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Forest hydrology for climate adaptation

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SALEM, OR
5 DECEMBER 2019

Forest water balance

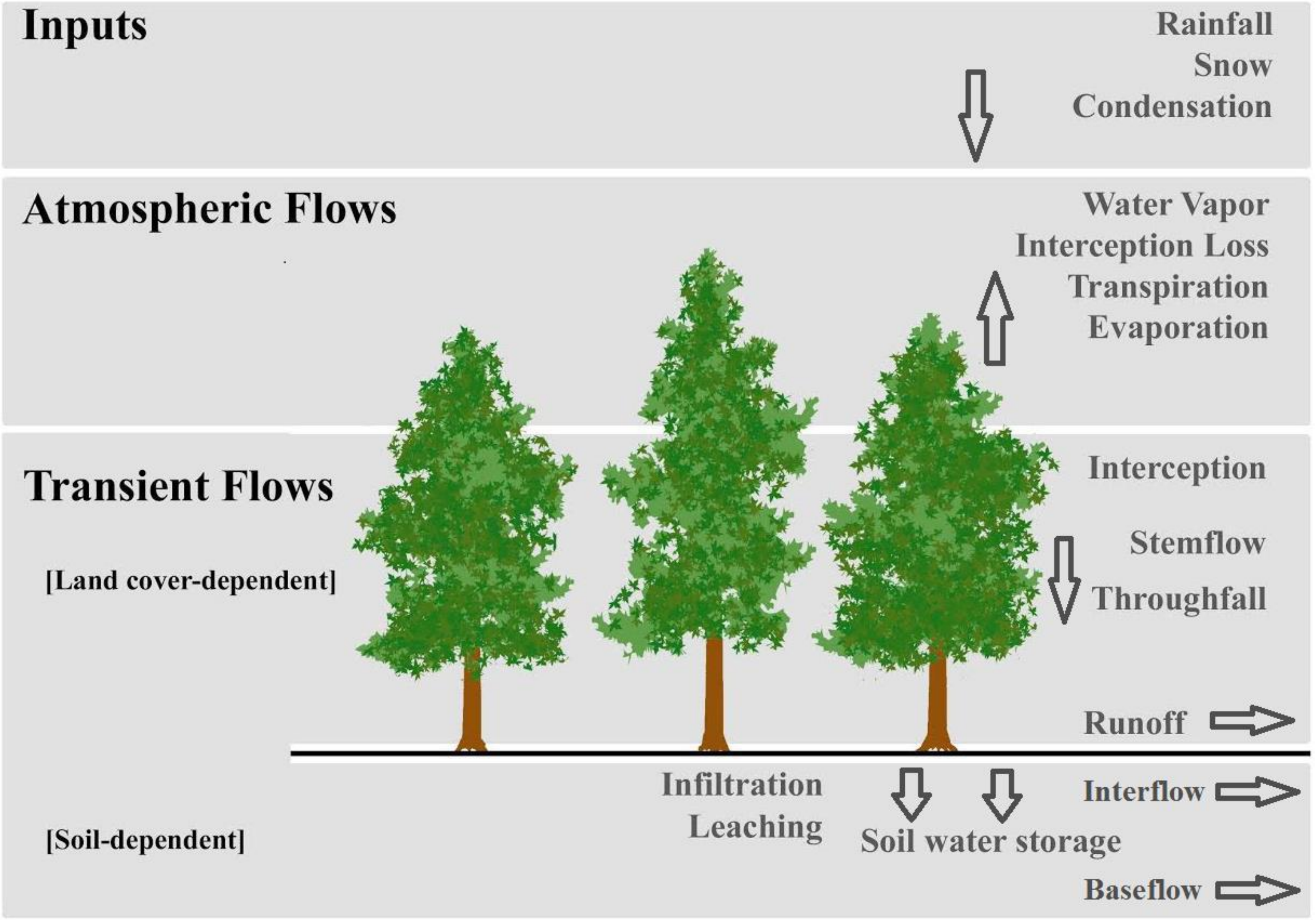
$$Q = P - ET \pm \Delta S$$

Q = streamflow, discharge

P = precipitation (rain and snow)

ET = evaporation + transpiration

S = storage (subsurface water in soils or groundwater)

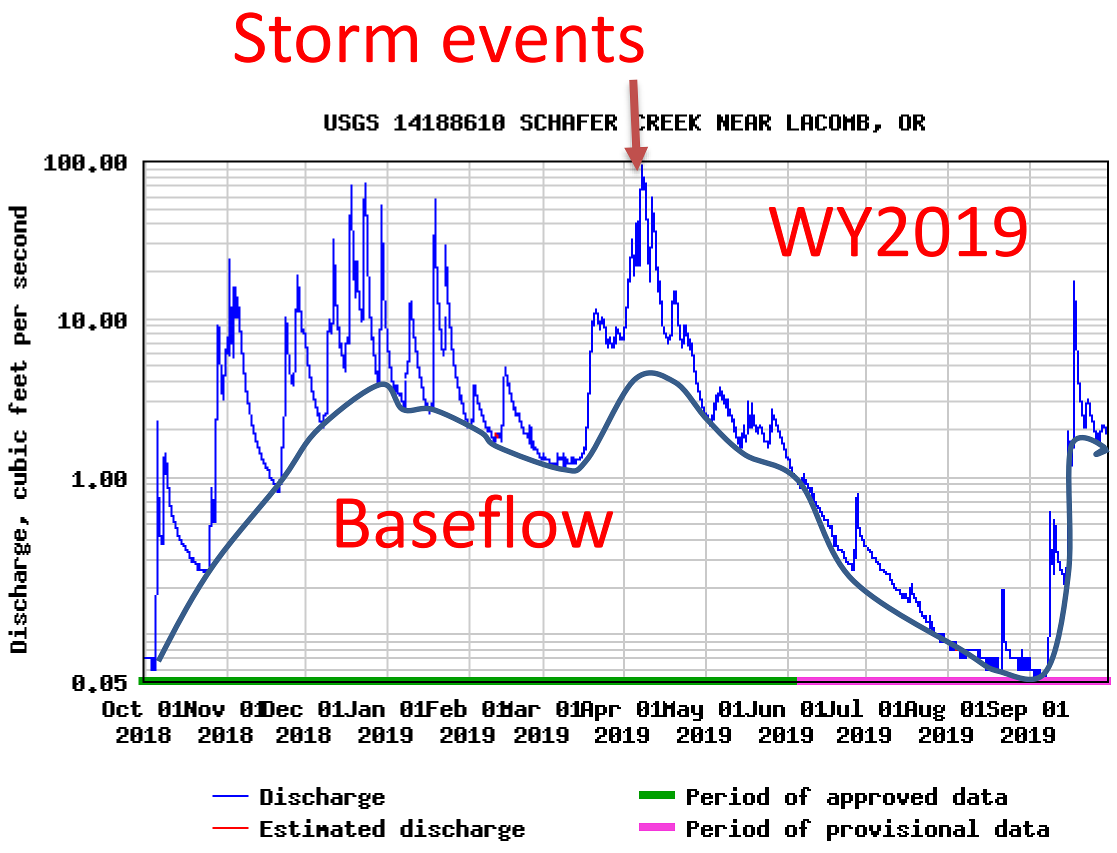


Watkins et al. 2015

Water cycle regulation

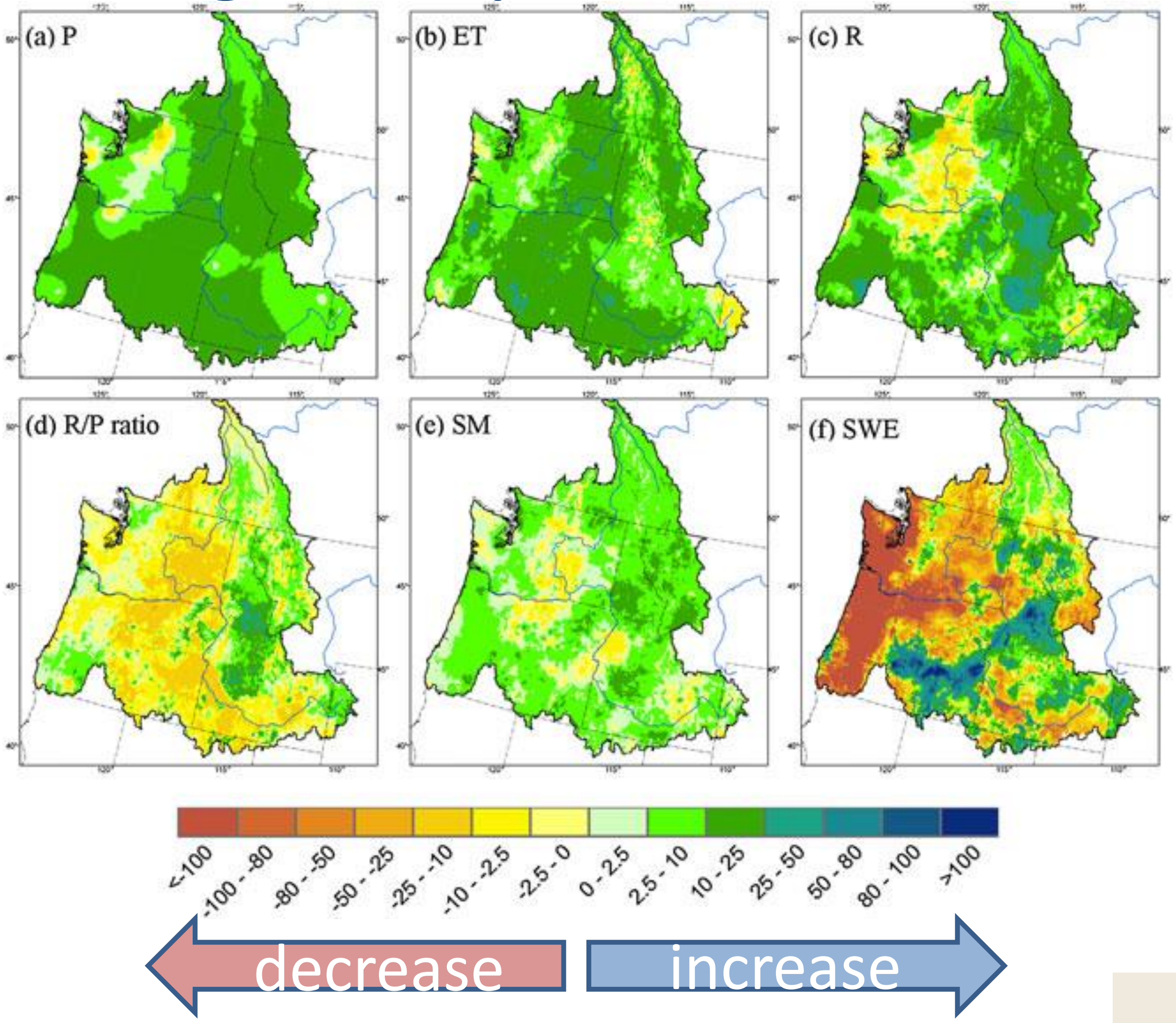
- Mediterranean climate:
  - Prolonged dry period
  - Growing season off set from period of high water availability

- Climate-related shifts in timing of water availability or quantity may have implications for tree water use (evapotranspiration rates) and streamflow



Climate trends in regional hydrologic components

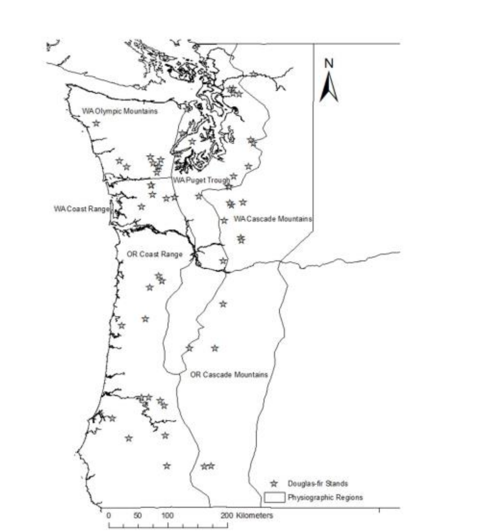
- Trends depict % change in 85 years (1921-2006)
- P = precipitation
- ET = evapotranspiration
- R = runoff
- R/P = runoff: precip.
- SM = soil moisture
- SWE = snow water equivalent

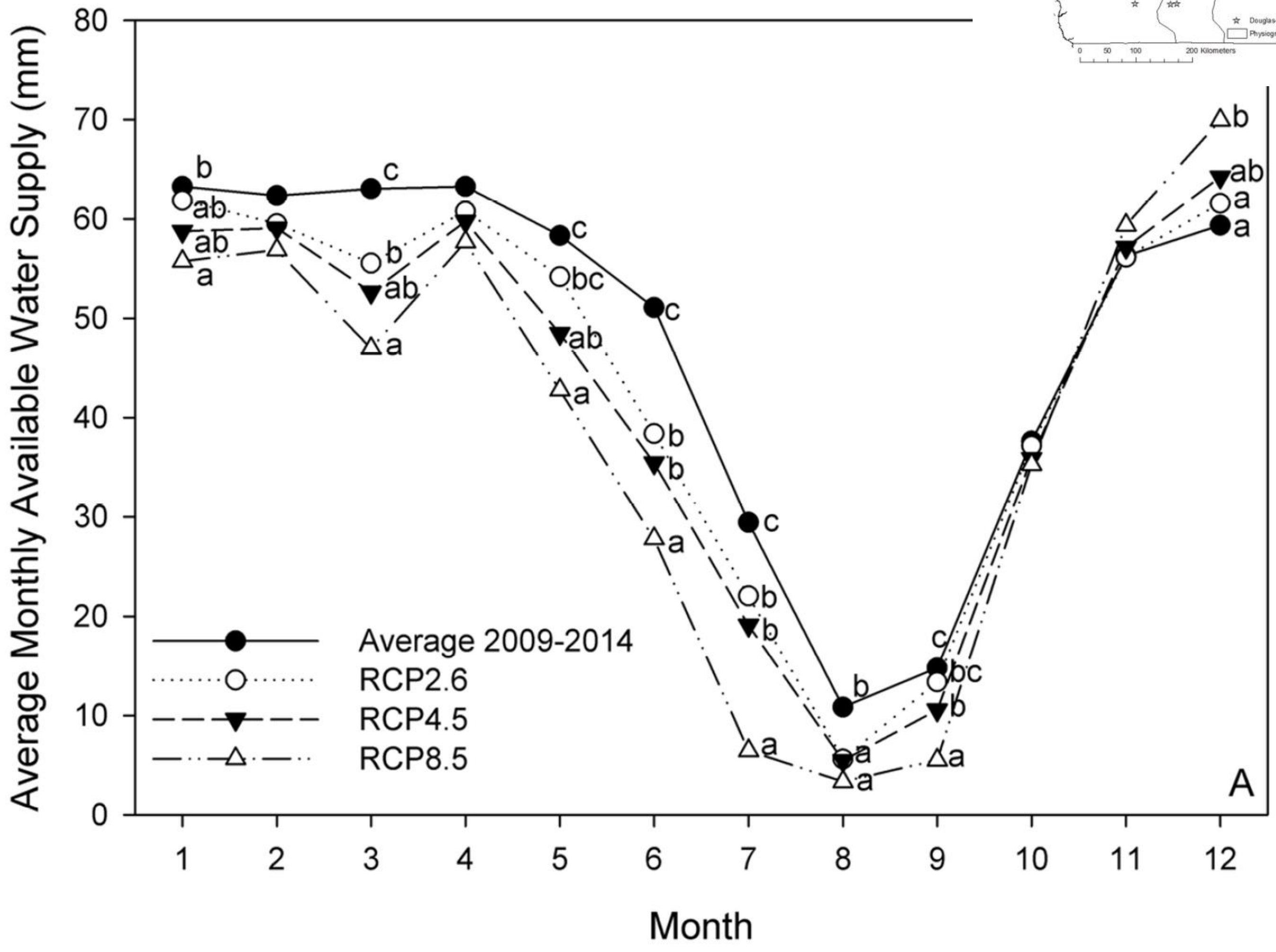


Liu et al. 2013

Decrease in shallow soil water in Douglas-fir forests

- Mild to severe climate change model scenarios suggest decrease in annual soil available water supply by 8 to 19%
- Summer available water supply will decrease 25 to 72%
- Greatest decreases in Washington and Oregon coast regions

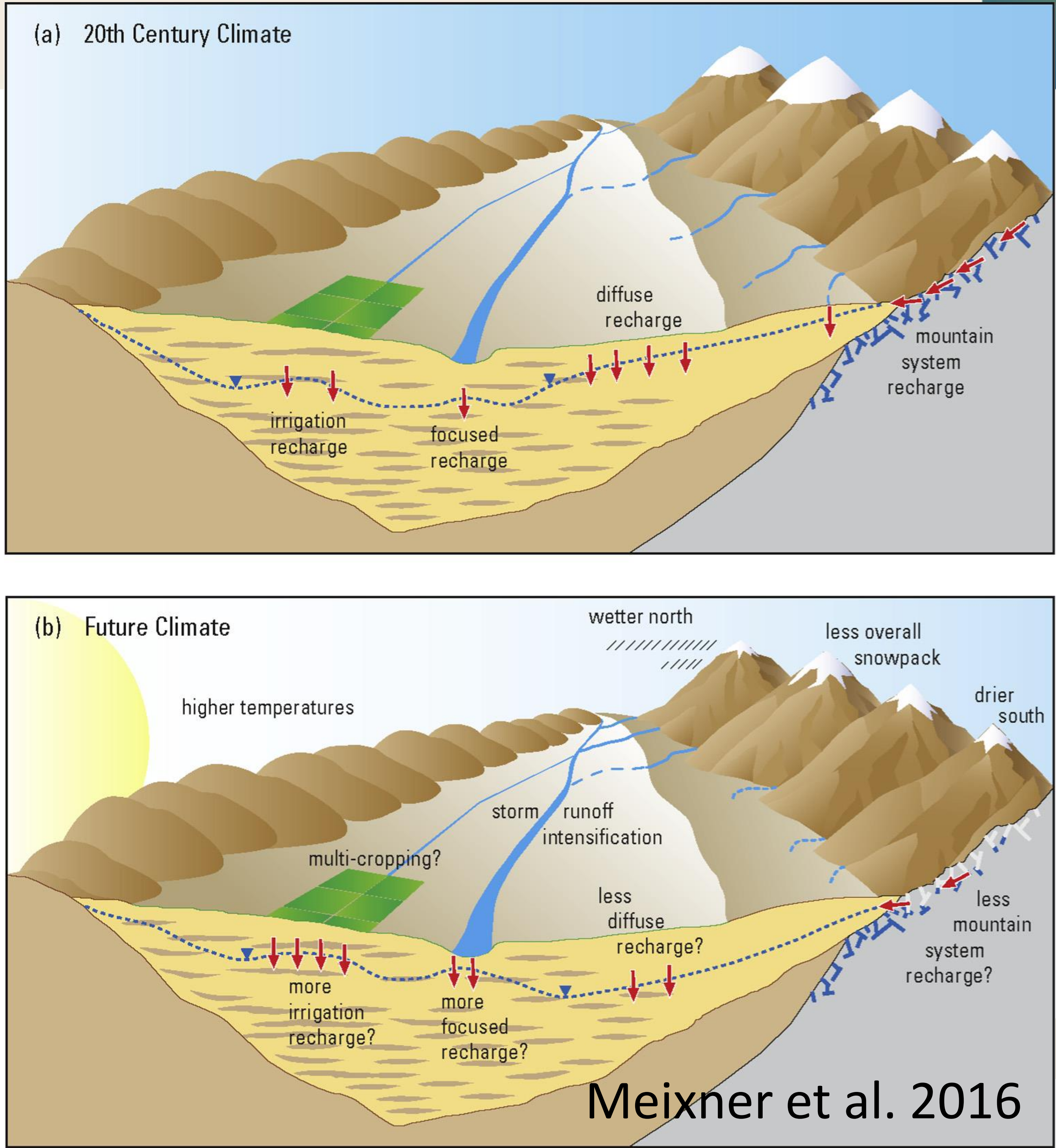




Littke et al. 2018

Groundwater – western U.S.

- Knowledge gaps in understanding hydrologic flowpaths in mountain systems
- Little change to slight increase in northern aquifers
- Decline in Mountain system recharge due to decreased snowpack (but dependent on elevation)



Meixner et al. 2016

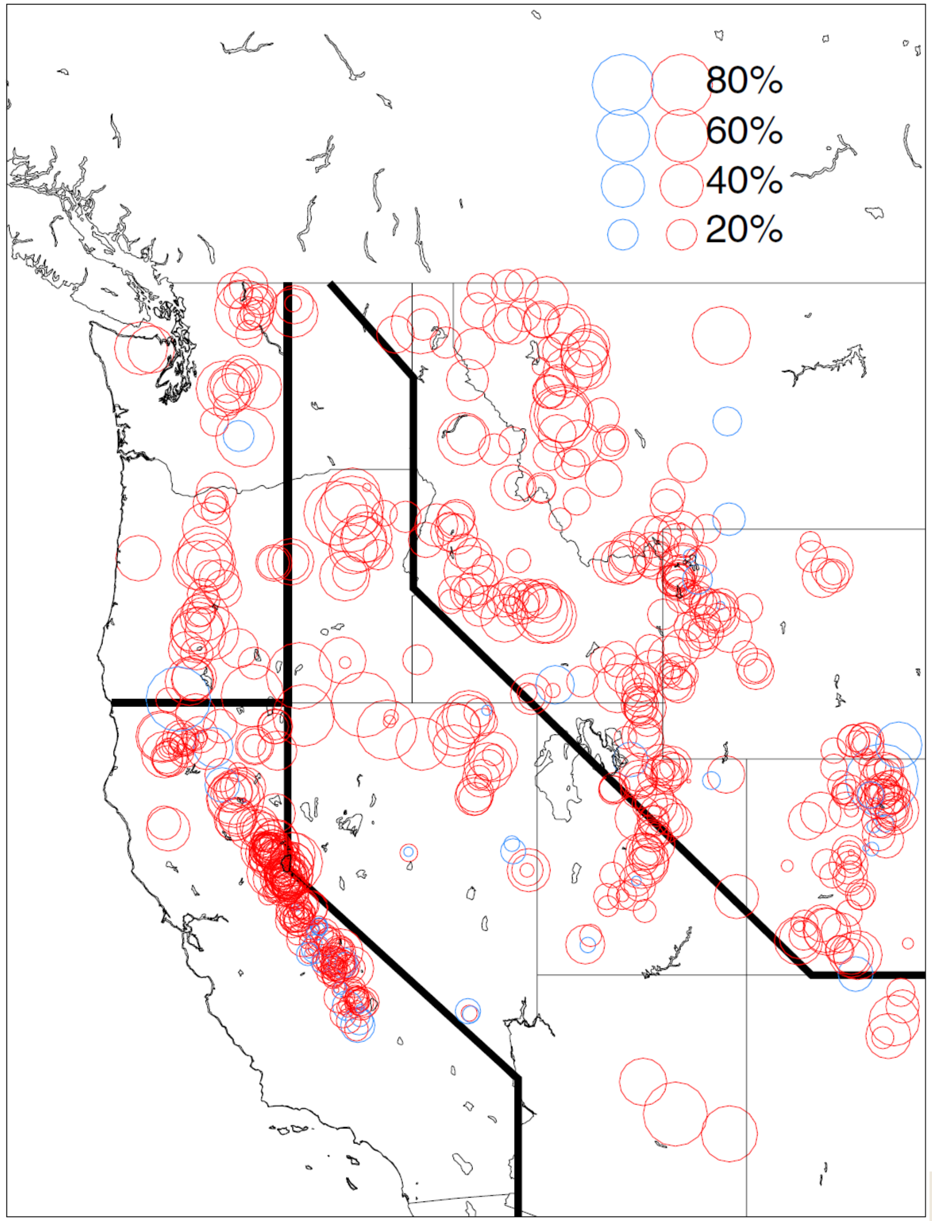
Declines in snowpack across the western US

- Snotel sites:
  - 90% declining trend
  - 33% significant declines (5% by chance)
  - 2% significant increases (5% by chance)

- Declining trends observed across all months, states, and climates

- Declines were largest in spring, Pacific states, and locations with mild winter climate

a) April 1 Observed SWE Trends 1955-2016

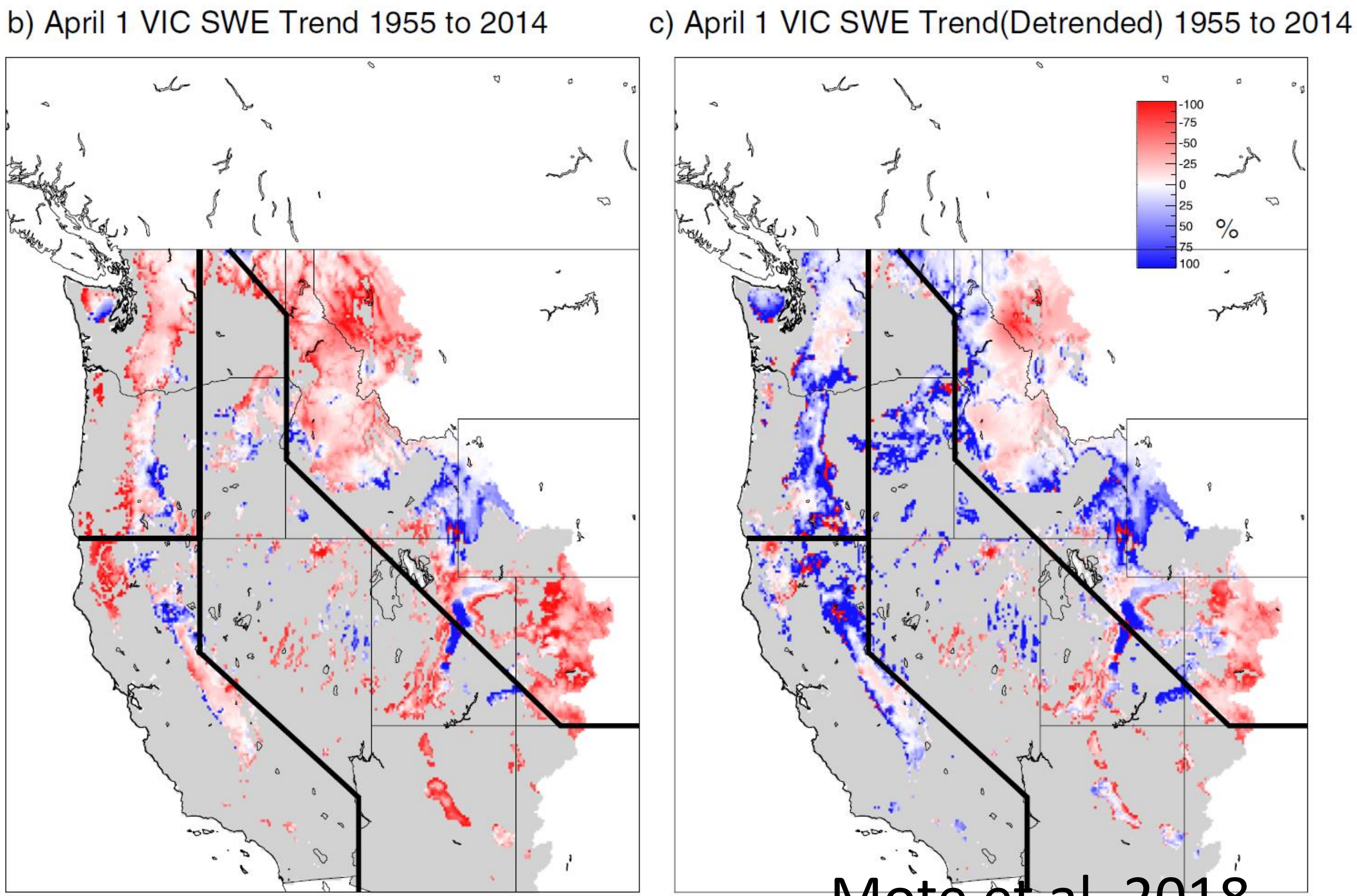


Mote et al. 2018

Role of warming in snowpack decline

- Red = decline
- Blue = increase

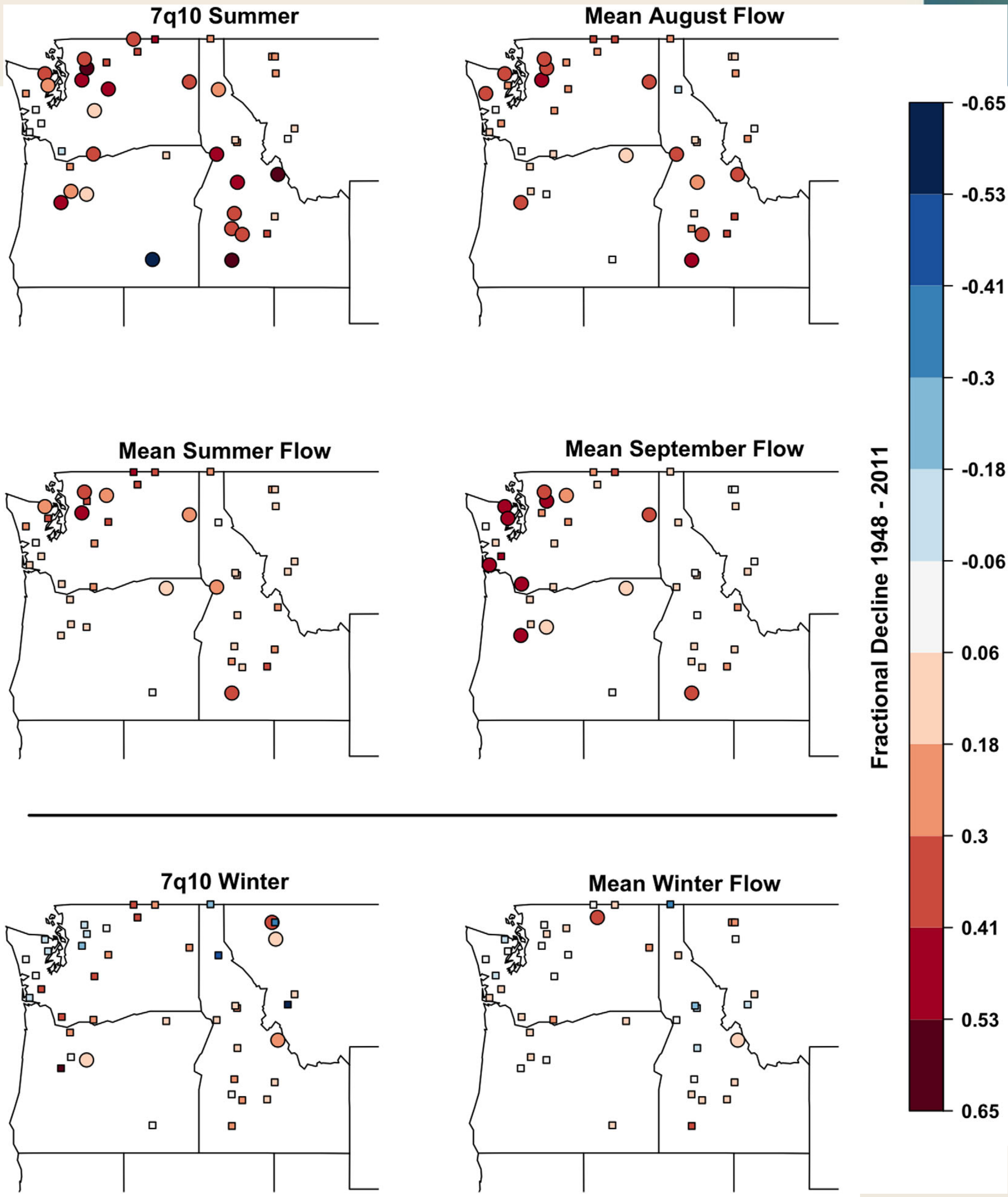
Modelled observations | Temperature removed



Mote et al. 2018

Streamflow declining in the PNW

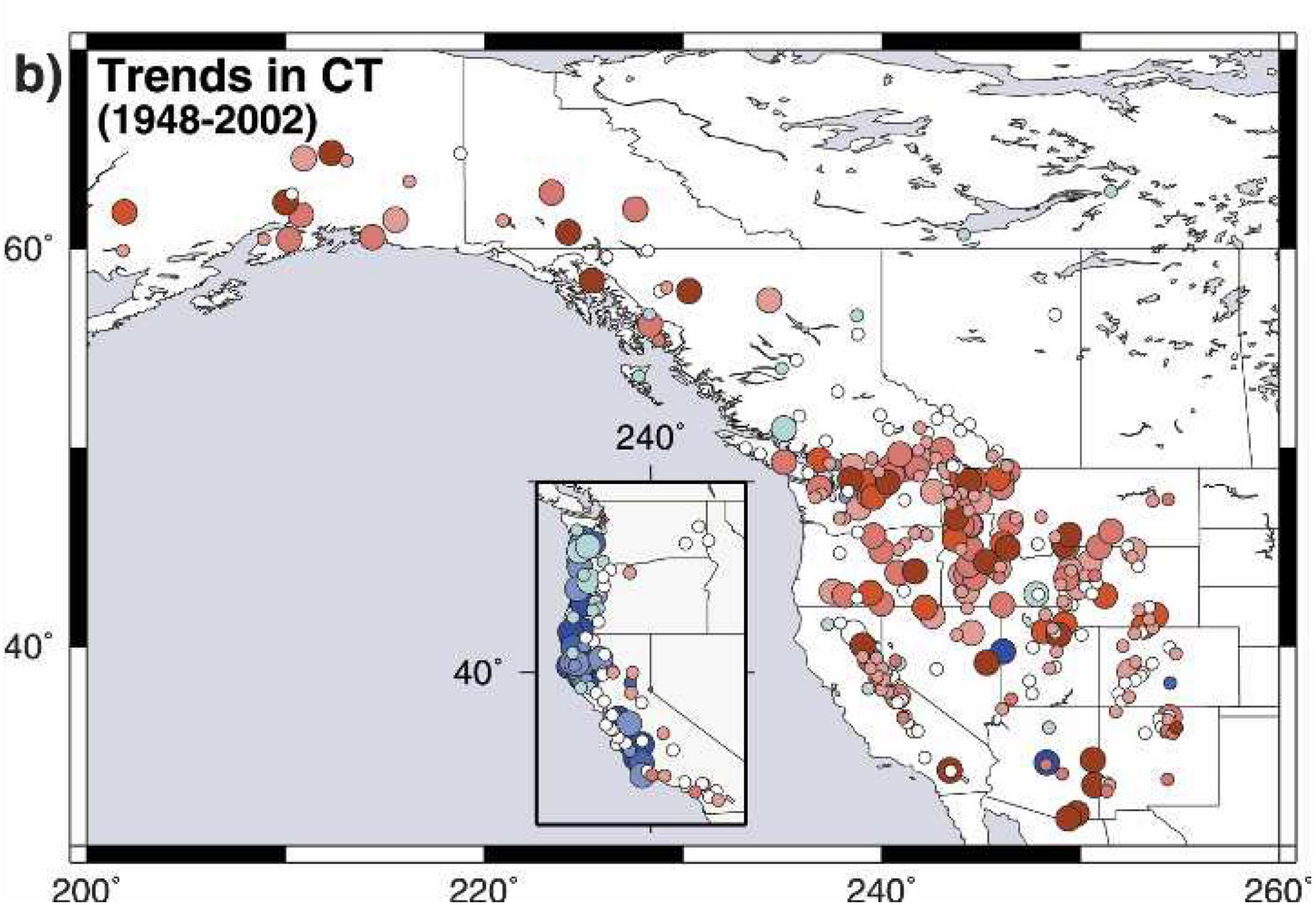
- Declines in annual total, summer mean, and peak streamflow since 1951 (Forbes et al. 2019)
- Majority of gauges show declining trends in low streamflow indices (Kormos et al. 2015)
  - 7q10 = minimum flow for 1 week with a probability of occurrence = 0.10



Kormos et al. 2016

Earlier streamflow timing

- Earlier onset of springtime snowmelt
- Earlier streamflow timing



Stewart et al. 2005

Hydrological response to ‘natural’ disturbance

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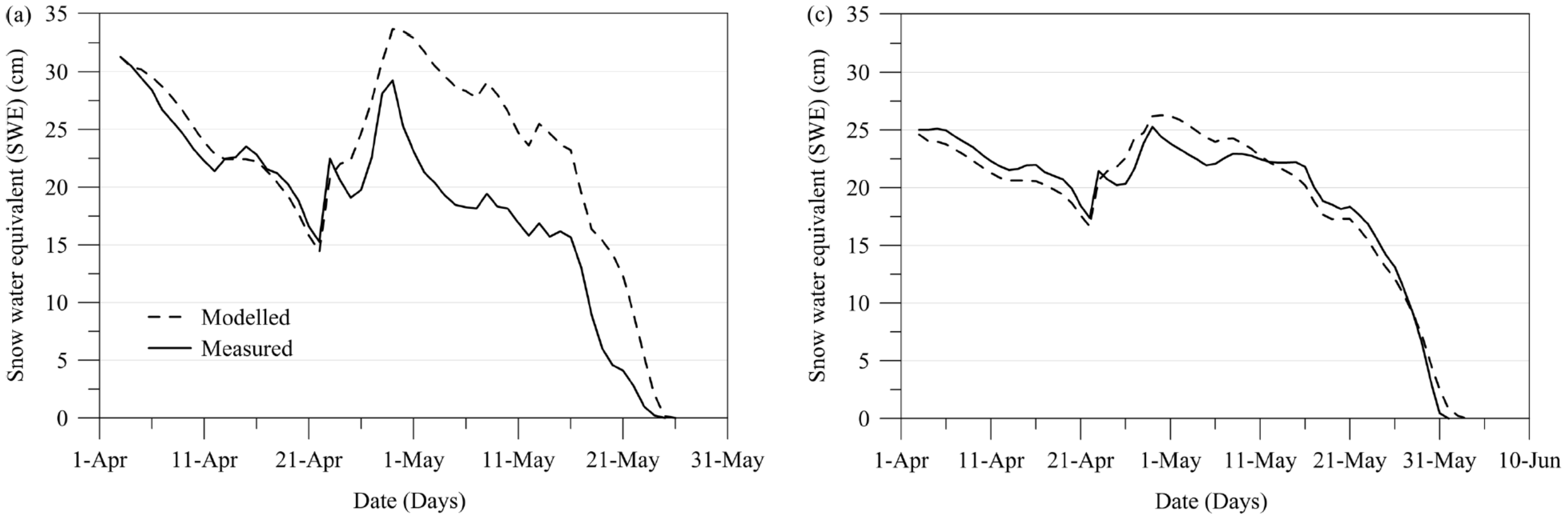
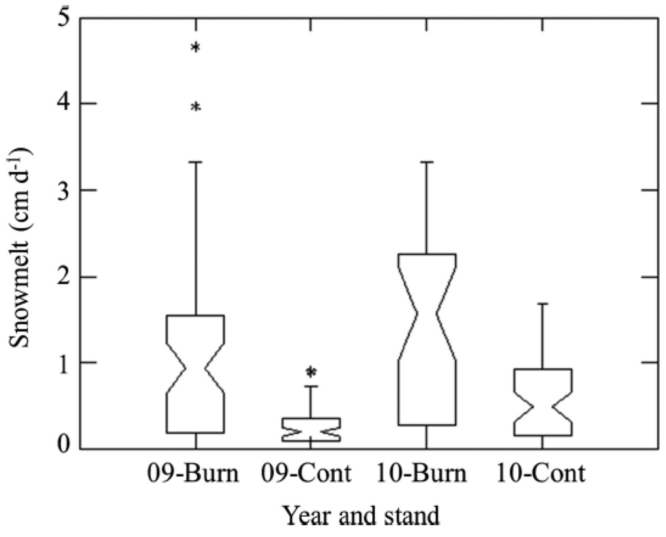
Snow response to fire

- More snow
  - Greater peak SWE in burned sites (40 to 45%)
- But melts faster
  - Snow melted 9 to 15 days earlier in burned than unburned stands (double the snowmelt rate; Burles et al. 2011)





Burles et al. 2011

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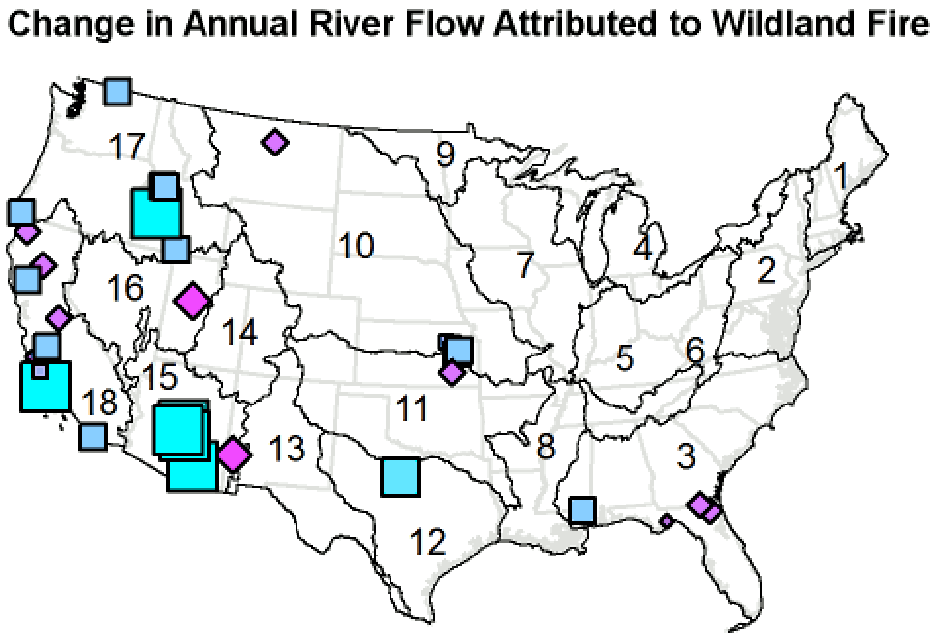
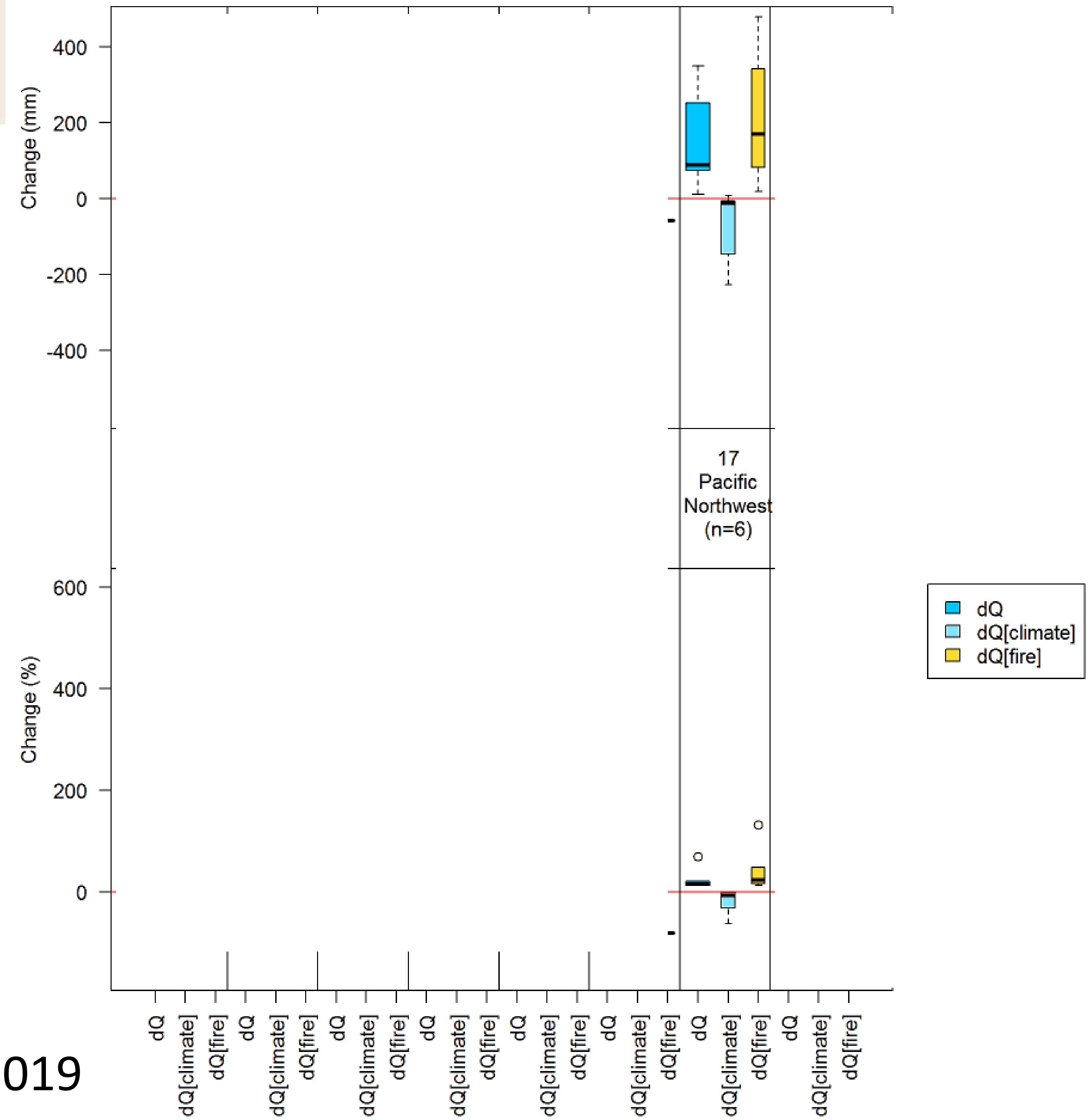
Streamflow response to fire





Sun et al. 2019

Streamflow response to fire

- Increased streamflow
- Increased peak flows, shortened time to peak flow, increased susceptibility to flash floods (2x to 5x increase in peak flow over 6-7 y following fire)

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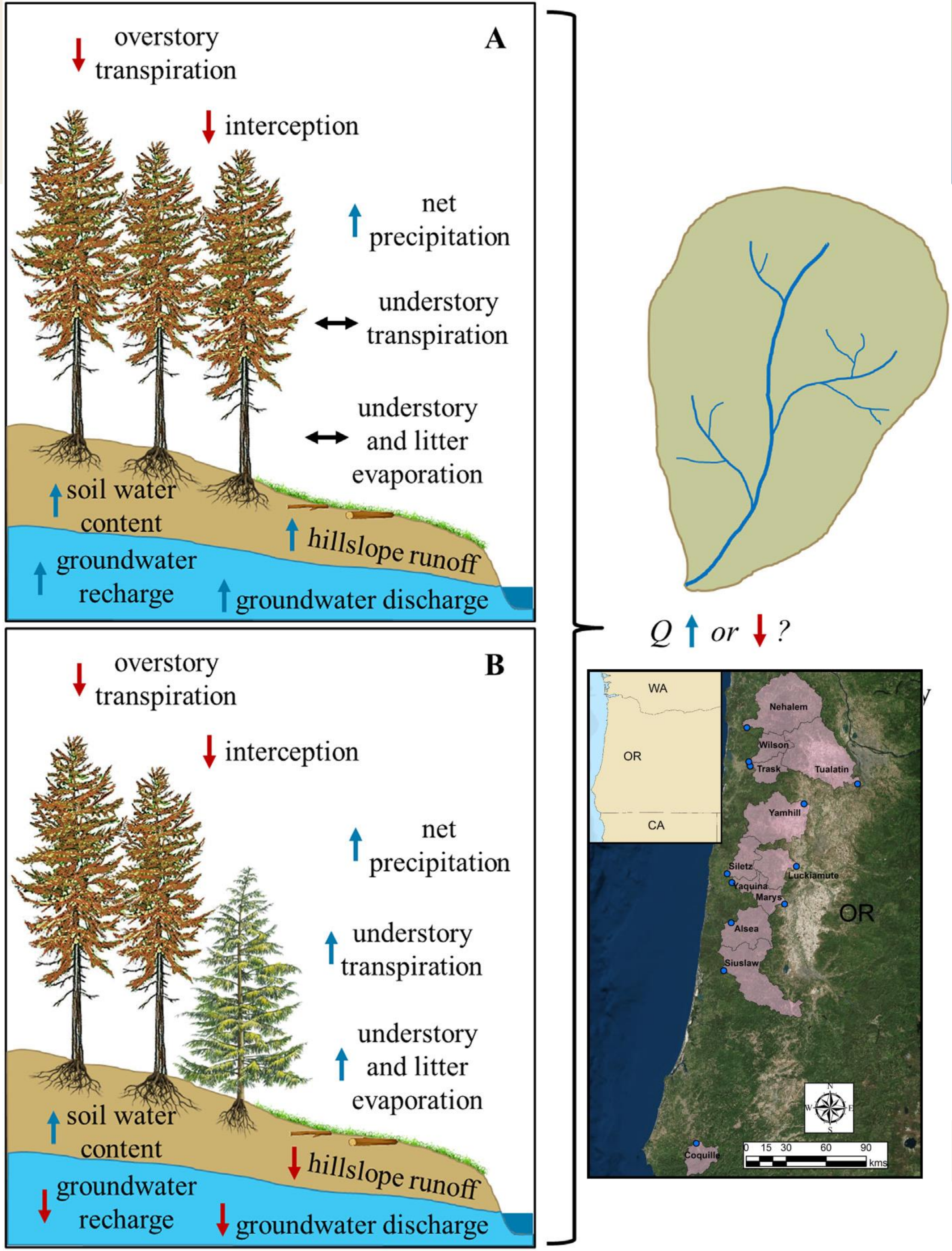
Hydrological response to Swiss Needle Cast

- Foliar disease leads to chronic foliar occlusion that affects canopy architecture
- Discharge generally increased with increasing percentage of Swiss Needle Cast in the watershed
- Managing for resilience (e.g., mixed species stands) may aid in buffering increases in streamflow



Bladon et al. 2019

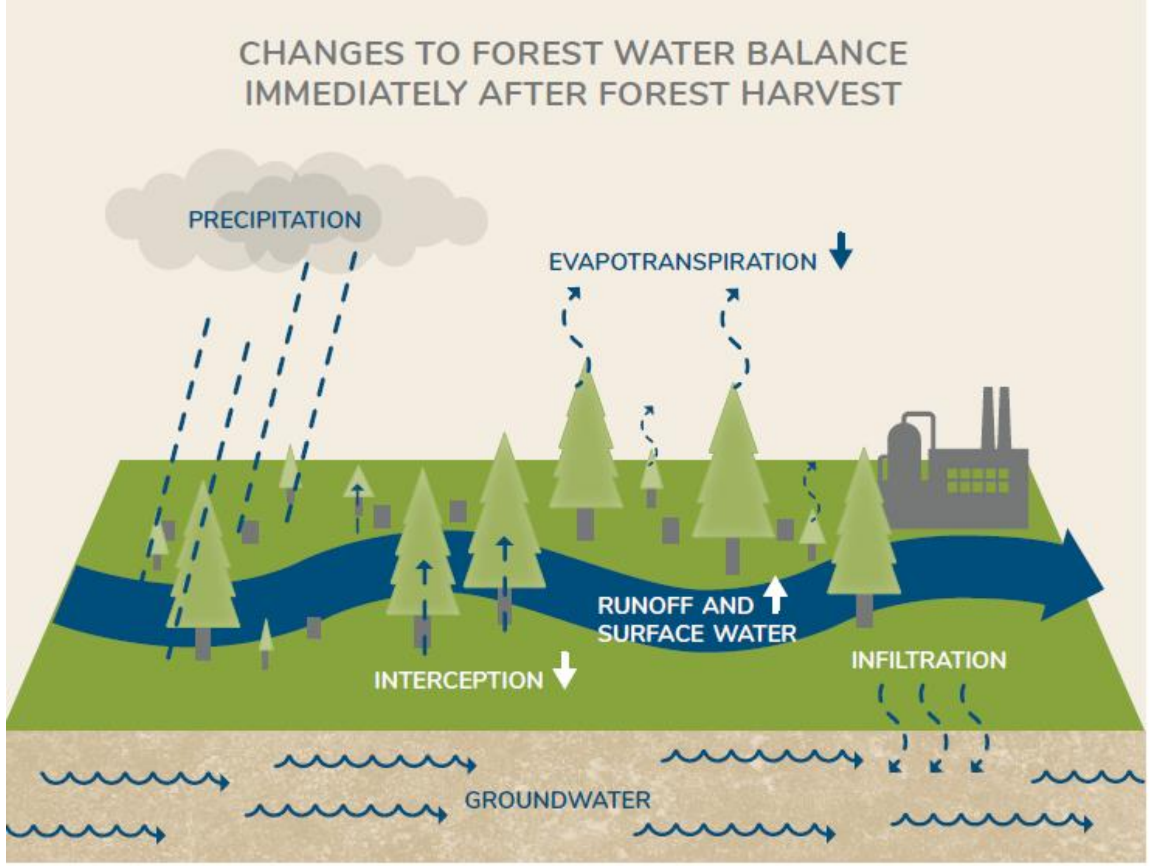
Hydrological response to forest management

Hydrological responses to forest harvest

- Immediate response to overstory forest harvest well documented

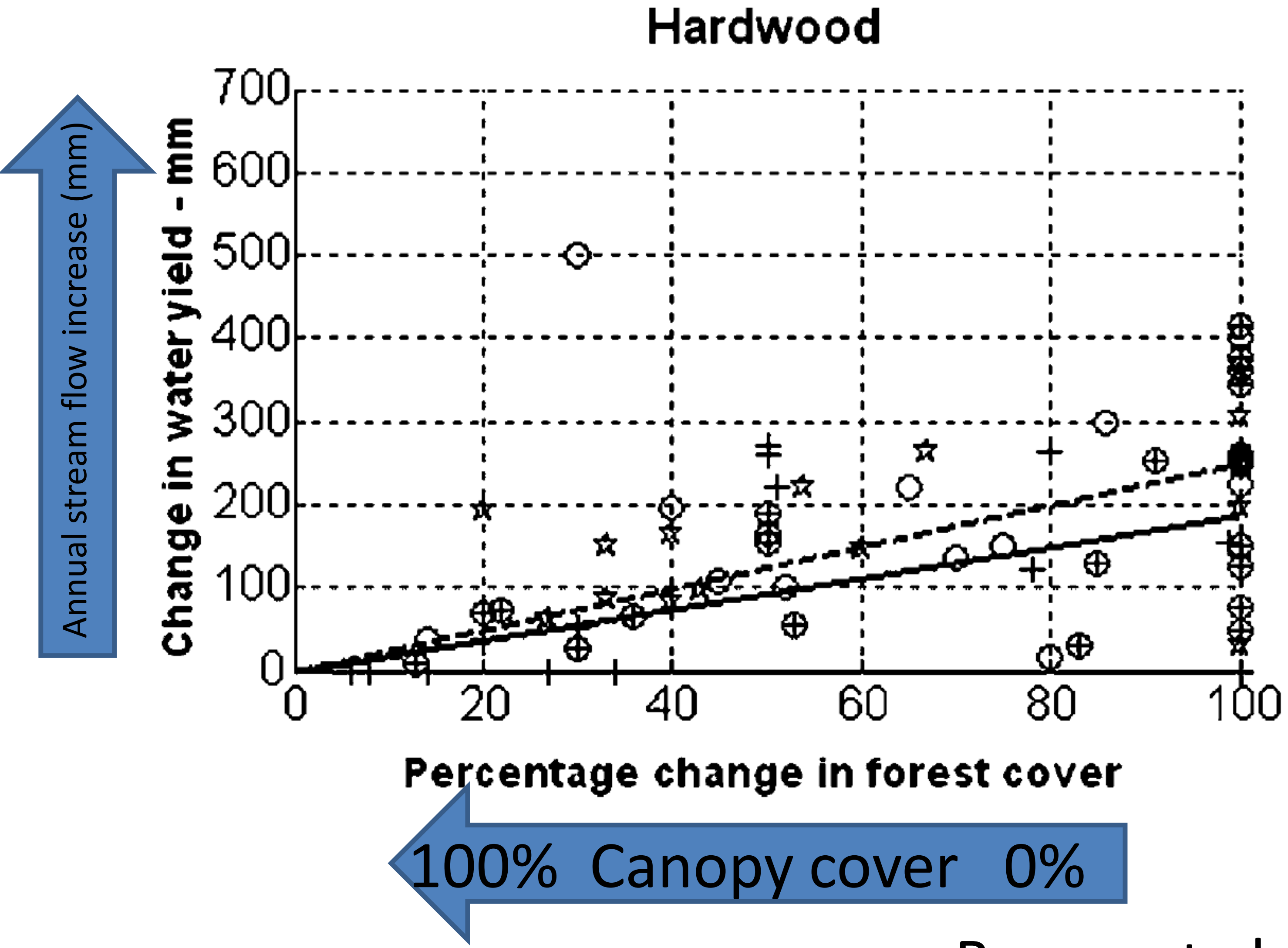
Typically:

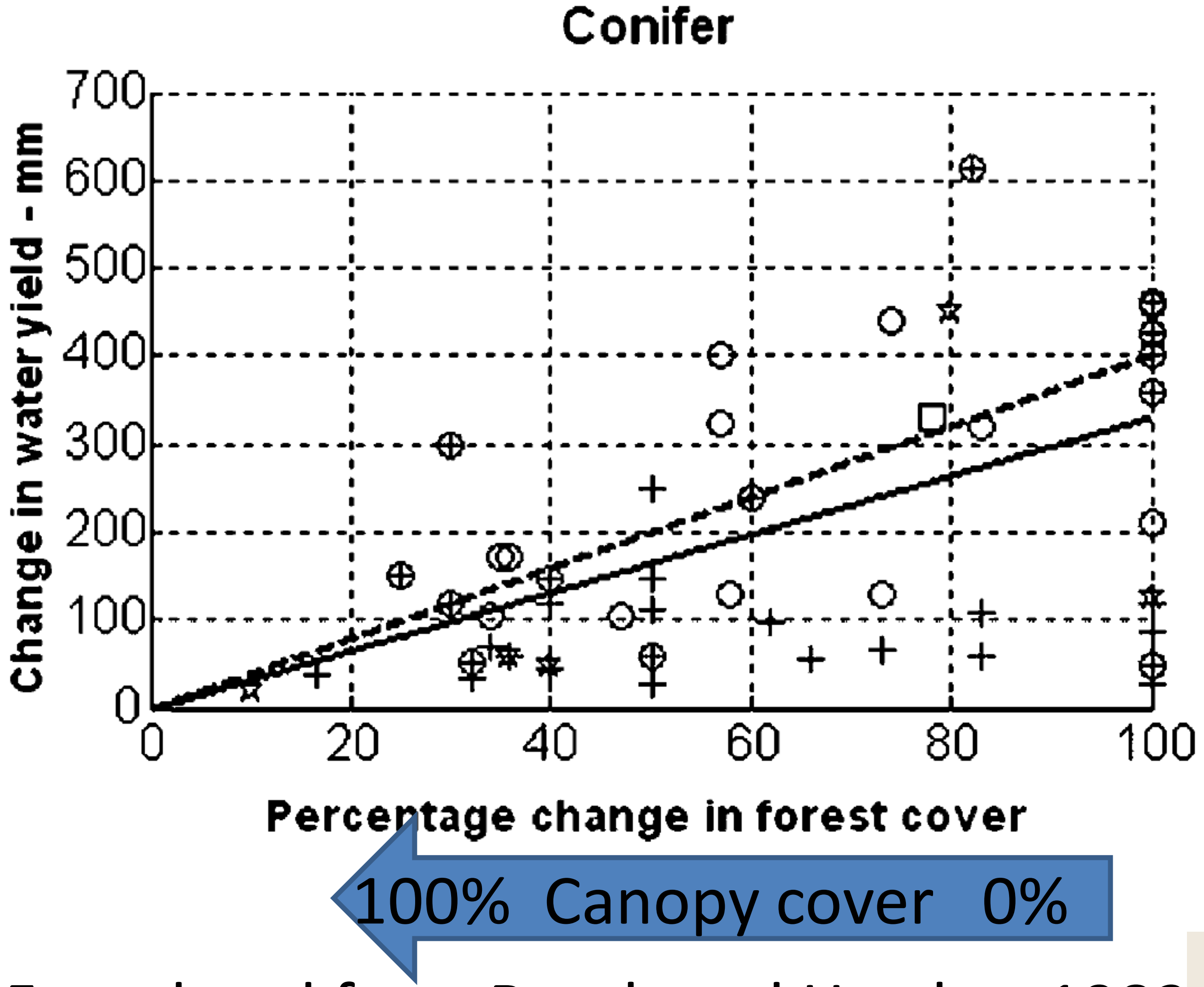
- Increase in streamflow
- Decrease in evapotranspiration
- Decrease in canopy interception



NCASI 2009

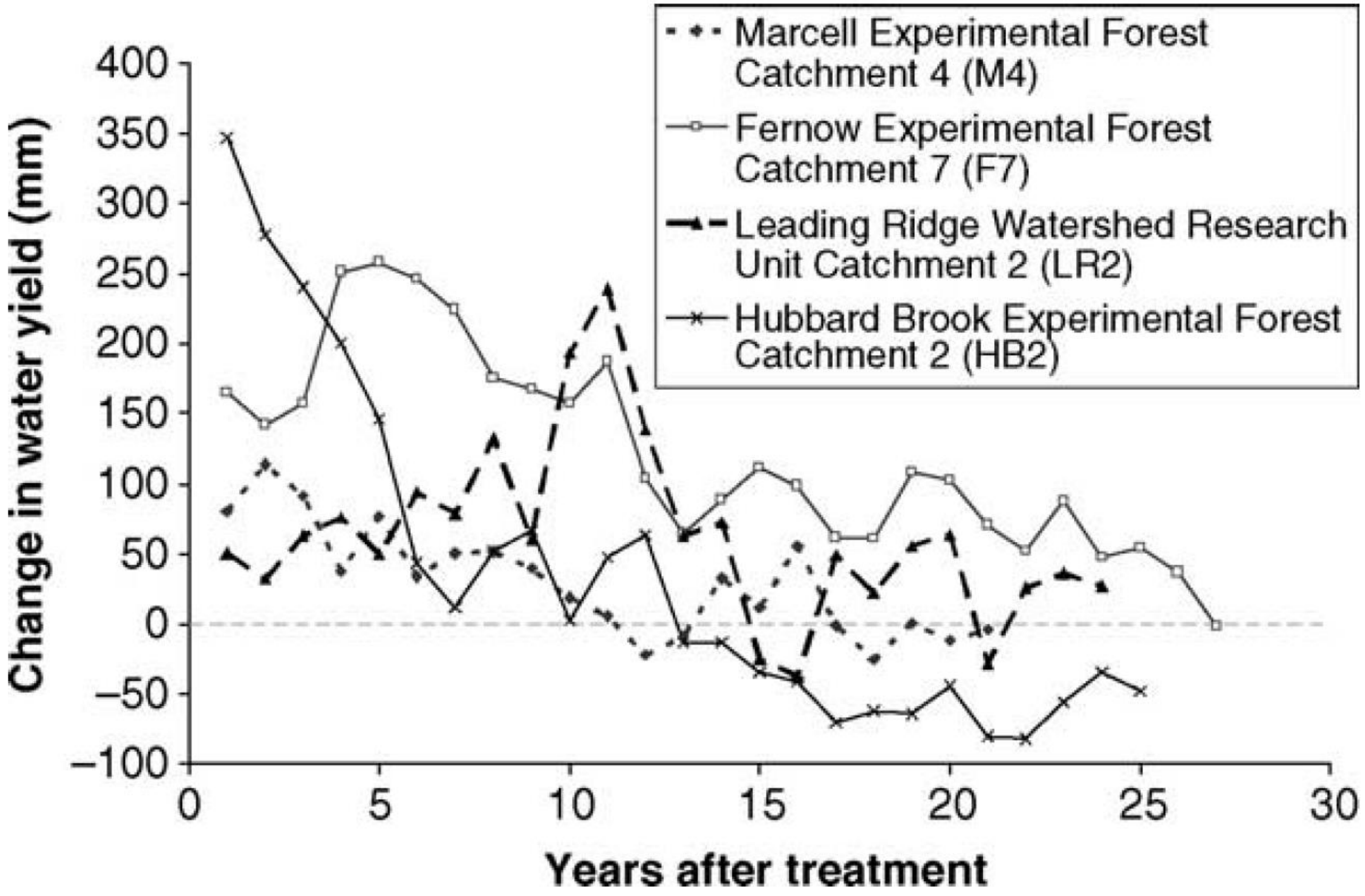
Reducing canopy cover increases annual streamflow





Brown et al. 2005, updated from Bosch and Hewlett 1982

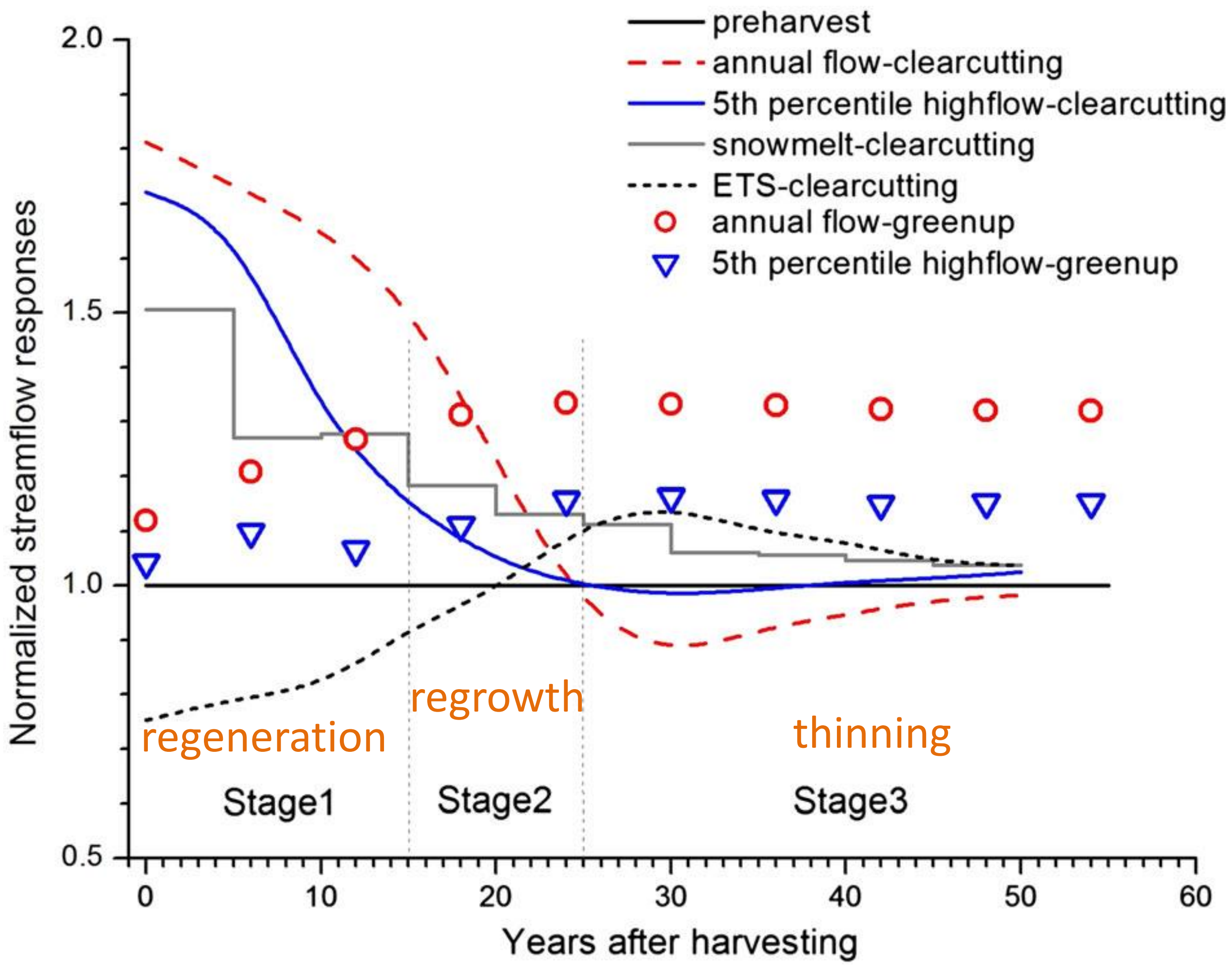
Hydrologic recovery to historical harvest (annual)



Brown et al. 2005

Stages of hydrologic recovery (annual)

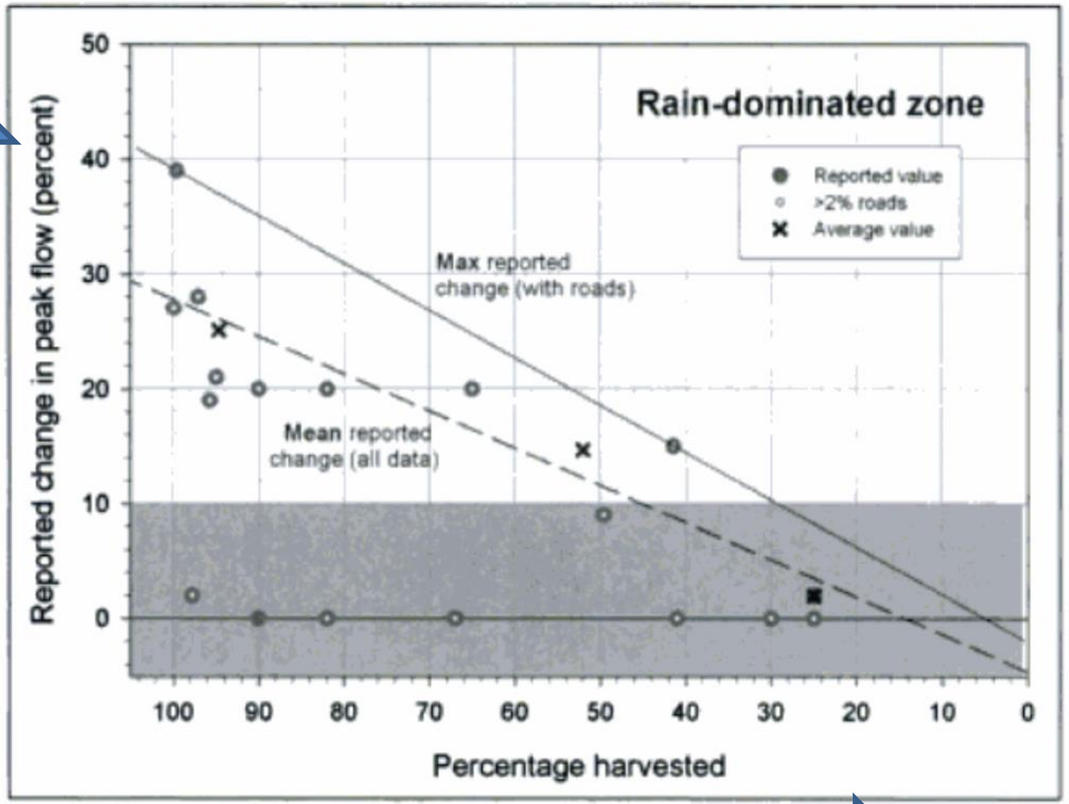
- Stage 1: regeneration
- Stage 2: regrowth
- Stage 3: canopy self-thinning, LAI declined with ETS and water yield recovering



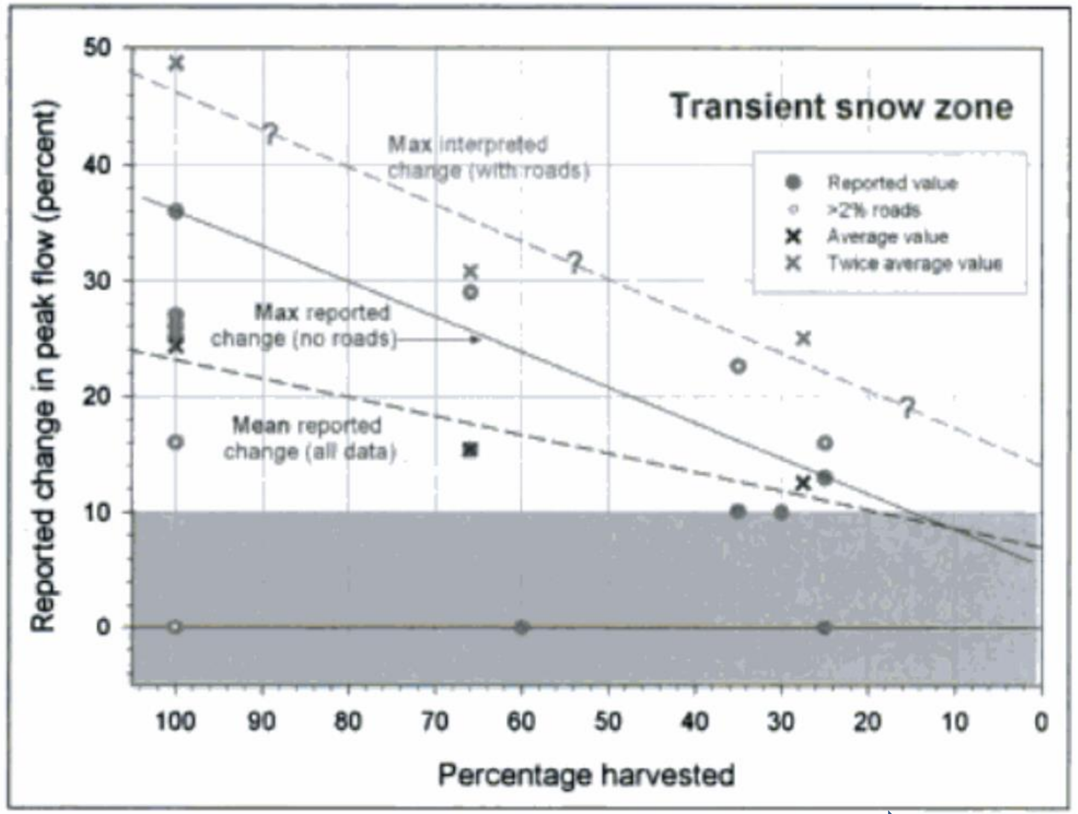
Du et al. 2015

Reducing canopy cover increases peak flow in the Pacific Northwest (immediate response)

Annual stream flow increase (%)



0% Canopy cover 100%



0% Canopy cover 100%

Grant 2008

Reducing canopy cover typically increases low flow in the Pacific Northwest (immediate response)

- Increased streamflow in low flow period
  - Alsea: Reduced number of low flow days post-logging
  - Hinkle: Increased August flow
- An exception –> Bull Run
  - Decreased low flow
  - Fog drip can be important hydrologic component

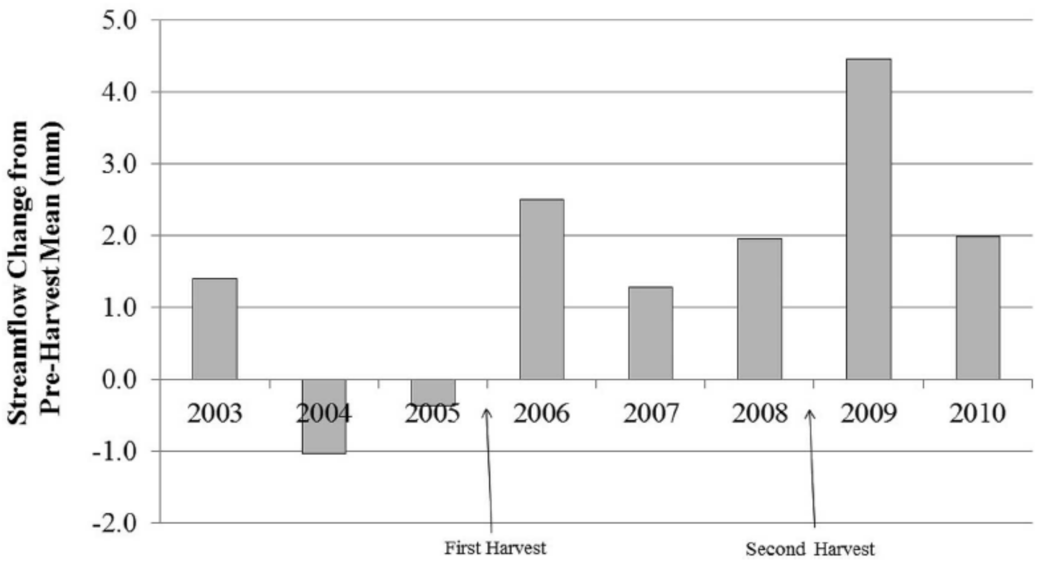
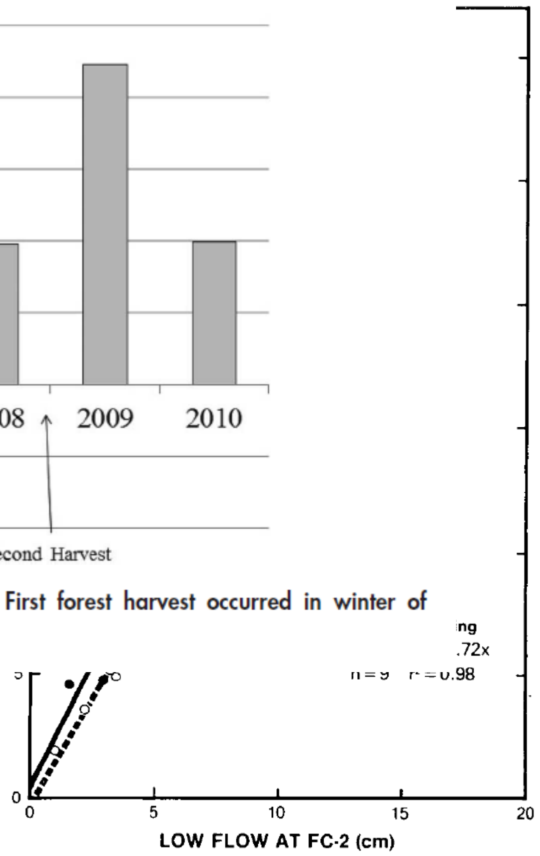


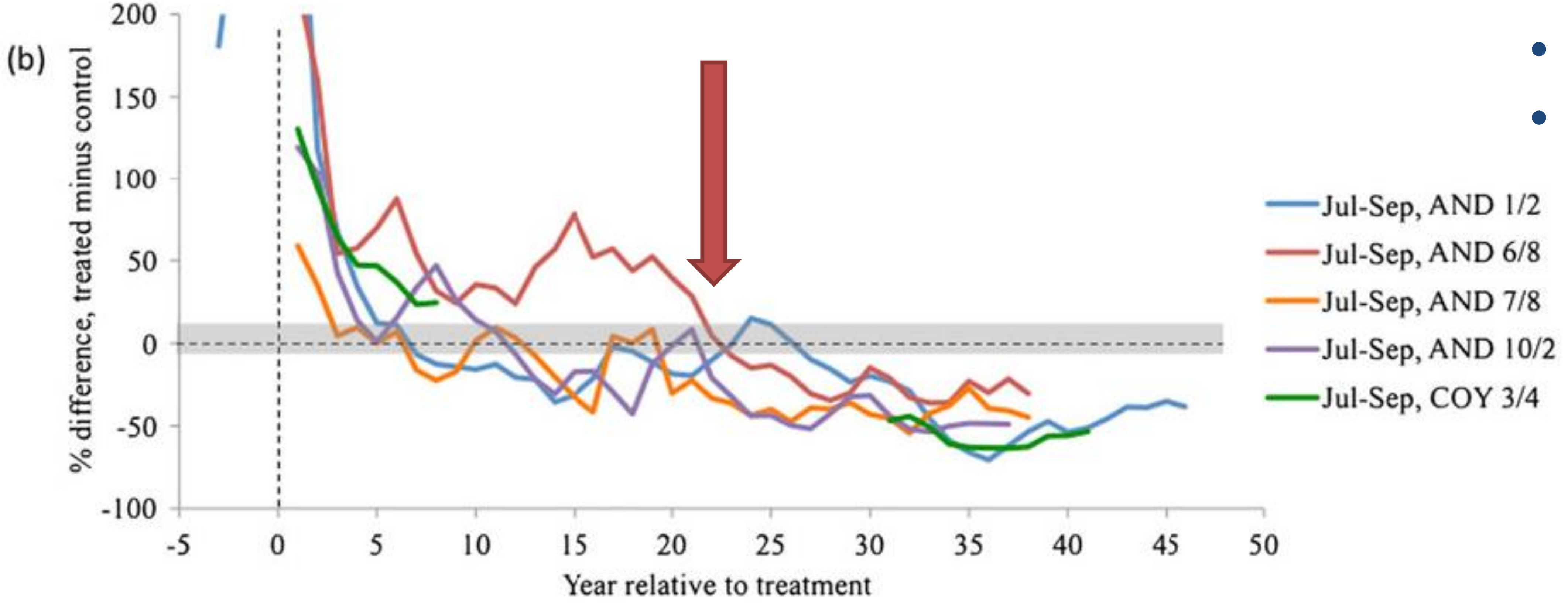
Figure 5. Change in August streamflow for the South Fork Hinkle Creek 2003–2010. First forest harvest occurred in winter of 2005–2006; second forest harvest in winter of 2008–2009.



Surfleet and Skaugset 2013

Harr 1980

Hydrologic recovery to historical harvest (summer low flow)



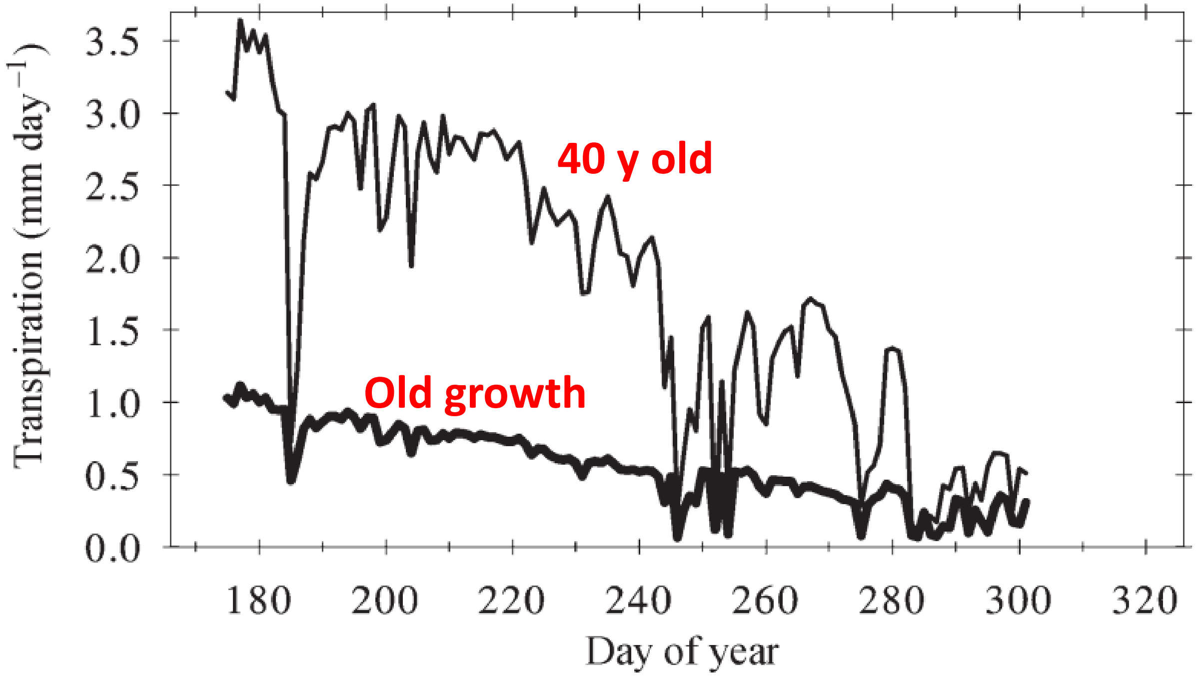
- H.J. Andrews (AND)
- Coyote Creek (COY)

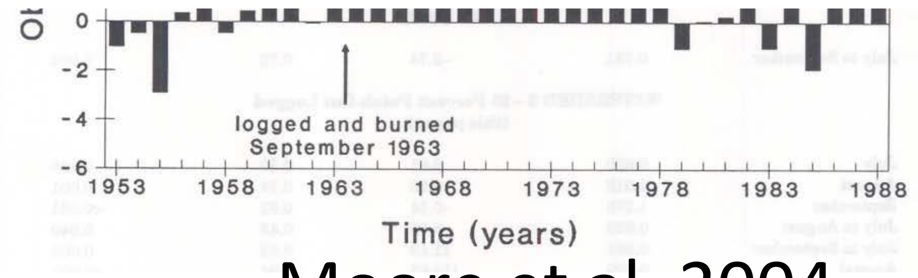
Perry and Jones 2016

How are summer low flow deficits related to forest harvest?

- H1: Establishment of alder in riparian zone following harvest for WS1 but not WS3 (Hicks et al. 1991)

- H2: Increased transpiration rates of young relative to old growth Douglas Fir (Moore et al. 2004; Perry and Jones 2016)





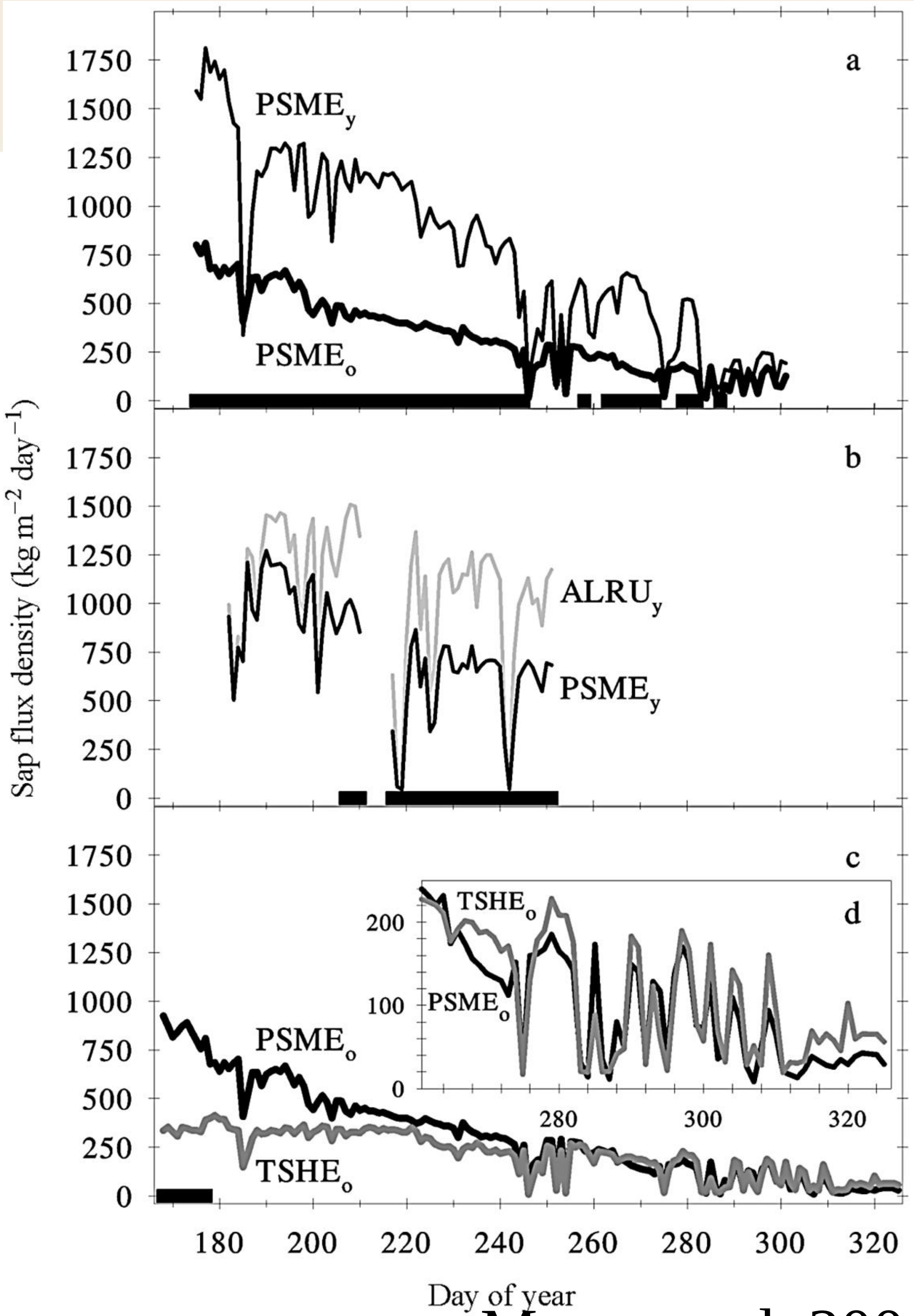
Moore et al. 2004

Hicks et al. 1991

Transpiration rates vary by age and species

- Sap flux density was 1.4X greater in young Red alder (*A. rubra)* than in young Douglas-fir (*P. menziesii)* from July - September

- Red alder water use was statistically different from Douglas-fir starting in late July

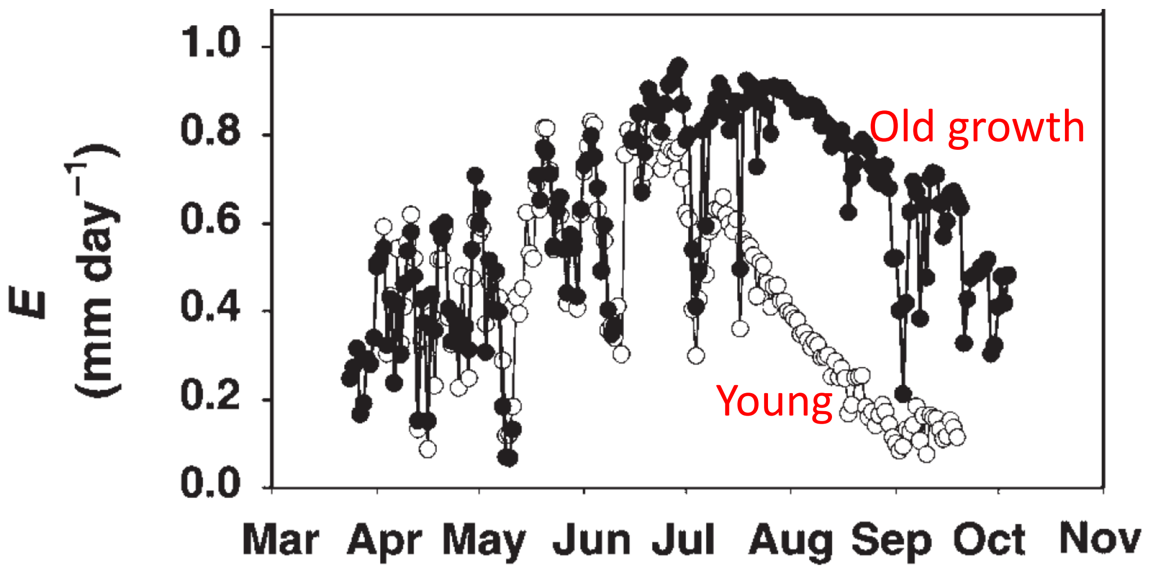


Moore et al. 2004

Age differences in seasonal drought response

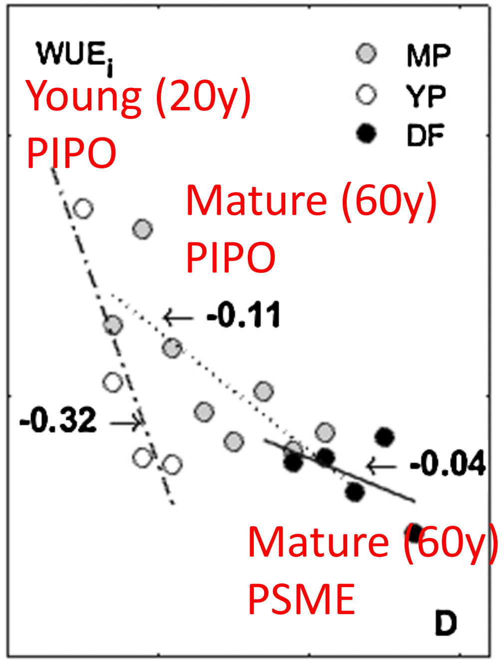
- ET declines in early seral conifer stands as the summer progresses (Irvine et al. 2002; Wharton et al. 2009; Kwon et al. 2018)

- Early seral trees
  - inability to induce stomatal closure for water conservation
  - a limited root system that may preclude access to deeper water sources
  - extreme microclimate (Irvine et al. 2002; Wharton et al. 2009).



Irvine et al. 2002

WUE = water use efficiency from ET



Kwon et al. 2018

Forestry best management practices (BMPs)

Forestry BMPs

Hydrologic response

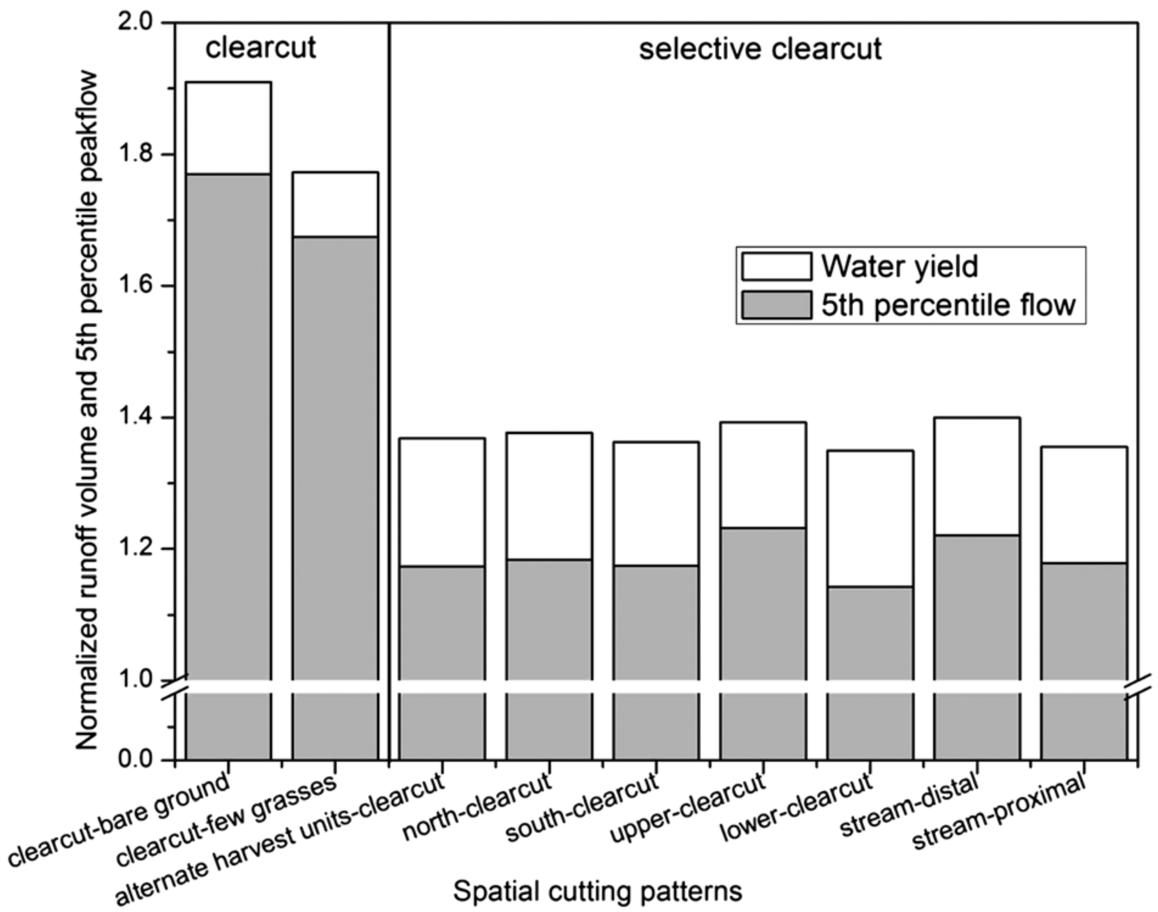
- Riparian buffers → Runoff, ET (microclimate)
- Leave tree requirements

- Stream crossings → Water routing, runoff, soil compaction/infiltration
- Forest roads, skid trails, and landings
- Erosion control

- Fertilizers and herbicides → ET (overstory & understory, species composition, density), hydrologic recovery
- Harvesting and reforestation
- Site preparation
- Limit size of harvest unit

How does placement of selective clearcut affect streamflow?

- 50% of trees were removed in different configurations
- On average increased annual yield by 37% (peak flow by 19%)
- Aspect (N vs. S)- similar
- Location – greater flow when clearcut placed upstream (39% & 23% increase) than when placed further downstream (35% & 14% increase) –
  - related to snowpack dynamics



Du et al. 2015

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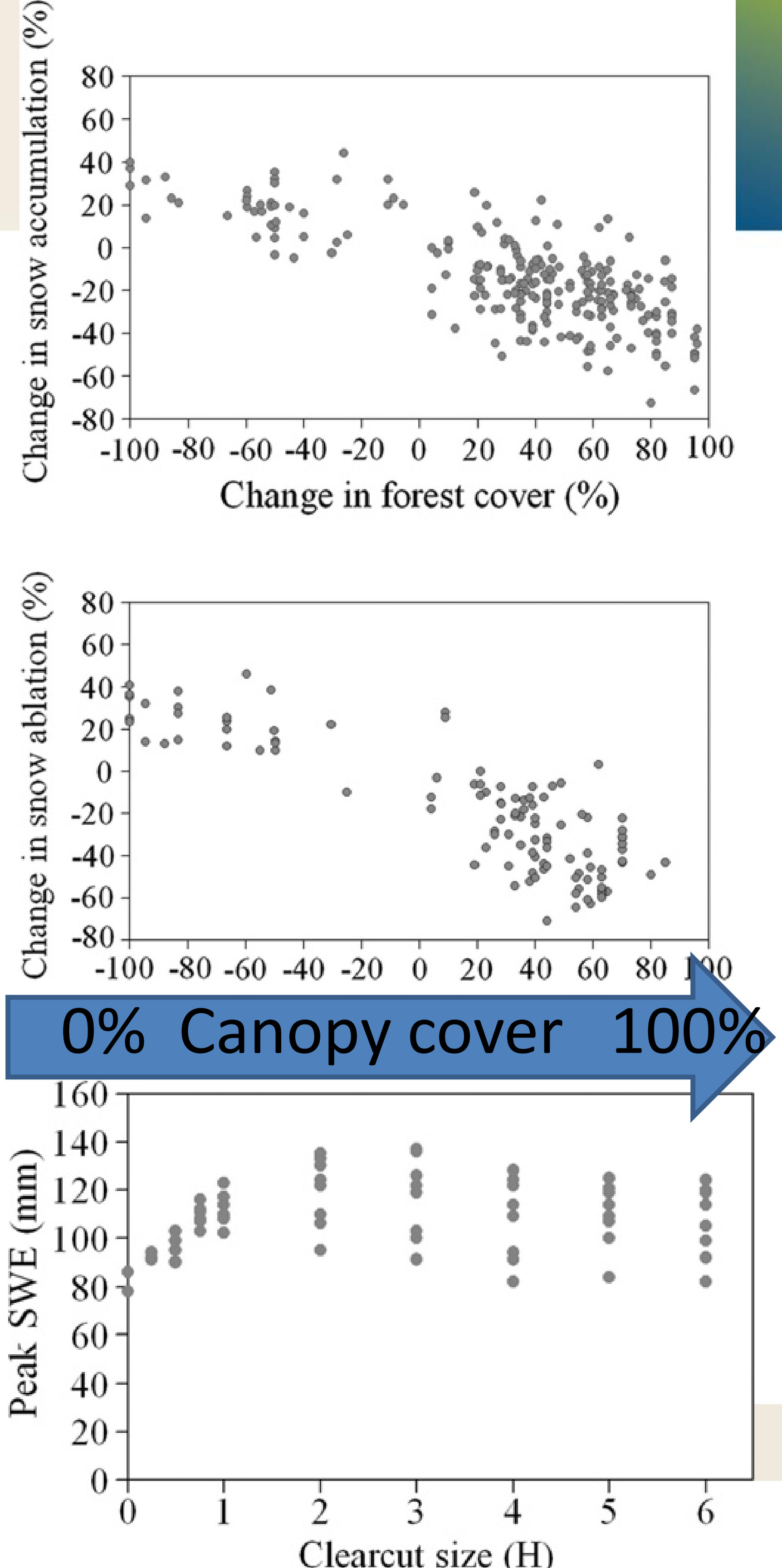
Forest harvest: snow response

- Review across 65 sites (32 studies):

- Snow accumulation increased with less forest cover (r^2 =57%)
- Snow accumulation generally increased with size of the clearcut

- However, snowmelt (ablation) rates also increase (r^2 =72%)
- Can result in earlier melt (e.g. 10 day) despite an (40%) increase in snow accumulation in a clearcut (i.e., Berndt 1965)



Varhola et al. 2010

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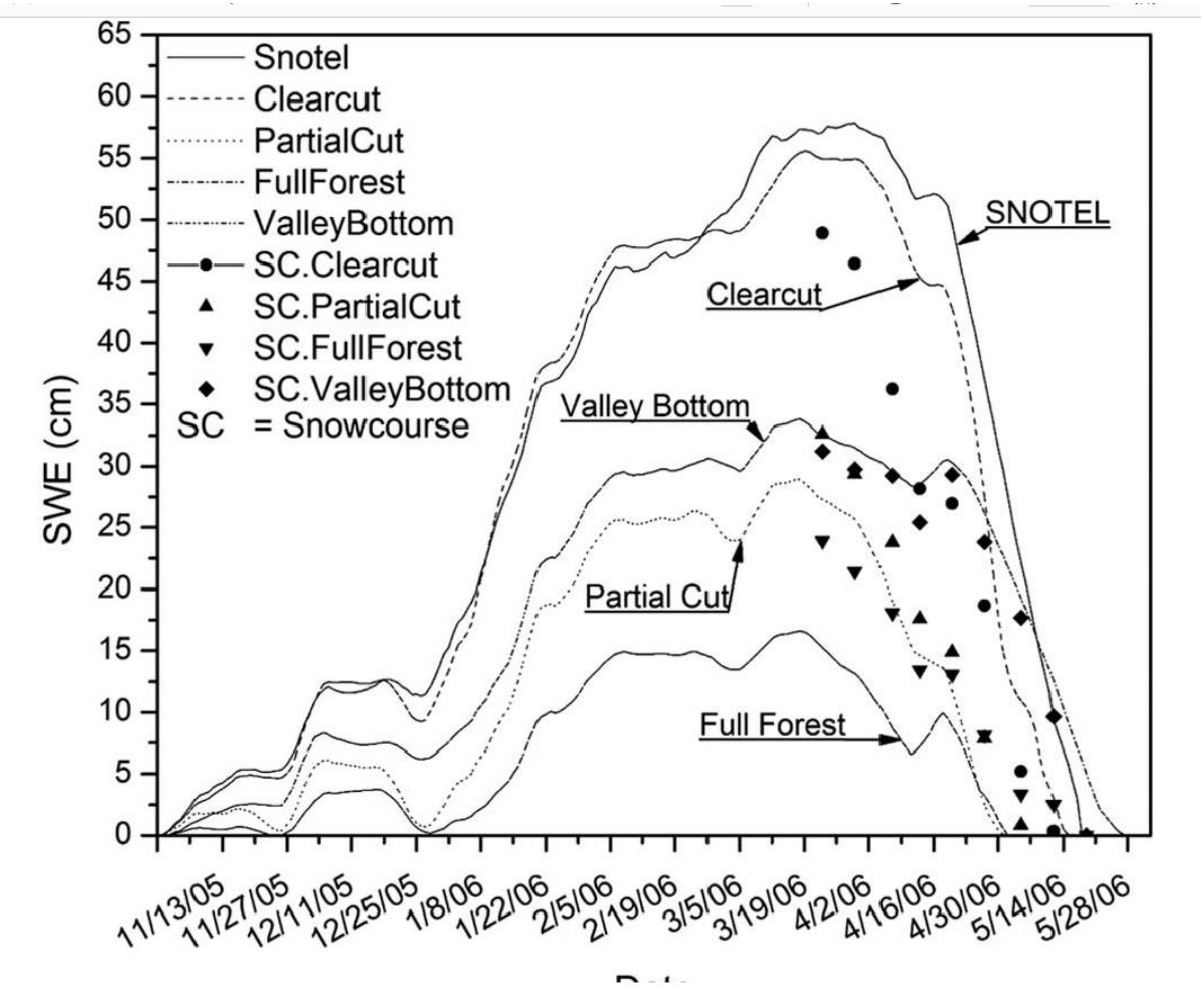
Forest harvest: snow response

- Peak SWE greater in clearcut than full forest and partial cut locations
- Clearcut SWE took longer to melt (53 days) than the fully forested site (36 days)
- Site specific microclimatic factors important and not well understood



Hubbart et al. (2015)

Adaptation strategies for forest hydrology

- Reduce flow routing (storm events)
  - Fewer forest roads
  - Reduce soil compaction (technological improvements)

- Consider ecosystem scale evapotranspiration throughout harvest rotation & seasonal dynamics
  - Tree species, age, and climate must all be considered
  - Reduced stand density?

- Increase snow accumulation and/or reduce snowmelt rate
  - Canopy gaps to increase snow accumulation
  - Mixed species stands or variable canopy structure to allow for greater snow accumulation

Courtesy of: Rolf Gersonde

Adaptation strategies for forest hydrology

- Group Selection Regeneration System for:
  - Snow retention in canopy gaps
  - Regeneration in gaps to reduce moisture stress
  - Regenerating mixed species
  - Matrix thinning to reduce transpiration and interception
  - Dispersed opening to reduce effects of rain-on-snow events

UBC Ministry of Forests, Introduction to Silvicultural Systems, second edition (July 1999)

Courtesy of: Rolf Gersonde

Questions?

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