Water Connects All: Climate Change and Mountain Hydrology in a Watershed Context

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Outline

• Mountain watersheds: Highlands and lowlands
• Climate change and snow at various scales
• Temperature variability and change
• New paradigm for examining water scarcity
Percent Rainfall & Snowfall in Mountain Regions of the Western US

(Based on Serreze et al. 1999)
"At-Risk" Snow in the US Columbia River Basin

'At-Risk' Snow:
A 2°C winter warming is projected to shift mid-winter precipitation from snowfall to rainfall.

Greatest impacts are for midwinter snow at lower elevations in the Western Cascades.

(Nolin and Daly, 2006; Nolin et al., accepted)
Willamette River Basin:
- 29,000 km²
- 70% of Oregon’s population
- Water use: hydropower, fish, irrigation, municipal

At-Risk Snow:
- For a 2°C temperature increase we project a 25% decrease in snow covered area
- Low elevation snowfall converts to rainfall
- ~4 km³ of water volume per year

(Nolin and Daly, 2006; Nolin et al., accepted)
When we make projections, we need to consider the geologic + climatic factors together.

High Cascades:
- Young volcanic rocks
- Groundwater-dominated

Western Cascades:
- Older, weathered volcanic rocks
- Surface runoff-dominated

Groundwater-dominated watersheds are more sensitive to changes in snowfall.

When we make projections, we need to consider the geologic + climatic factors together.
Measured and modeled flows, McKenzie River at Clear Lake, OR (elev. 918-2051 m)

Month

Portion of Annual Discharge

+1.5°C

2001-2005

1948-1952

Measured

Modeled using RHESSys

Snow = 56% of annual precip.

From Jefferson et al., 2008; Hydrological Processes
Measured SWE at Santiam Junction on April 1 (elev. 1143 m)

-1 cm/year

Significant at 0.99 level

Water volume loss in a 500-m elevation band = 0.5 km³
Average annual trends in **maximum** temperature at the HJA: 1973 - 2003
Earlier Spring at the HJA

Trend towards earlier spring at the HJA from 1958-2007

-0.9 days/year

The result?
Warming allow trees to use water from the soil earlier in the year

Courtesy C. Thomas, Oregon State University
Runoff Ratio (Streamflow/Precipitation) at forested “control watersheds (all values shown are statistically significant)

<table>
<thead>
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<th>Average runoff ratio</th>
<th>WS02 1958-05</th>
<th>WS08 1963-05</th>
<th>WS09 1968-05</th>
<th>Mack 1980-05</th>
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<td>Yr</td>
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<td>-0.09</td>
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Trends in Seasonal Streamflow at the HJ Andrews LTER

*Courtesy K. Miles, J. Jones, Oregon State University*
Water volume loss = 0.57 km³
Observations and models help us conceptualize and quantify connections and feedbacks

Two major challenges:

• Monitoring systems are sparse, inadequate
• Integrated conceptual framework is needed
NRCS snow sites miss the high elevation snow

Area-Elevation Relationship for Snow in the McKenzie River Basin
A 2.5 degree C warming may cause this change in elevation of the snow zone, depending on how complex terrain interacts with warming processes.
Elevation distribution of HJA sites with records longer than 30 years

Cumulative % of area of Andrews Forest vs. Elevation (m)

- Lookout Creek
- Reference stands
- Met stations and stream gages
During “stable” atmospheric conditions, cold air flows downslope and pools in the valleys. The valleys become decoupled from the uplands.

Temperature differences between uplands and valleys

**Tmax** Shows a seasonal pattern

Seasonal pattern is obscured because of cold air pooling.
HJ Andrews Temperature Map for Projected Warming

The valleys show much less change than the uplands.
Changes in Land Cover and Land Use Modify Streamflow

But how much, when?

\[ I^* = S \left( 0.27 + \frac{46}{\rho_s} \right) LAI \]

- Fire
- Beetle Kill
- Timber Harvest

Figure 2.81: Mass flows associated with the disposition of winter snowfall in a boreal forest (after Parton and Schmidt, 1993).
Water flows downhill but policy and population pressures flow uphill

Water scarcity is the relationship between supply and demand

- Annual vs. seasonal scarcity
- Local vs. regional
ENVISION

Climate Change
- Climate Scenario Assessment and Downscaling

Hydrologic System

Eco-System

Socio-Economic System
- Water Use
- Land Use

Landscape Change
- Human Landscape
- Biophysical Landscape
- Hydrologic Landscape

Multi-Agent Decision Modeling

Human Impacts

Analysis and Evaluation of Adaptation and Mitigation Responses: Policy, Management and Other Interventions

Courtesy OSU Willamette Water 2100 team (McDonnell, PI; NSF Hydrologic Sciences)
In summary:

• Snowpack is changing and long records are key
• Complex topography creates complex temperature patterns
• Measurement systems should be adapted so that they measure patterns of change
• Integrated modeling framework is needed to address issues of water scarcity
Water connects all

Hearty thanks to my many collaborators and contributors:

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