Watershed Hydrology Changes Across Scales Resulting from Land Cover and Climate Changes

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NCASI
IMPACT. SCIENCE. SOLUTIONS.

USDA

NSF

PotlatchDeltic

Objective and Questions

- Develop a more ***holistic*** understand of the hydrologic future in the interior Pacific Northwest
- Question: How are flow regimes in a watershed spanning the rain/snow transition zone expected to change?
  - Due to forest harvest and regeneration?
  - Due to climate change?
  - **Similarities and differences?**
  - Across scales? (1^{st} to 4^{th} order watersheds)

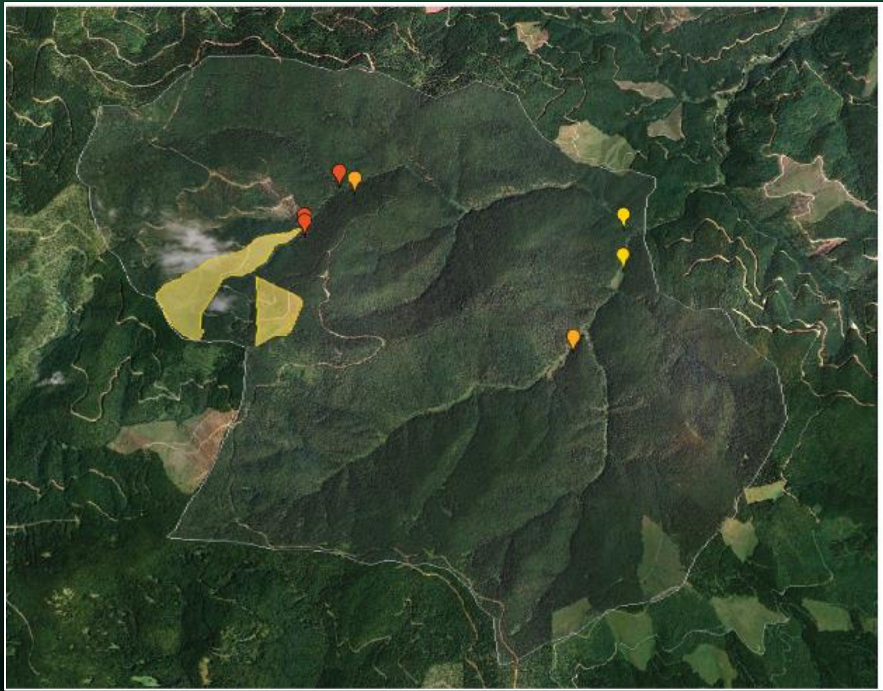
Baseline: ~80 year 2^{nd} growth forest

Land Cover Change

Montane Forested Watersheds

Many Experimental Watershed Studies:

- Discrete Impact → Forest Regeneration
- 50 -100% harvest
- Low age diversity

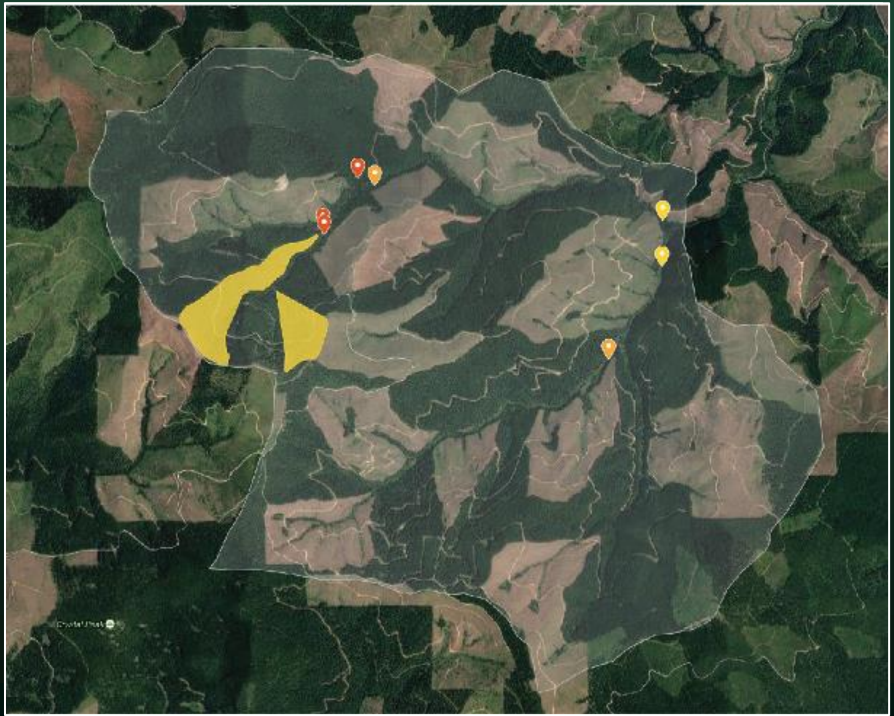


Land Cover Change

Montante Forested Watersheds

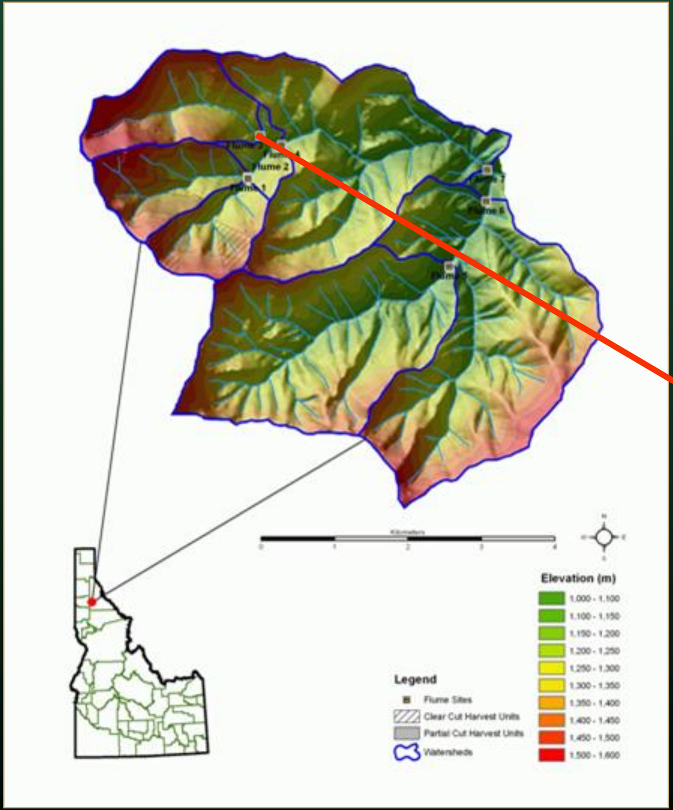
Working Forests:

- Successive Disturbance →→→→→
- Continuous Regeneration



<u>Age diversity generally increases with scale</u>

Mica Creek Experimental Watershed



Location:

N. Central Idaho

Climate:

- Continental/Maritime
- Transitional Snow Zone

Site Characteristics

- Size
  - 27 km^2
  - ~6700 ac
- Elevation
  - 1000-1625 m
  - 3200 – 5240 ft
- Precipitation
  - 1440 mm/yr
  - ~57 in/yr
- Vegetation: ~80 yr Mixed conifers
- Active Forest Management
  - <u>**Diversity of age classes**</u>

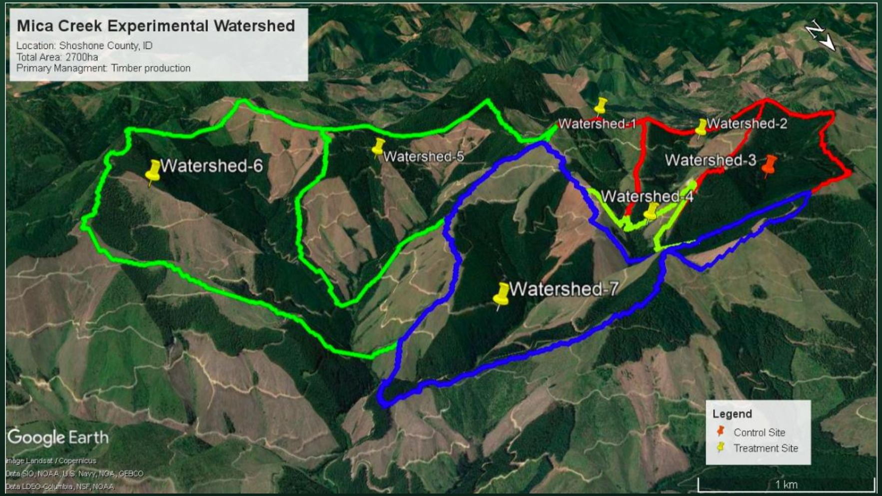
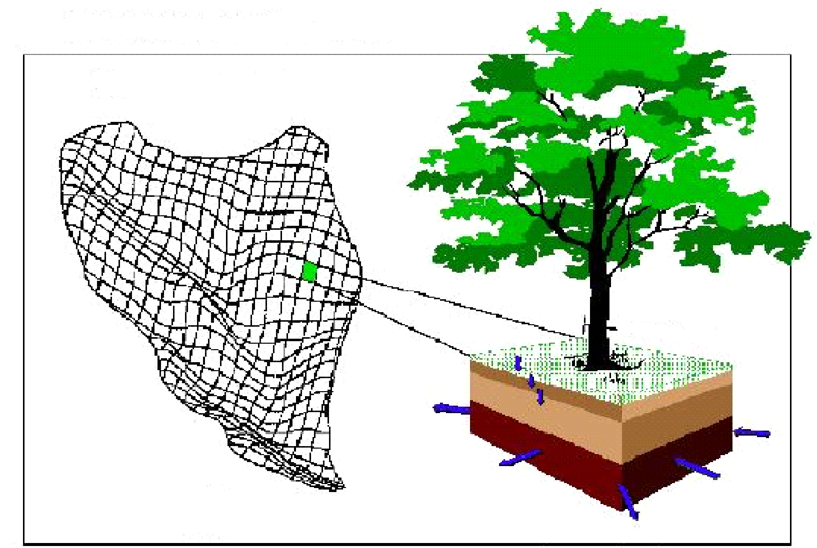


Image courtesy of C. Deval

Simulation Approach:
Physically-Based, Virtual Experimental Watershed

- Distributed Hydrology Soil Vegetation Model (**DHSVM**)
- Detailed Internal Watershed Data
  - Parameterization
  - Validation
- Quasi Monte-Carlo Parameterization
- **Simulate Alternative Futures**

DHSVM schematic



(Wigmosta, 1994)

Mica Creek: Data Collection

Soil properties

Soil moisture

Flow, chemistry & isotopes

Distributed Hydro-meteorology

Throughfall

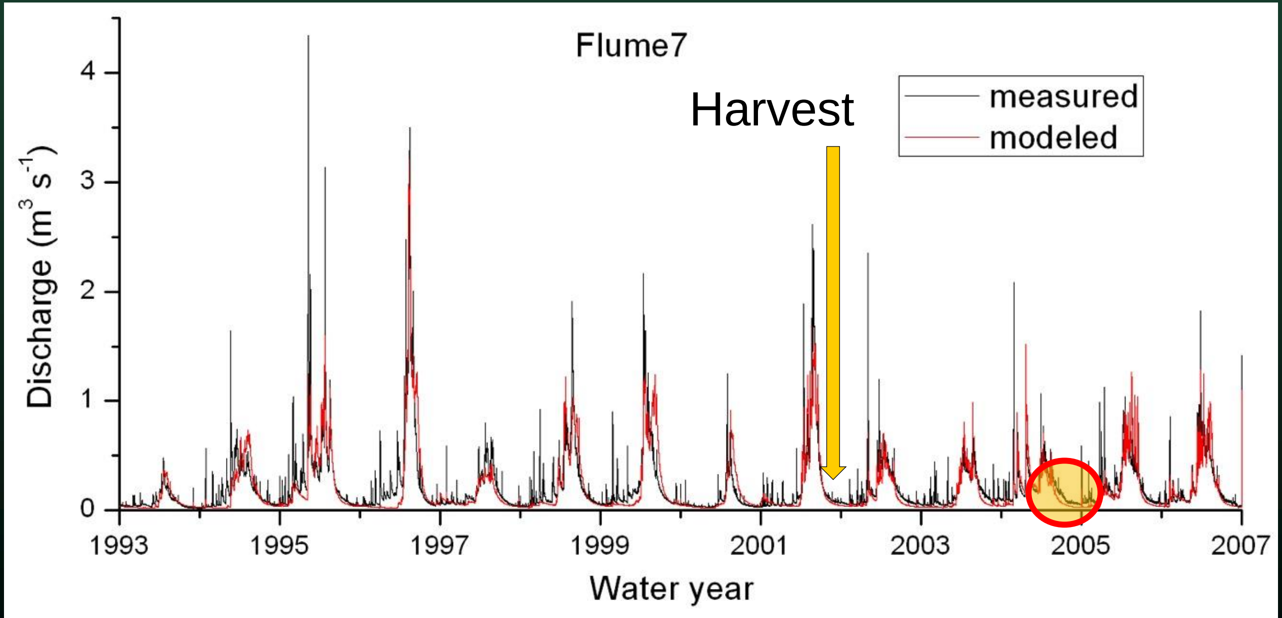
Sap Flux

Snowpack properties

To get the correct answer for the correct reasons!

Model Performance Assessment

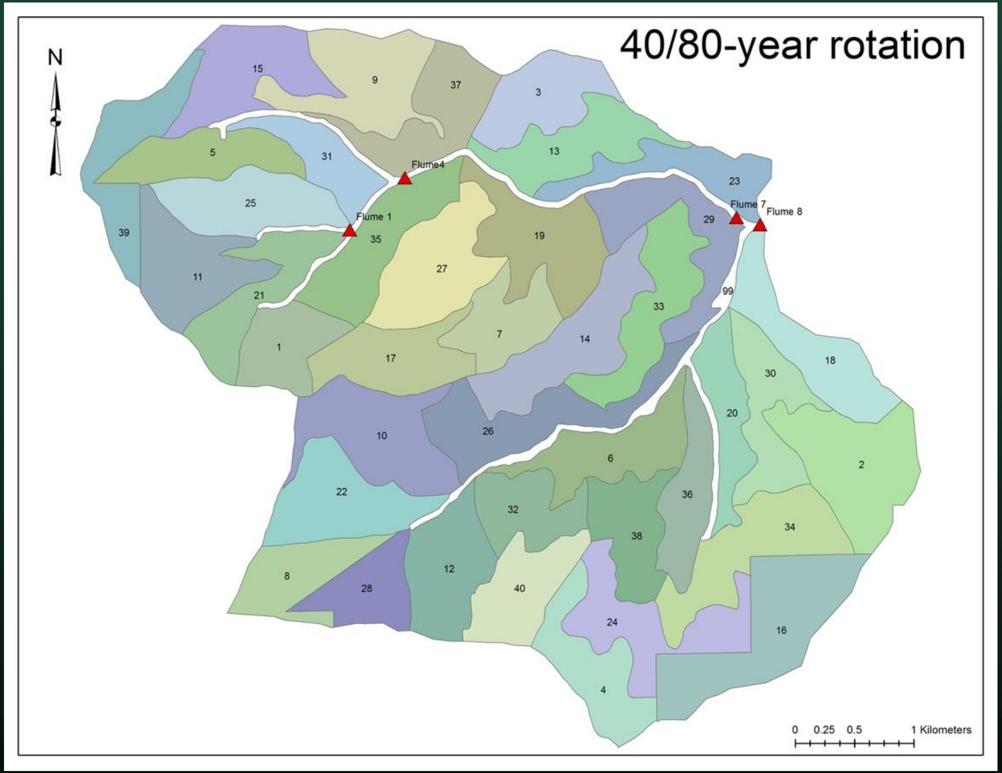
- **Streamflow Example**
  - ME: 0.62 to 0.72
- Also: Snow, soil water, and sapflow



Du et al., 2014, Hyd. Proc.

Simulated Harvest Units

- 40 yr rotation = ~2.5% per year
  - ~50 yr rotation in practice
- 80 yr rotation
  - Not discussed here

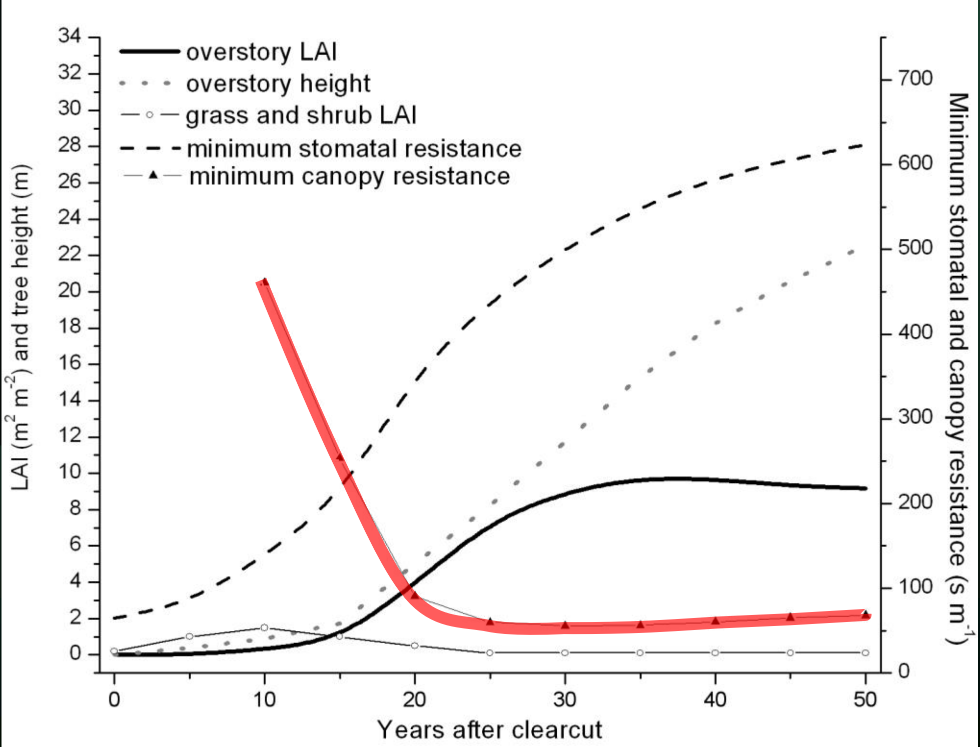


Forest Growth Simulation

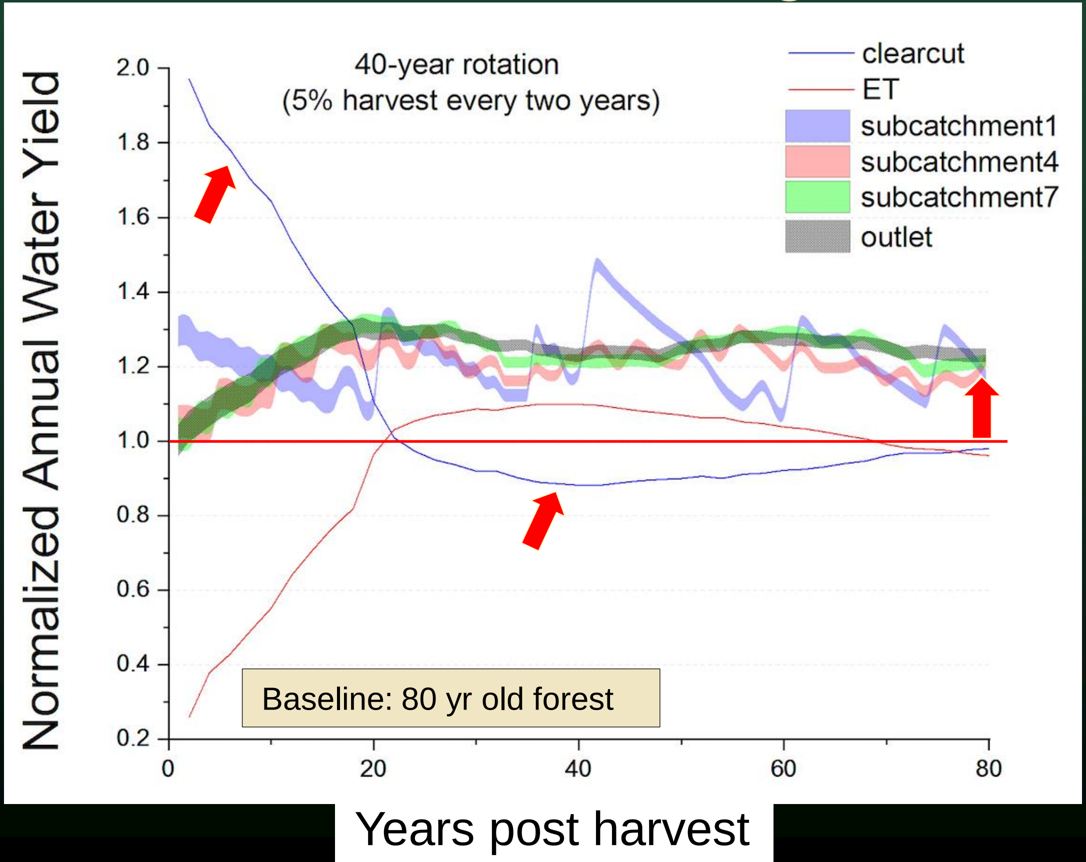
Biophysical parameter estimation

- LAI and DBH: 3-PG
- Tree height: PROGNOSIS
- Minimum stomatal resistance (R_{smin}):

- Based on *in situ* observations
- Empirical relationship to tree height

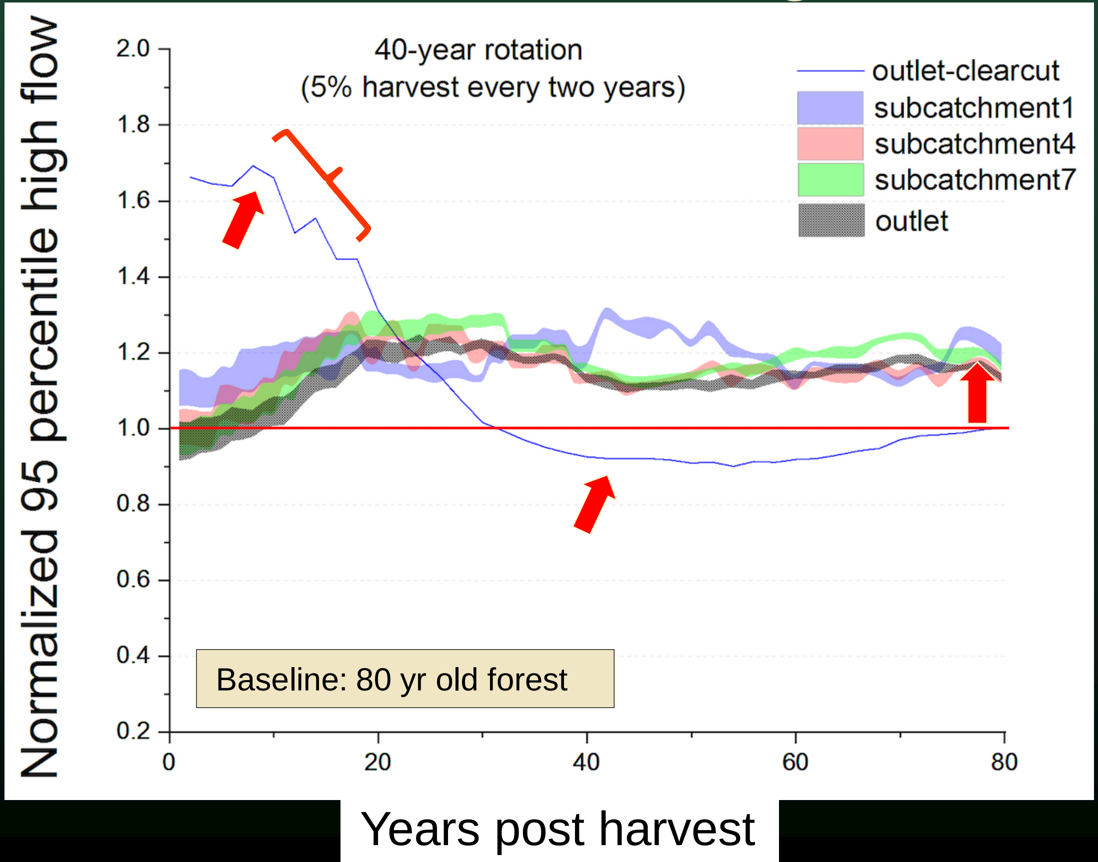


Annual Water Yield
Land Cover Change



Sustained increases at larger scales

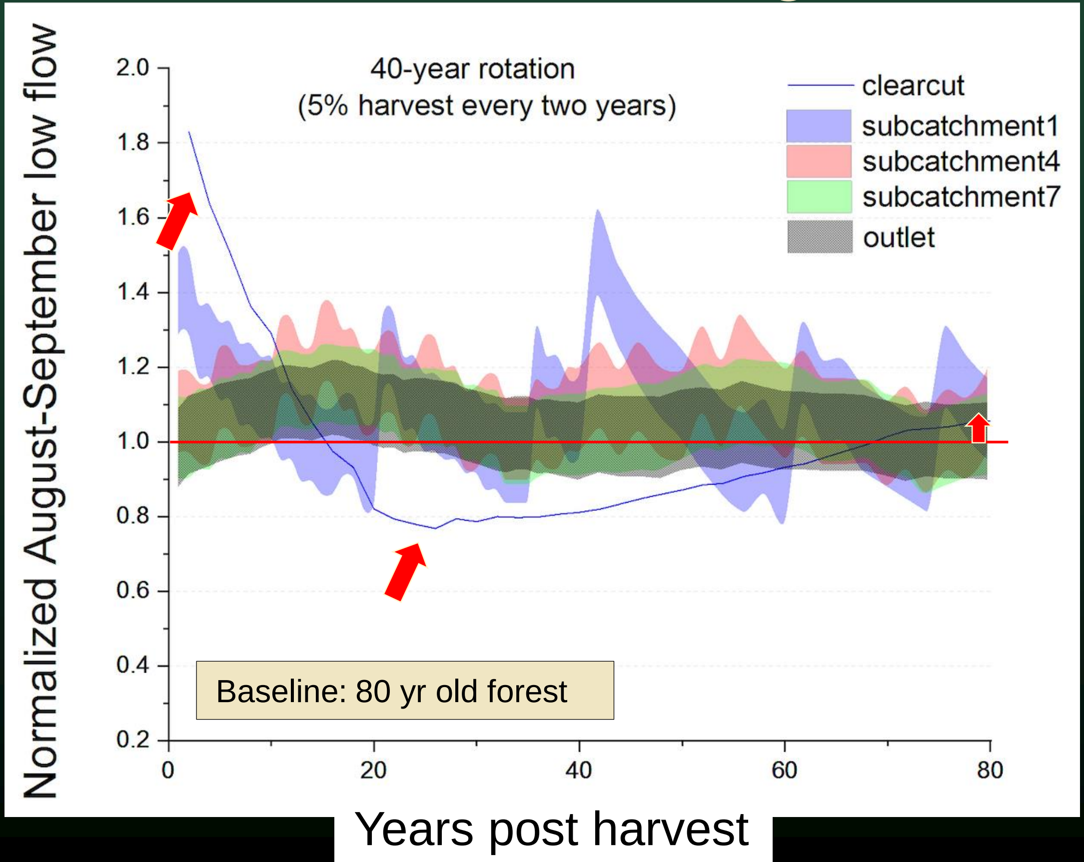
High Flows (95th Percentile)
Land Cover Change



Sustained increases at larger scales

Aug – Sep Low Flows

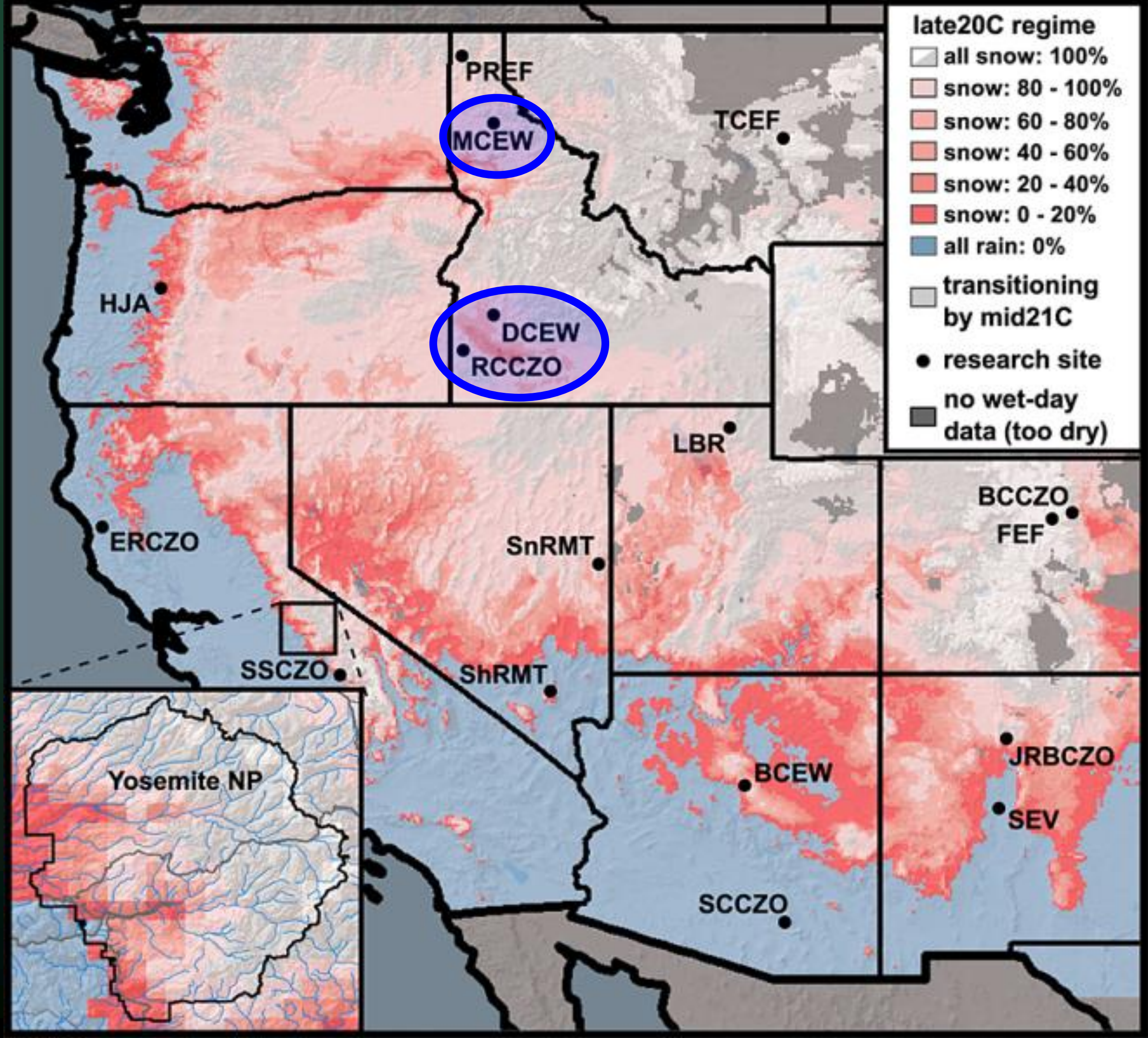
Land Cover Change



Large Scales:
May slightly offset climate effects

Small Scales:
May offset or exacerbate climate effects

Depends on age



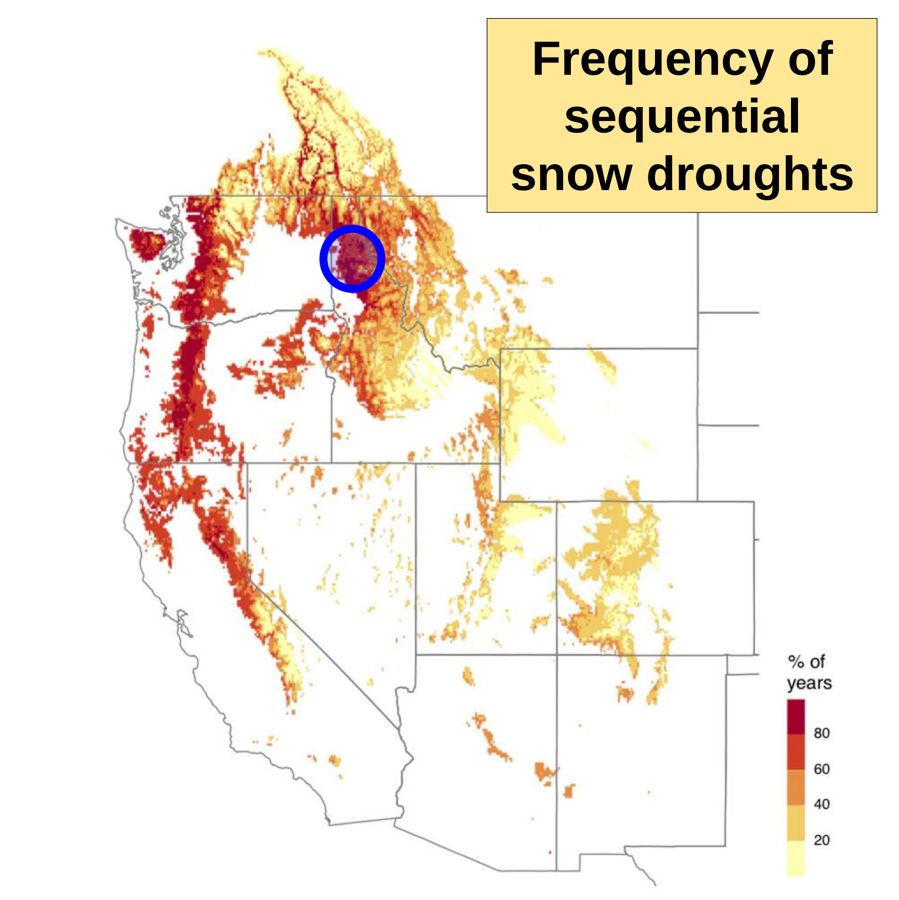
Climate Change

Winter (DJF) Rain:Snow Regime

Klos, P. Z., Link, T. E., & Abatzoglou, J. T. (2014). Extent of the rain-snow transition zone in the western U.S. Under historic and projected climate. *Geophysical Research Letters*, 41, 4560–4568. doi:10.1002/2014GL060500

Climate Change

- Patterns of snow metrics are all similar:
  - Rain:snow ratio
  - Peak snow depth
  - Melt timing
  - Successive snow droughts
- Declining low flows…

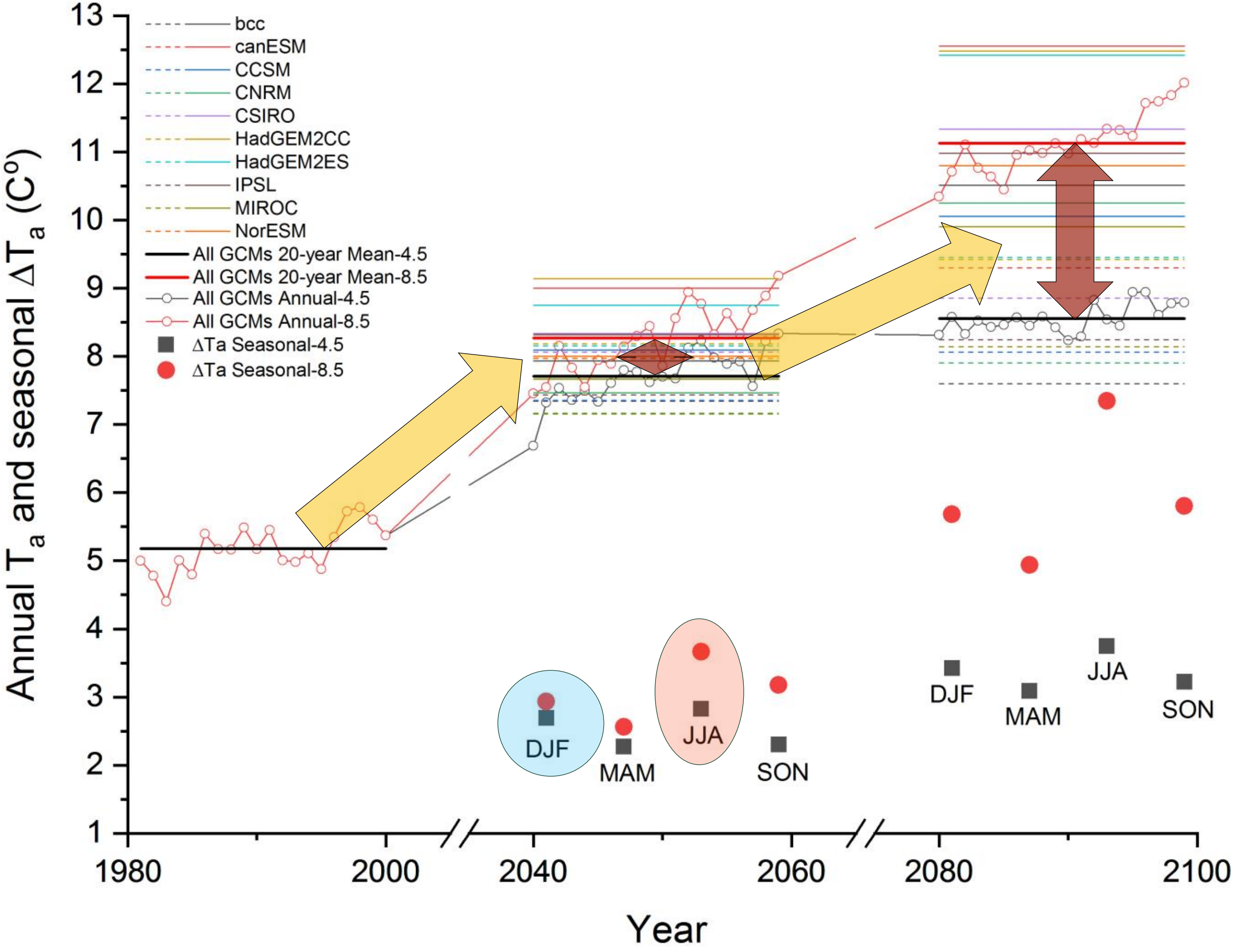


Marshall, A. M., J. T. Abatzoglou, T. E. Link, and C. Tennant. 2019. Projected changes in interannual variability of peak snowpack amount and timing in the western United States. Geophysical Research Letters, 46(15), 8882-8892. https://doi.org/10.1029/2019GL083770.

Projected Temperatures

AR5, RCP 4.5 & 8.5

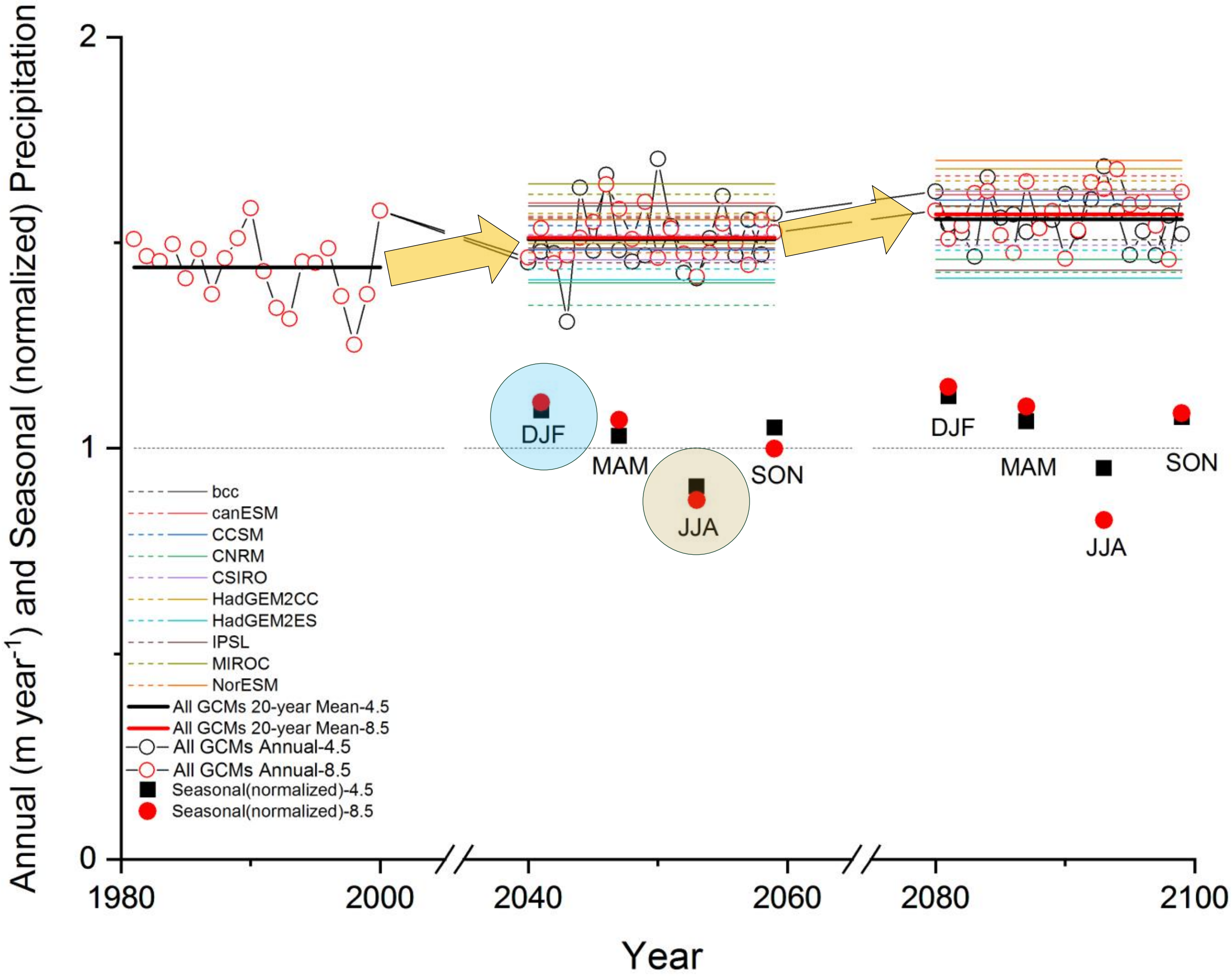
- Warmer
- Less in winter
- High uncertainty



Projected Precipitation

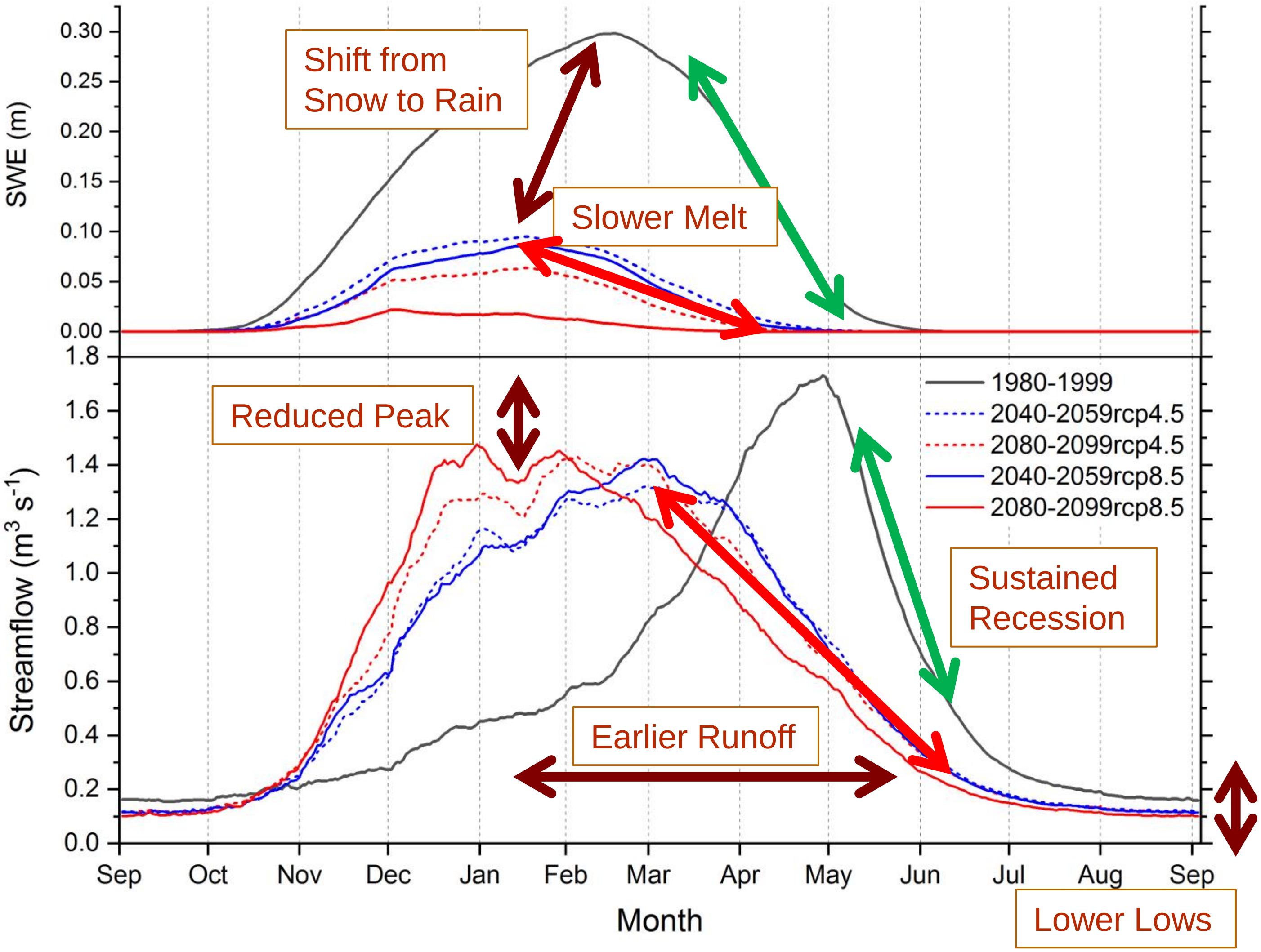
AR5, RCP 4.5 & 8.5

- Annual increase
- Wetter winters
- Drier summers



Projected Snow and Streamflow

10 GCM ensemble

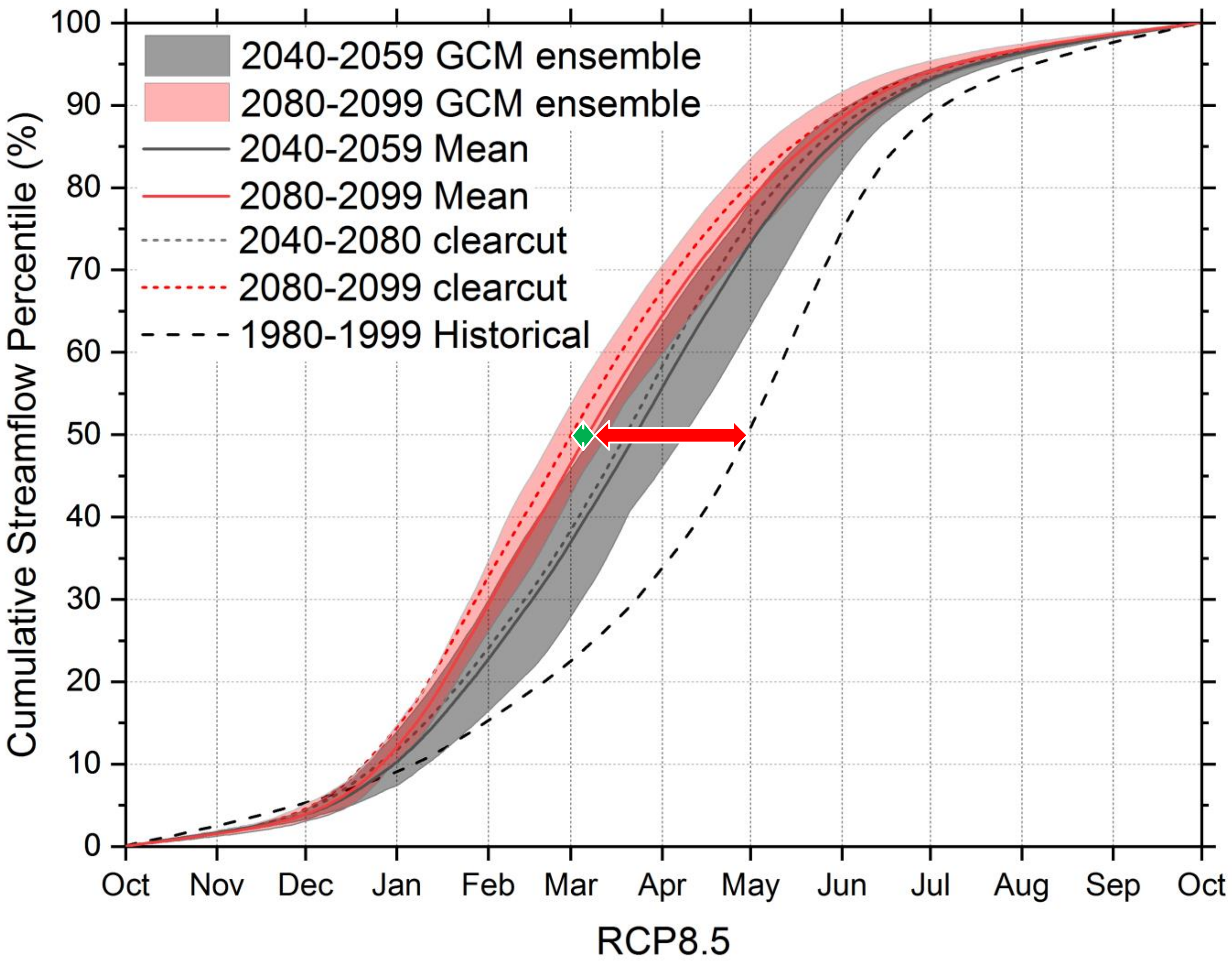


Landcover
+
Climate Effect:

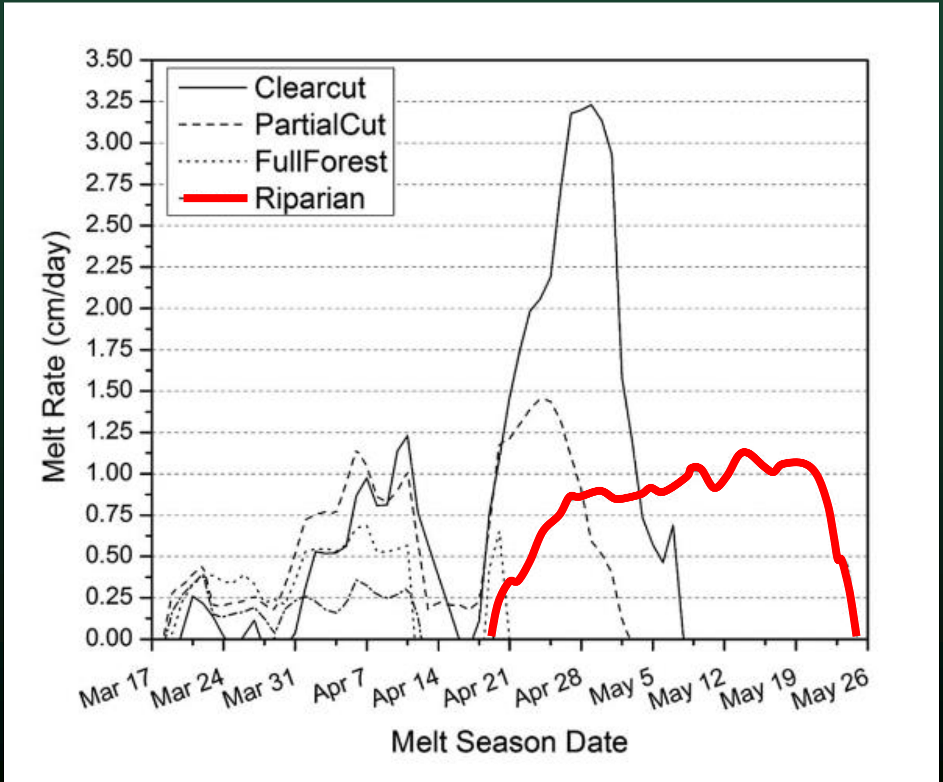
Cumulative Streamflow

Harvest
Effect is Minimal
Compared to Climate
12 vs 69 days

- Based on 100% Harvest!



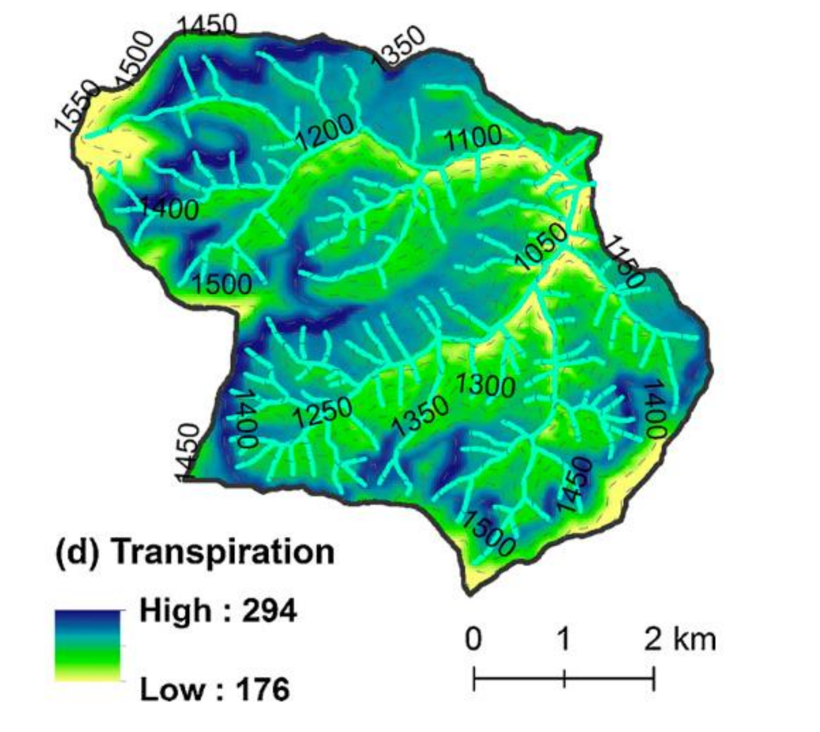
Hydrometeorological Mythology and Future Directions…

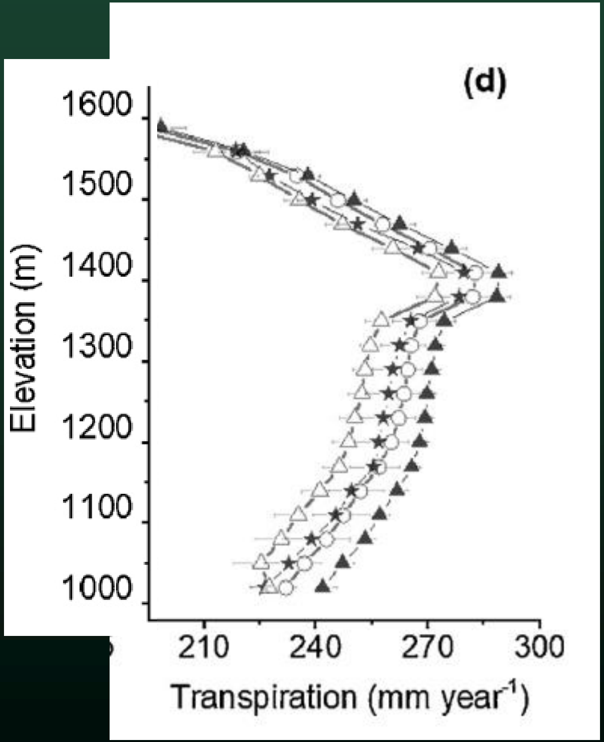


- Ta decreases with elevation
- SDD increases with elevation
- Extent and persistence of cold air pools
- Buffer for climate effects?

Hubbart, J. A., Link, T. E., and Gravelle, J. A. (2015), Forest Canopy Reduction and Snowpack Dynamics in a Northern Idaho Watershed of the Continental-Maritime Region, United States, *Forest Science*, *61*(5), 882-894, doi:10.5849/forsci.14-025.

Hydrometeorological Mythology and Future Directions…

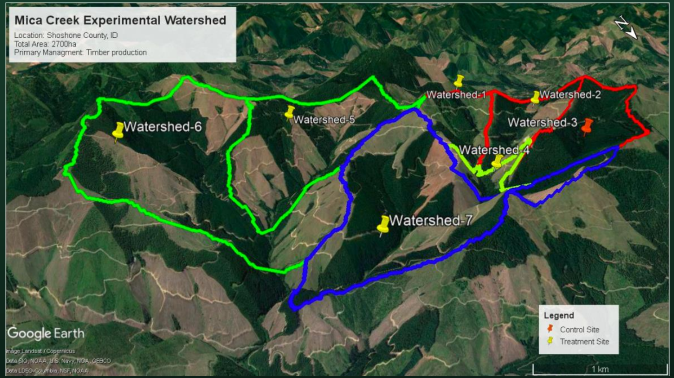




Wei, L., Zhou, H., Link, T. E., Kavanagh, K. L., Hubart, J. A., Du, E., Hudak, A. T., and Marshall, J. D. (2018), Forest productivity varies with soil moisture more than temperature in a small montane watershed, Agricultural and Forest Meteorology, 259211-221, doi:10.1016/j.agrformet.2018.05.012.

Summary

- Profound climate-driven flow regime changes are underway
  - Across all scales
  - Expected to slow in late century
- <u>Climate</u> changes have larger effects on <u>timing</u>
- <u>Land cover</u> changes have larger effects on <u>flows</u>
  - Harvest effects on <u>annual</u> and <u>low</u> flows ***<u>reverse as scale increases</u>***
  - Reduces or exacerbates climate effects



Mica Creek Experimental Watershed History

1990: Equipment Installed
- 7 flumes, met “tower”, SNOTEL

1991 – 2002: Baseline monitoring

2003 – 2007: 1st Intensive Field Campaign
- snow, sap flux, isotopes, micromet, stream temperatures, …

2008 – 2019: Baseline monitoring

2020…: Transfer to UI, Equipment replacement underway

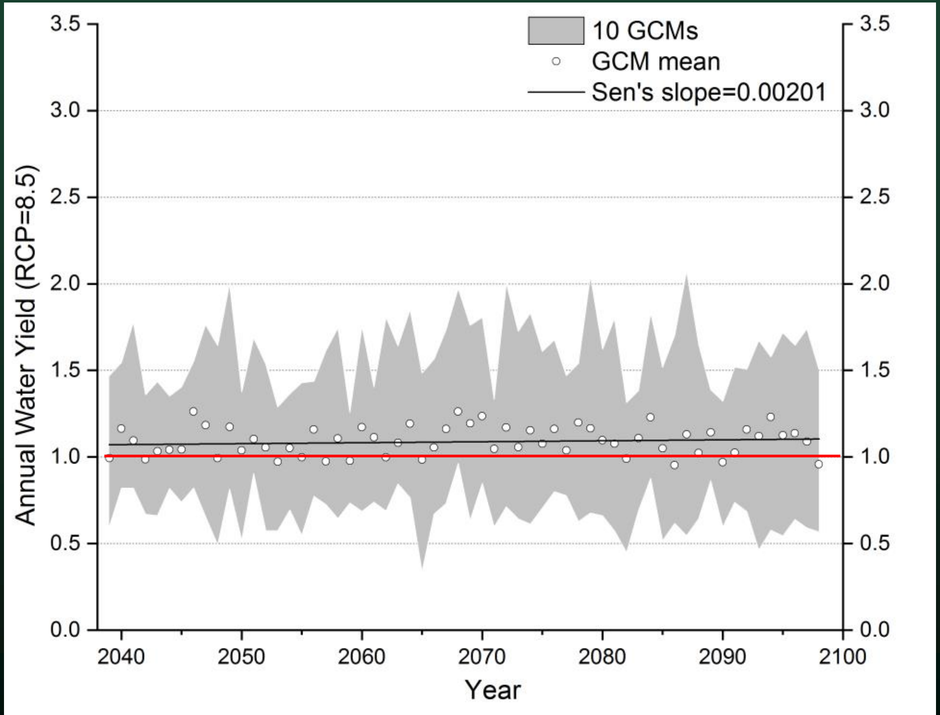
Thank You!

Questions?

Extra Slides

Projected Annual Water Yield

RCP 8.5



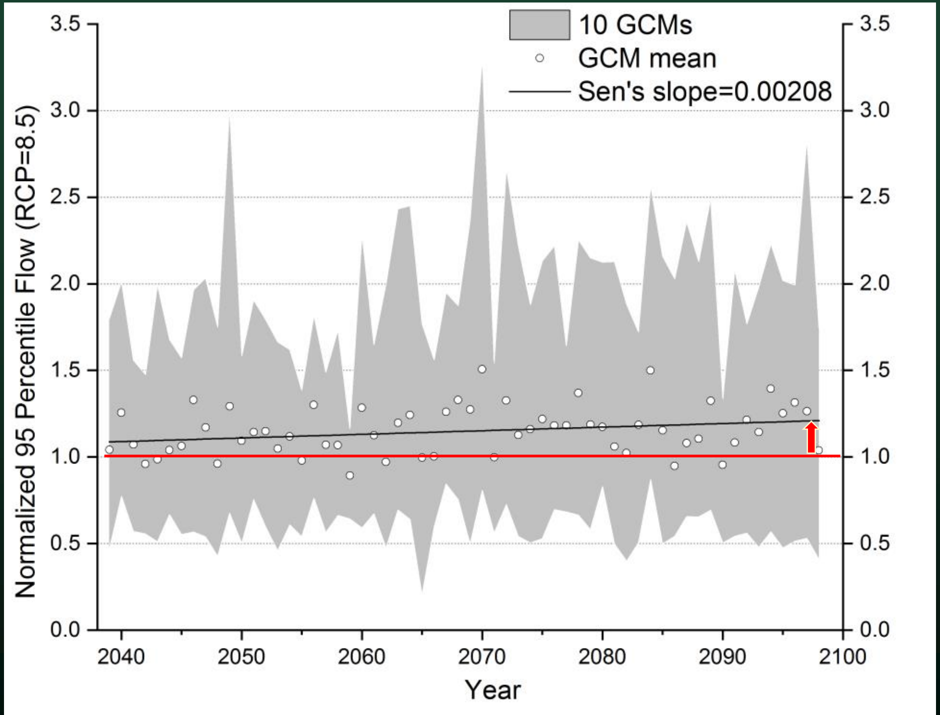
Negligible increasing trend

Baseline: 1980- 2000

*preliminary simulations

95^{th} Percentile Flows

RCP 8.5

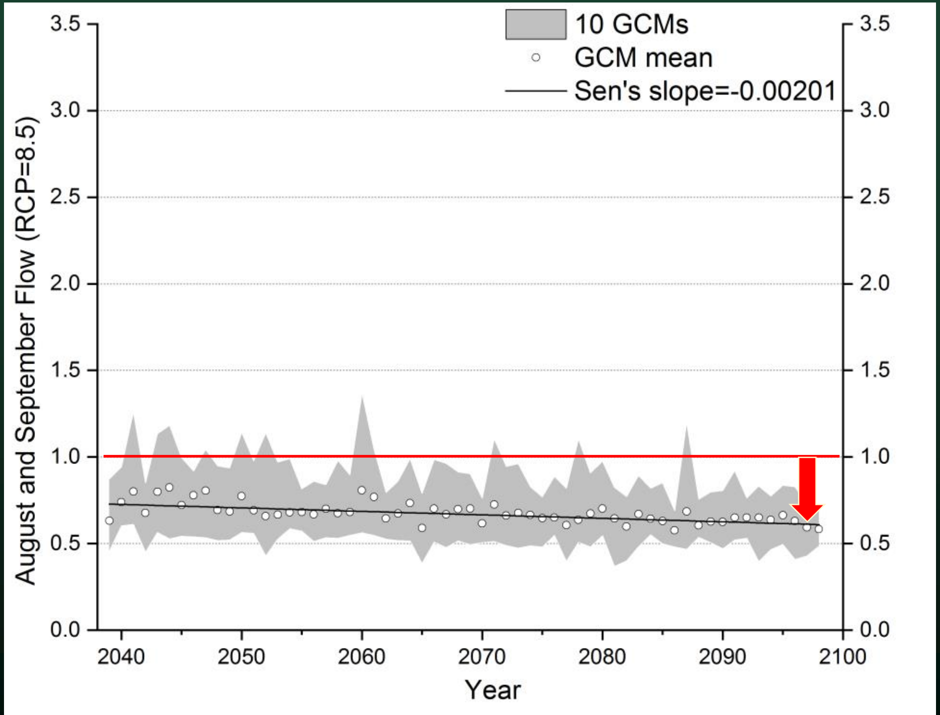


Slight Increasing trend

Baseline: 1980- 2000

*preliminary simulations

Aug - Sep Low Flows
RCP 8.5



Decreasing trend

RCP 4.5:
Effects more muted

Baseline: 1980- 2000

*preliminary simulations

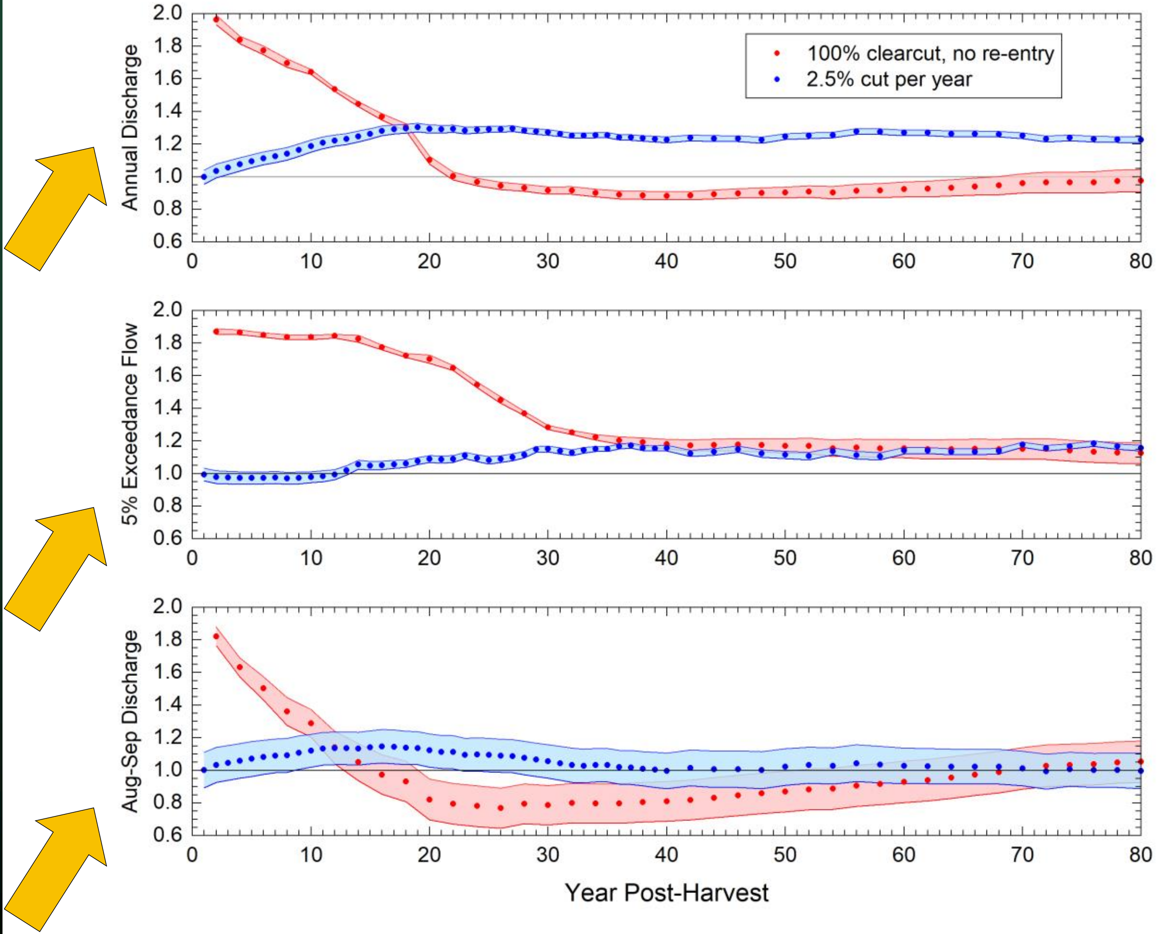
Findings

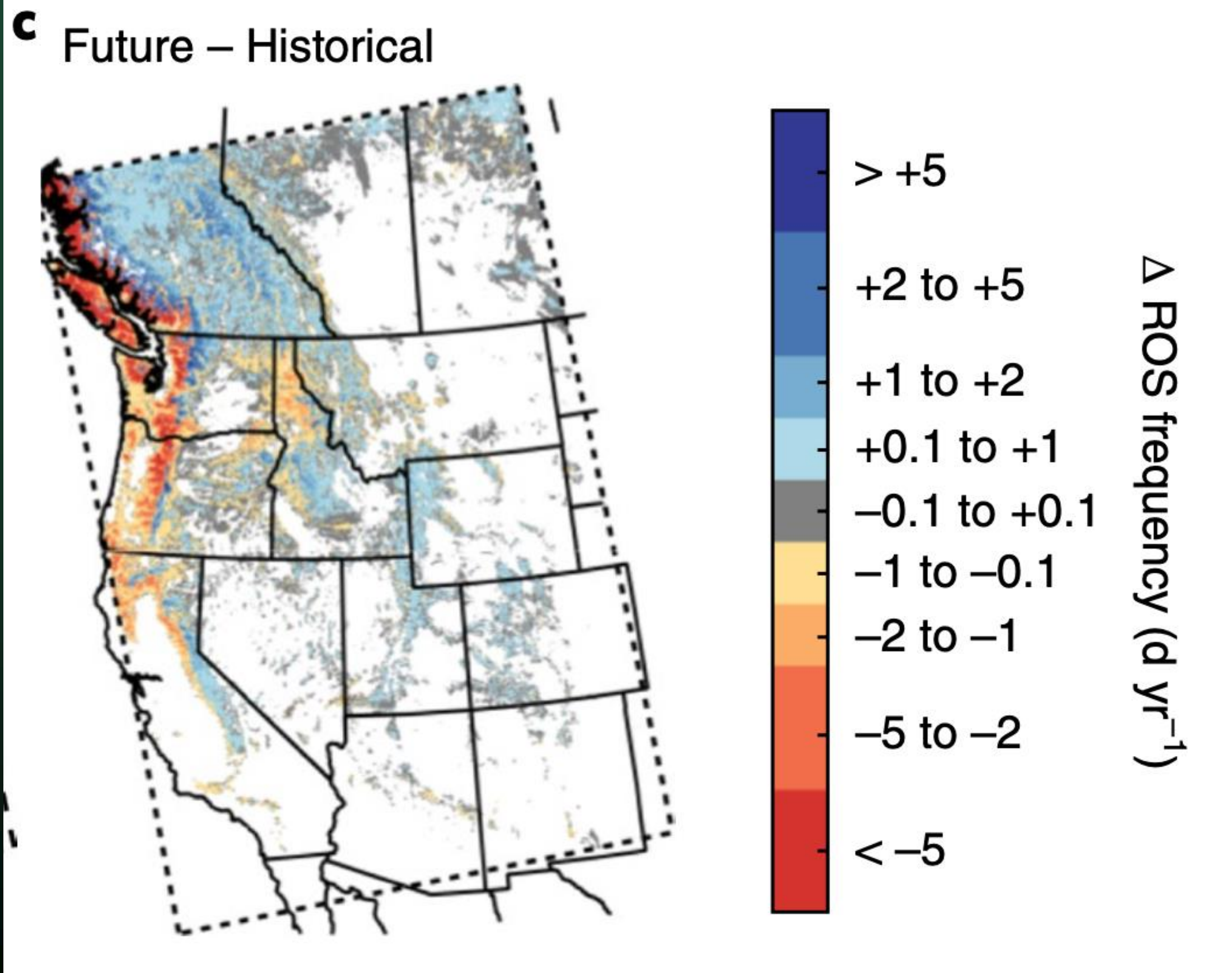
- <u>Land Cover Changes</u>:
  - Small scales: Variable flow changes over time
  - Large scales: Sustained flow increases
  - Timing: Minimal effects
- <u>Projected Climate Changes</u>:
  - Small yield and highflow increases
  - Declining low flows
  - Timing: Large shift
  - Across all scales

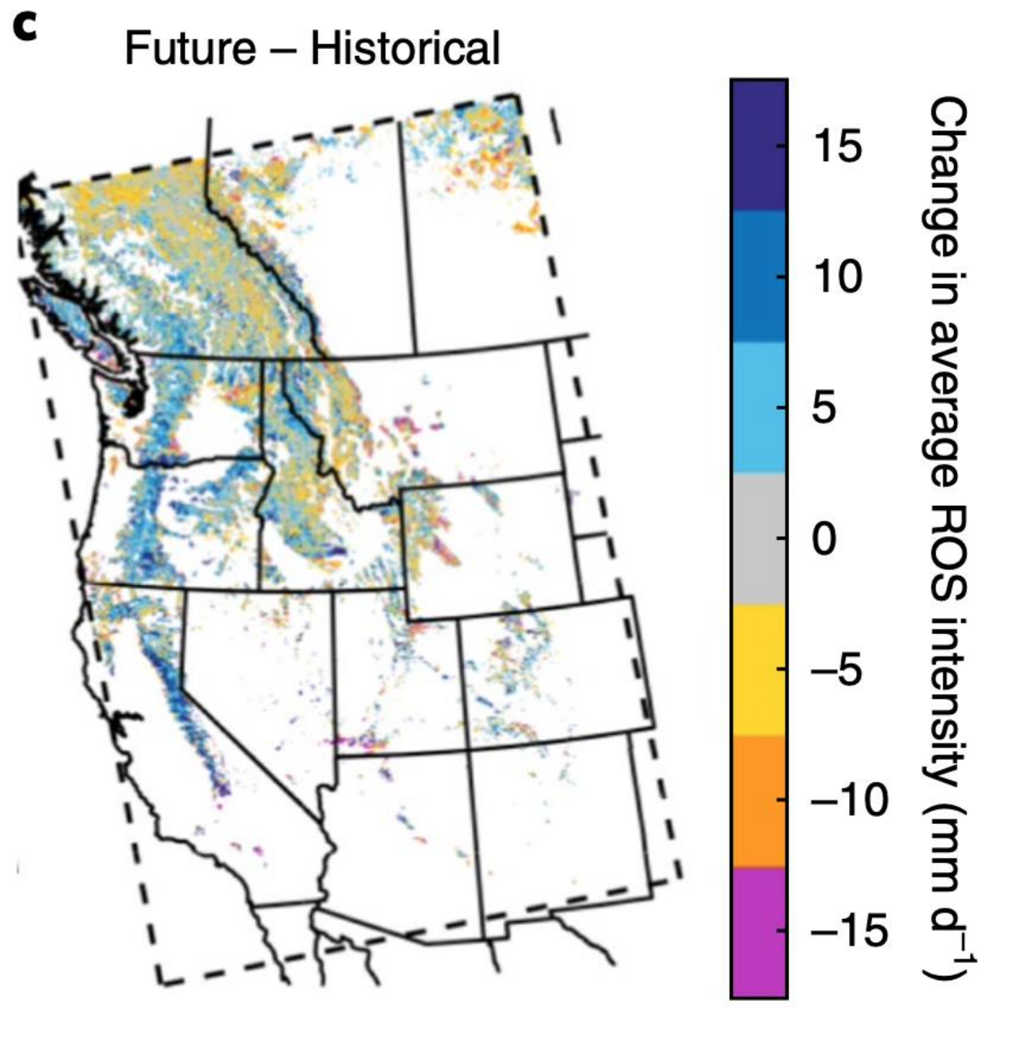
Degree of Disturbance and Downstream Flow Changes

-

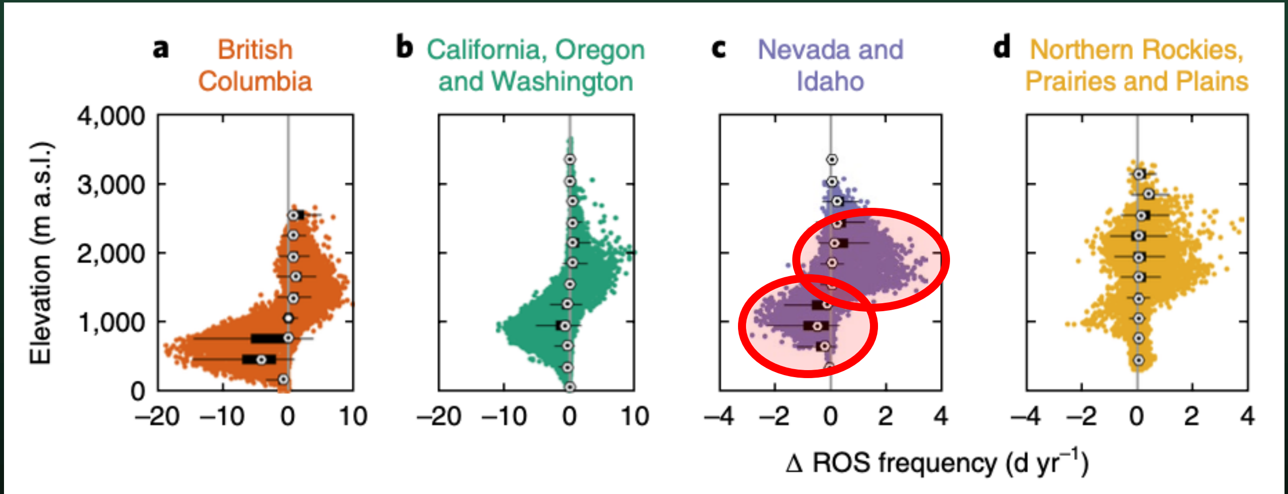
10 parameter sets




c
Future – Historical
> +5
+2 to +5
+1 to +2
+0.1 to +1
–0.1 to +0.1
–1 to –0.1
–2 to –1
–5 to –2
< –5
Δ ROS frequency (d yr^{-1})

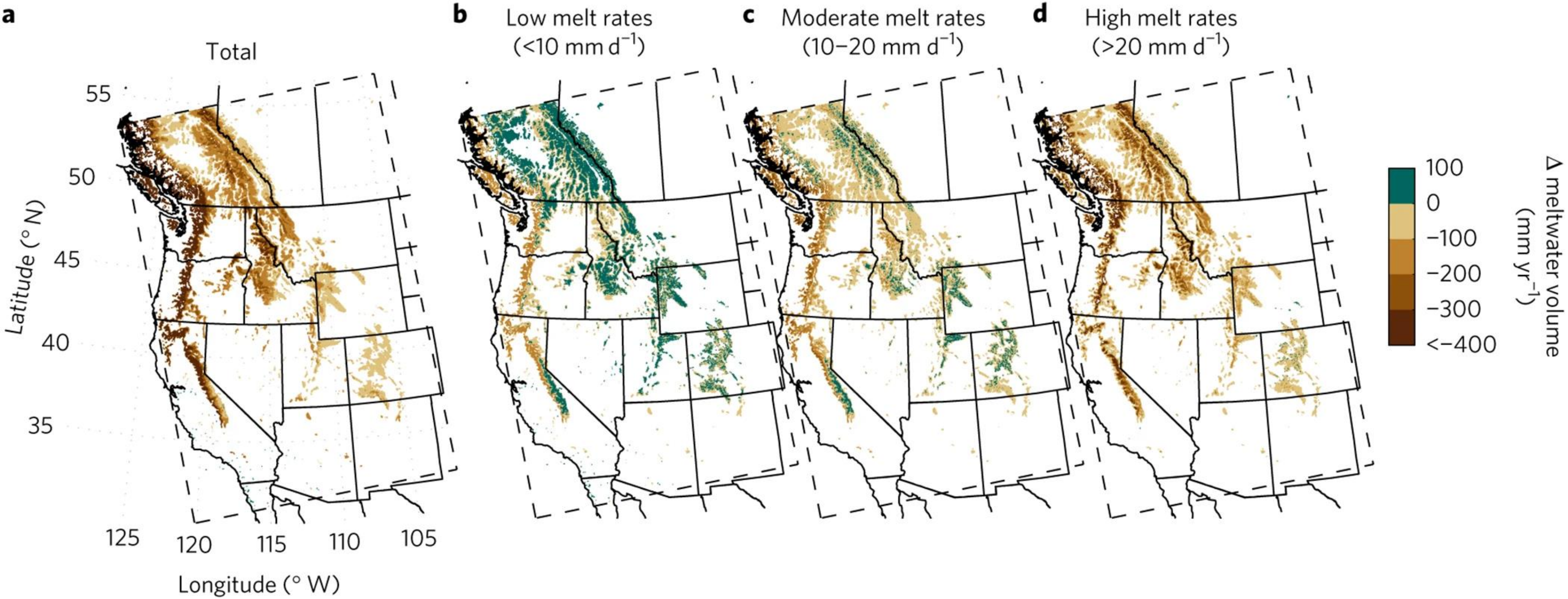

c
Future – Historical
15
10
5
0
–5
–10
–15
Change in average ROS intensity (mm d^{-1})

Changing Rain-on-Snow (ROS) Regime



Musselman, K. N., Lehner, F., Ikeda, K., Clark, M. P., Prein, A. F., Liu, C., Barlage, M., & Rasmussen, R. (2018). Projected increases and shifts in rain-on-snow flood risk over western North America. Nature Climate Change, 8, 808-812.

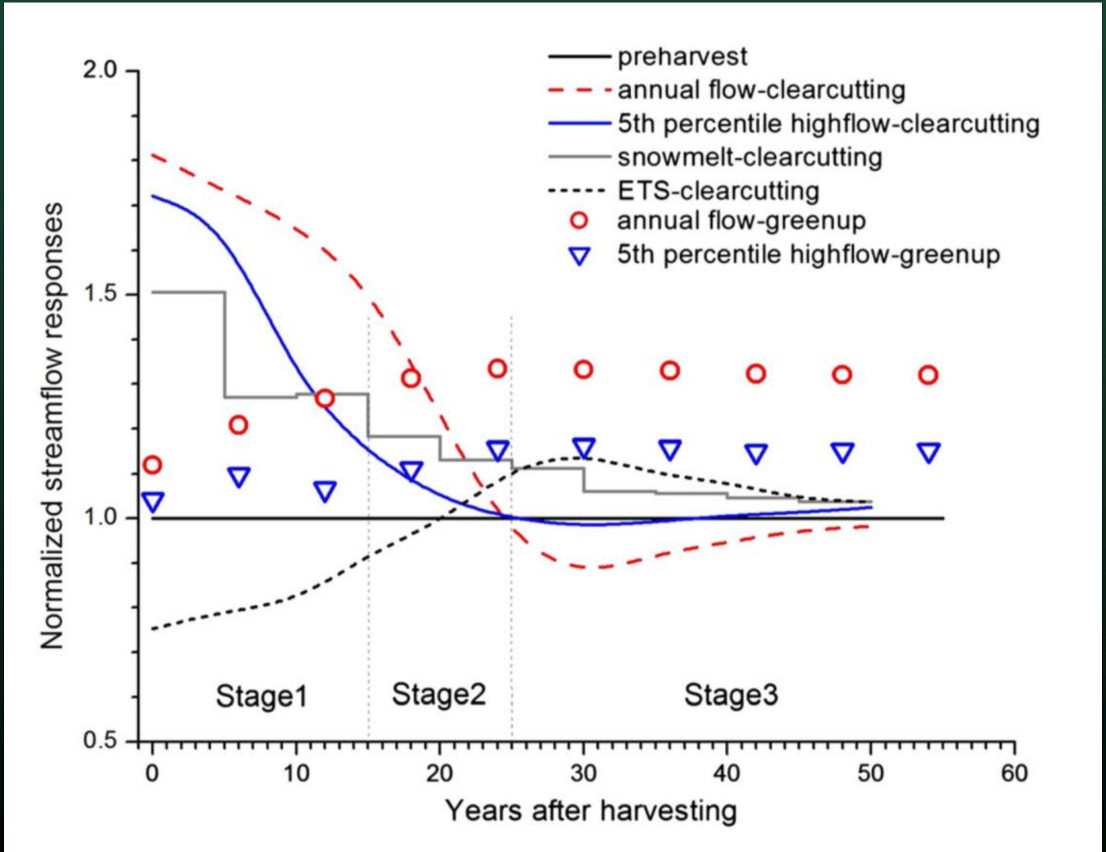
Slower Melt in a Warmer World



2071-
2100

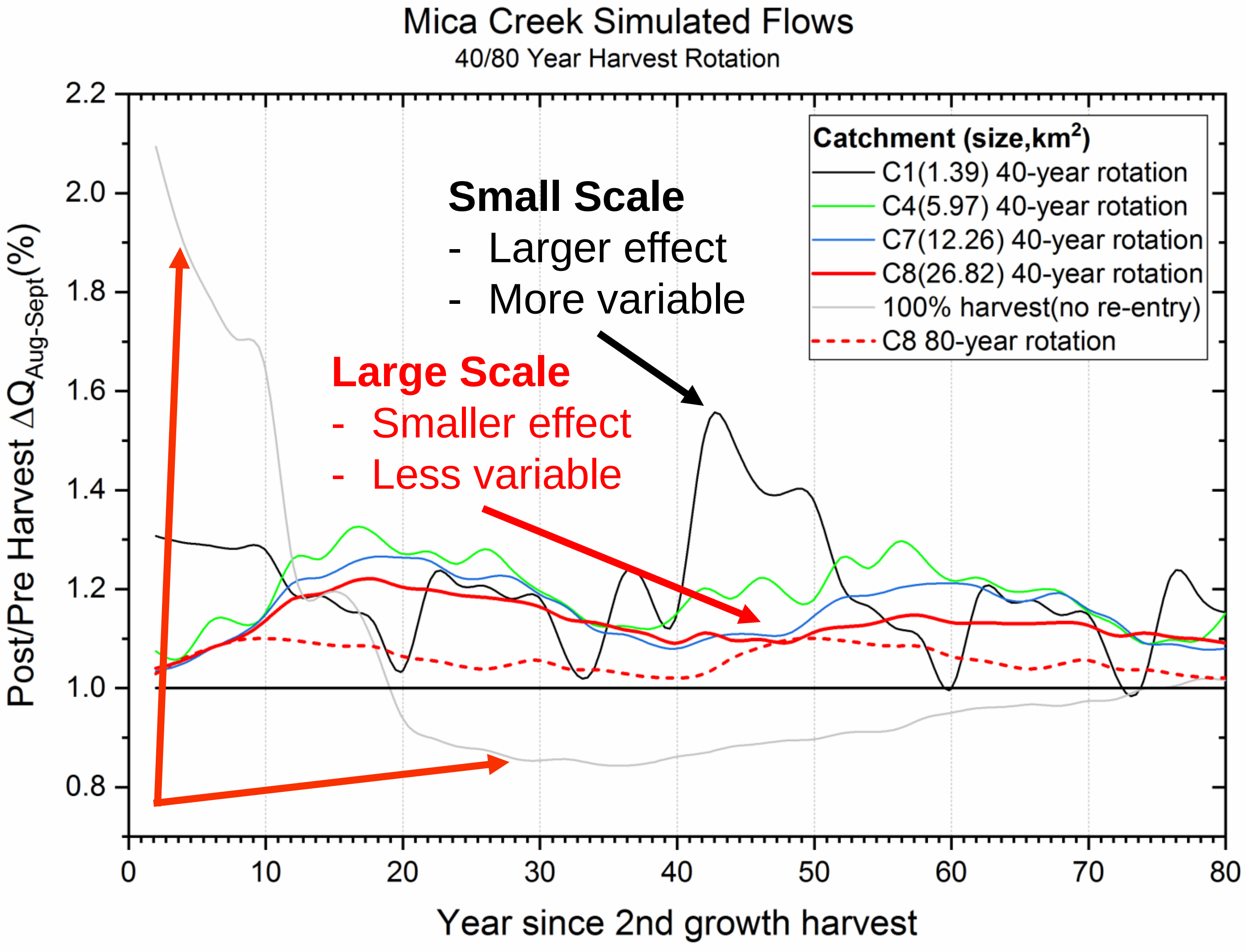
Musselman, K. N., Clark, M. P., Liu, C., Ikeda, K., & Rasmussen, R. (2017). Slower snowmelt in a warmer world. Nature Climate Change, 7(3), 214-219.

Results: Rotation Harvesting



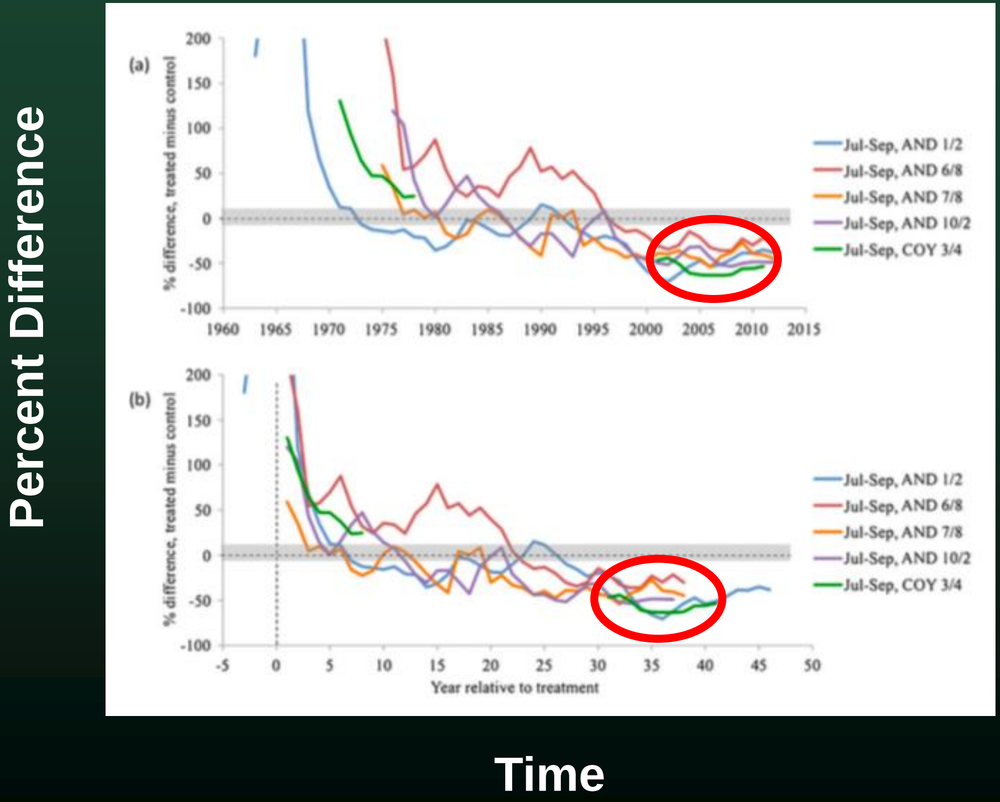
- ET & S
- Annual flow
- 5th Percentile flows

Low Flow Changes Across Scales



Coble, A. A., Barnard, H., Du, E., Johnson, S., Jones, J., Keppeler, E. et al. (2020). Long-term hydrological response to forest harvest during seasonal low flow: Potential implications for current forest practices. Science of The Total Environment, 138926.

Forestry and Low Flows



Western OR

~100% harvested

~50% decline in low flows

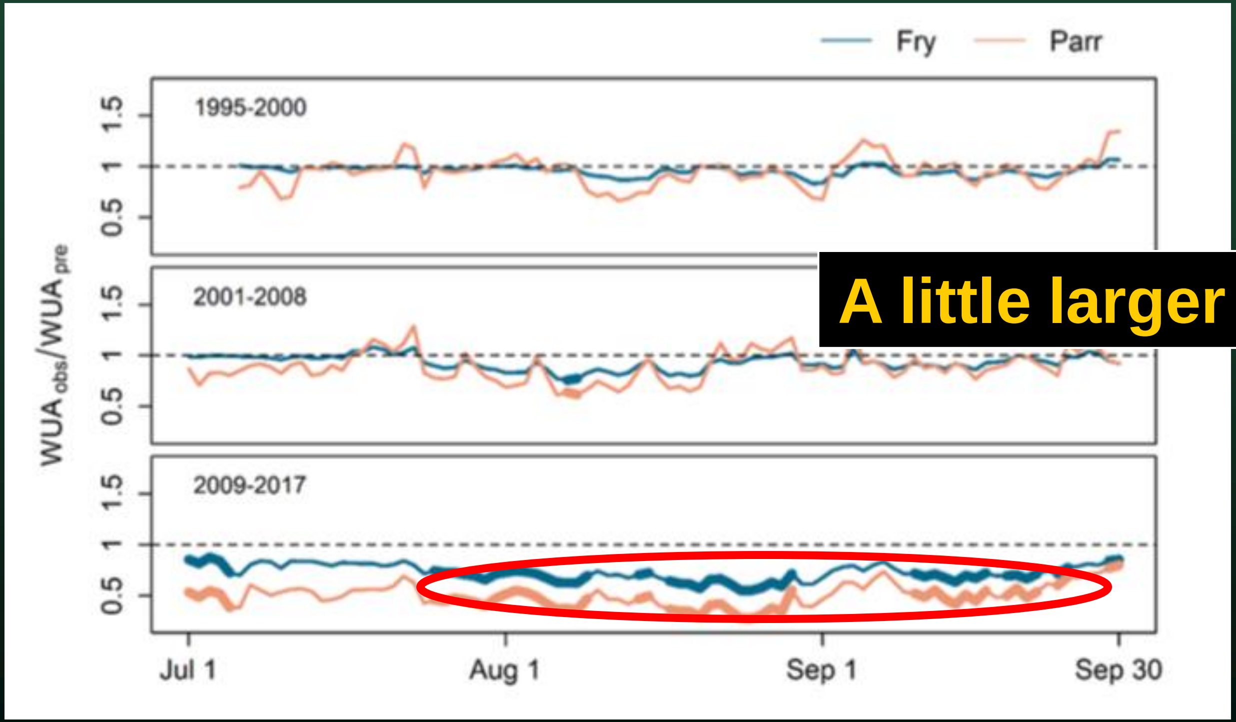
- Basin sizes:
  - 9 to 101 ha
  - 22 to 250 ac

← Small!

- Following harvest & regrowth

Perry, T. D., & Jones, J. A. (2016). Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. *Ecohydrology*, *10*(2), e1790.

Forestry, Low Flows, and Fish



A little larger →

Southern BC

- **~50% harvested**
- Basin sizes:
  - 494 to 373 ha
  - 1221 to 922 ac
- decrease in low flows
- **20-50% decrease in fish habitat**

Gronsdahl, S., Moore, R. D., Rosenfeld, J., McCleary, R., & Winkler, R. (2019). Effects of forestry on summertime low flows and physical fish habitat in snowmelt-dominant headwater catchments of the Pacific Northwest. *Hydrological Processes*.

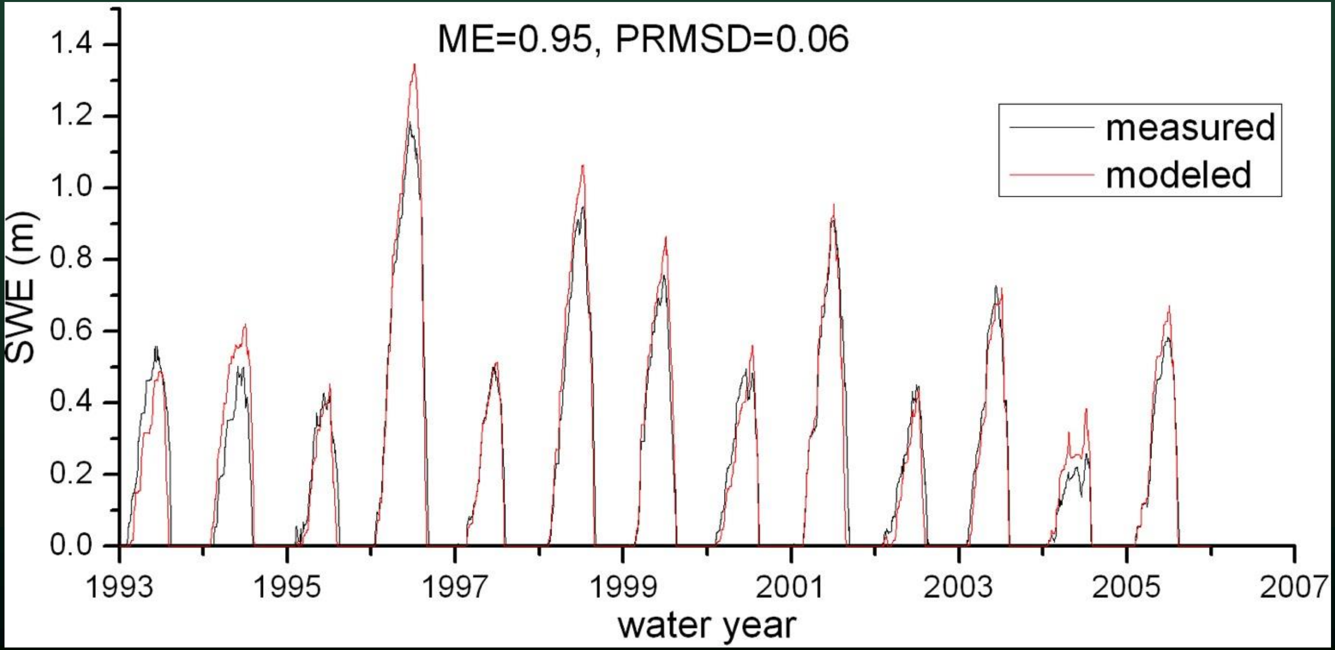
Background

- Timber Harvest and Flow Regime Questions
  - Annual Yield (e.g. Stednick, 1996)
  - Peak Flow Magnitude (Jones & Grant, 1996; Thomas & Megahan, 1998; Bowling et al., 2000)
    - …and effects on geomorphology and fish (Tonina et al., 2008)
  - Peak Flow Frequency (Alila et al., 2009; Green & Alila, 2012)
  - Low flow declines (Perry and Jones, 2016)
    - …and effects on fish habitat (Gronsdahl et al., 2019)
  - Low flow enhancement (Sun et al., 2018)

} **The Motivation**

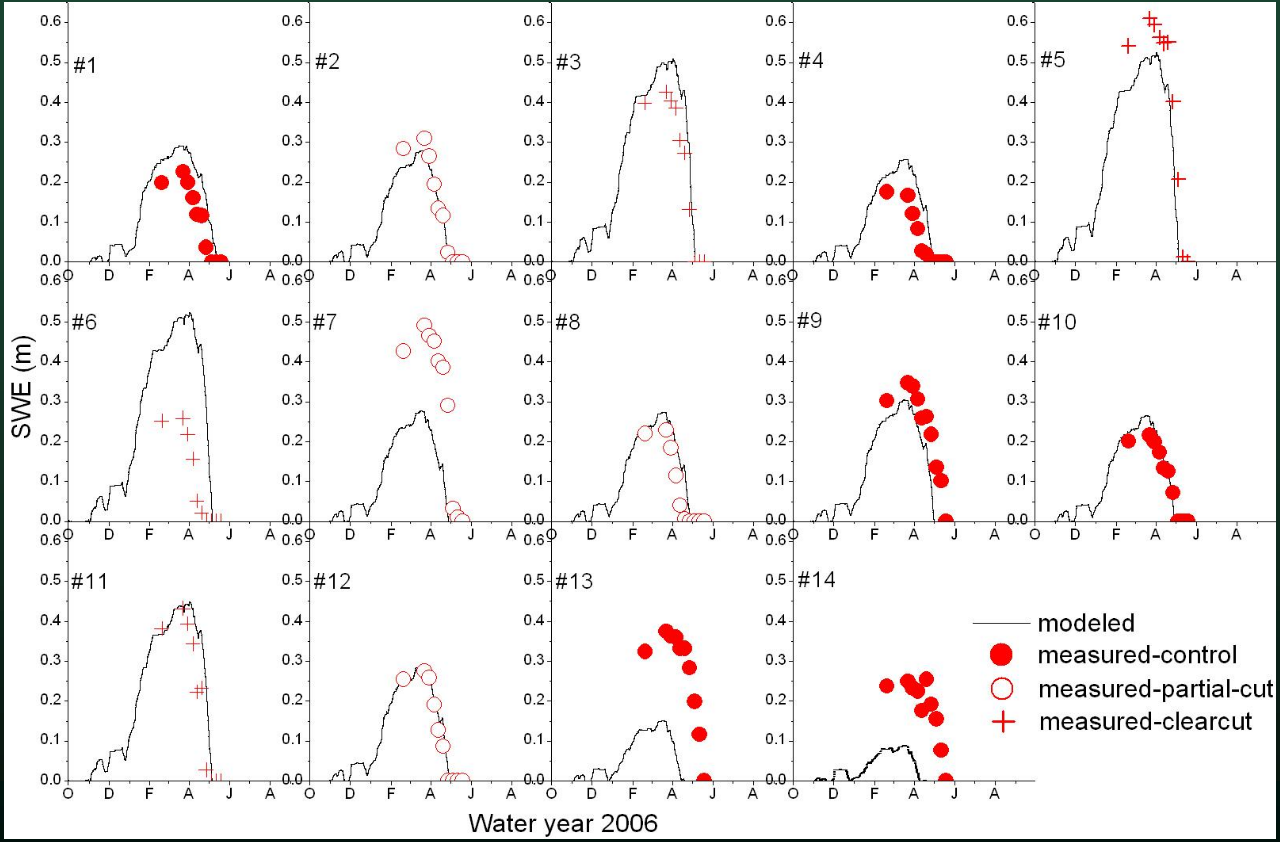
Model Performance Assessment

- **Snow**
  - ME: 0.95



Du et al., 2014, Hyd. Proc.

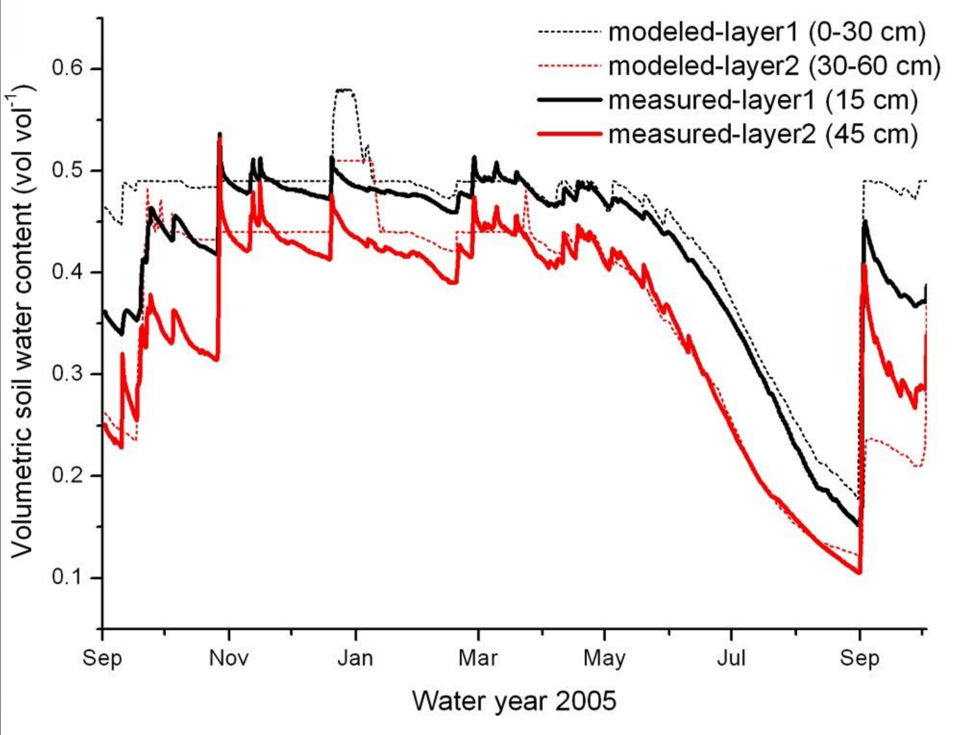
Model Validation: SWE 2006



Du et al., 2014, Hyd. Proc.

Model Performance Assessment

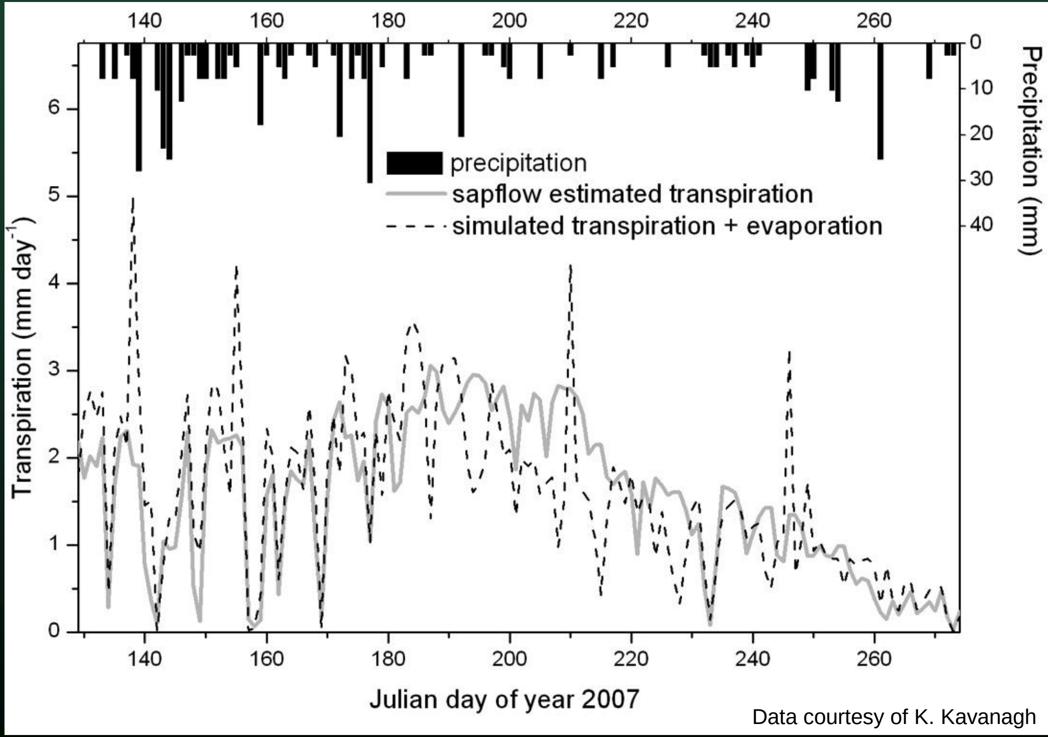
- **Soil Water Content**



Du et al., 2014
Hyd. Proc.

Model Performance Assessment

- **ET and Sapflow**



Du et al., 2014, Hyd. Proc.