Water & Sierra Nevada forests: recent findings & lingering questions

How well can we estimate the mountain water cycle?

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Topics in this talk:

1. Southern Sierra Nevada CZO
2. The mountain water cycle – recent results
3. Water security & managing ecosystems
Motivating questions

How do regolith development & properties control, limit or modulate effects of climate change, management or disturbance on hydrology, biogeochemistry & ecology?

How will this landscape & the hydrologic processes connecting it alter w/ climate warming & landcover change?

William Prosser, Sabrina Lake
Mountain hydrology – fluxes

How well can we estimate any of these fluxes & stores?

My bias: We need measurements, not just modeling, to answer these questions

Reservoirs:
Snowpack storage
Soil-water storage
SSCZO site location, gradients & infrastructure

4 instrumented sites along steep climate gradient: 12°C, 60 km

Co-located w/ USFS watershed research site: 8 headwater catchments ~ 100 ha each

Lower SSCZO site proposed for NEON core

Winter access to upper sites over snow

Encourage collaboration
SSCZO conceptual model

Feedbacks across time scales: regolith-atmosphere coupling along elevation transect

Glacial
- Subalpine forest 2700 m

Millennial
- Mixed conifer forest 2000 m

Century
- Pine/oak forest 1100 m

Decadal
- Oak savannah 400 m

Annual

Feedbacks across spatial scales
- Pore to plot
- Hillslope to catchment
- Basin to regional

3000 m elevation gradient
Oak savannah
$T_{\text{ave}}$ 14.4°C
P 500 mm
0 d snow
$H_{\text{tree}}$ 11 m
25% tree cover

Pine/oak forest
$T_{\text{ave}}$ 10.9°C
P 850 mm
11 d snow
$H_{\text{tree}}$ 29 m
63% tree cover

Mixed conifer forest
$T_{\text{ave}}$ 8.9°C
P 1000 mm
130 d snow
$H_{\text{tree}}$ >30 m
53% tree cover

Subalpine forest
$T_{\text{ave}}$ 4.1°C
P 1100 mm
184 d snow
$H_{\text{tree}}$ 22 m
31% tree cover
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Basic water balance

**Precipitation** = Evapotranspiration + Runoff

Evapotranspiration refers to evaporation plus water use by vegetation
Sierra Nevada precipitation & snow water equivalent (SWE) – climatological estimate

Bales et al., 2006
Current operational snow measurements

From a regional view, operational snow measurements look like a dense network.

Main basis for seasonal water supply estimates.
American River basin

Zoom in – network does not look so dense

2 snow pillows in N. fork, 1 in Middle Fork, 8 in S. Fork

Non-representative network – index sites

Stations are on flat ground, in clearings, at mid elevations

Despite these limitations, snow pillows are widely used by modeling community as ground truth
What elevations provide the most snowmelt?

Values estimated from time series of satellite snowcover depletion & daily snowmelt

Most snowmelt comes from elevations above most measurement of precipitation or snowpack

Rice & Bales, 2013
LiDAR-derived snow depth, Kaweah R. basin

Kirchner et al., in prep.
Comparison of SWE measured by LiDAR w/ indirect estimates of SWE & precipitation, Kaweah R. basin

WY 2010

Future: data from distributed, wireless sensor networks, blended w/ remote sensing data

Kirchner et al., in prep.

SWE: Guan et al., 2013
Basic water balance

Precipitation = Evapotranspiration + Runoff

Evapotranspiration refers to evaporation plus water use by vegetation
Evapotranspiration (ET) across an elevation transect

Mid-elevation forests show neither summer nor winter shutdown:
- deep rooting & resiliency to moisture stress
- warmer canopy-level temperatures despite snow

Goulden et al., 2012
Weathered material extends down at least 10 m – subsurface storage in saprolite & saprock

This deeper storage provides buffering against moisture stress & accounts for the year-round ET
Midmontane forest – year round ET results in high annual ET

Subalpine forest – minimal ET in winter reduces annual ET
Basic water balance

Precipitation = Evapotranspiration + Runoff

Evapotranspiration refers to evaporation plus water use by vegetation
KREW: 8 instrumented headwater catchments
Increase in water yield with elevation, from rain to snow dominated.

Decreasing temperature → Increasing snow fraction → Decreasing LAI → Coarser soils

Implication for 2°C warmer climate: Reduce runoff by 10-40% in mixed conifer forest (assuming ecosystems adapt).

Hunsaker et al., 2013
Topics in this talk:
1. Sierra Nevada hydrologic setting
2. Measuring the mountain water cycle
3. Water security & managing ecosystems
Making a water-secure world – the three I’s

**INFRASTRUCTURE**
to store, transport & treat water

**INSTITUTIONS**
Stronger & more-adaptable

**INFORMATION**
Better & more-accessible

**HARD**

**SOFT**

Water security lies at the heart of adaptation to climate change.

**Water security**: the reliable availability of an acceptable quantity & quality of water for health, livelihoods & production, coupled w/ an acceptable level of water-related risks.
Water management translates into managing ecosystem services. Adapting to climate change also means managing ecosystem services.
ACWA Policy Principles on Improved Management of California’s Headwaters

“... managing California’s headwaters is integral to optimizing ... water supplies ... Increasing water yield and quality; reducing the risk and impacts of catastrophic wildfire; and enhancing natural features and functions; are all benefits to be derived, locally and statewide, from improved headwaters stewardship. Enhancing the resiliency and adaptability of headwaters is overdue. California can no longer afford to relegate management of its headwaters to the margin.”
A new generation of integrated measurements

- eddy correlation
- embedded sensor networks
- isotopes & ions
- low-cost sensors
- sap flow
- sediment
- lidar
- satellite snowcover
Wireless embedded sensor network nodes

Sensor node

Hopper node
Embedded sensor network technology – Providence Creek

Wireless network layout & equipment

- Sensing node
- Hopper node

Node w/ antenna

Embedded base station
Integrate these sensors with remotely sensed data, forecasting tools & decision support

Platform for research & core element of new water information system
Strategically place low-cost sensors to get spatial estimates of snowcover, soil moisture & other water-balance components
Node construction at Alpha site
Some recurring questions around water & forests

1. How will the post-fire water yield differ from before?

2. What will be the water yield with climate warming, vs. today?

3. What was the historical water yield prior to fire suppression?

Photos are Rim Fire area

Photos: J. Power & D. Buckley, USFS
Some background questions

1. How different were forests prior to fire suppression vs. today, pre-fire and post-fire?

2. Can we take forests back to pre-fire-suppression conditions?

Upper Yosemite Valley from Columbia Point, 4800’
Forest density, Stanislaus NF

Tree density, stems per ha

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Live tree C, Mg ha

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Collins et al., Ecosphere, 2011
Measuring forest effects on snow accumulation

1200 measurements

STEF snow survey
March 7, 2013

1200 measurements

open
drip_edge
closed

Stanislaus - Tuolumne Experimental Forest
Variable Density Thinning Study
Post-Harvest (2012)
Thinned unit w/ control in background
Impact of thinning on evapotranspiration & streamflow

P303 headwater catchment, Southern Sierra CZO/KREW, Sierra NF
Rain-snow transition, 2000 m elev
Results based on very-detailed pretreatment data & hydrologic modeling
5-yr average, 2004-2008
What is the slope of this line in different forests???

Saksa et al., in prep
Research Summary

1. High ET across a wide swath of mixed conifer forest
   – Resiliency to water stress – combined snowpack & soil-water storage
2. Low water yield in rain zone, much higher in snow dominated
   – product of longer-tem processes
   – shorter growing season in snow zone
   – Timing & amount of runoff are sensitive to small $\Delta T$
3. Sustained forest management can provide measurable benefits for water supply – will require both investment & verification
4. Better information is a critical foundation for water security, especially in a warming & more-variable climate
   – Mountain water cycle is poorly measured
   – The technology is readily available to accurately & routinely estimate water-balance components
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