Water Security in a Changing Climate: Observations from Drought in the Sierra Nevada

Roger Bales

Topics in this seminar

- California hydrology
- Drought history in California
- Drought in the Sierra Nevada
- Water security
Enterprise Bridge over Lake Oroville, Feather R. July 20, 2011

Oct 23, 2015
Hydrologic context
Basic water balance

Precipitation = Evapotranspiration + Runoff + ΔStorage

Evapotranspiration refers to evaporation, sublimation plus water use by vegetation
Calif. water sources

More precipitation & runoff north of Delta
More water use south of Delta

CA Water Plan, 2013
Water supplies:
Agriculture: 80% (33 MAF)
Urban 20% (8 MAF)

Data from DWR, adapted from Nor. Cal. Water Assn.
American Fire one year later, spring 2014

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Development of the drought

Drought originates from a deficiency of precipitation over an extended period of time – usually a season or more – resulting in a water shortage for some activity, group, or environmental sector.
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1100 yr drought record

Reconstructed flows of San Joaquin R. 
Color shading marks below-median periods ≥4 yr 1-6 per century

Meko et al. 2014 report
The current experiment: 2011-2015 drought

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Context: century-long experiment: suppressing fire
Questions motivating research

Response of southern Sierra water cycle to drought?

How does forest vegetation cope with extended dry periods?

Is the ongoing mortality a new pattern, or a natural cycle?

How do forest density, regolith water storage, other factors buffer drought?

Credit to M. Goulden & SSCZO team for questions
Southern Sierra – Conceptual Model

Feedbacks across time scales

Diel

Subalpine forest 2700 m

Millennial

Mixed conifer forest 2100 m

Seasonal

Pore to plot

Hillslope to catchment

Annual

Pine/oak forest 1100 m

Decadal

Oak savannah 400 m

Basin to region

2300 m elevation gradient
Field measurements

E-W transect of flux towers

San Joaquin Experimental Range 400 m
Soaproot Saddle 1100 m
CZO Providence 2000 m
Shorthair Creek 2700 m

Southern Sierra Critical Zone Observatory

Ground measurements of precipitation, evapotranspiration, discharge, soil-moisture storage, snowpack storage

(Shorthair not available)
Flux-tower measurements

Cumulative water-year evapotranspiration (ET)
2011 (wet)
2014 (3\textsuperscript{rd} drought yr)

Mixed-conifer forest, 2000 m
2152 vs 634 mm precip
20\% drop in ET

Pine-oak forest, 1100 m
1320 vs 390 mm precip
47\% drop in ET

*Bales et al., almost submitted*
Scaling evapotranspiration (ET)

Annual ET measured by flux towers, correlated with MODIS NDVI (greenness)

Conceptual

High LAI → High ET & NPP

Feedback over a few yr

High LAI → High NDVI

NDVI indicates ET needed to support the current LAI

ET calculated across the southern Sierra using this calibration

Goulden & Bales, 2014
Scaling ET across Kings R. basin

ET calculated across the southern Sierra using the ET-NDVI correlation from flux towers

Goulden & Bales, 2014
Kings R. basin water balance by elevation

Before drought

\[ P = ET + Q - \Delta S \]

During drought

Bales et al., almost submitted
Matric potential at 2-m depth at Providence showed recharge during drought, but not at Soaproot.

Soil moisture also showed gradual decline during drought, and no recharge below 1-m depth at Soaproot.

*Bales et al., almost submitted*
Multi-year whole-basin water balance

Kings River basin

1000 mm per yr

Water year

Bales et al., almost submitted
Interpretation

Parts of the Southern Sierra forest reached a tipping point

Regolith storage sufficient to buffer drought, if mean annual precipitation exceeds annual evapotranspiration
Decline in evapotranspiration during drought greatest where recharge to deeper root zone was limited
Next: predict where forests are resilient vs vulnerable

Predictions require spatial information:
- Climate (precipitation & temperature)
- Vegetation density
- Evapotranspiration
- Regolith water storage

Porosity based on seismic refraction

Depth, m

Distance, m

Holbrook et al., 2014
Management response: restore (thin) forest → reduce ET

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Thinned unit w/ control in background

E. Knapp photo
Making a water-secure California – the three I’s

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

**INFORMATION**
Better & more-accessible

**INSTITUTIONS**
Stronger & more-adaptable

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
Moving toward sustainability

Sustainable Groundwater Management Act (SGMA) could change everything

Big questions:
Depletion vs. sustainability
Level of sustained supply
Storage

CA Water Plan, 2013
Who uses California’s water

Family farms

Pistachios

Walnuts

Almonds

Food for the U.S.

Big questions:
Allocation decisions – water rights
What beneficial uses – water-quality implications
Decision context for investments in water data & information

Comprehensive plan, w/ background

Grey infrastructure (built facilities)

Societal investments

Green infrastructure (natural capital)

Groundwater recharge

Sites.miis.edu/

R. Ridgeman & B. Rust, USFS

Headwaters

Many more implementation decisions & operational decisions

Priorities
Limited accurate data on water fluxes & stores

Example – Sierra Nevada seasonal forecasts – uncertainty can be high
- Mainly monthly, manual measurements
- Few automated, but non-representative measurements
- Statistical forecasts, vs. hydrologic models

New, mature technology available: blending data from satellites, aircraft, wireless sensor networks, advanced modeling tools
Research
14 clusters of sensors
140+ sensor nodes
Spatially representative sampling
Snow-covered portion, ~2000 km²

Prototype, core element of new Sierra Nevada measurement system
A modern water information system is a key investment for water management.
Management-relevant science summary

1. High evapotranspiration across a wide swath of mixed-conifer forest
2. Higher water yield & resiliency to moisture stress in snow zone

3. Sustained forest management among the many infrastructure investment needs
4. Better information is a critical foundation for water security, especially in a warming & more-variable climate
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