Implications of climate change for hydrology and water resources

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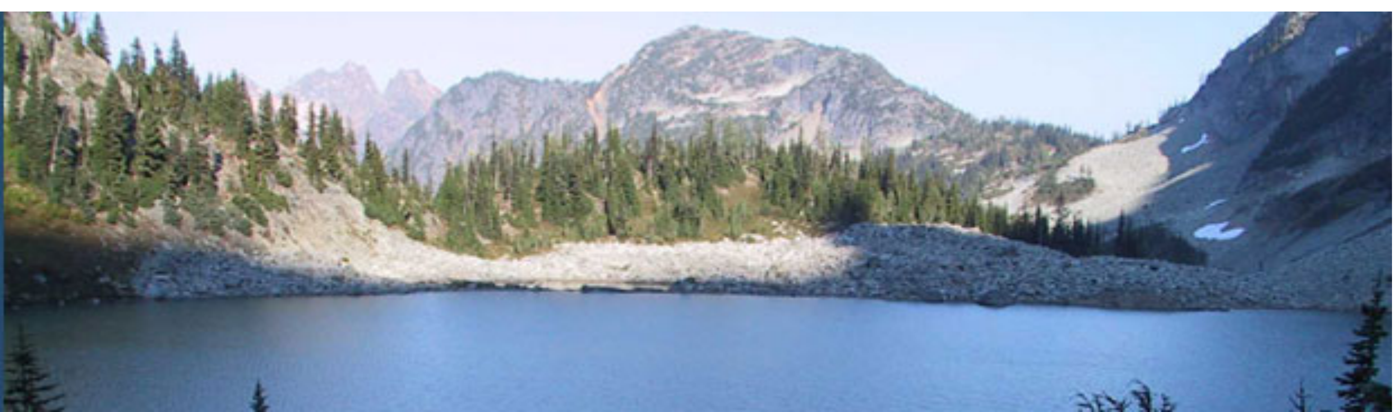


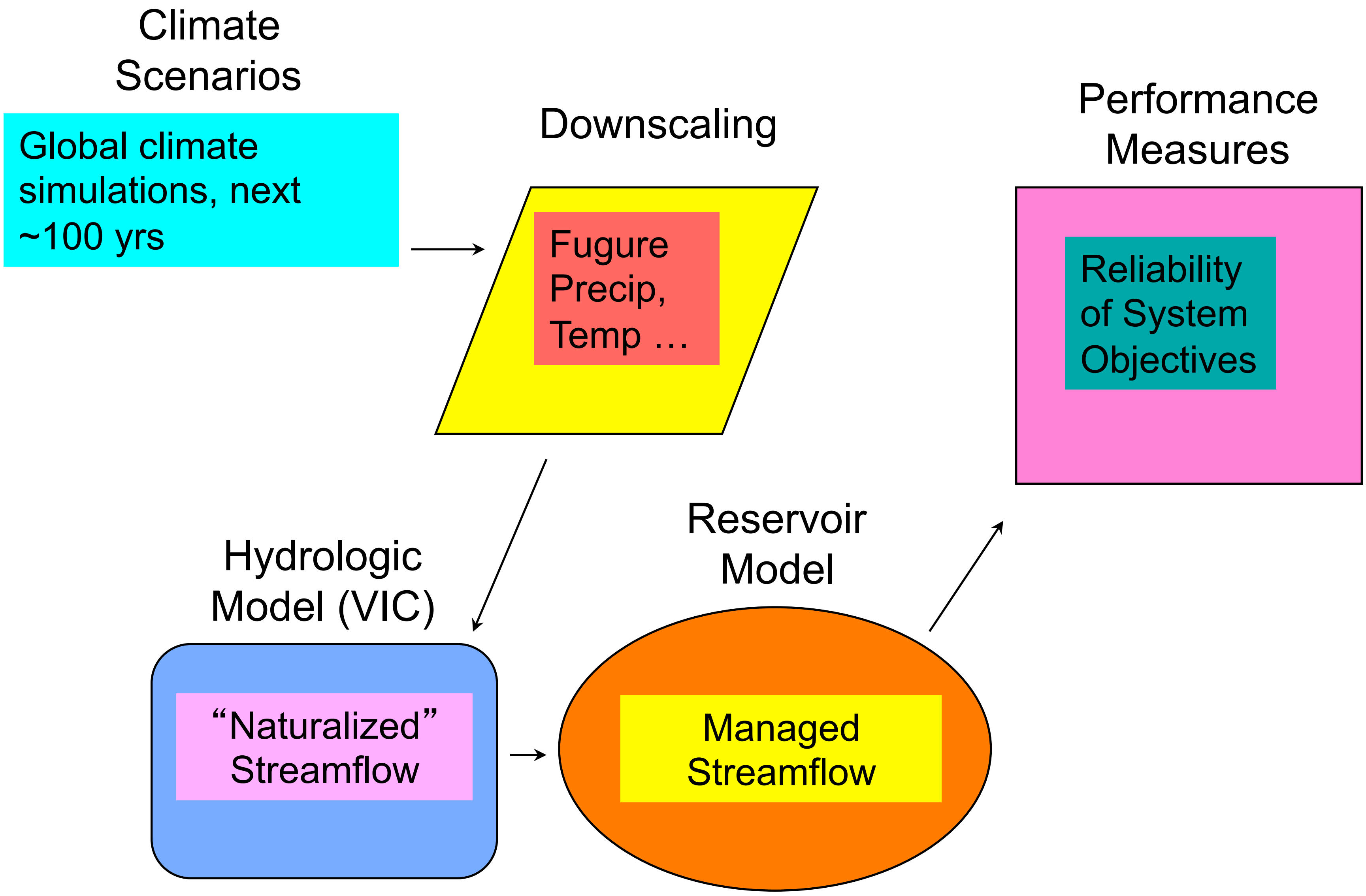
UNIVERSITY OF WASHINGTON

Department of Civil and Environmental Engineering

Outline of this talk

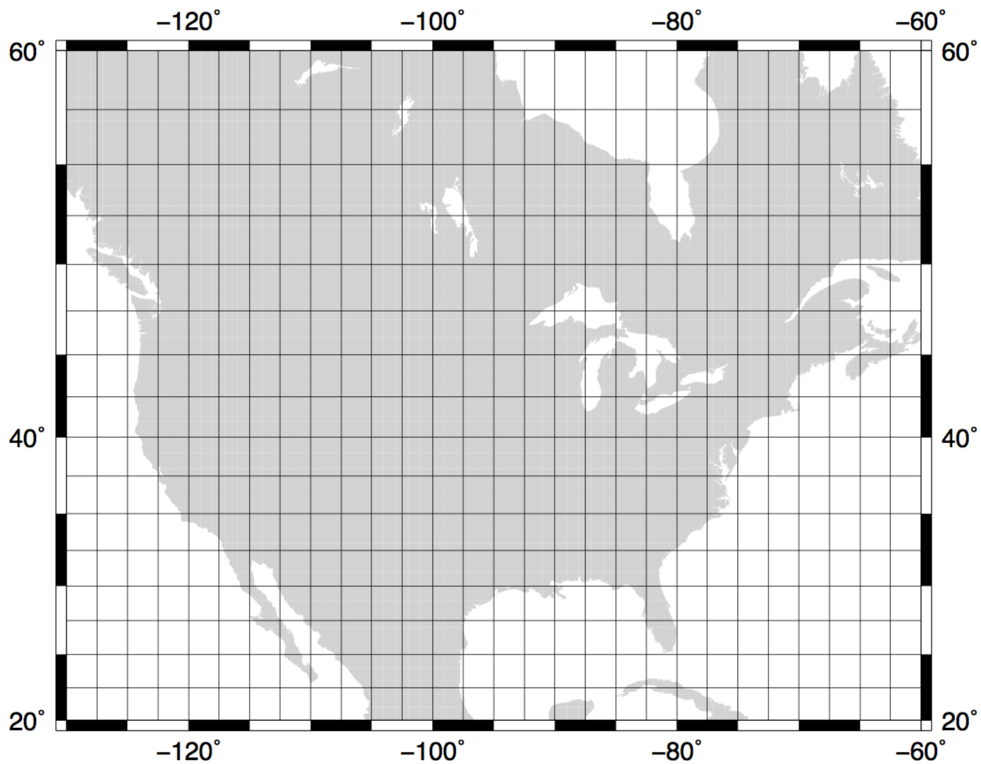
1) Assessment approaches
2) Hydrologic sensitivities
3) Hydrologic extremes
4) Implications for Washington's water resources

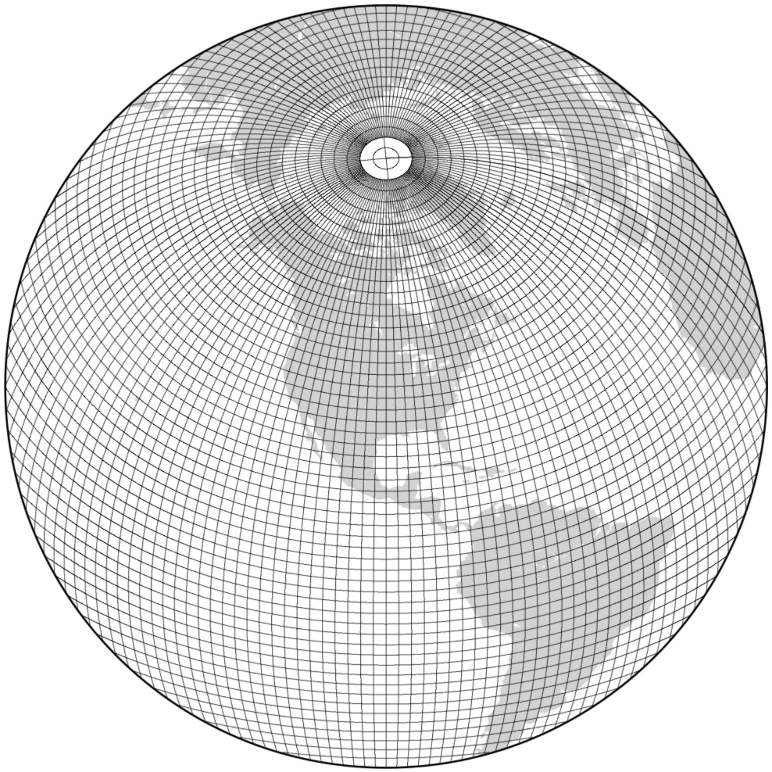
1) Assessment approaches



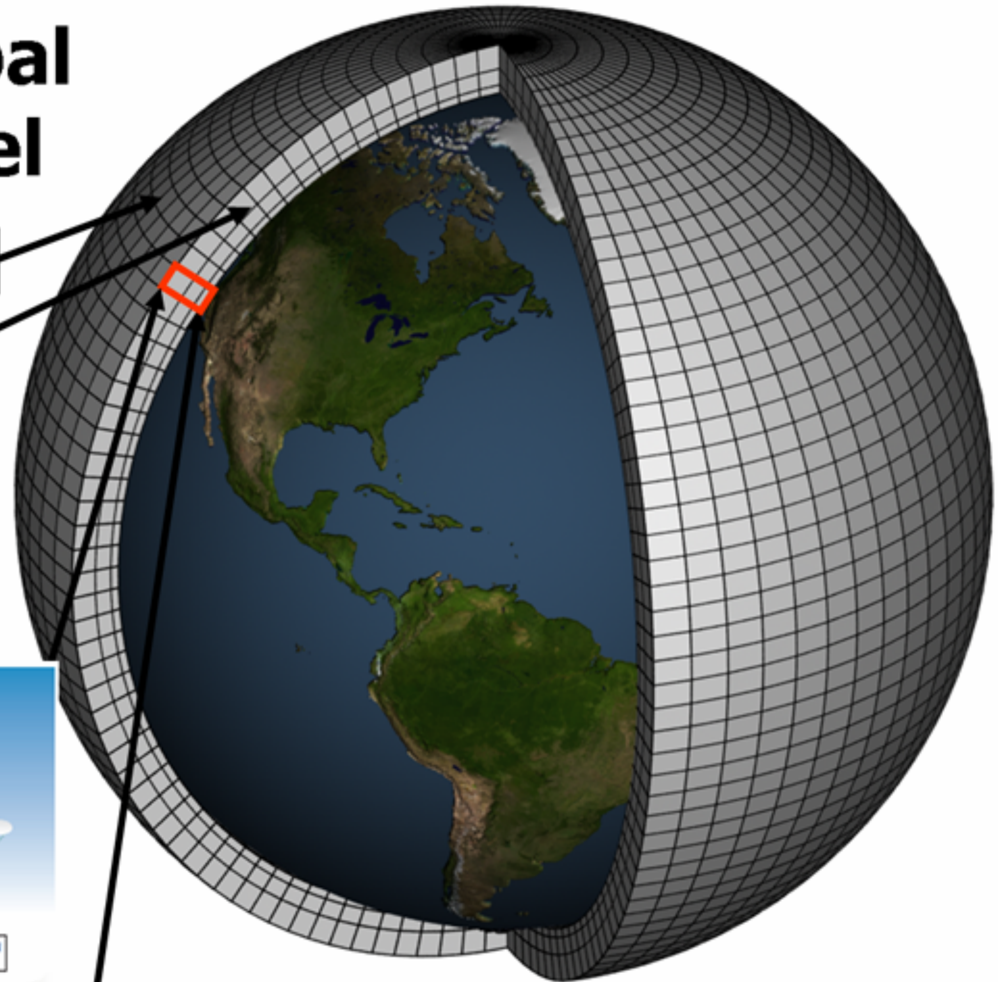
Climate Scenarios
Global climate simulations, next ~100 yrs
Downscaling
Fugure Precip, Temp …
Performance Measures
Reliability of System Objectives
Hydrologic Model (VIC)
"Naturalized" Streamflow
Reservoir Model
Managed Streamflow

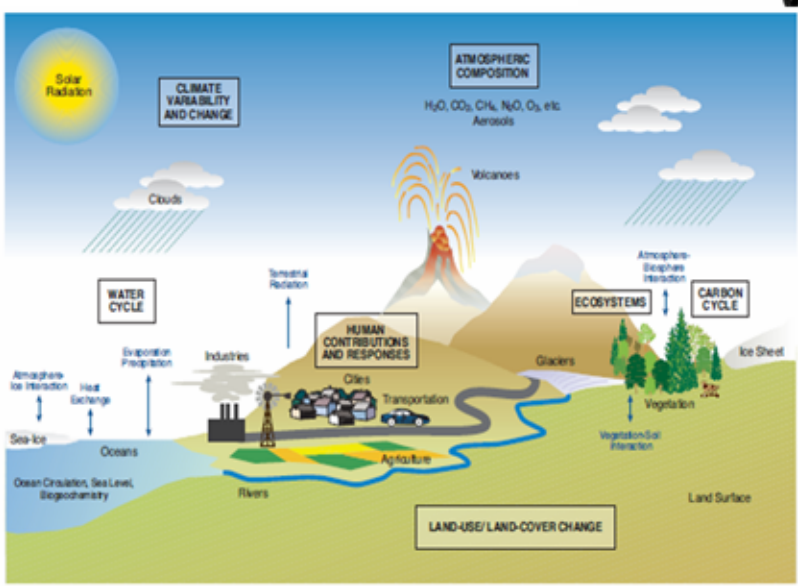
Global Climate Model grid mesh (~2 degrees latitude-longitude)





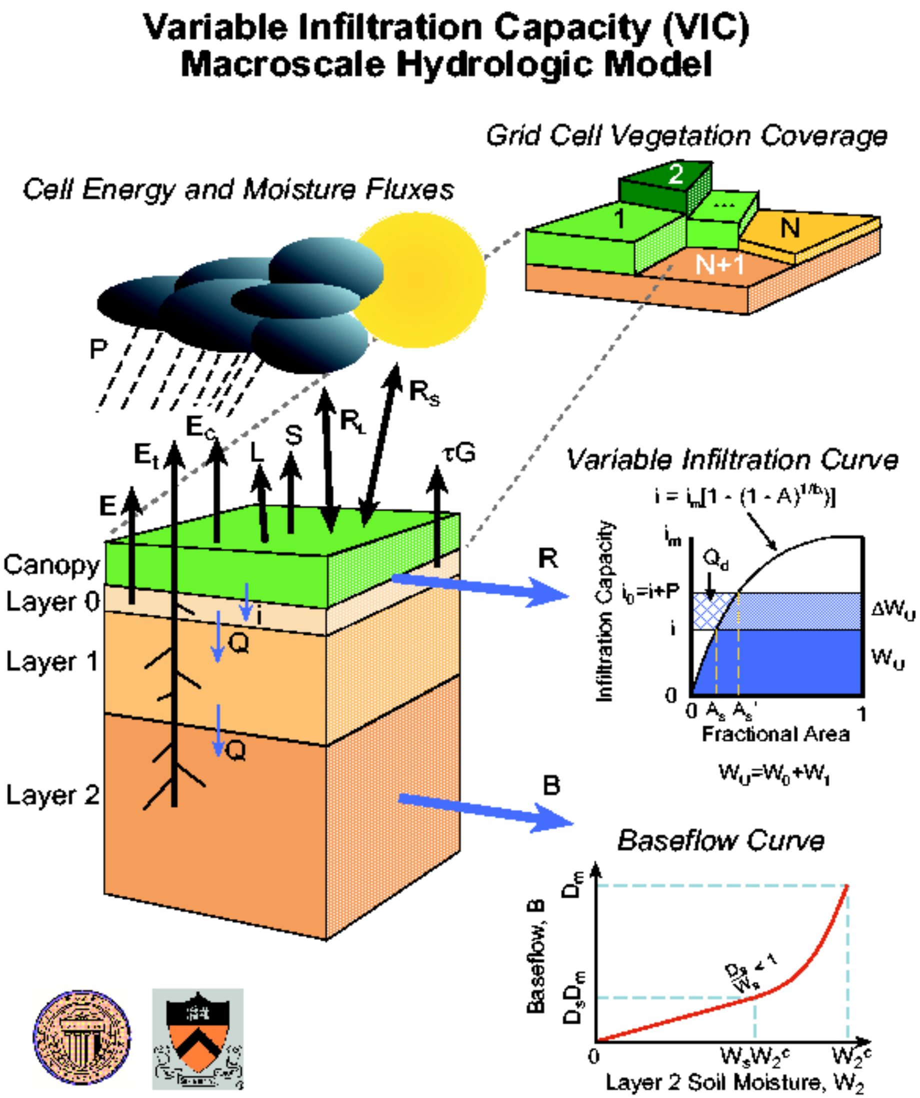
Schematic for Global Atmospheric Model

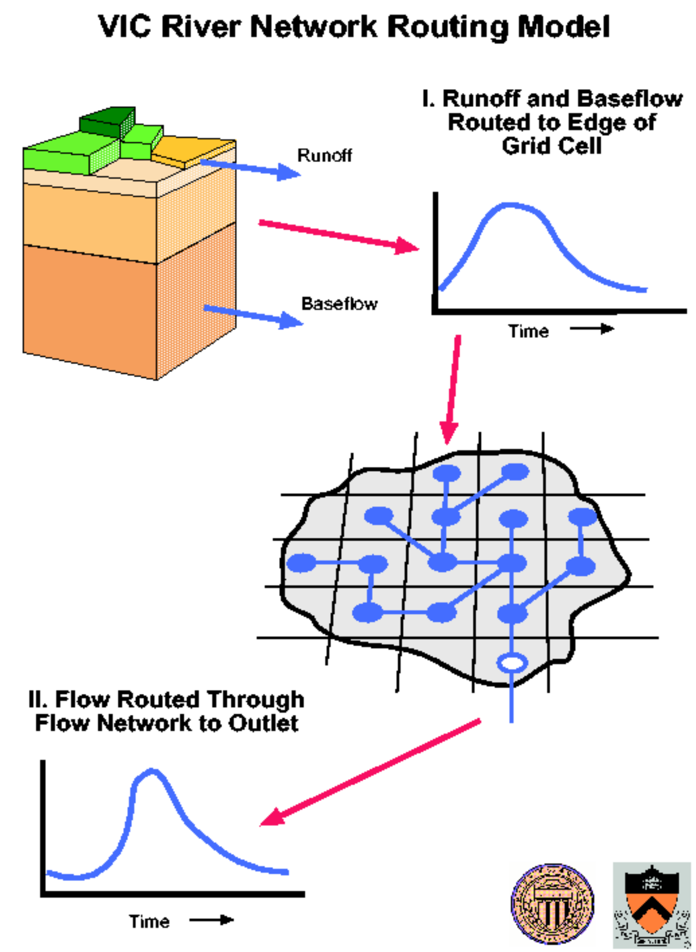




visual courtesy Wikipedia

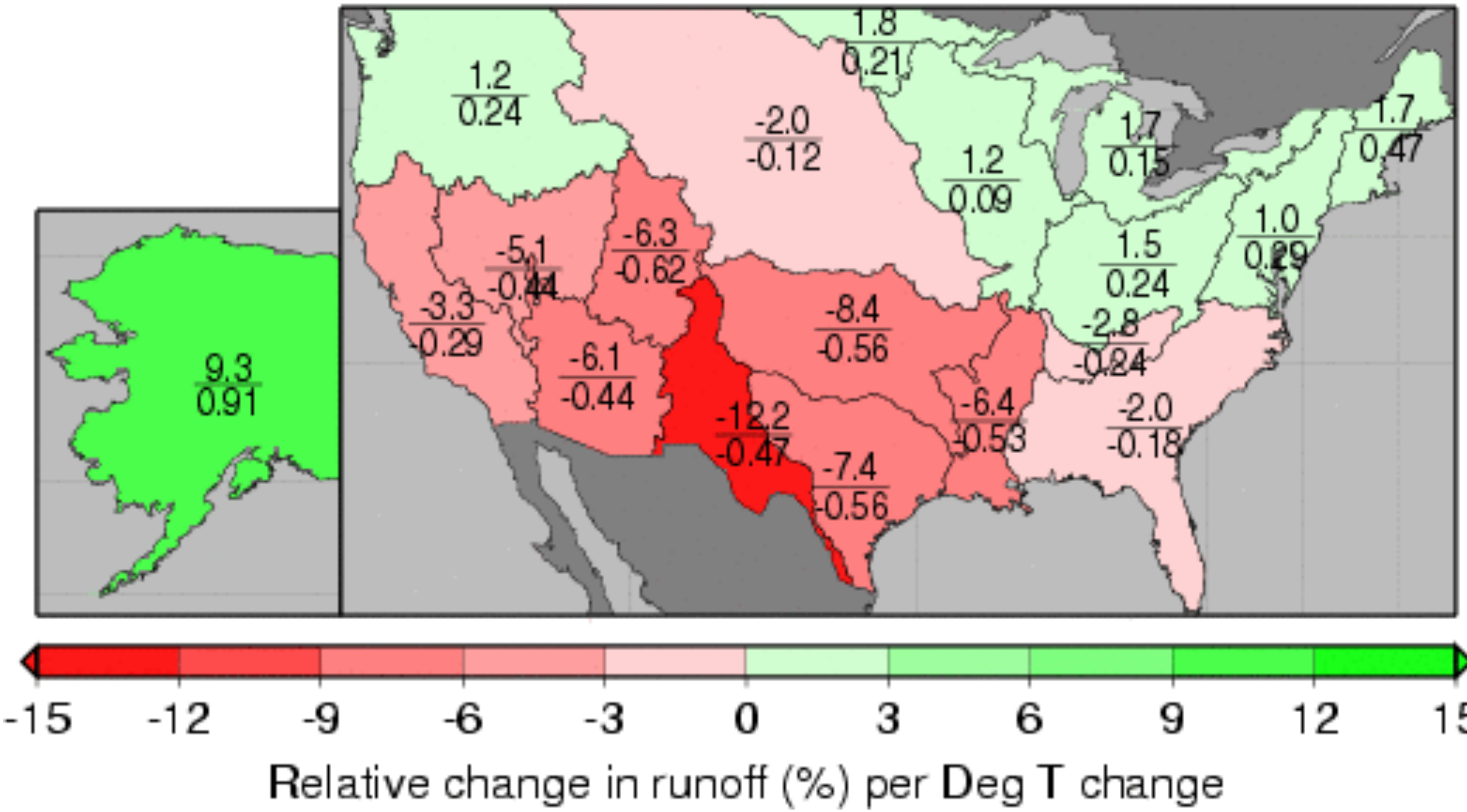
Variable Infiltration Capacity (VIC) Macroscale Hydrology Model



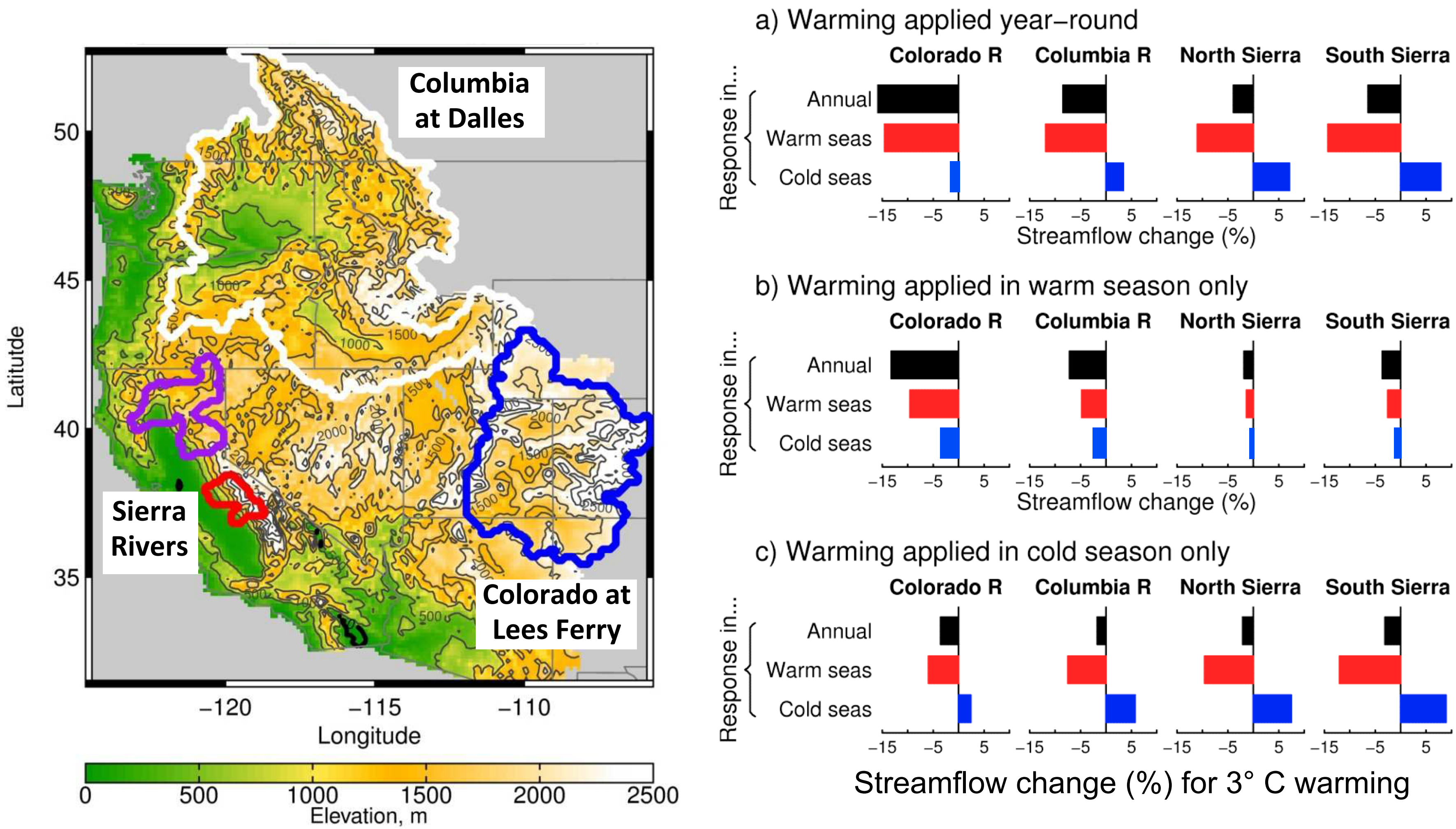


2) Hydrologic sensitivities

Annual runoff sensitivities per degree of global warming, continental U.S. and Alaska

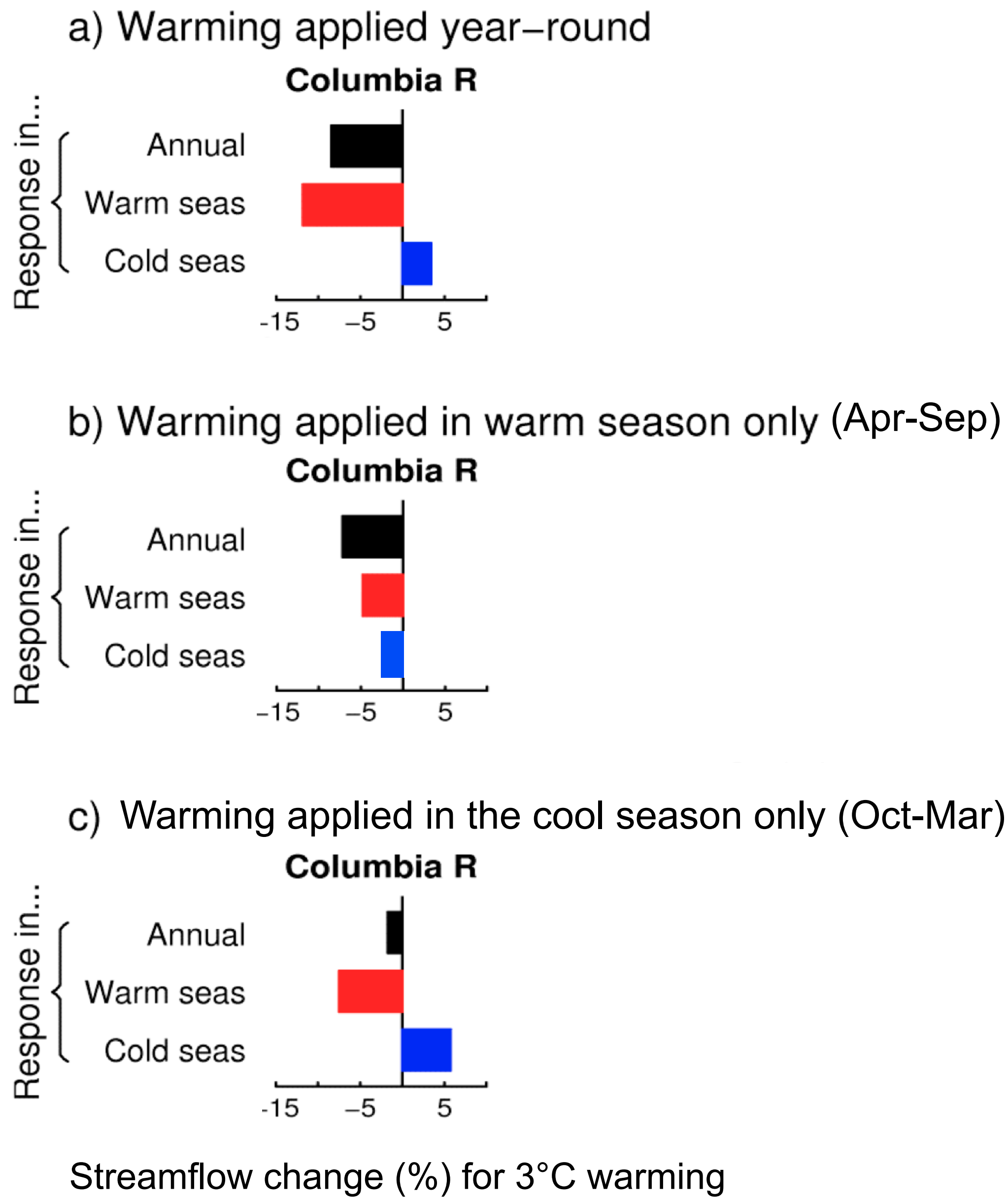


Summer and winter warming sensitivities for major Western U.S. River basins



Figures from Das et al., 2011 in Geophysical Research Letters, color scheme modified

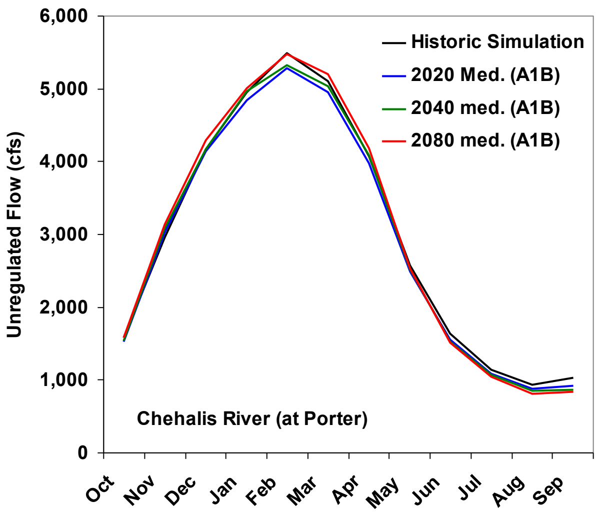
Seasonal differences (3°C warming) at the Dalles



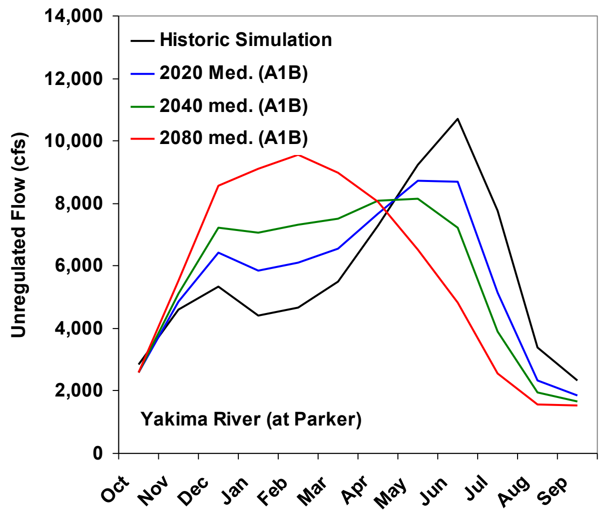
Figures from Das et al., 2011 in Geophysical Research Letters, color scheme modified

Variations in seasonal streamflow patterns and sensitivities in the PNW

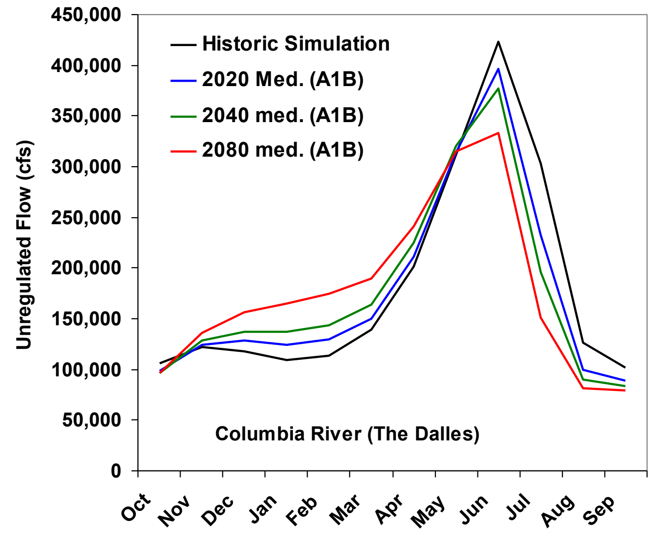
Rain dominant watershed



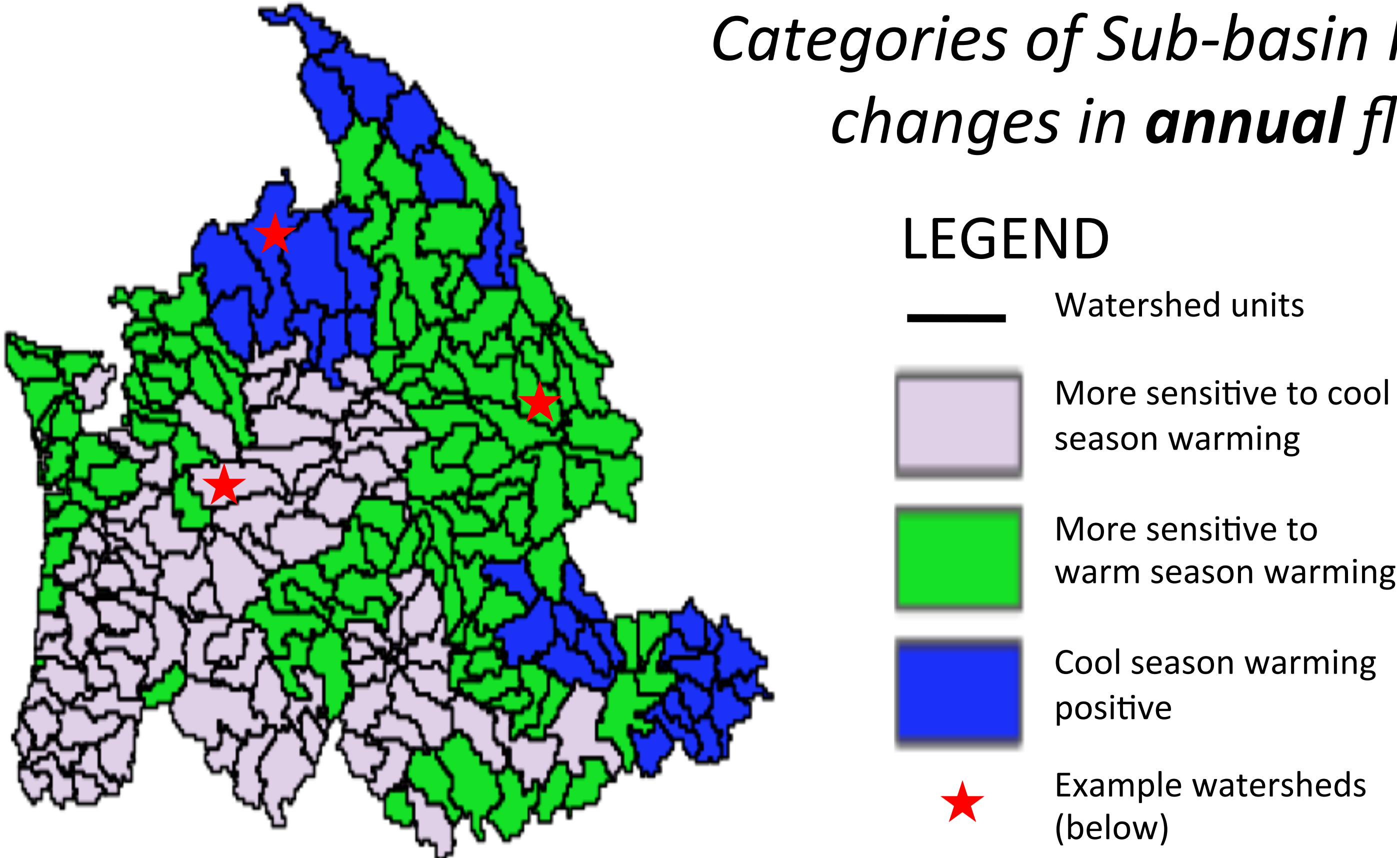
Transient rain-snow watershed



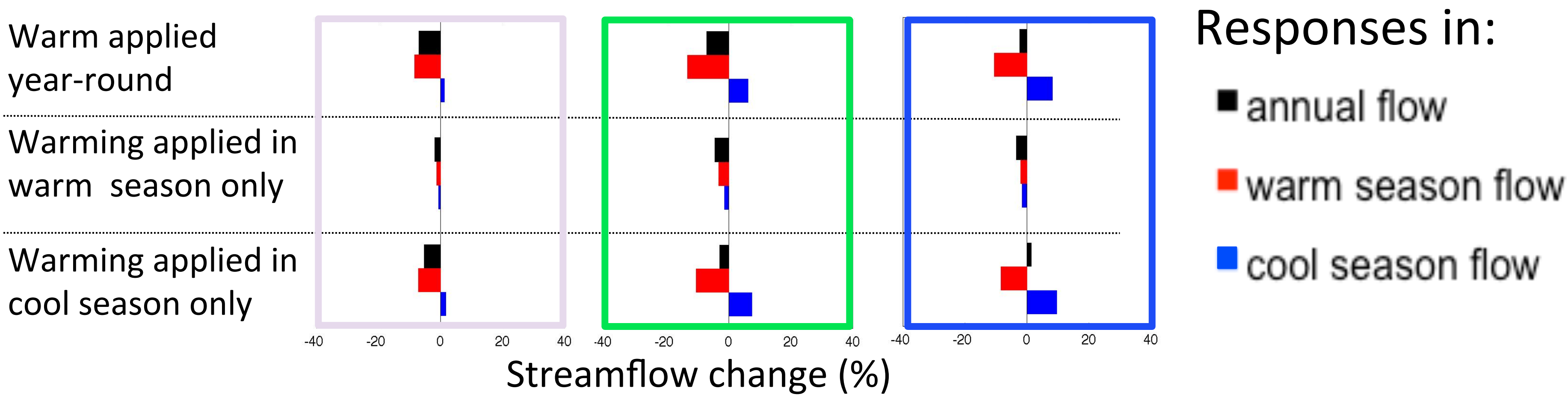
Snowmelt dominant watershed



*Categories of Sub-basin Responses to changes in **annual** flow (VIC)*

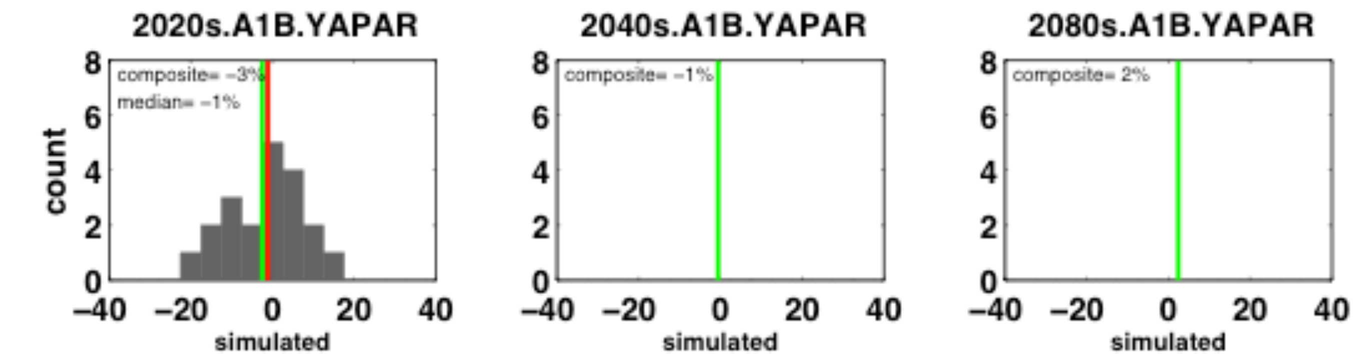


Example watersheds:



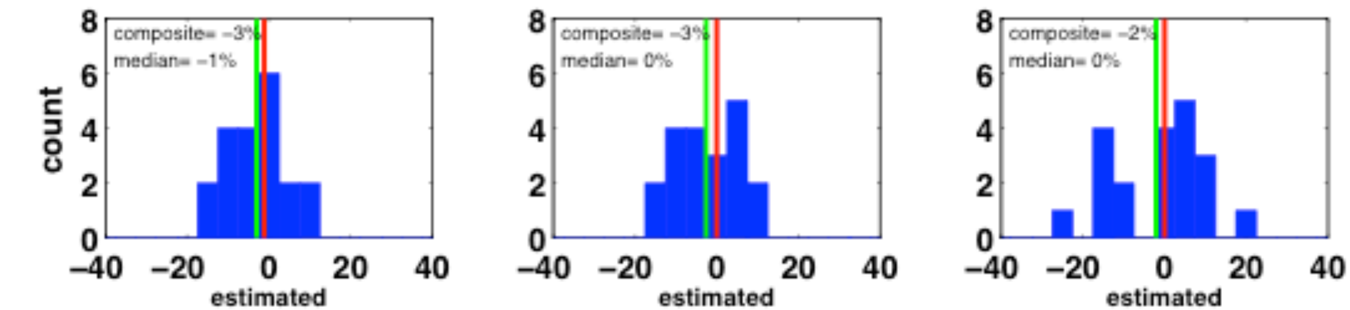
Future scenarios: Long-term annual average

Multi-model approach



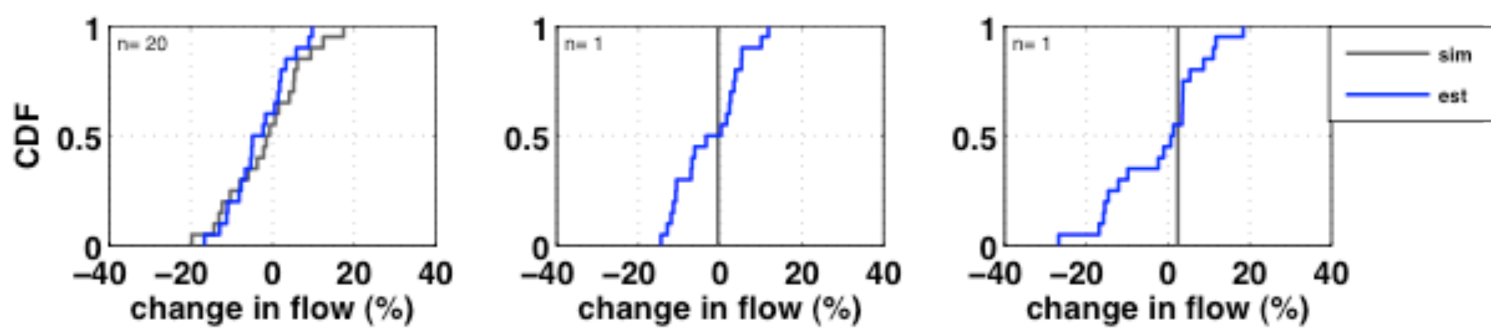
$\%\Delta Q_{simulated} = (Q_{sim} - Q_{hist})/Q_{hist}$

Hydrologic Sensitivities approach



$\%\Delta Q_{estimated} = \Delta T * T_{sensivity} + \%\Delta P * P_{elastcity}$

Comparison of approaches for LONG-TERM annual change in streamflow (Q)



2) Hydrologic extremes

Extreme precipitation should be increasing as the climate warms

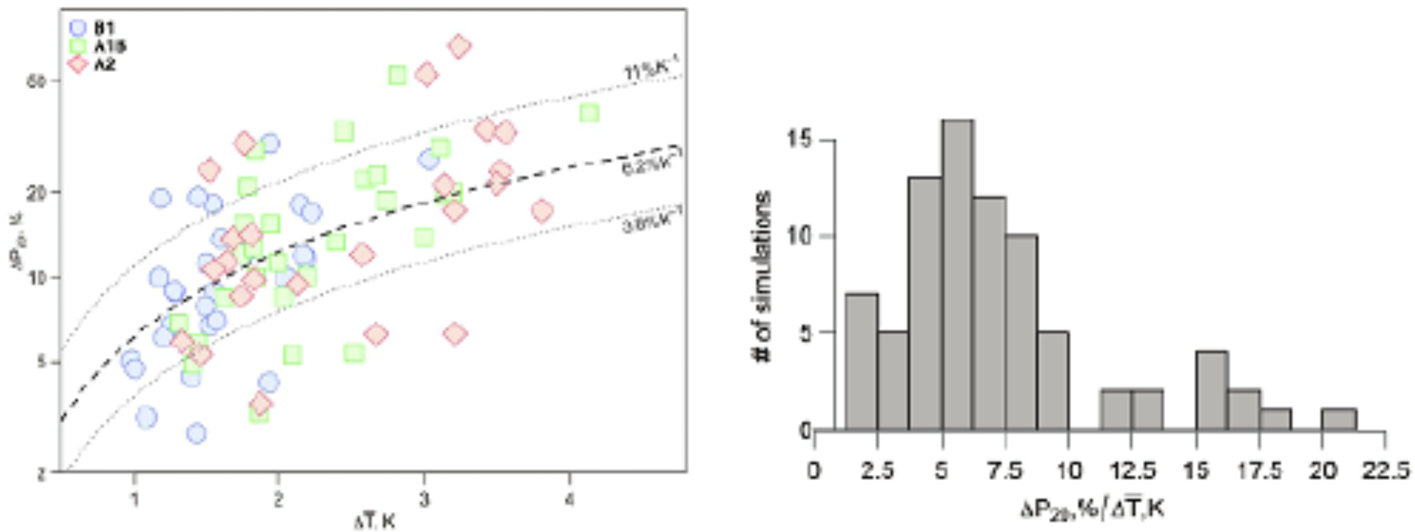
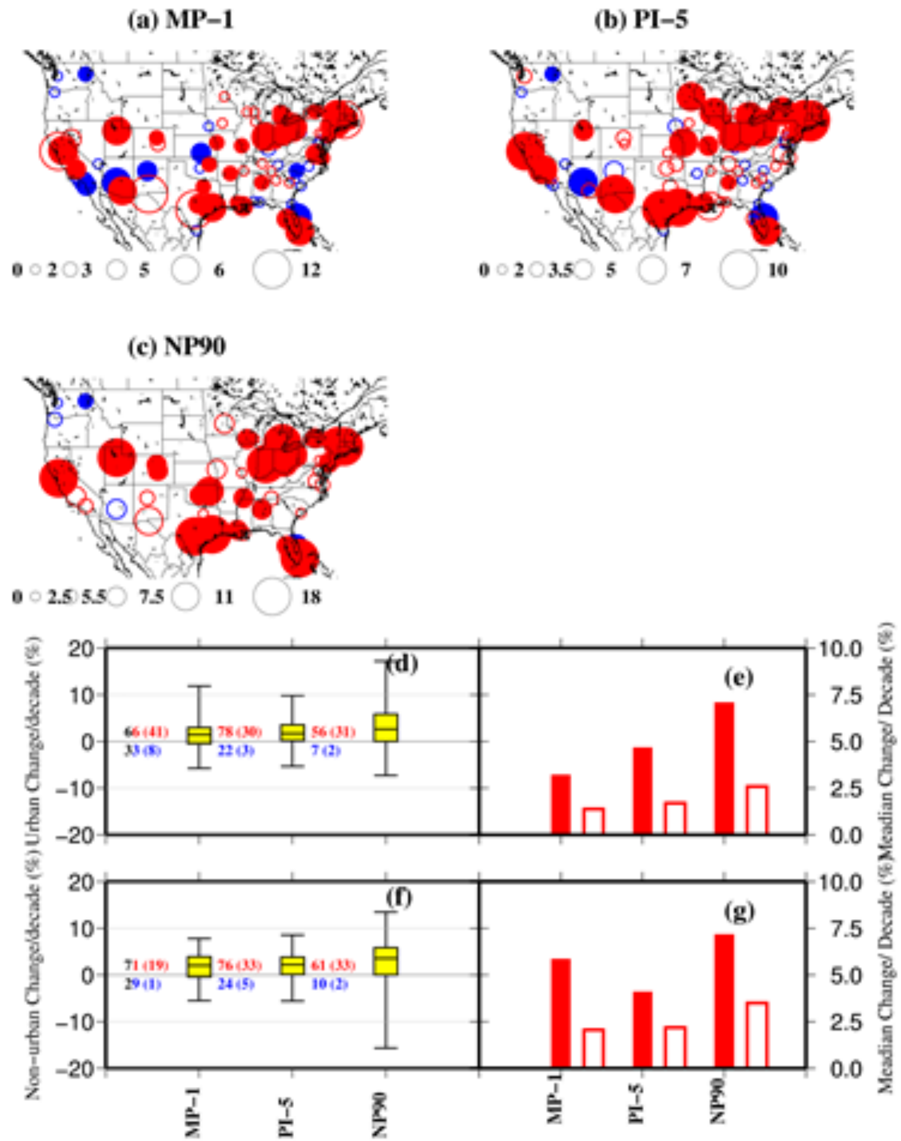


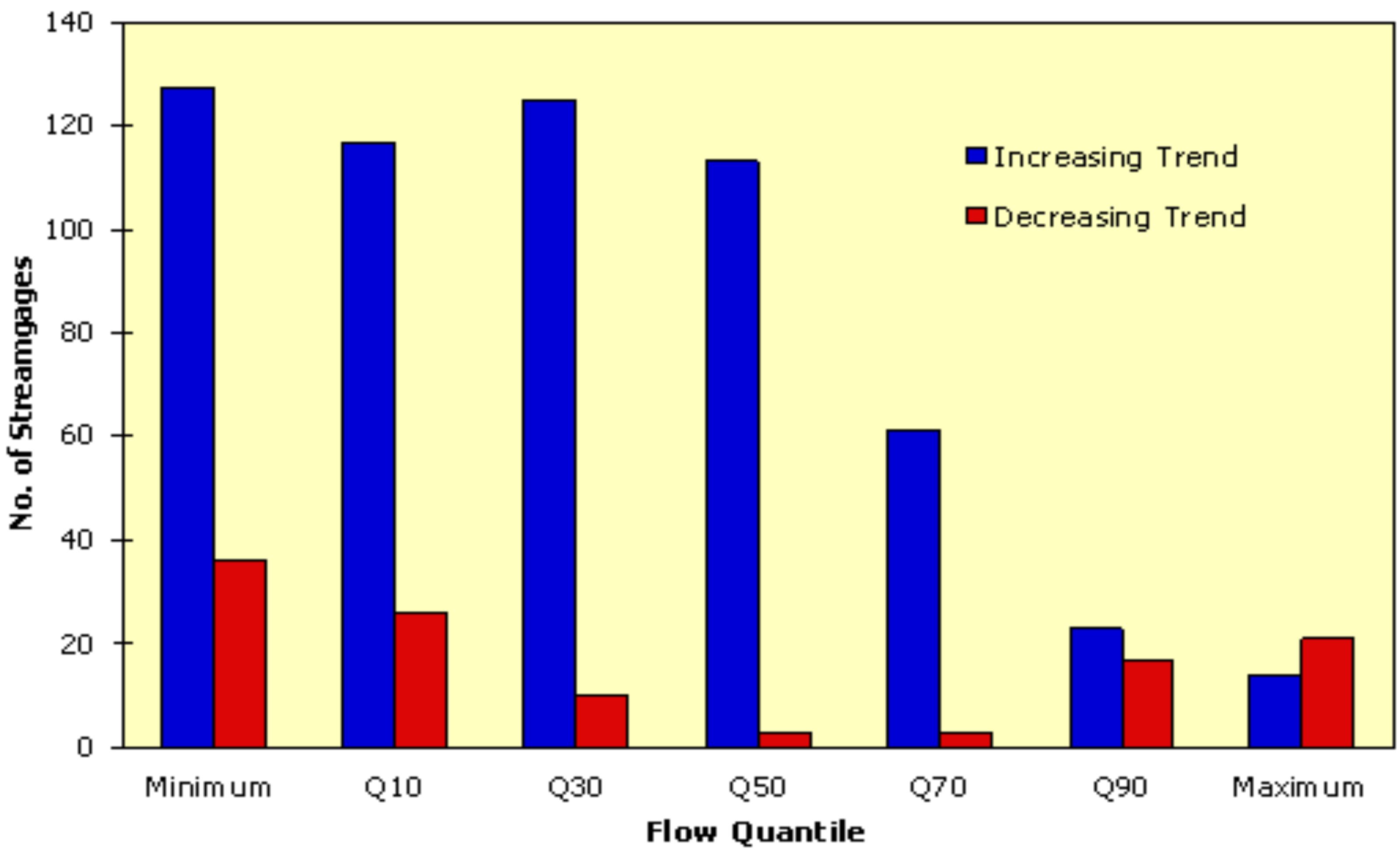
Figure 4.10: Relative changes in 20-yr return values averaged over the global land area of annual 24-h precipitation maxima ($\Delta P20$) as a function of globally averaged changes in mean surface temperature for B1, A1B, and A2 global emissions scenarios, with results pooled from 14 GCM runs and for 2046–65 and 2081–2100 relative to 1981-2000. In the left panel, the pooled results are shown along with the median slope of 6.2%/°C and the 15th and 85th percentiles (dashed and dotted lines, respectively). The right panel shows the results as a histogram. Replotted from Kharin et al (2007; Figure 16).

Trends in annual precipitation maxima in 100 largest U.S. urban areas, 1950-2009

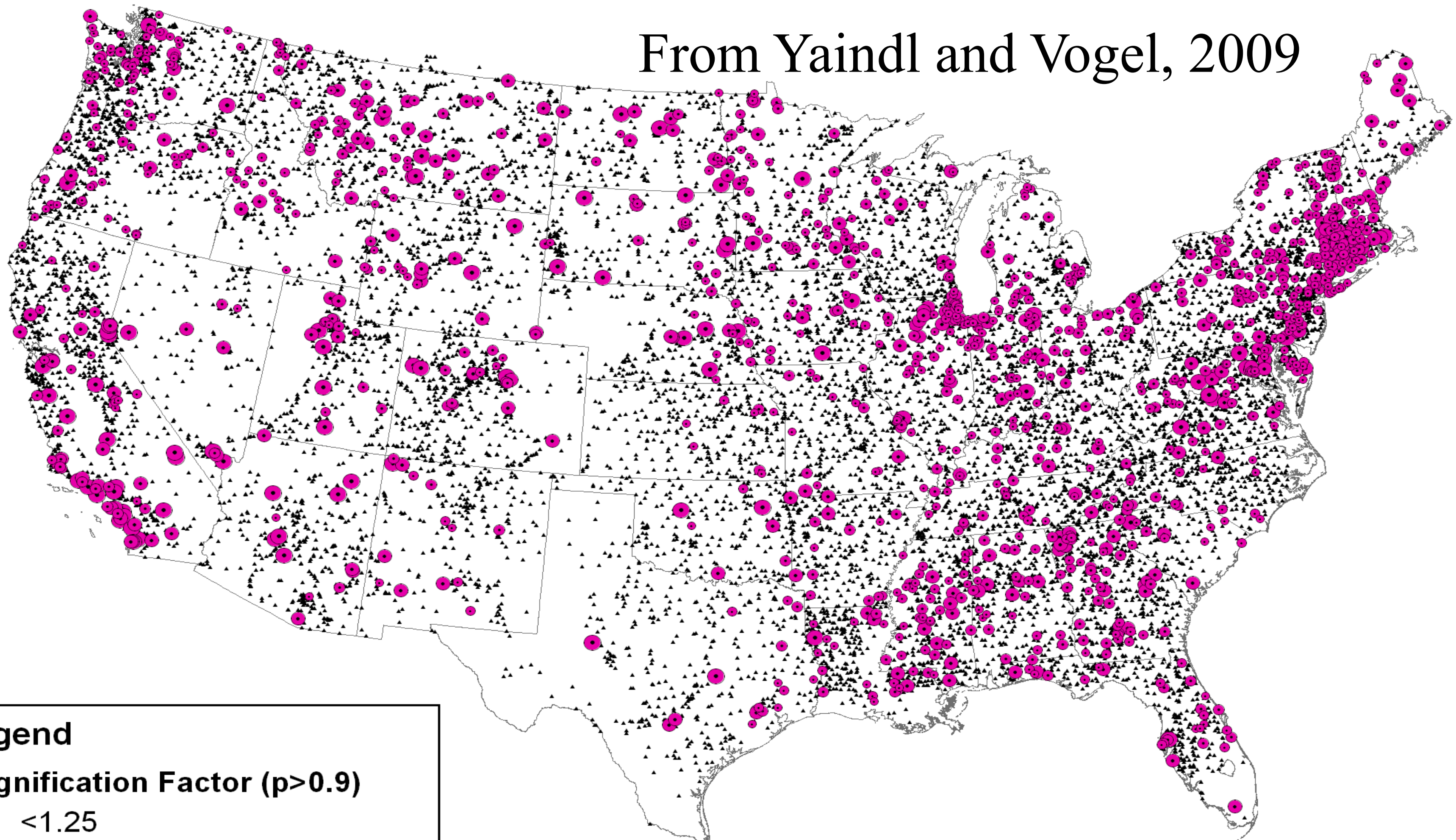


from Mishra and Lettenmaier, GRL 2011

Number of statistically significant increasing and decreasing trends in U.S. streamflow (of 395 stations) by quantile (from Lins and Slack, 1999)



From Yaindl and Vogel, 2009



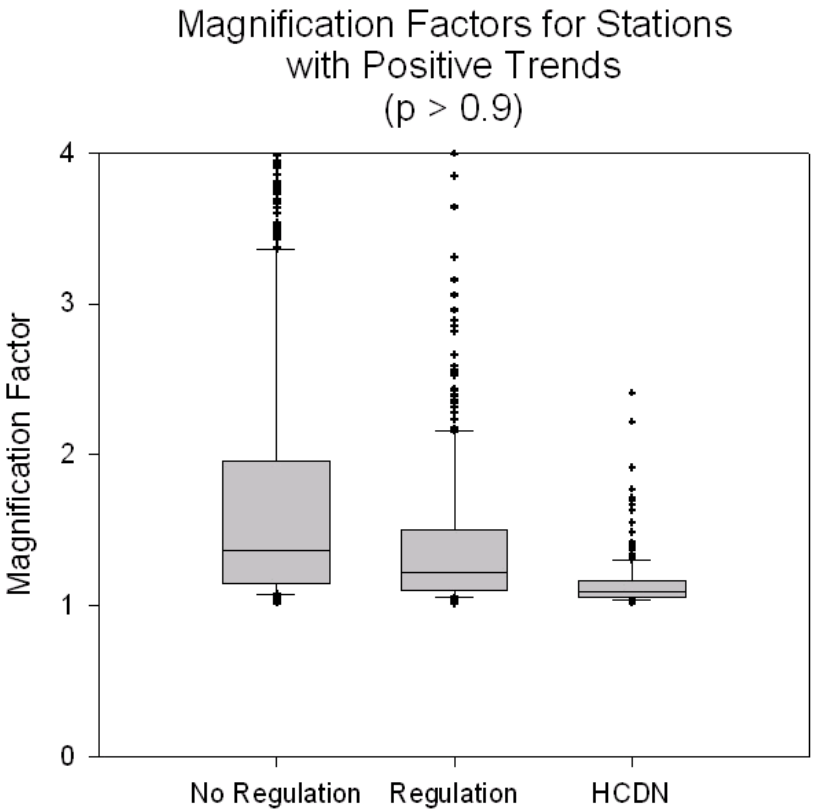
Decadal Magnification Factors of Floods – Sites w/ no regulation

1,642 of 14,893 USGS Gage Sites with M>1 and p>0.9

visual courtesy Rich Vogel

Results
Decadal Flood Magnification Factors

Tufts University



3 Groups of USGS Gages

Group Of Sites	Total Number of Sites	Number of Sites with Significant Positive Trends	Percentage of Sites With Significant Positive Trends
Unregulated	14,893	1,642	11%
Regulated	4,537	481	11%
HCDN	1,588	208	13%

From Yaindl and Vogel, 2009

visual courtesy Rich Vogel

Reconstructed U.S. soil moisture trends, 1915-2003

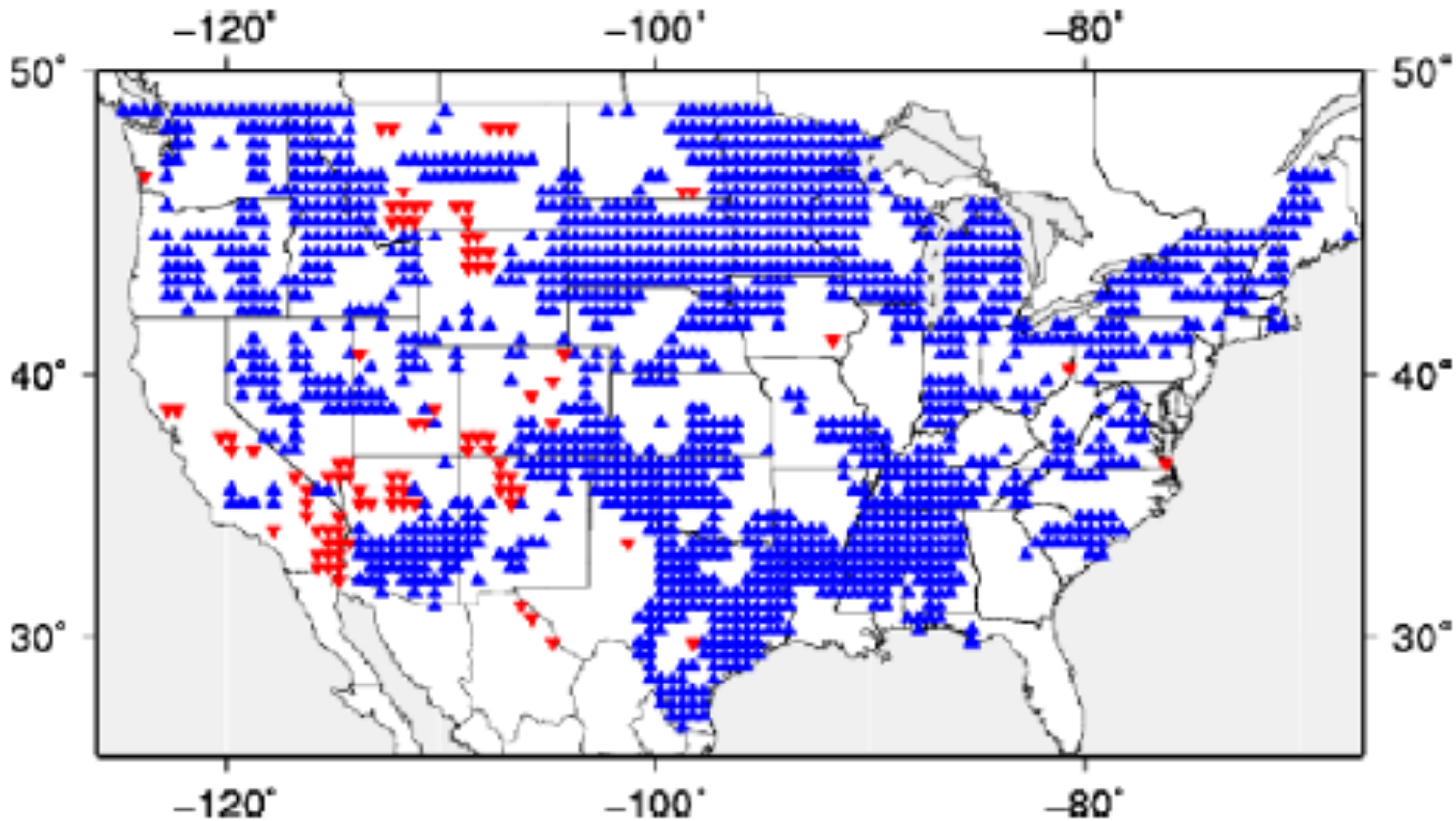


Figure 1. Annual trends in model soil moisture. Blue triangles show upward trends, while downward trends are shown as red inverted triangles.

from Andreadis and Lettenmaier, GRL 2006

Trends in U.S. drought duration, 2915-2003

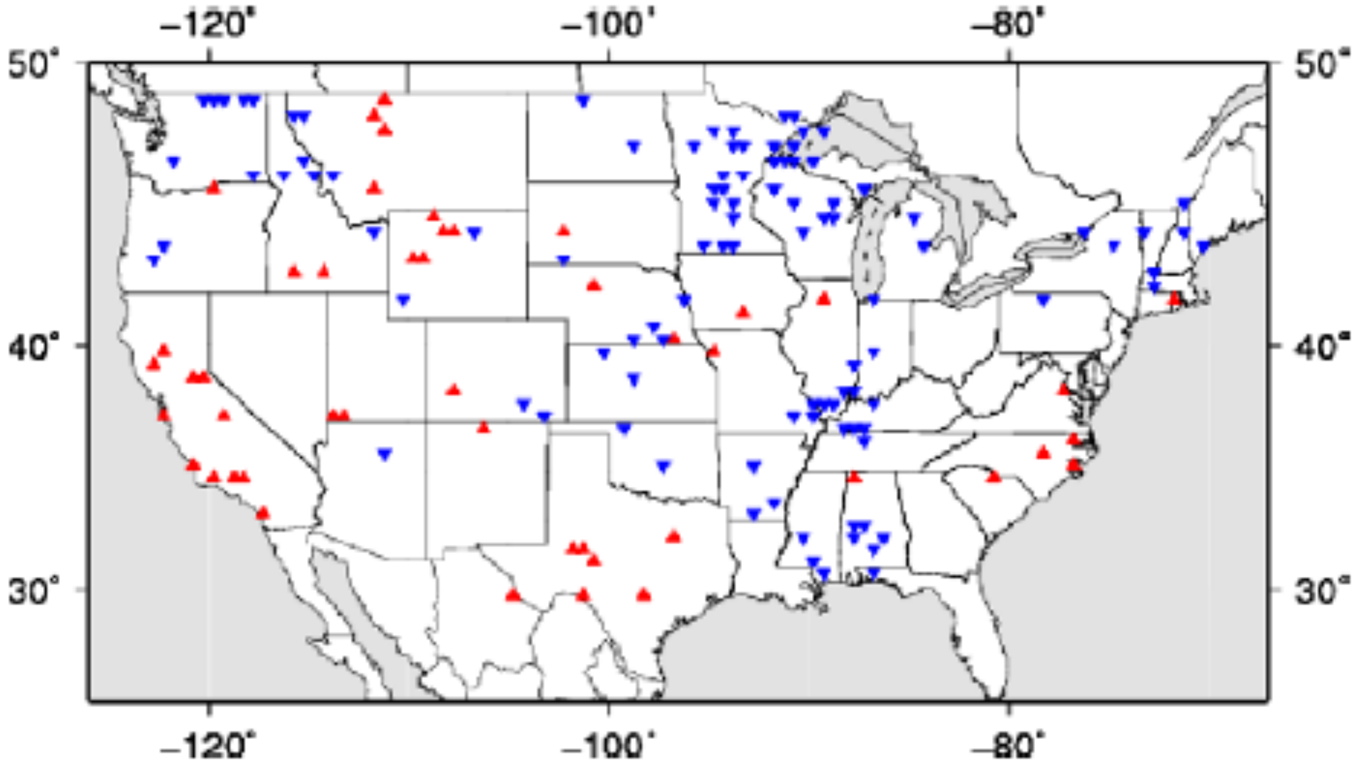


Figure 3. Trends in drought duration. Blue inverted triangles show downward trends, and red triangles show upward trends.

from Andreadis and Lettenmaier, GRL 2006

Trends in U.S. drought severity, 1915-2003

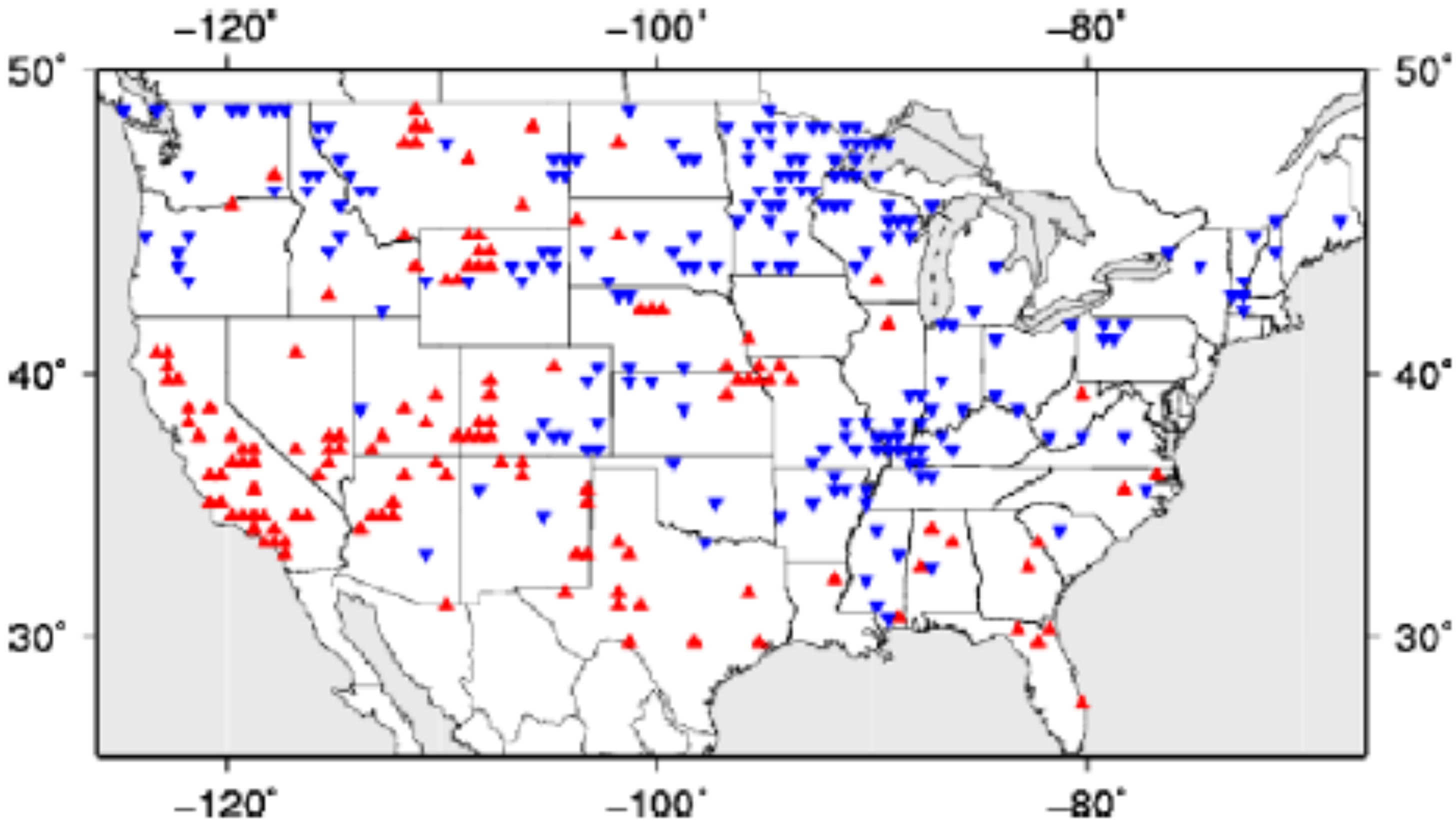
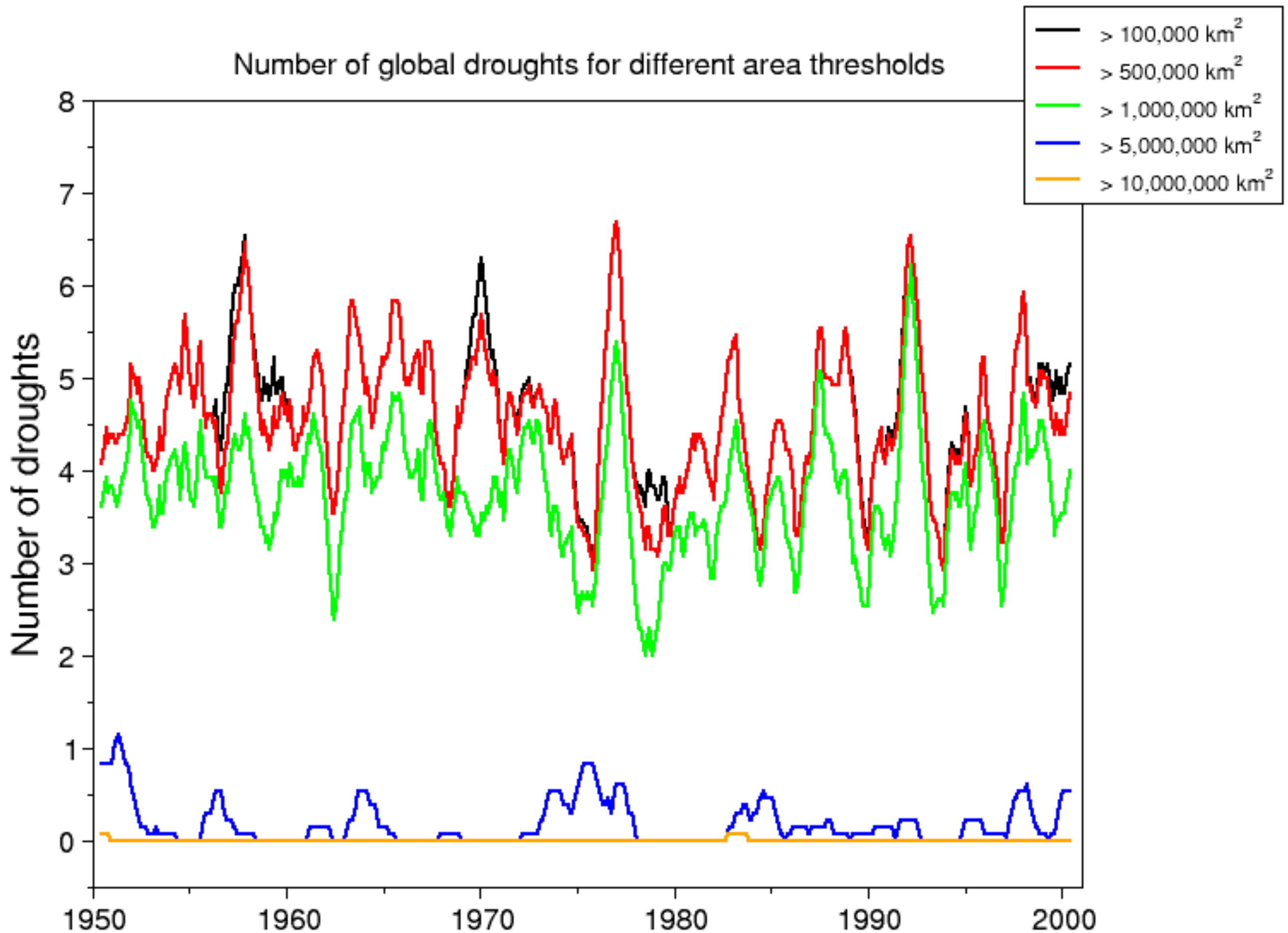


Figure 4. Trends in drought severity. Upward trends are shown as red triangles, while downward trend as blue inverted triangles.

from Andreadis and Lettenmaier, GRL 2006

Trends in number of global droughts, 1950-2000



from Sheffield and Wood, J Clim, 2008

4) Implications for Washington's water resources

Washington Climate Change Impacts Assessment

2007 State Legislature of Washington passed HB 1303 which mandated *the preparation of a comprehensive assessment of the impacts of climate change on the State of Washington* to be performed by the UW Climate Impacts Group

The assessment was to be focused on the impacts of global warming generally, and specifically in relation to:

public health,
agriculture
coastal zone
forestry
Infrastructure (specifically stormwater)
water supply and management
salmon and ecosystems
energy

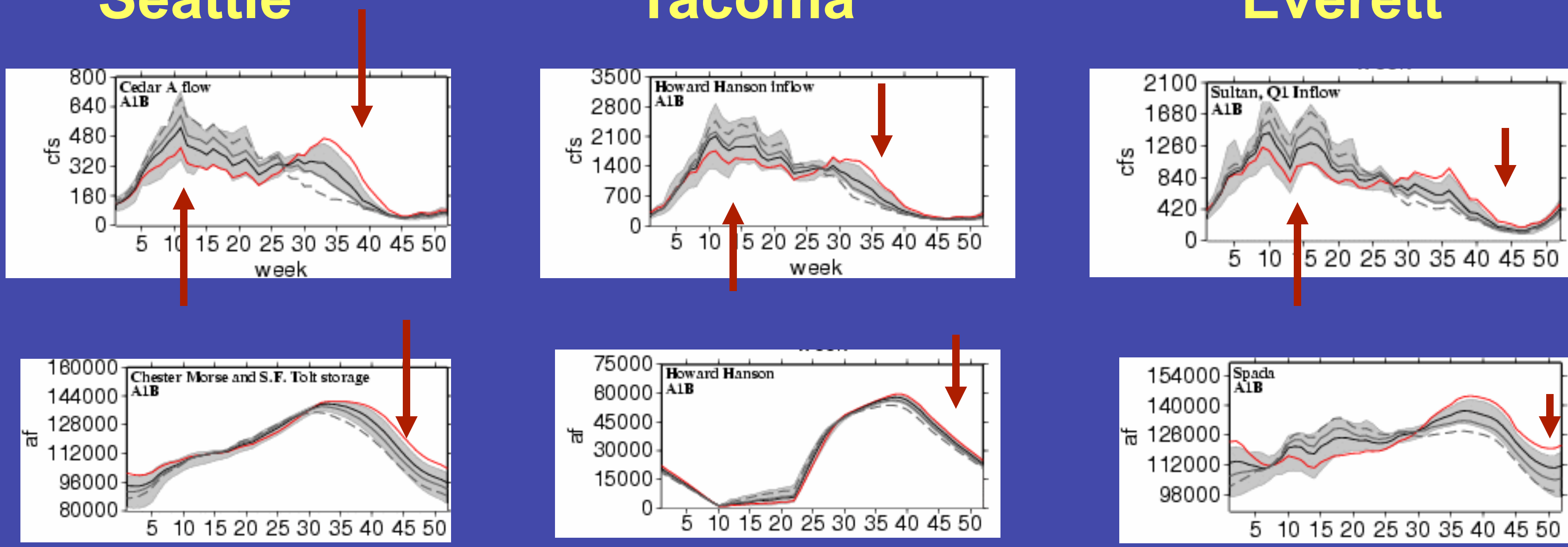
For summary see Miles et a., Climatic Change 2010 (V. 102, No. 1-2)

Focus Watersheds

- Puget Sound
  - Green River
  - Snohomish River
  - Cedar River
  - Tolt River
- Yakima River

Puget Sound Basin

Seattle · Tacoma · Everett



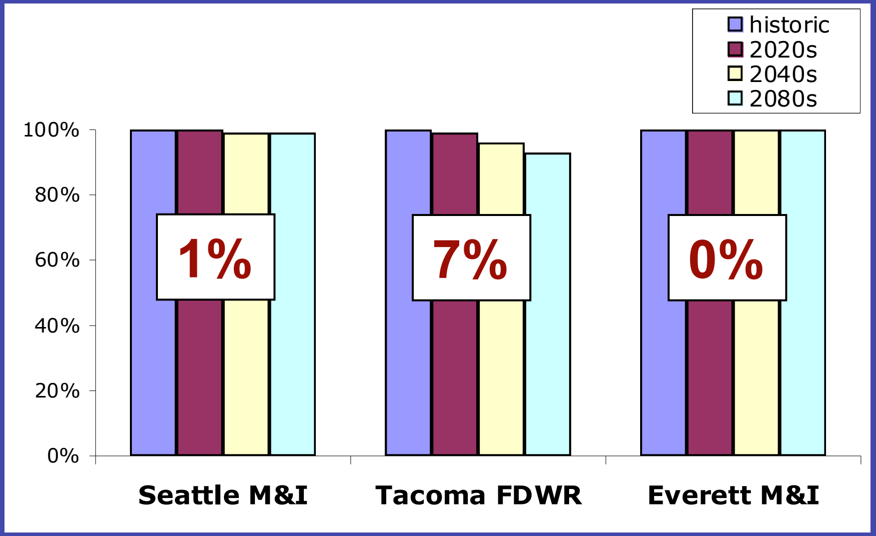
Variations in impacts within and between systems (A1B)

- Seattle, M&I and environmental flows
- Tacoma, flood control, more constrained storage
- Everett, hydropower, more interannual variability

Puget Sound Basin

municipal supply - current demand

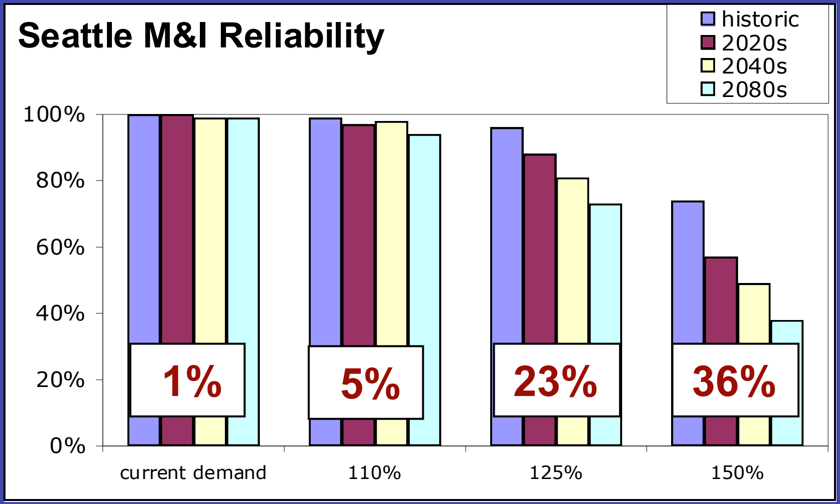
- M&I reliability measures, differ for all systems
- Current demand, reliability little impact from future change (A1B)
- Tacoma, water allocations closer to current system capacity
- Everett, largest system capacity
- Note: simulations prior to adaptations

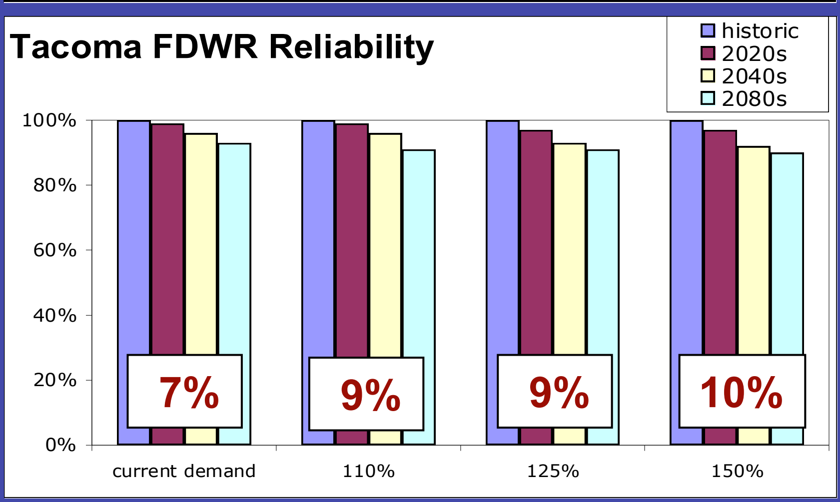


Puget Sound Basin

municipal supply - changing demand

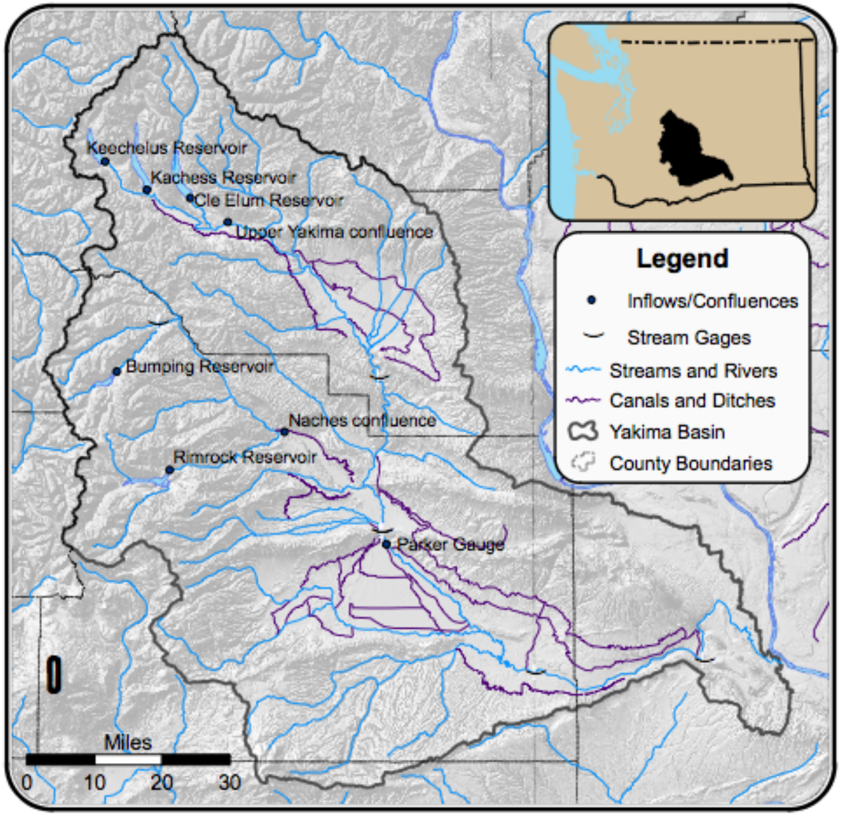
- With demand increases, climate change has more impact reliability
- Importance of conservation measures/reduced demand
- Systems respond different depending on storage capacity, basin transitions, system demands, adaptive capacity
- Note: simulations prior to adaptations





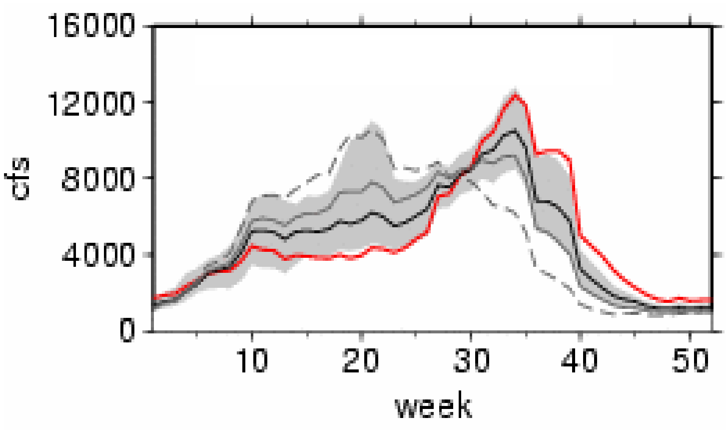
Everett M&I Reliability — 0% diff, all 100%

Case study 2: Yakima River Basin



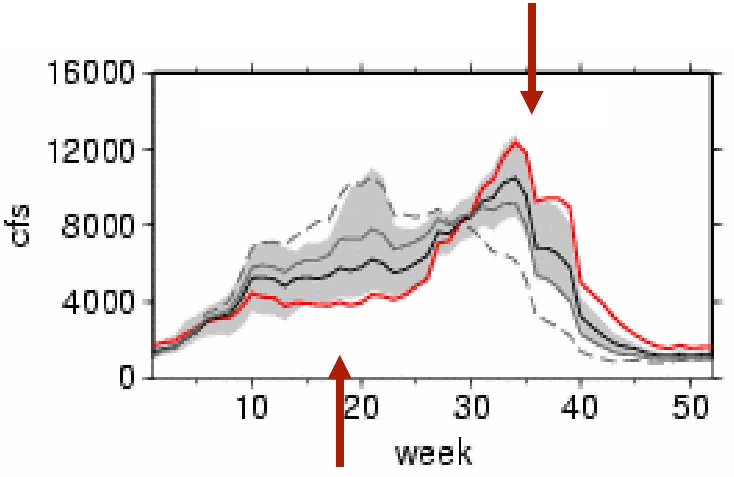
- Irrigated crops largest agriculture value in the state
- Precipitation (fall-winter), growing season (spring-summer)
- Five USBR reservoirs with storage capacity of ~1 million acre-ft, ~30% unregulated annual runoff
- Snowpack sixth reservoir
- Water-short years impact water entitlements

Yakima River Basin



Unregulated

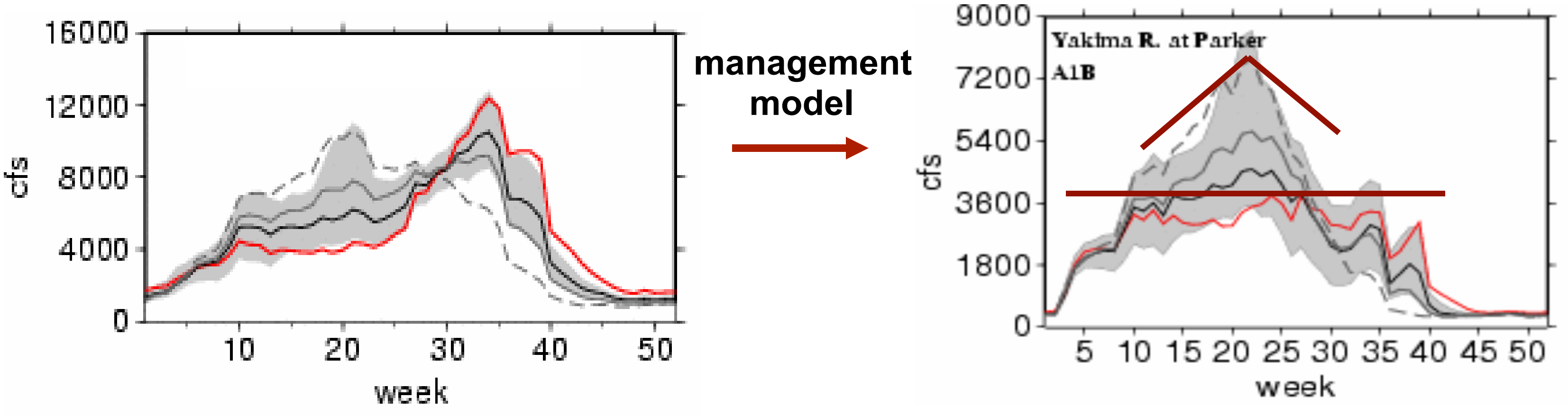
Yakima River Basin



Unregulated

- **Basin shifts from snow to more rain dominant**

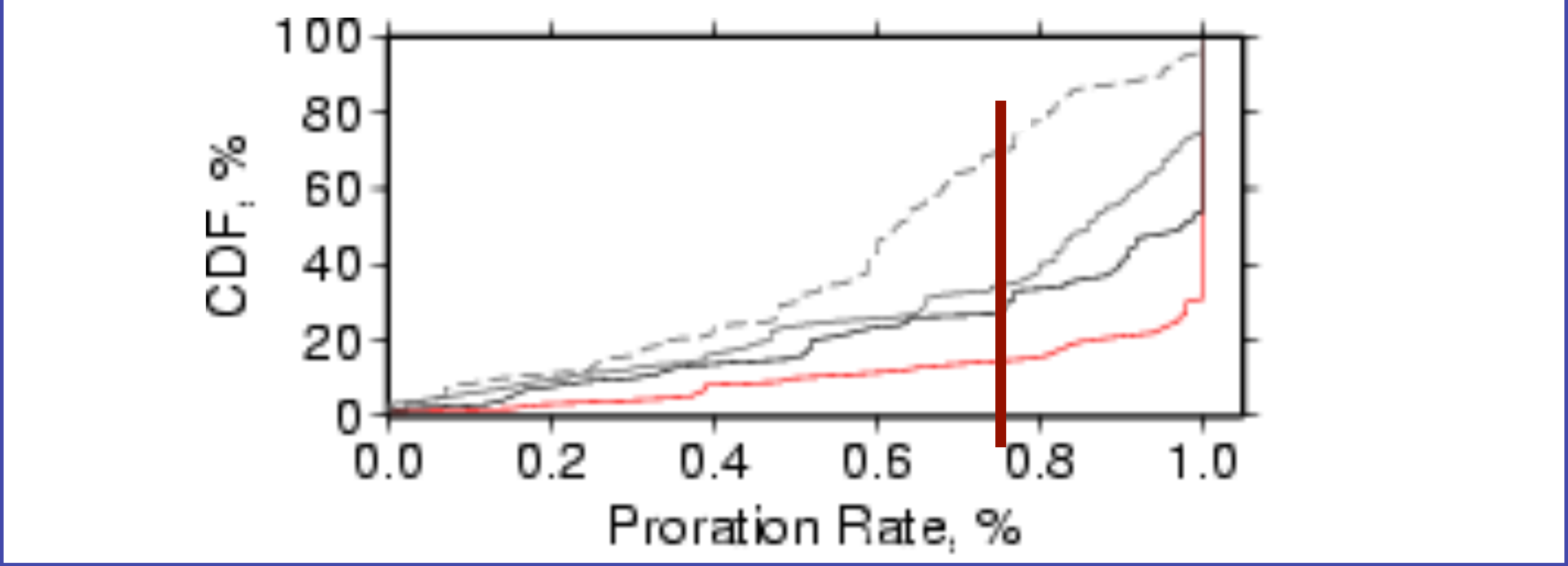
Yakima River Basin



Unregulated **Regulated**

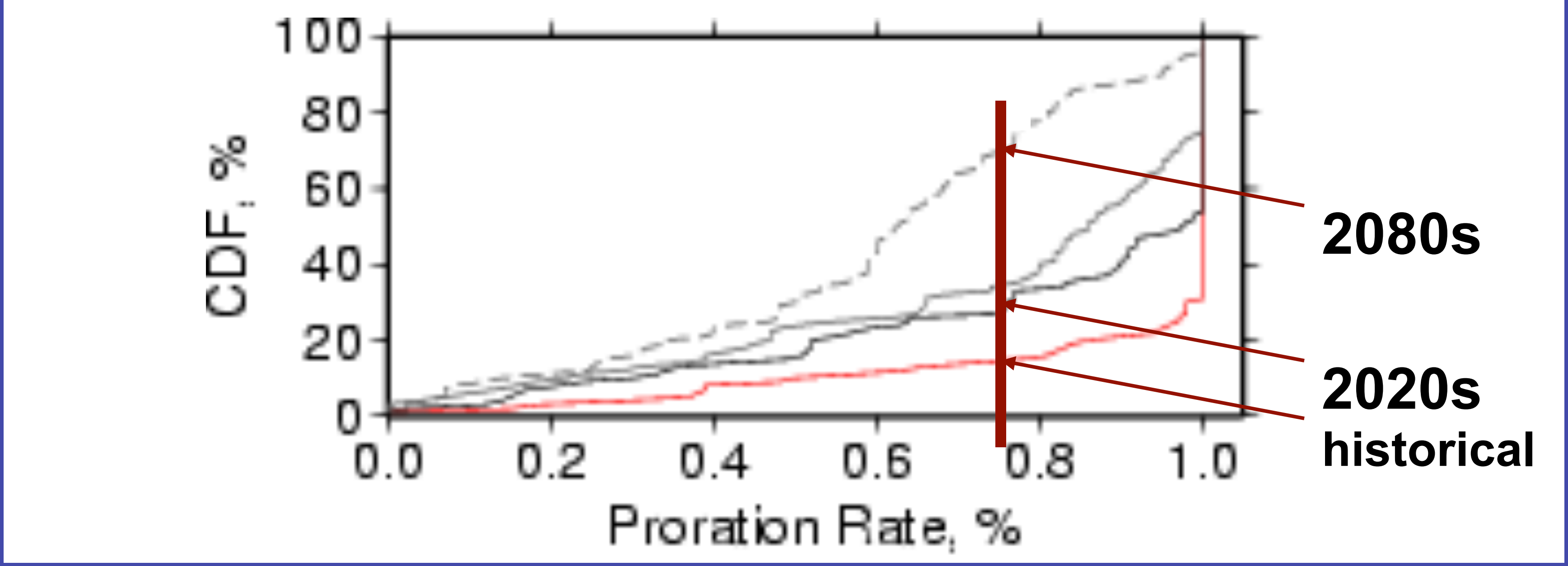
- **Basin shifts from snow to more rain dominant**

Yakima River Basin



- Basin shifts from snow to more rain dominant
- Water prorating, junior water users receive 75% of allocation

Yakima River Basin



- Basin shifts from snow to more rain dominant
- Water prorating, junior water users receive 75% of allocation
- Junior irrigators less than 75% prorating (current operations):
  14% historically
  32% in 2020s A1B (15% to 54% range of ensemble members)
  36% in 2040s A1B
  77% in 2080s A1B

Conclusions

- Compared with the rest of the U.S. (and especially the southern tier) Washington is in an area of modest annual runoff sensitivity to climate warming.
- But, there are substantial differences between summer and winter sensitivities, and seasonal (not annual) changes in runoff and streamflow are the major issue here.
- On a continental basis, there is some evidence of increasing extreme precipitation – although still difficult to detect. The picture for floods is much less clear, and it's not obvious whether changes in flooding that has been observed is primarily driven by land cover change or climate.
- Washington's west side water supply systems (dominantly urban) are fairly robust to shifts in the seasonality of streamflow (so long as demand remains stable, or continues to go down).
- The situation is much different in the Yakima (probably the state's most climatically sensitive water resources system). Even modest changes in streamflow patterns (increased winter flow, reduced spring and summer) will substantially erode the system's reliability.