Causal Influences on Increasing Hydrologic Drought Severity: Northwest U.S.

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Decreasing April 1 Snowpack (SWE)





Earlier Streamflow Timing

Question 1: Is the future already apparent?

- Climate change projections predict:
 - Warmer temperatures, little precipitation change
 - Less snow, more rain
 - Earlier runoff timing
 - Lower low flows

- We have seen less snow
- We have seen earlier timing
- Are we also seeing lower low flows?

Defining 7Q10

- Minimum 1-week flow
- With probability of occurrence of 0.10

Constrained June 1 – Nov 15









Question 2: Do we really know the reason?

Can we now attribute these lower low-flows to climate change?

Or phrased alternatively

Are the declines a consequence of warming temperatures, or ... ?



Can we get there another way?



Less P => Less SWE?

Less P => Earlier Timing?



After Luce et al., 2014



The Plot Twist

Declines in Annual Runoff from Mountain Basins 1948-2013



Luce et al., 2013



and Streamflow Not Measured in the Same Places!

Orographic Precipitation Enhancement

Windoward Mountain

Remard

The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest USA

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Trends in streamflow timing and volume in the Pacific Northwest United States have been attributed to increased temperatures, because trends in precipitation at lower-elevation stations were negligible. We demonstrate that observed streamflow declines are probably associated with declines in mountain precipitation, revealing previously unexplored differential trends. Lower-troposphere winter (November to March) westerlies are strongly correlated with high-elevation precipitation but weakly correlated with low-elevation precipitation. Decreases in lower-tropospheric winter westerlies across the region from 1950 to 2012 are hypothesized to have reduced orographic precipitation enhancement, yielding differential trends in precipitation across elevations and contributing to the decline in annual streamflow. Climate projections show weakened lower-troposphere zonal flow across the region under enhanced greenhouse forcing, highlighting an additional stressor that is relevant for climate change impacts on hydrology.

Despite the importance of mountains as sources of water and the conservation of biodiversity, particularly in a changing climate, our understanding of climate change in them is limited because of sparse observational data and difficult modeling conditions (1). Although the consequences of increased temperature for mountain snow are relatively well understood and severe (2–4), poor information about both historical and projected changes in mountain precipitation may lead to substantial misjudgment of risks and maladaptation. In particular, ecosystems and water supplies may be more sensitive to declines in precipitation than to increases in temperature (5–7).

We synthesized across multiple data sources to infer substantial historical declines in precipitation in the Cascades and Northern Rockies of the Pacific Northwest (PNW) United States and linked them to observed changes in atmospheric circulation. These historical declines contradict published assessments that there have probably been no significant declines in PNW precipitation over the past 60 years (4, 8, 9). The information basis for the lack of historical decline is the estimation of trends from the U.S. Historical Climate Network (HCN) precipitation stations in the PNW

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The Upshot

Precipitation declined over this period in the mountains
Don't assume it is not climate change related



Two signals:

- Height of snowman (timing) •
- •



Sensitivity Analysis for Minimum Weekly Flow (7Q)







Effects of Having Trees

- Less annual runoff
 - Lower low flows
- Timing ... later in cold snow ... earlier in warm snow







Changes to Monthly Yield from Fire – Boise R.









Context of Moisture



Lessons and Reminders

- Keep alternative paths to a result in mind!!
 - "Sure you have found a solution, but have you found the only solution?"

- Trends and Sensitivities are contextual
 - Keep spatial patterns in mind
 - Use them to find testable relationships
- The Case is still under investigation ...