Observations from drought in the Sierra Nevada: evapotranspiration, climate & regolith weathering

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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?
Basic water balance

Precipitation = Evapotranspiration + Runoff + ΔStorage

Evapotranspiration refers to evaporation, sublimation plus water use by vegetation
More precipitation & runoff north of Delta
More water use south of Delta

CA Water Plan, 2013
Applied water use

Water supplies:
Agriculture: 80% (33 MAF)
Urban 20% (8 MAF)

Precip: 200 MAF
Applied: 80 MAF

Data from DWR, adapted from Nor. Cal. Water Assn.
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.
1100 yr drought record

Reconstructed flows of Sacramento R.
Color shading marks below-median periods ≥4 yr 1-5 per century

Meko et al. 2014 report

www.wildlandart.com

Horizontal line at median
The current experiment:
2011-2015 drought
Context: century-long experiment: suppressing fire
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

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 (3rd 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)

High LAI \rightarrow\text{High NDVI}

NDVI indicates ET needed to support the current LAI

Feedback over a few yr

<table>
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<tr>
<th>High LAI</th>
<th>High ET &amp; NPP</th>
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ET calculated across the southern Sierra using this calibration

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

\[ R^2 = 0.9 \]

Goulden & Bales, 2014
Kings R. basin water balance

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

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.
Interpretation
Regolith storage buffers drought if mean annual precipitation exceeds annual evapotranspiration. Tree dieoff greatest where recharge to deeper root zone was limited. Parts of the forest reached a tipping point.
Thinned unit w/ control in background

Management response:
restore (thin) forest → reduce ET
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

Holbrook et al., 2014
Regolith heterogeneity depends on small differences in bedrock composition, weathering & dust deposition.
Acknowledgements: M. Conklin & many collaborators, students; research support through NSF Critical Zone Observatory and other sources.