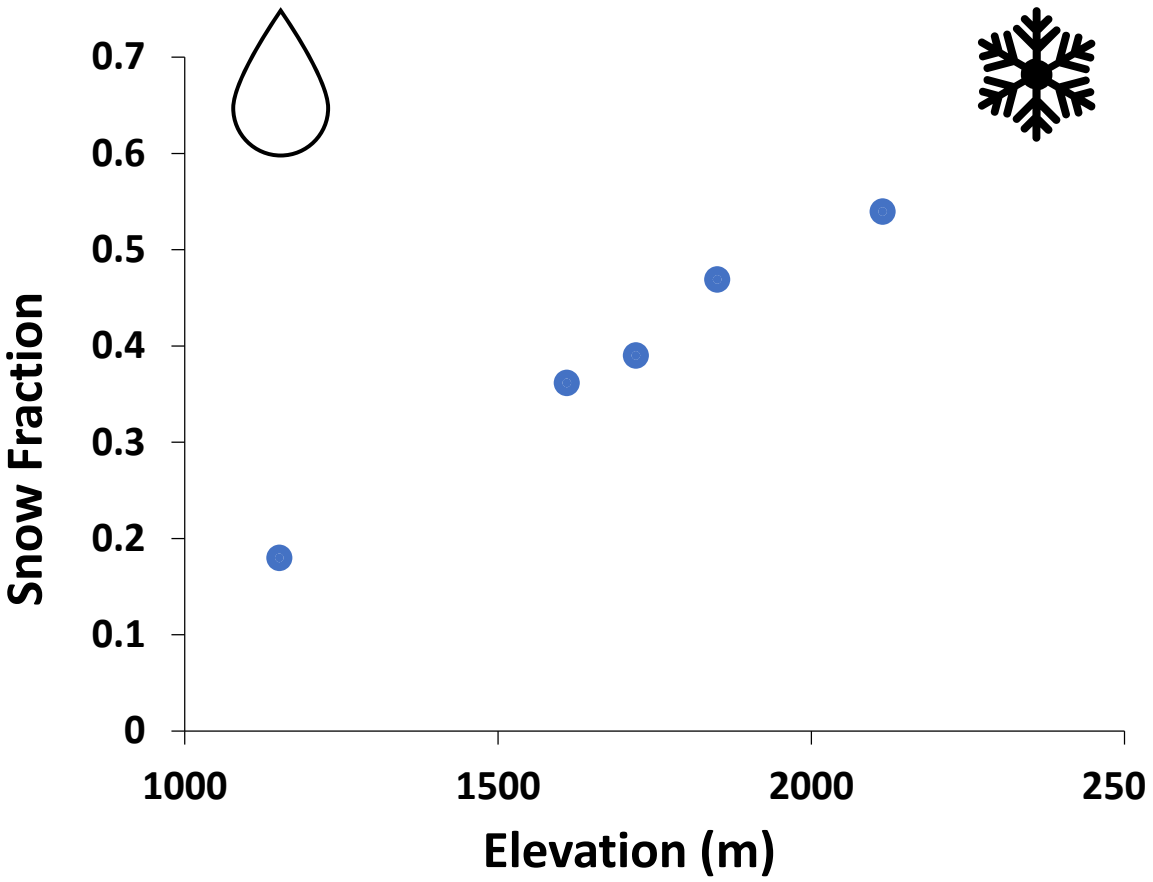
Change in
Proportion of Annual Flow

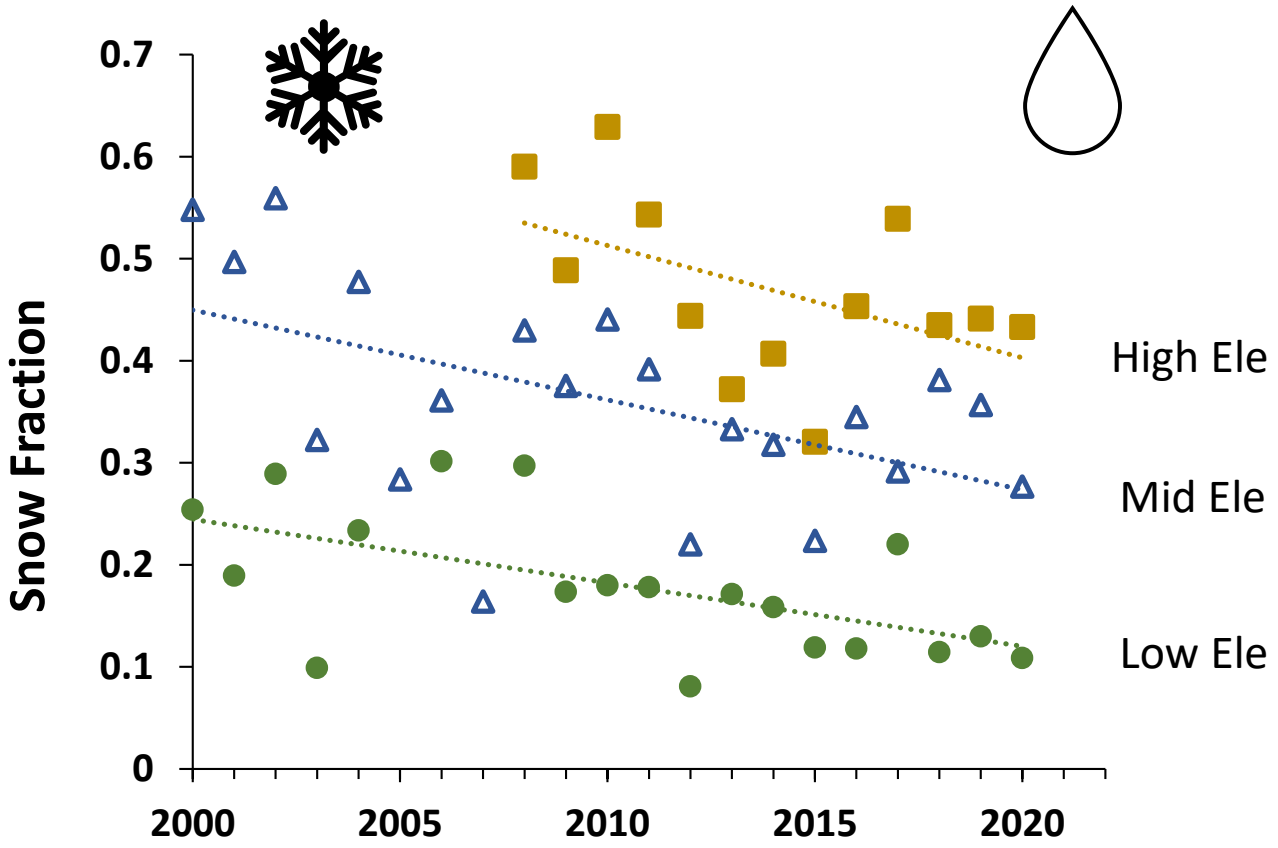


Chris Graham (unpublished)

Spatial Rain to Snow

Temporal Snow to Rain





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Motivation

nature climate change

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Letter | Published: 18 May 2014

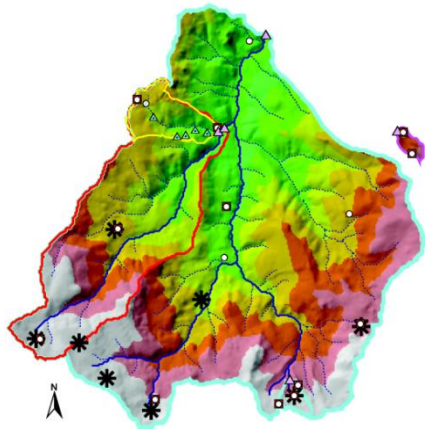
A precipitation shift from snow towards rain leads to a decrease in streamflow

W. R. Berghuijs, R. A. Woods & M. Hrachowitz

Nature Climate Change **4**, 583–586 (2014) | Cite this article

Snow-dominated catchments produce more runoff than rain-dominated catchments.

Question



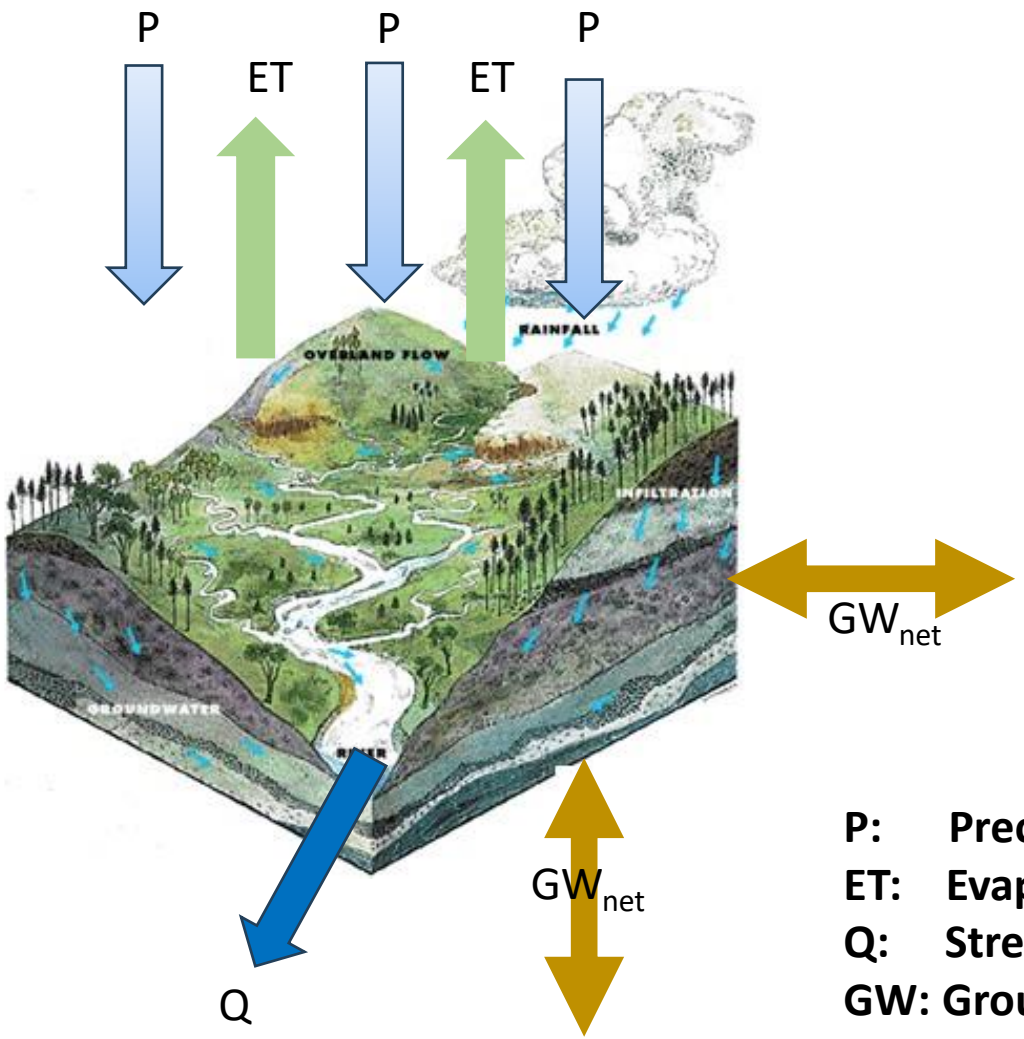
Do snow-dominated **years** produce more streamflow than rain-dominated years within a catchment?

- **Analysis of Long-term observations in experimental catchments**

If so, why?

- **Models as virtual laboratories**
  - **Cold Regions Hydrology Model**
  - **ECH2O**

Water Balance Basics



$$P = ET + Q + GW_{net} + \Delta S$$

$$1 = \frac{ET}{P} + \frac{Q}{P}$$

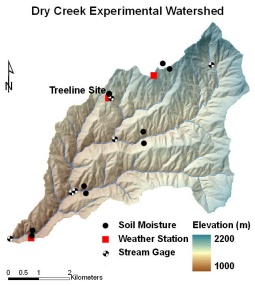
Runoff Fraction

$$P = Rain + Snow$$

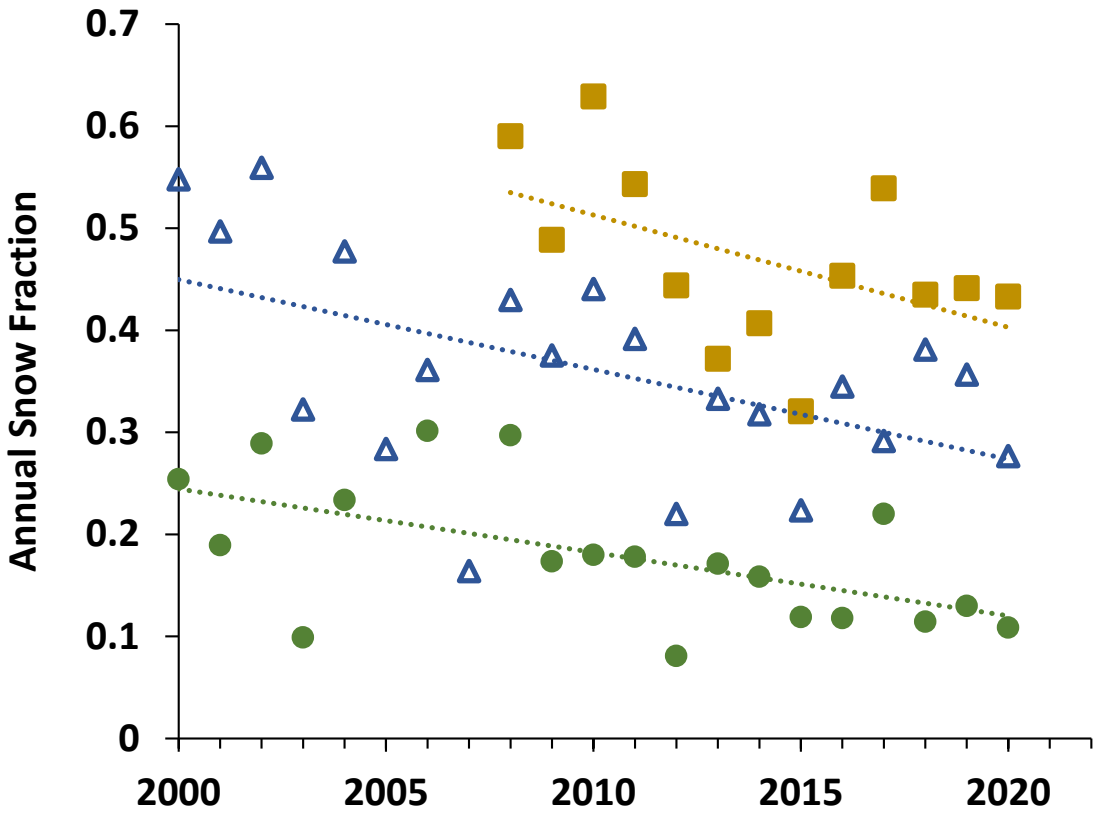
$$1 = \frac{Rain}{P} + \frac{Snow}{P}$$

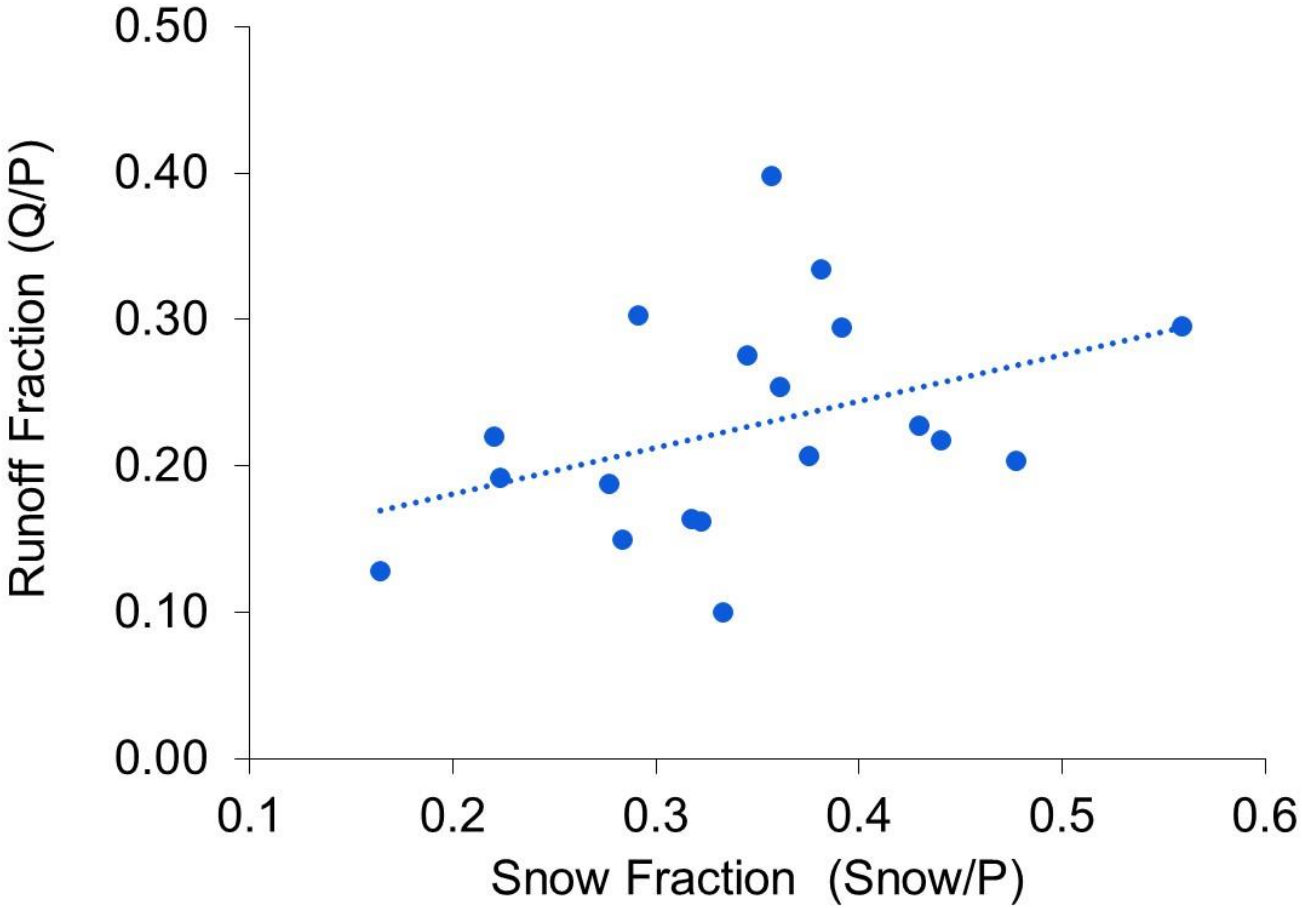
Snow Fraction

P: Precipitation
ET: Evapotranspiration
Q: Streamflow (discharge, runoff)
GW: Groundwater



Do Higher Snow Fraction YEARS Produce More Streamflow Within a Catchment ?





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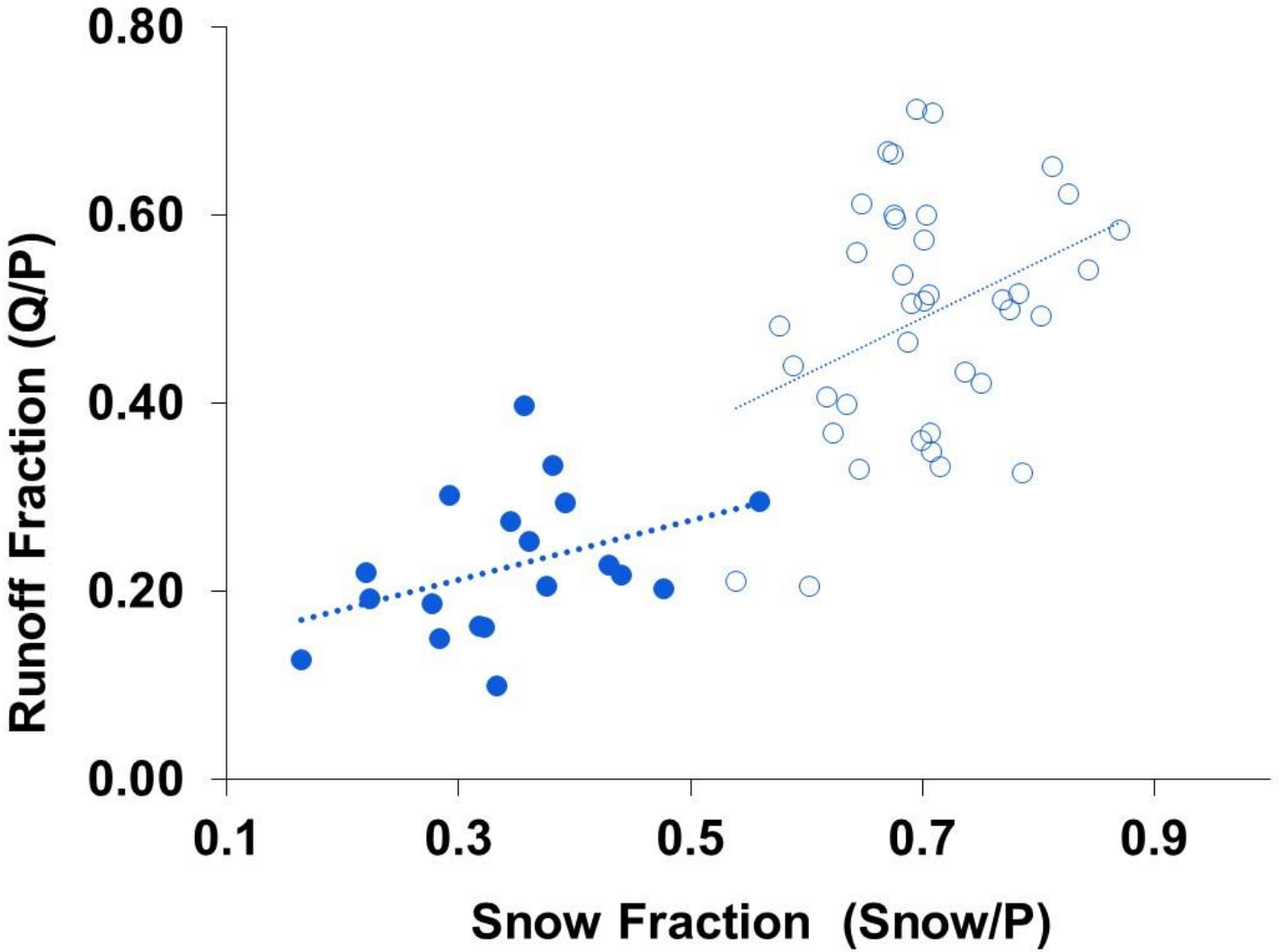
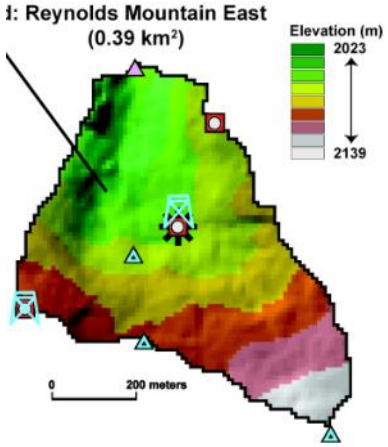
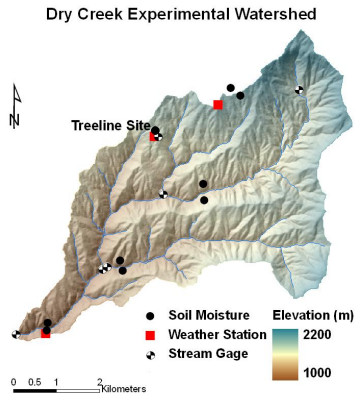
Snow Dominated Years Produce More Streamflow than Rain Dominated Years

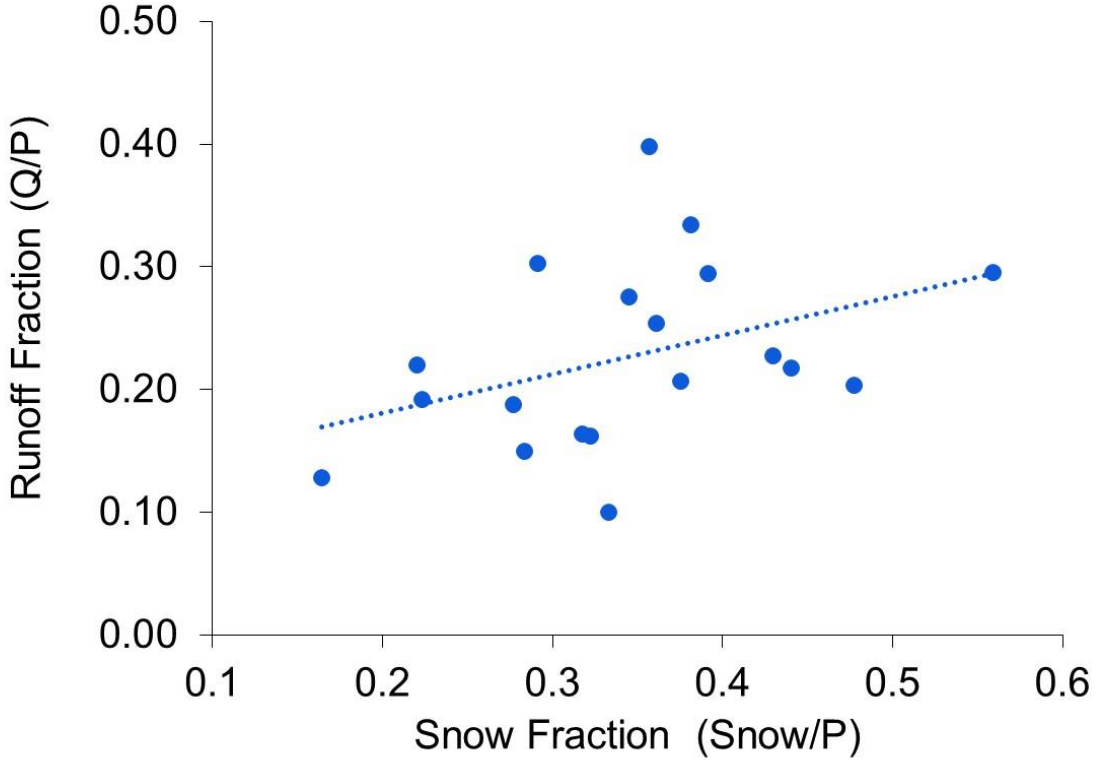






Do Higher Snow Fractions Years Produce Less Evapotranspiration?

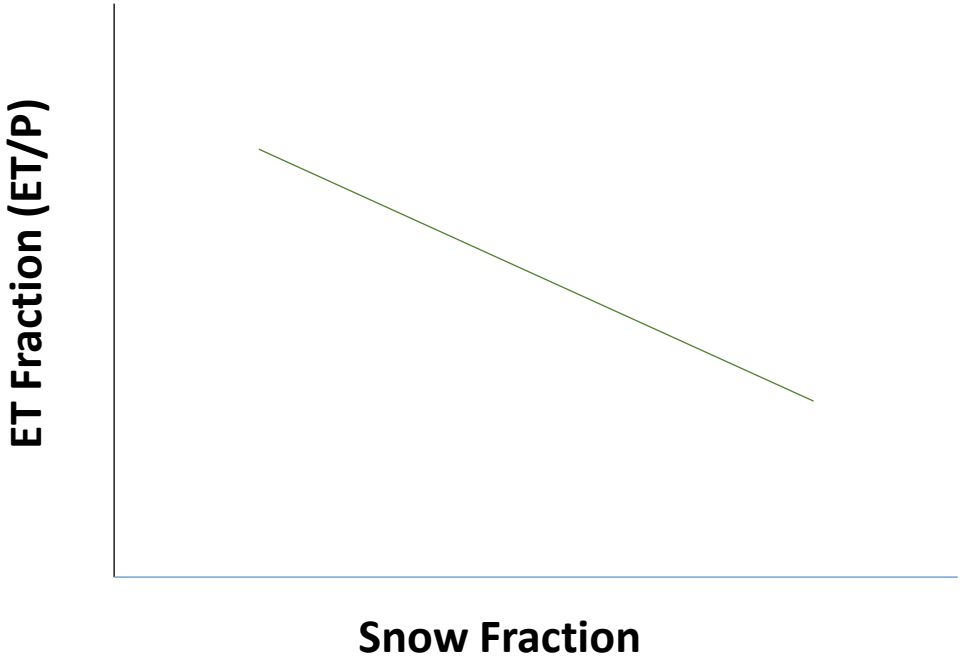
If this is true…



And this is true…

$$1 = \frac{ET}{P} + \frac{Q}{P}$$

Then this must be true…



Catchment Evapotranspiration

Point Scale

$$ET = \frac{\Delta(K+L) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\lambda_v(\Delta + \gamma(1 + \frac{r_a}{r_s})}$$

Penman-Monteith

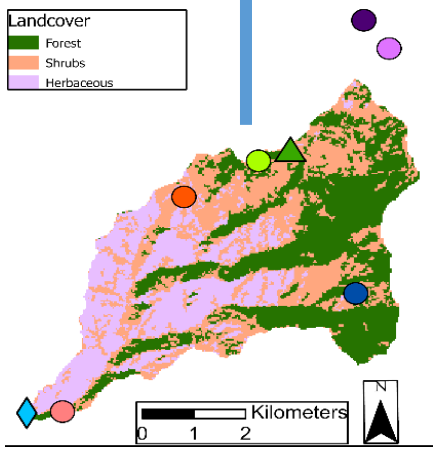
$$r_s = LAI * k * g_c^{mod}$$

Plant Conductance

$$g_c^{mod} = g_c^{max} f(R) f(T) f(D) f(W)$$

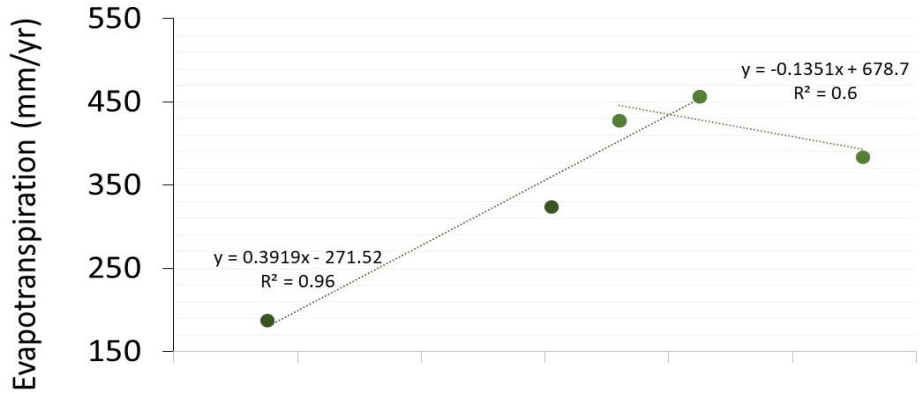
Stewart (1988) mods

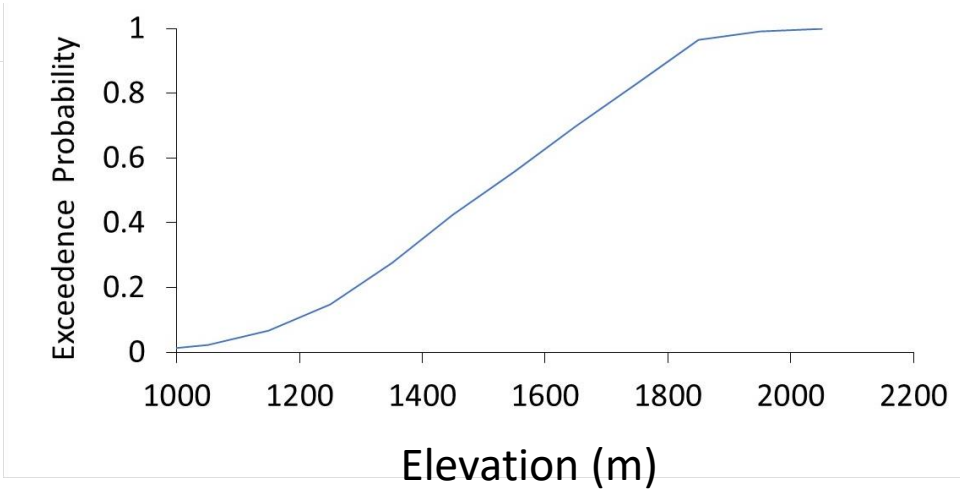
- Shortwave radiation
- Air Temperature
- Vapor Pressure Deficit
- Soil Moisture Deficit



Catchment Scale

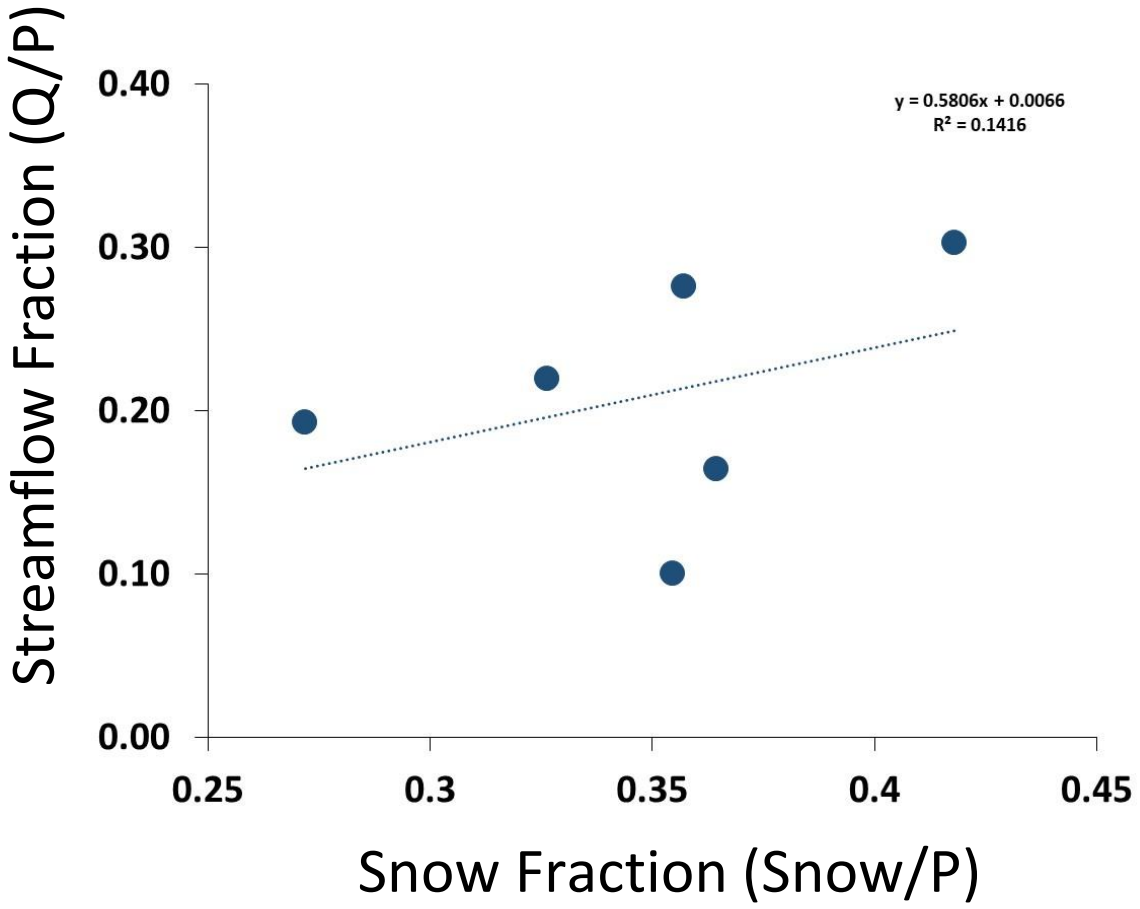
$$ET_c = \sum_{i=1}^{n} w_i ET_i$$



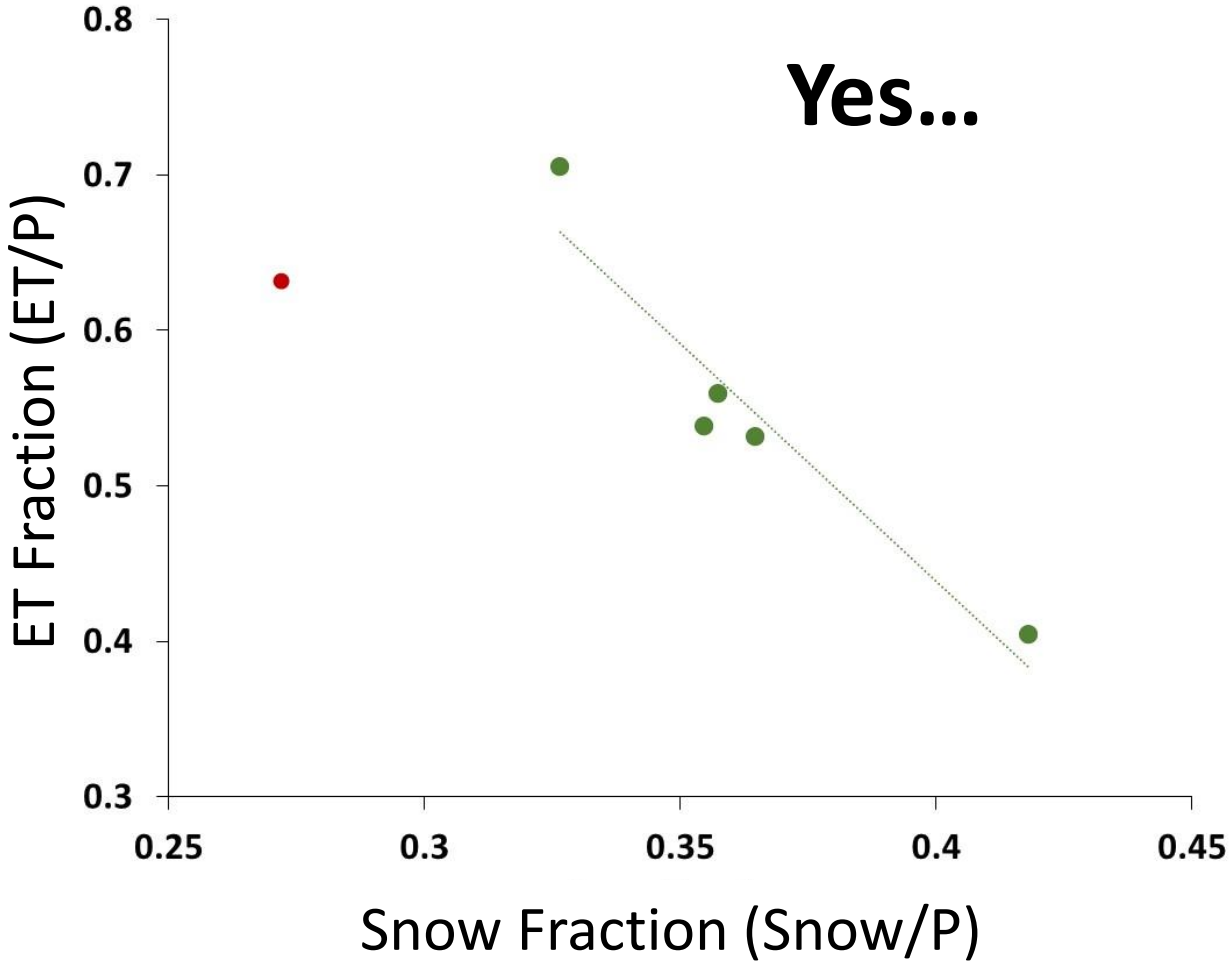


Do Higher Snow Fractions Produce Less Evapotranspiration?

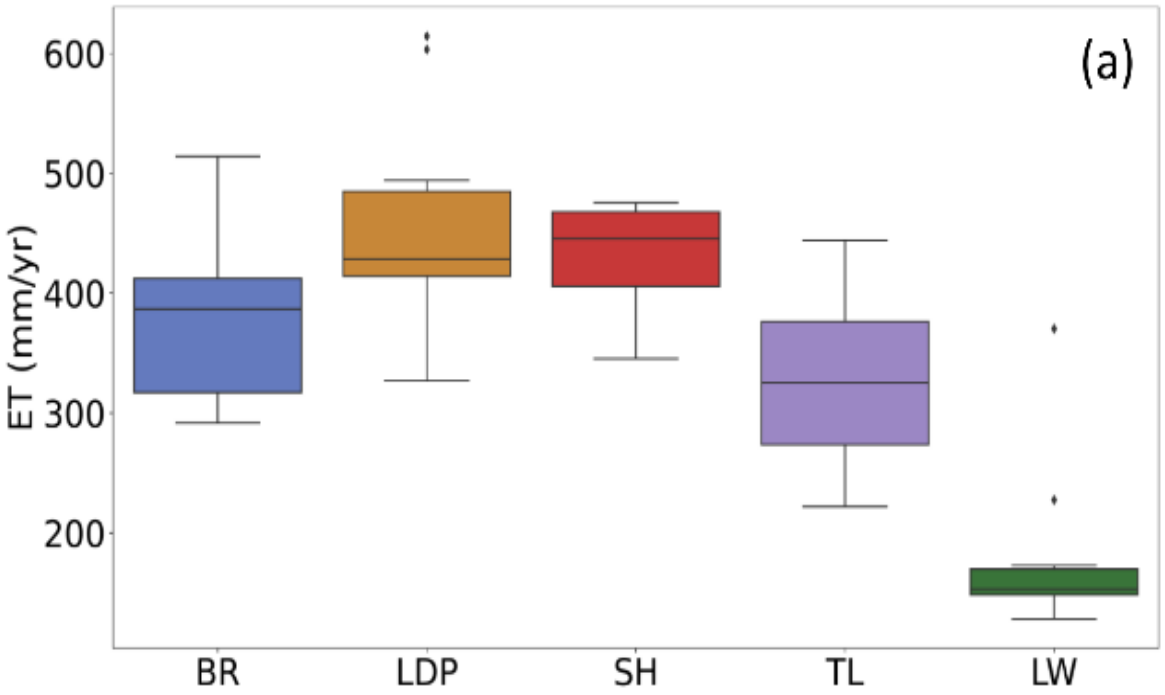
$$ET_c = \sum_{i=1}^{n} w_i ET_i$$

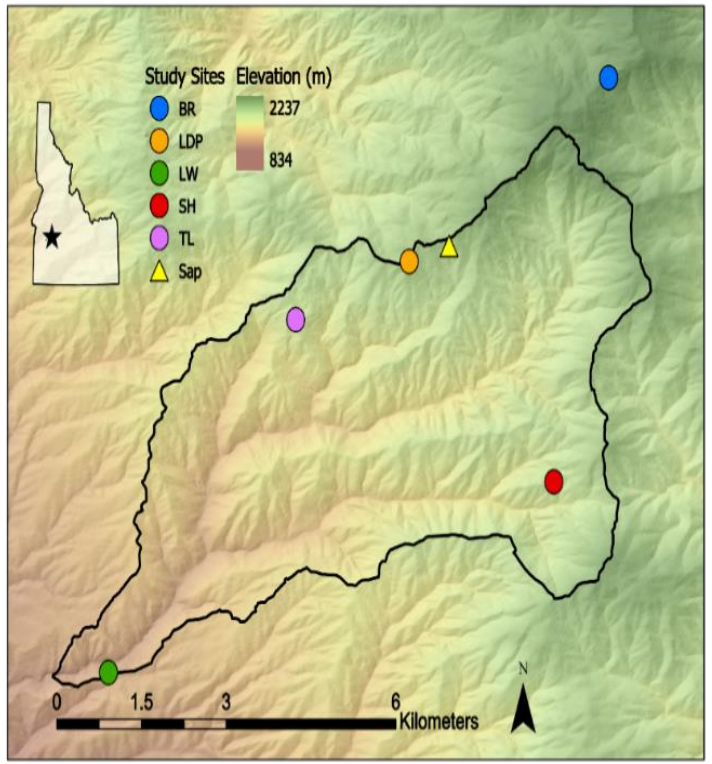


Yes…



Catchment Evapotranspiration





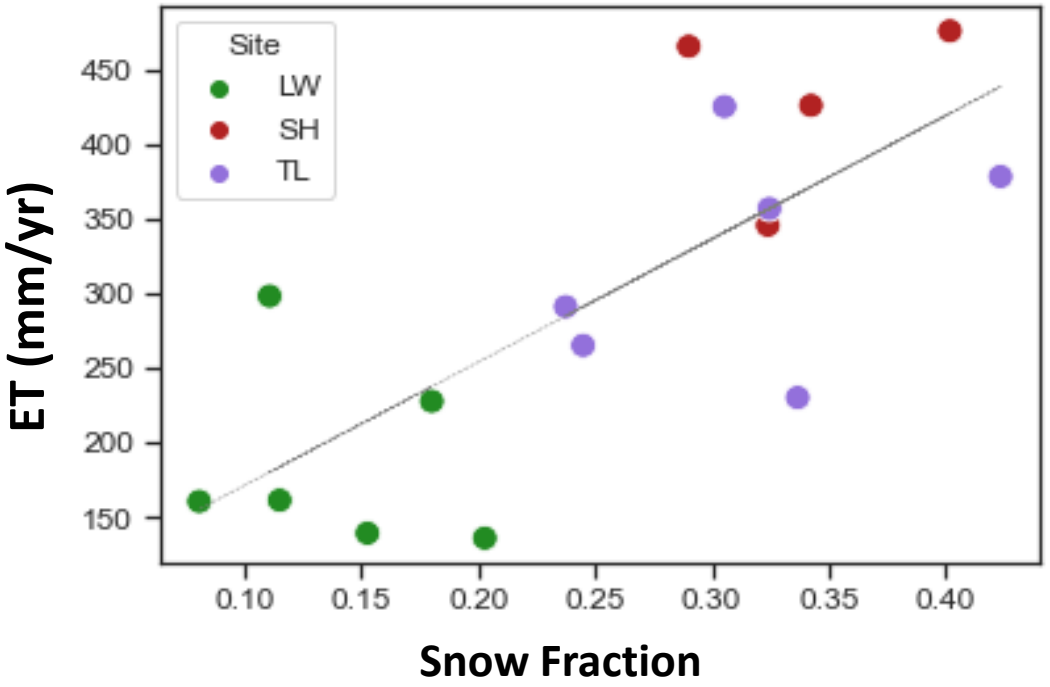
High Elevation

Low Elevation

Kraft and McNamara (2022)

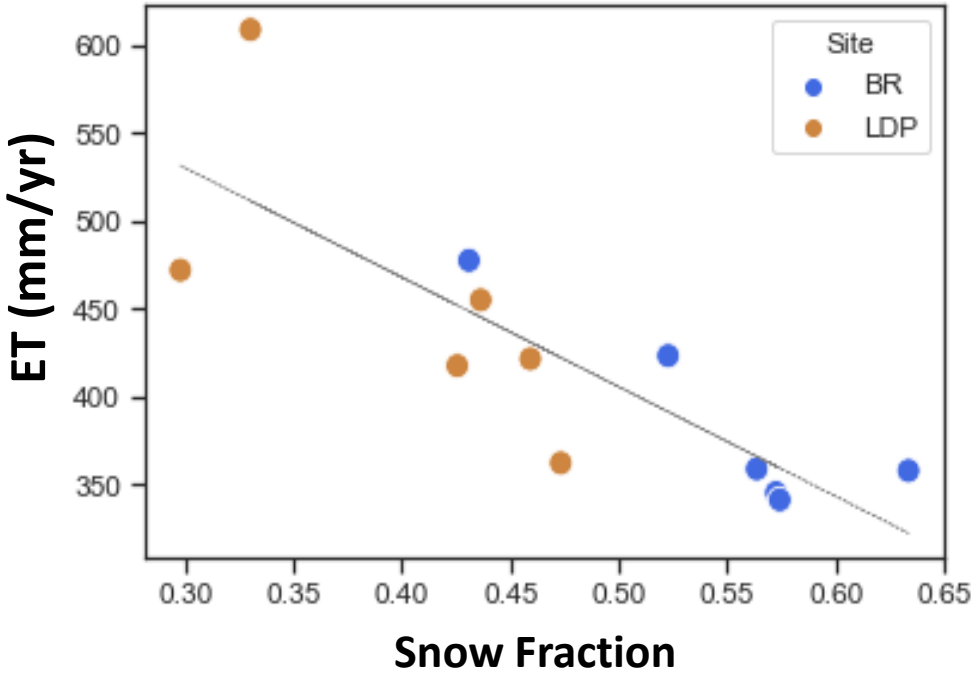
Kraft and McNamara (2022)

Rain-Dominated Zone
Generally water-limited



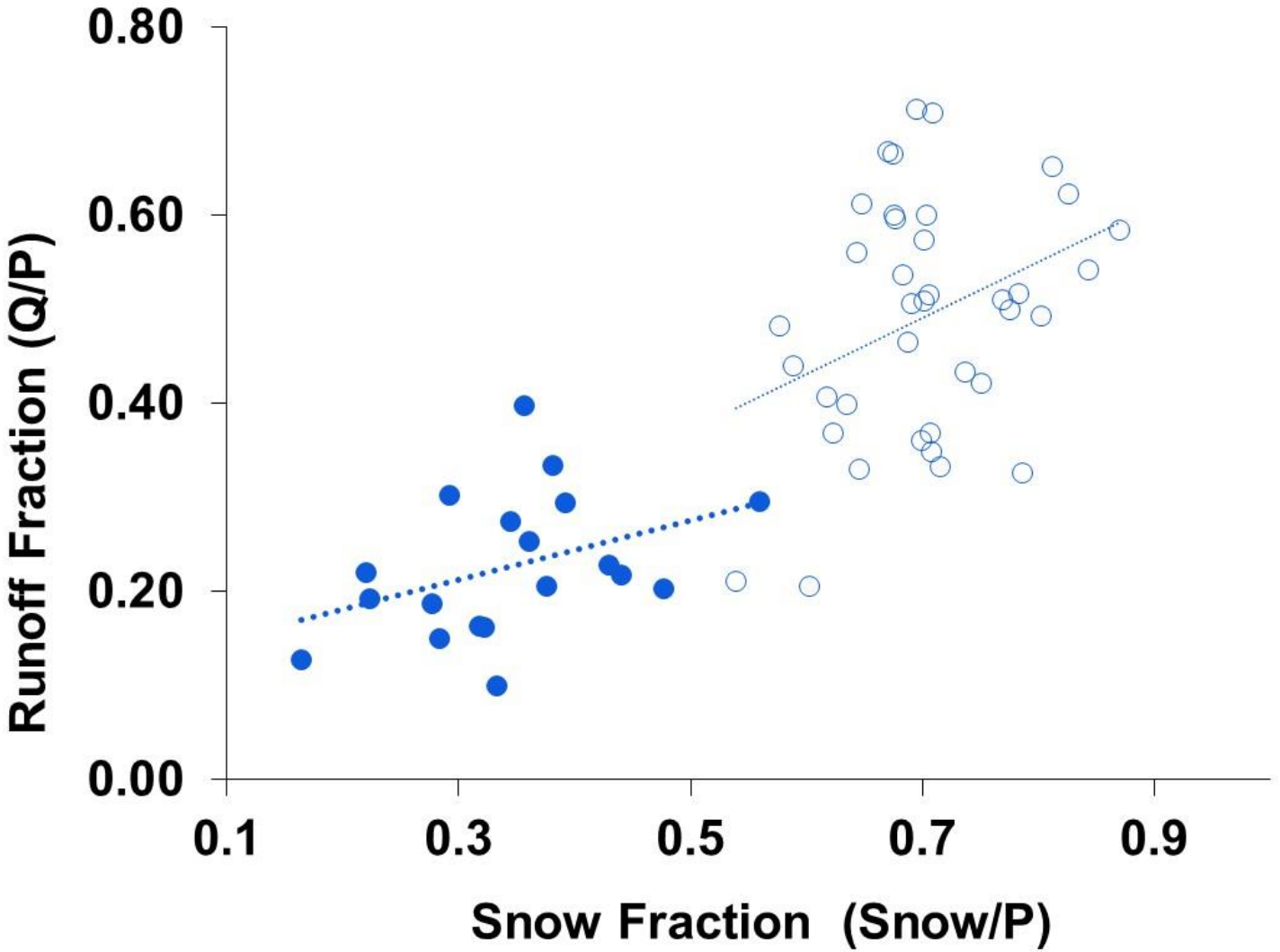
- Snow fraction and ET increase with elevation
- No correlation within a site

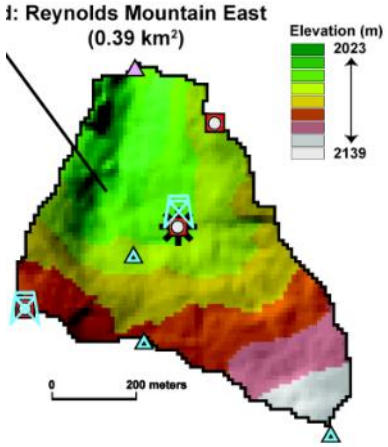
Snow-Dominated Zone
Generally energy-limited

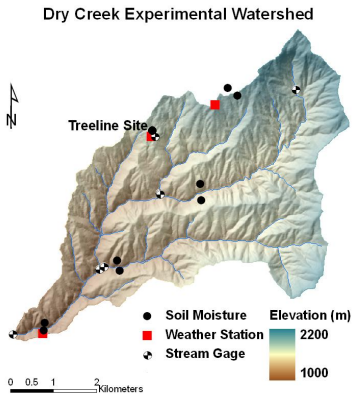


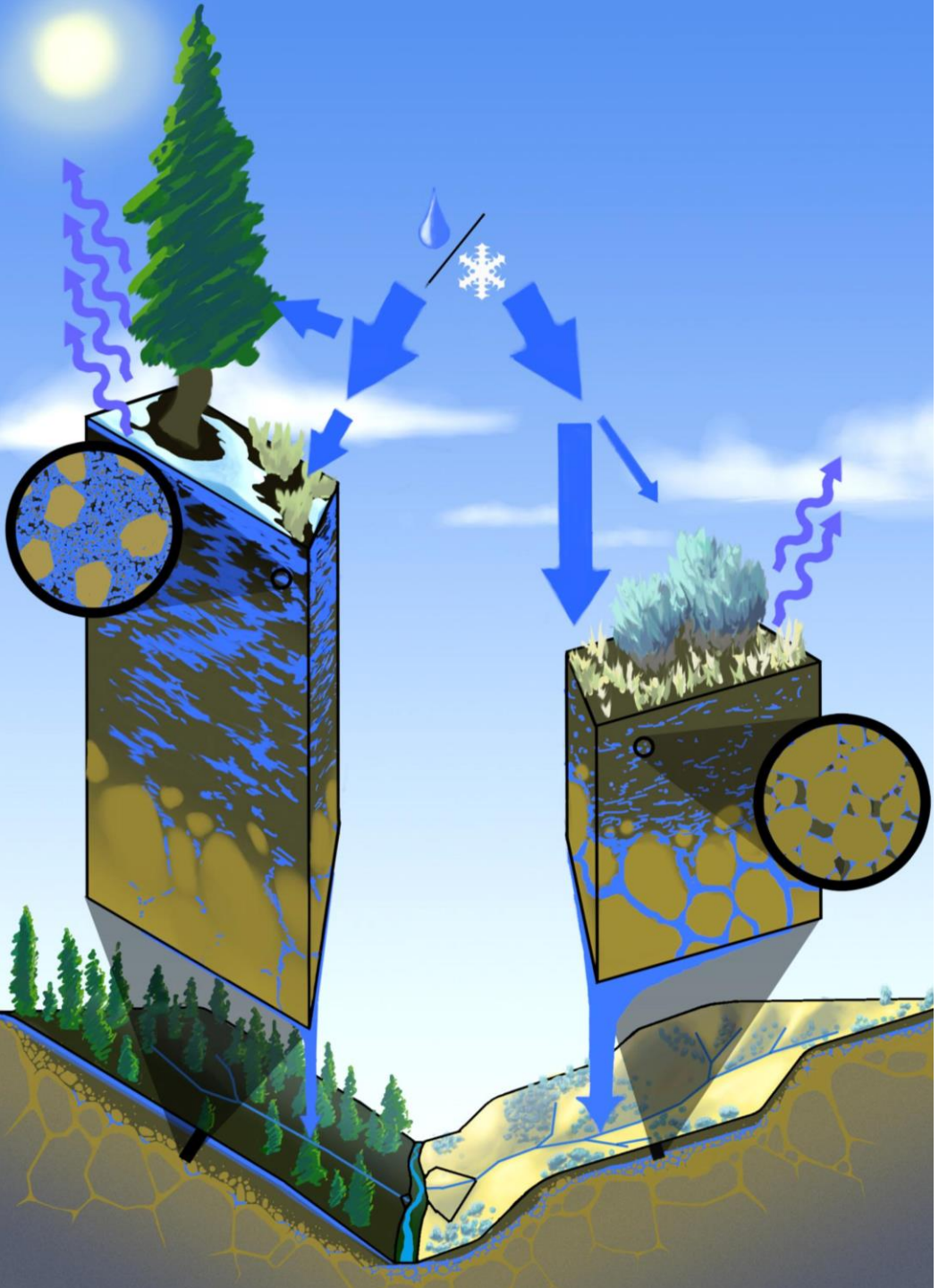
- Snow fraction increases and ET decreases with increasing elevation
- ET decreases within and across sites with increasing snow fraction

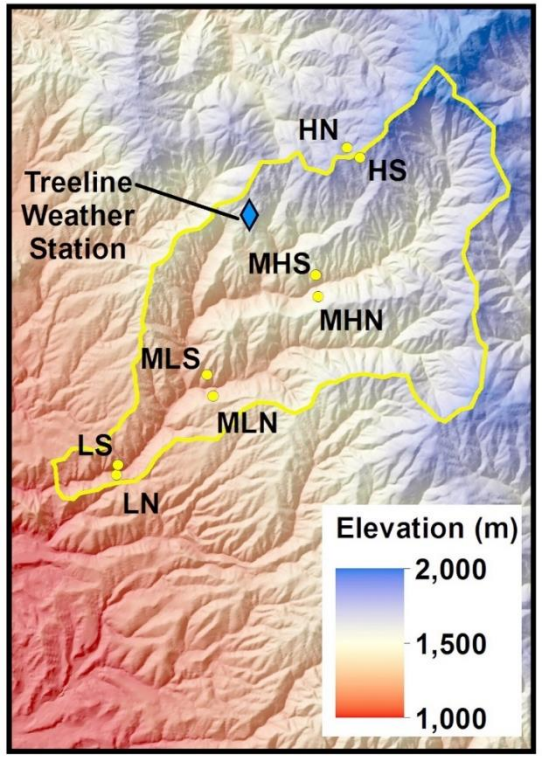
Why Does Snowmelt-driven Streamflow Response to Warming Vary?



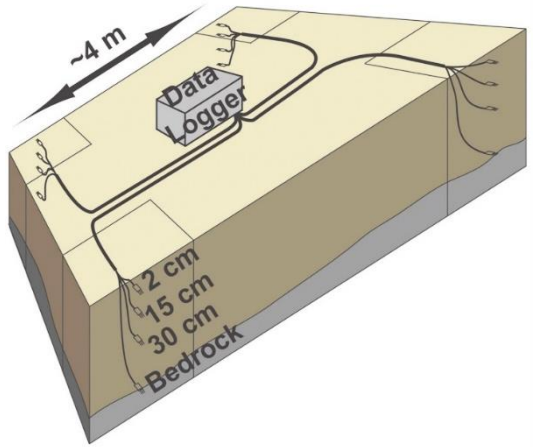




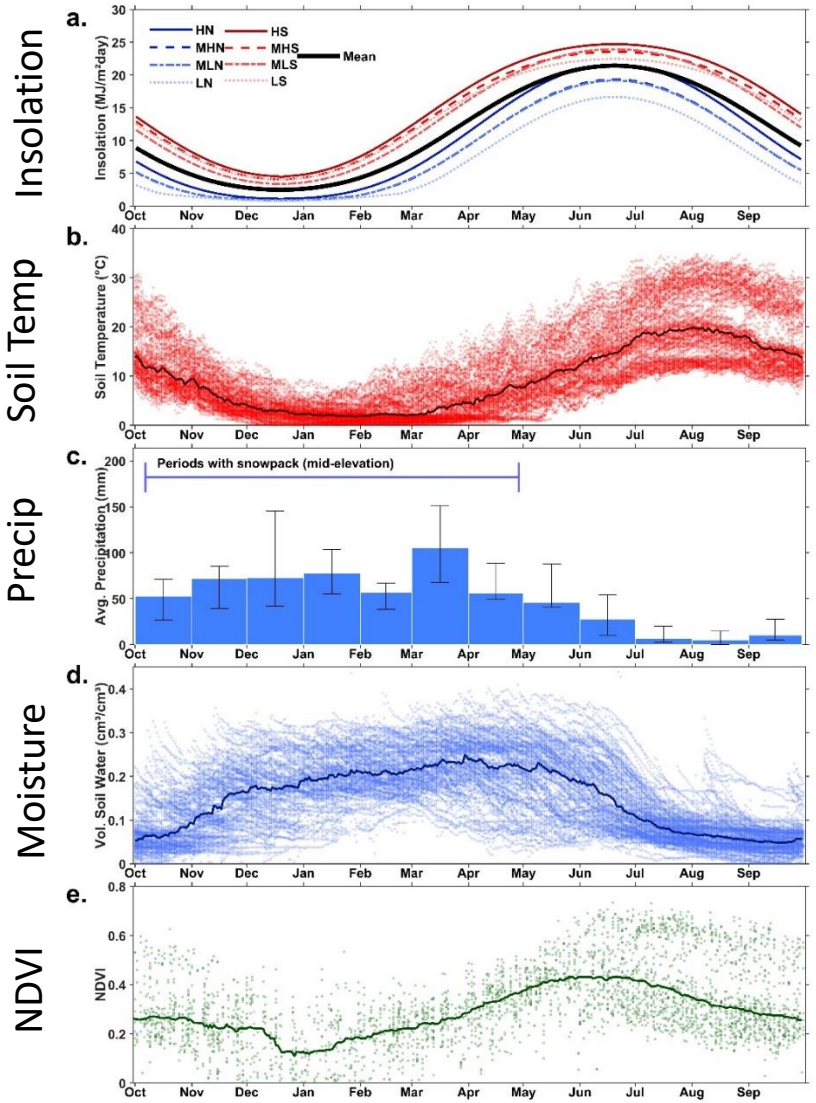




Soil Moisture and Temperature
Sensor Array Layout

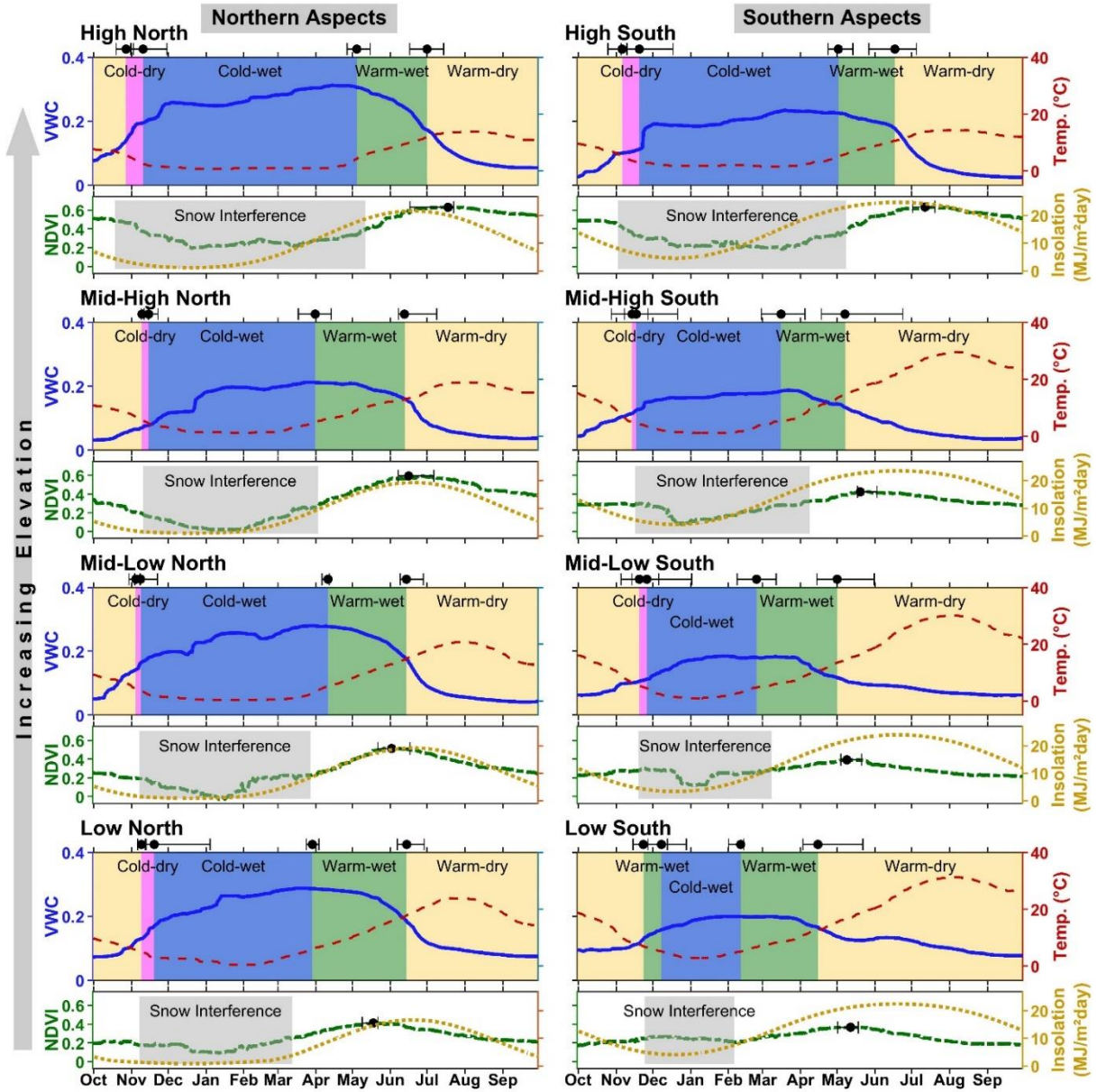


10-year soil moisture record



Poulos et al. (2021)

Soils, Aspect, and Growing Seasons



Average growing season durations are similar at all elevations and aspects, but shifted in time

Low elevations and south aspects start growing earlier but run out of water 30-60 days earlier

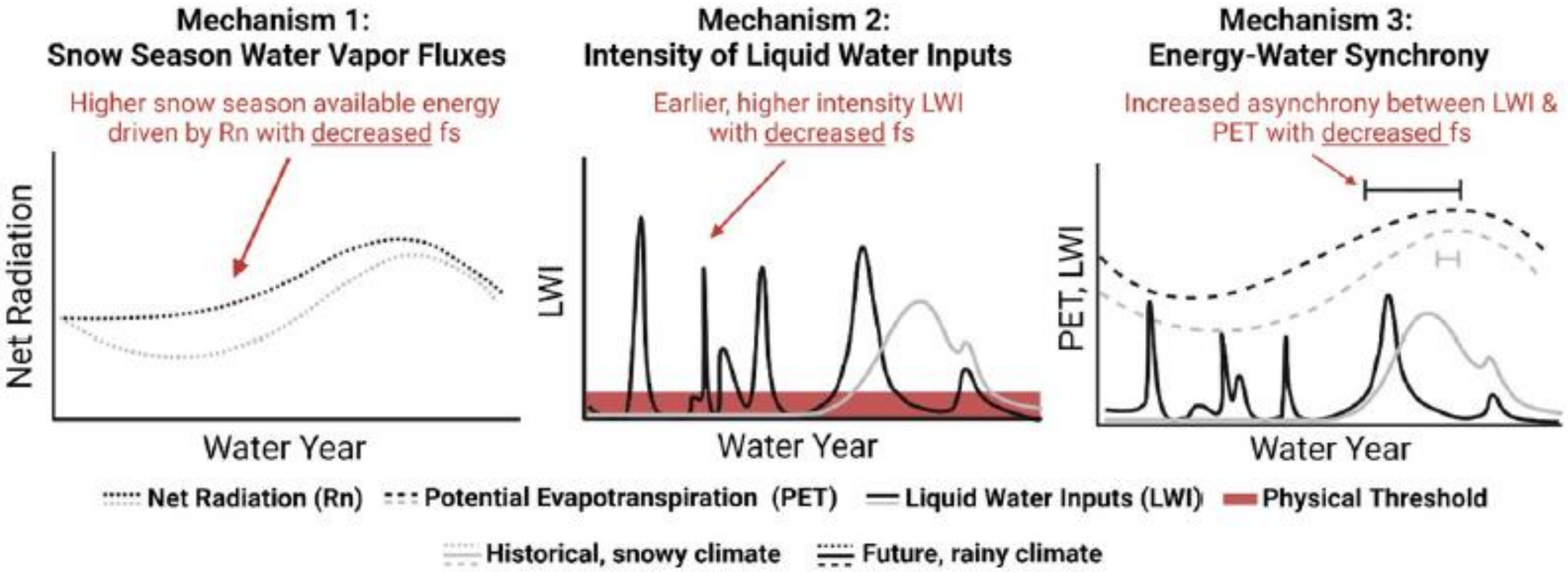
High elevations start growing when snow melts but run out of energy

Enhanced soil water storage capacity at high elevations and north aspects IMPROVES energy-water synchrony and promotes high intensity water use

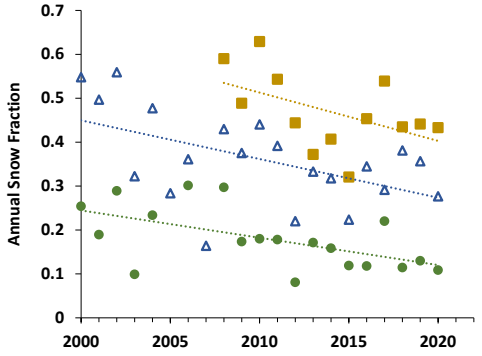
Poulos et al. (2021)

Why Does Snowmelt-driven Streamflow Response to Warming Vary?

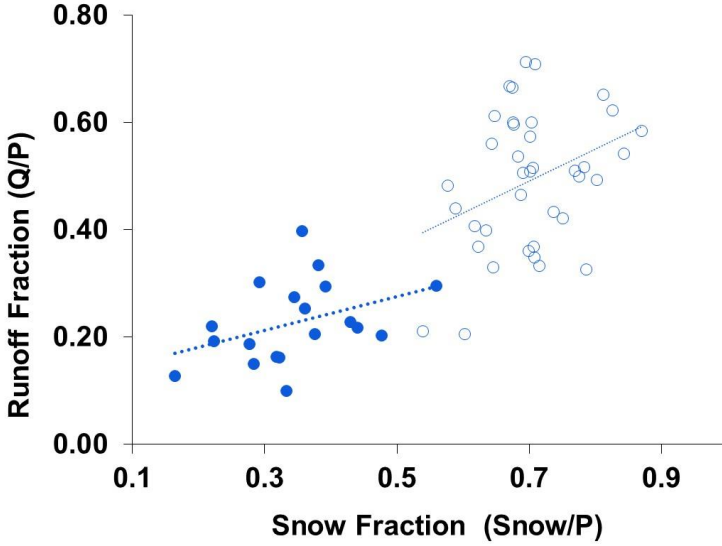
Beatrice L Gordon *et al* 2022 Environ.Res. Lett. 17 053004

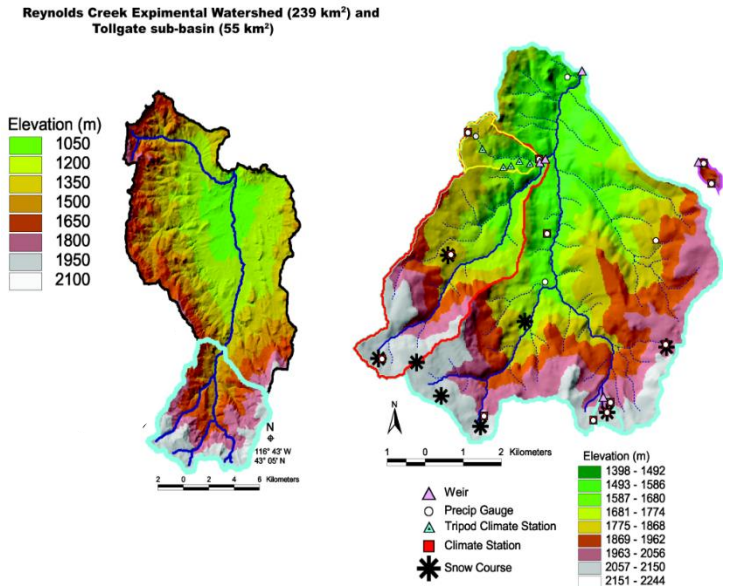


CRHM as a Virtual Laboratory



CRHM

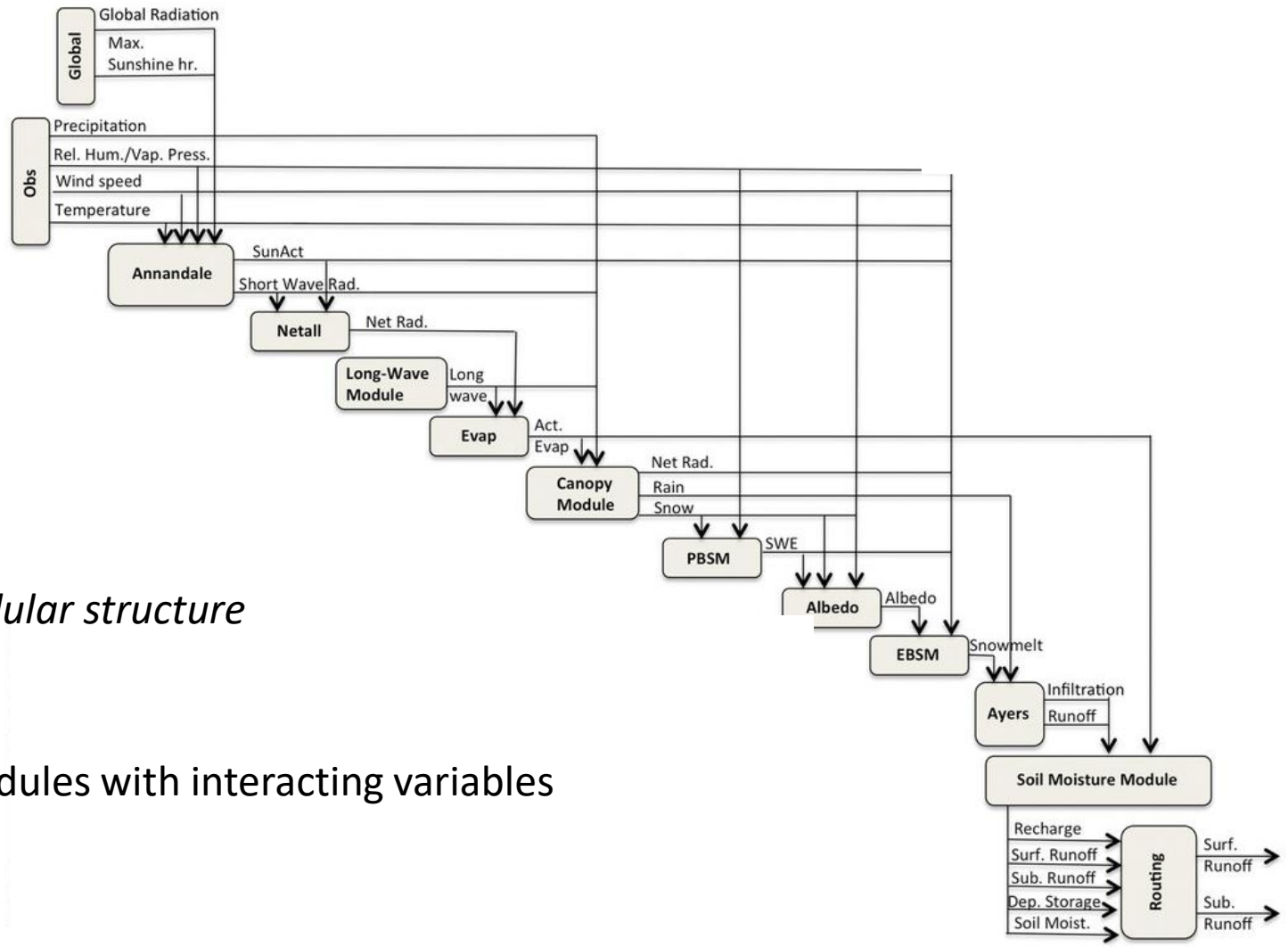




Can we reproduce Snow Fraction – Runoff Ratio relationship with CRHM?

What mechanisms are responsible for variability in hydrology response to declining snowpack?

Cold Regions Hydrologic Modeling Platform (CRHM)



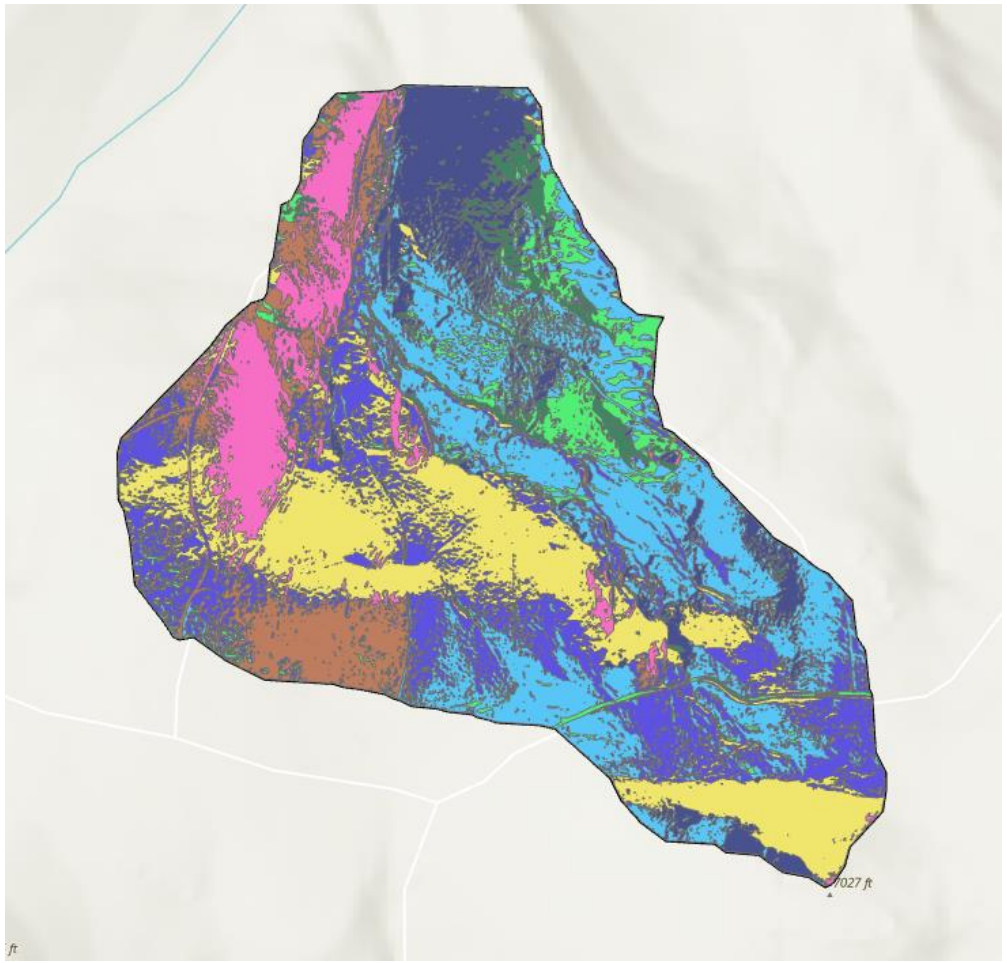
- CRHM - *Modular structure*

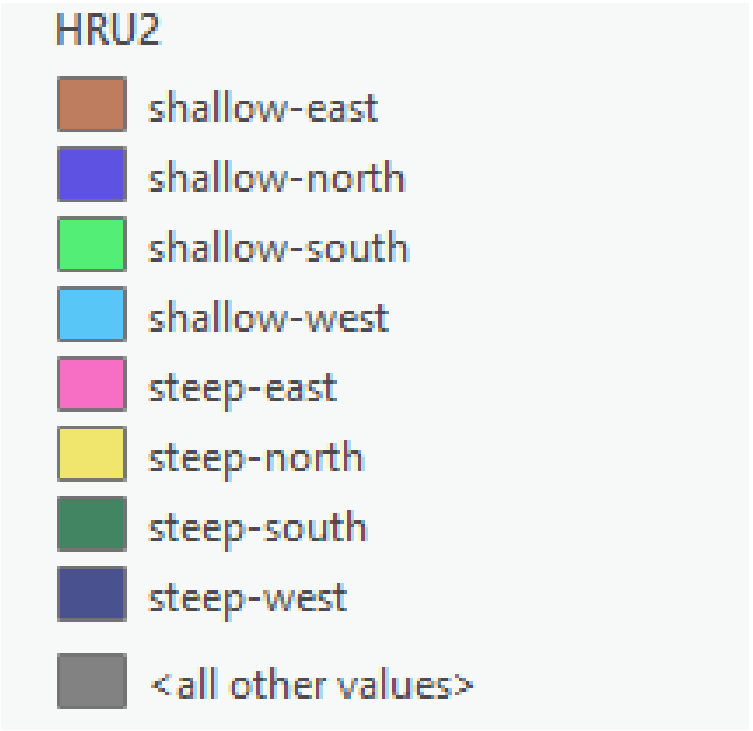
- Series of modules with interacting variables

(Pomeroy et al, 2022; Krogh et al., 2015)

Progress – MS Student Jamie Turner

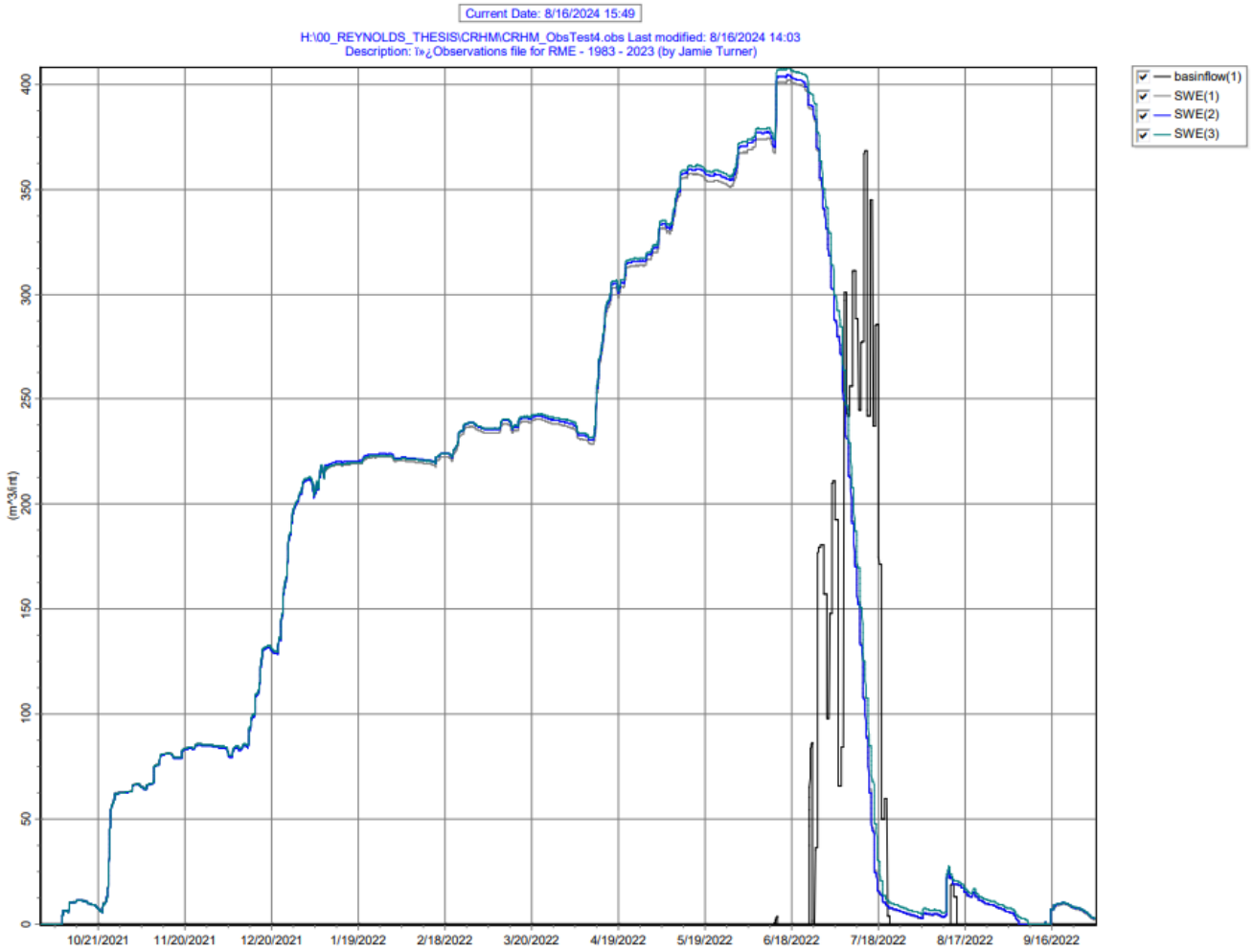
Created hydrologic response units in RME where CRHM has been run previously





Progress – MS Student Jamie Turner

Produced SWE and Streamflow curves to learn CRHM structure.

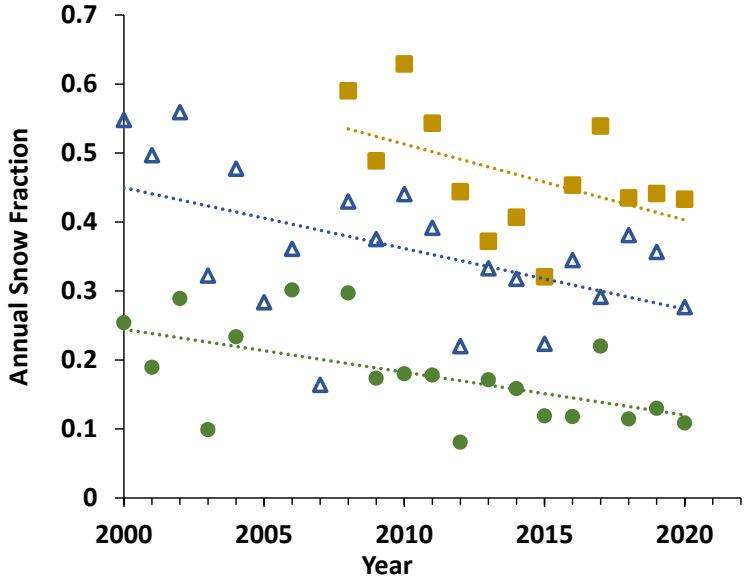


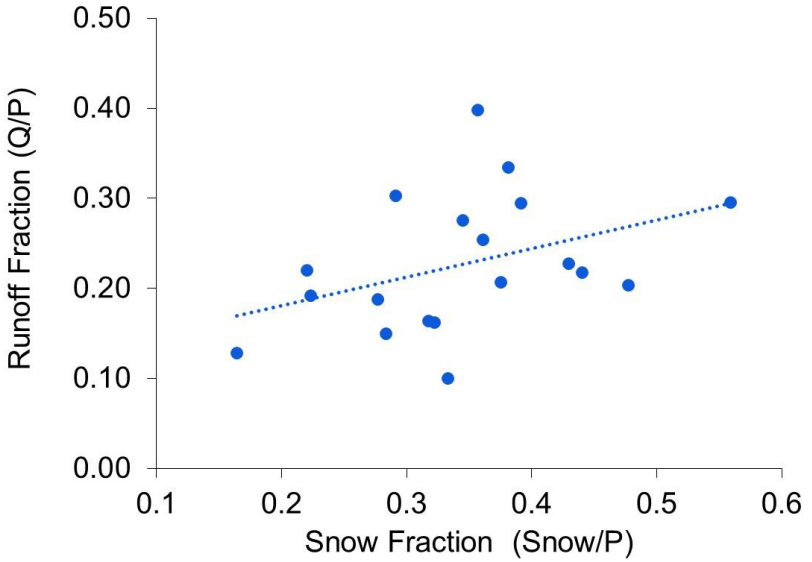
Example for 2022 (Q & SWE)

CRHM model currently “thinks” RME outlet is ephemeral?

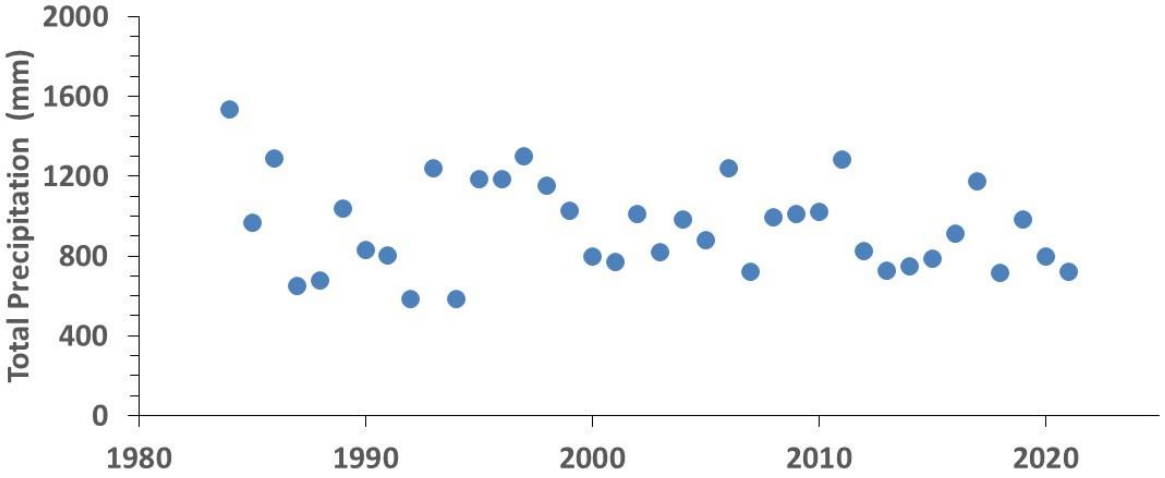
Summary

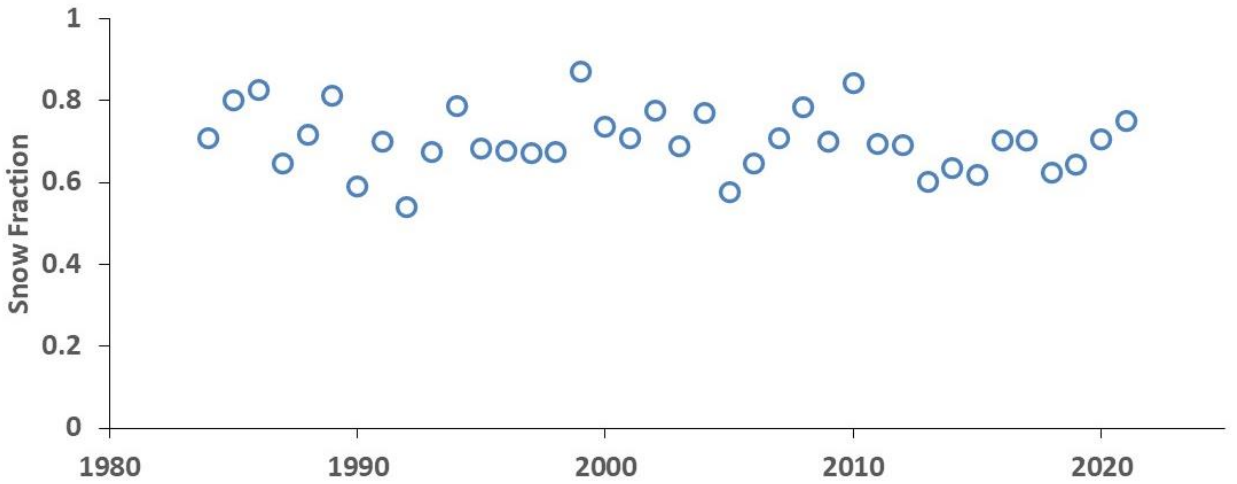
- Snow fractions are declining at all elevations, but not as significant in higher elevations.
- Years with low snow fractions produce less runoff
- High snow years limit growing season at high elevations, reducing ET and increasing runoff
- Catchment-scale changes in ET are dominated by the impact that snow has on growing season length at high elevations, which is enhanced by greater soil water holding capacity
- Variability in streamflow response to snowpack may be related to the role of snow in aligning water and energy availability

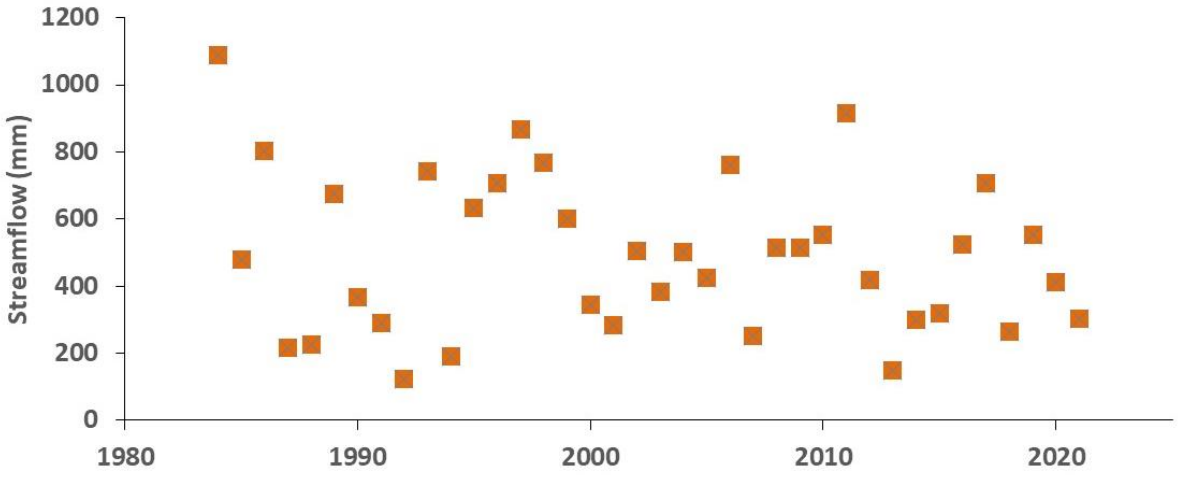


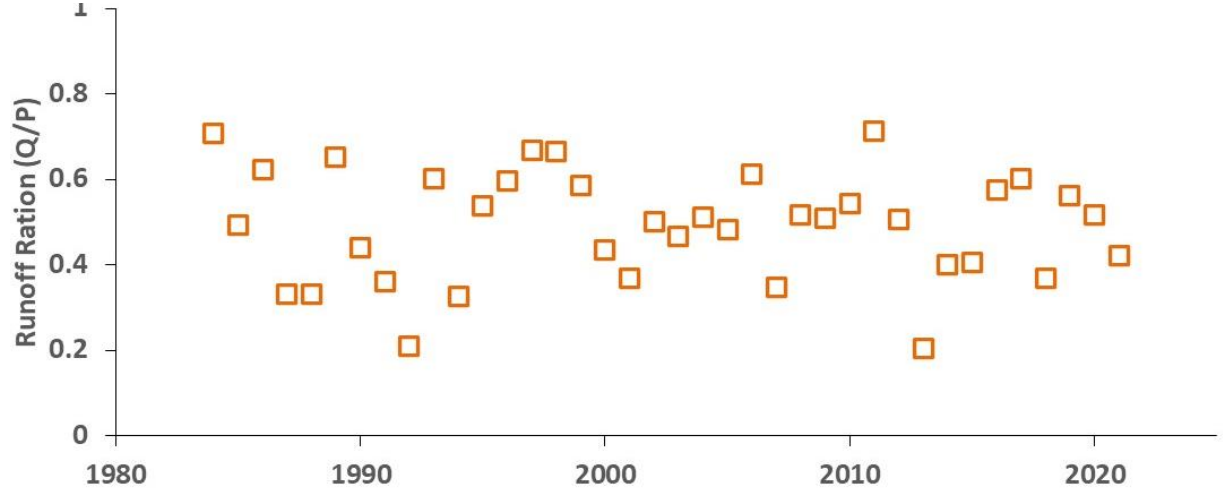


No Temporal Trends

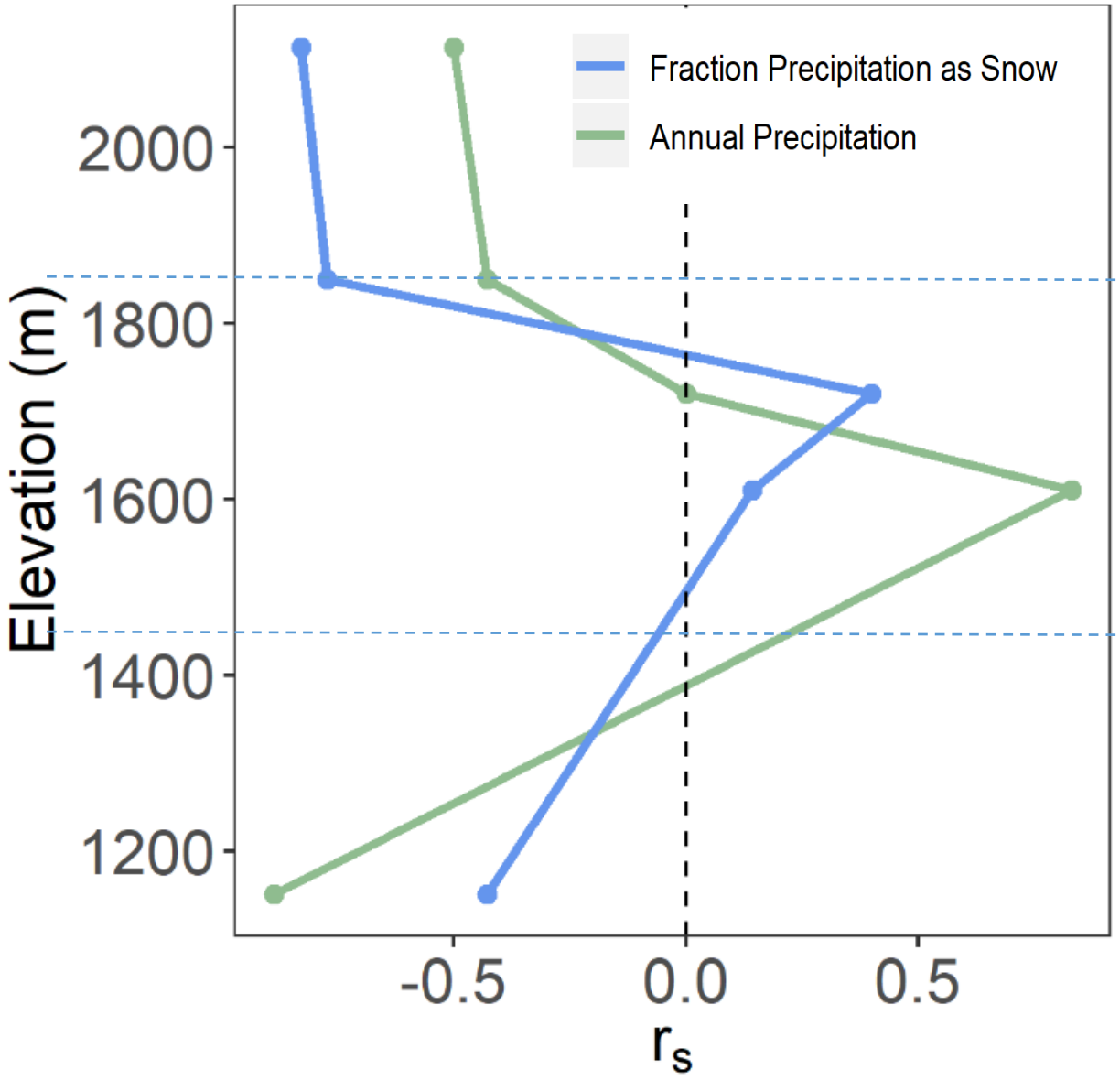








Mid Elevation ET Optimum



Snow truncates growing season, Energy-limited zone becomes water limited

Water and energy availability aligned for optimum ET

Cloudy days reduce ET, Water-limited zone becomes energy limited

Kraft and McNamara (2022)