Assessment of hydrologic impacts of climate change in the Sierra Nevada

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Collaborators: Roger Bales, Ryan Bart, and Weichao Guo
No trend in precipitation, temperature is on the rise

Data source: unpublished data, FEWS Lab, UC Merced
Changing Forest Landscape

Tree density has increased by 40% (Fig. A)

Average basal area has declined 20% (Fig. B)

McIntyre et al., 2015
Climate change and CO$_2$ are the two dominant drivers of vegetation change (1982–2009)

Zhu et al., 2016, NCC
The recent “experiment”: 2012-2016 drought

Photo: Margot Wholey, Dec 2015
Reimagining climate change impacts

How Climate Change Impacts Our Water Supply?

What is the role of vegetation in predicting terrestrial hydrologic response to climate change?

How and where forest management can help mitigate and adapt to climate change?

Climate change impact pathways

Vegetation change

- Leaf conductance
- Distribution
- Composition
- Structure
- Diseases and pests
- Net primary productivity

Hydrological change

- Snowpack
- Runoff
- Evapotranspiration
- Soil Moisture

Climate change

\( (\Delta T, \Delta P, \Delta CO_2) \)
Sensitivity of precipitation phase to temperature

Most sensitive (1000-2500 m) as compared to other regions of the western US
Why Dry Season Runoff?

(D) +1.1 °C Warming
SFE = 34 MAF

(E) +1.8 °C Warming
SFE = 49 MAF

(F) +3.0 °C Warming
SFE = 24 MAF

SFE = 27 MAF

SFE = 23 MAF

SFE = 17 MAF
Average = 201 mm
Average = 136 mm
Average = 101 mm

32% loss
50% loss

*Statewide: 48% loss under lower warming range and 65% under higher warming range (Pierce and Cayan 2013)
Both ET and Q will increase and more so at higher elevations

$\Delta \text{ET} = 5\%$
$\Delta \text{Q} = <1\%$
$\Delta \text{SM} = -3\%$

$\Delta \text{ET} = 9\%$
$\Delta \text{Q} = 15\%$
$\Delta \text{SM} = -2\%$

Increase in ET and Q is equivalent to 3-5% of the annual precipitation.
Climate change sensitivity is higher in the northern Sierra
Warming and elevated CO\textsubscript{2} have opposing influences on transpiration

\[ \Delta \text{ET} = 9\% \]
\[ \Delta \text{Q} = 15\% \]
\[ \Delta \text{SM} = -2\% \]

\[ \Delta \text{ET} = 0\% \]
\[ \Delta \text{Q} = 24\% \]
\[ \Delta \text{SM} = 9\% \]

Transpiration -CO\textsubscript{2} feedback may offset the warming impact?
Effects of climate change on Sierra carbon flux

HadGEM2-ES365 (warm and dry)
## Overall increase in NPP and total biomass -> higher ET

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Model</th>
<th>ANPP (TgC)</th>
<th>AGPP (TgC)</th>
<th>Total Biomass (TgC)</th>
<th>Veg Biomass (TgC)</th>
<th>Soil Biomass (TgC)</th>
<th>ET (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP45</td>
<td>CanESM2 (average)</td>
<td>9.97</td>
<td>43.42</td>
<td>113.99</td>
<td>155.61</td>
<td>-40.05</td>
<td>32.140</td>
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<td></td>
<td>CNRM-CM5 (cool-wet)</td>
<td>11.05</td>
<td>44.39</td>
<td>153.06</td>
<td>168.43</td>
<td>-26.32</td>
<td>32.881</td>
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<tr>
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<td>HadGEM2-ES (warm-dry)</td>
<td>6.38</td>
<td>32.56</td>
<td>37.21</td>
<td>83.39</td>
<td>-33.97</td>
<td>8.564</td>
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<td></td>
<td>MIROC5 (complementary)</td>
<td>8.34</td>
<td>32.90</td>
<td>109.75</td>
<td>94.15</td>
<td>-1.63</td>
<td>3.950</td>
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<tr>
<td>RCP85</td>
<td>CanESM2</td>
<td>12.49</td>
<td>59.30</td>
<td>83.03</td>
<td>159.90</td>
<td>-56.15</td>
<td>19.891</td>
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<td>CNRM-CM5</td>
<td>14.73</td>
<td>62.82</td>
<td>171.07</td>
<td>209.04</td>
<td>-39.05</td>
<td>20.316</td>
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<td>HadGEM2-ES</td>
<td>9.78</td>
<td>52.17</td>
<td>68.26</td>
<td>126.85</td>
<td>-44.62</td>
<td>-0.179</td>
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<td>MIROC5</td>
<td>12.76</td>
<td>51.03</td>
<td>175.29</td>
<td>157.72</td>
<td>-6.67</td>
<td>-2.907</td>
</tr>
</tbody>
</table>

Unit in TgC; Tg = 1 million metric tons
Climate change impact pathways

Vegetation change

- Leaf conductance
- Distribution
- Composition
- Structure
- Diseases and pests
- Net primary productivity

Climate change

- $\Delta T$, $\Delta P$, $\Delta CO_2$

Hydrological change

- Snowpack
- Runoff
- Evapotranspiration
- Soil Moisture

More confidence

Highly uncertain
Decline in ET and Q during the peak growing season

Mean Daily Streamflow

Mean Daily ET

Scenario

- Historical
- 8.5

Streamflow (mm)

ET (mm)
**Solution**

Reduce biomass density: drought resiliency, lower wildfire, better water quality, more runoff, carbon sequestration, health, jobs ...

Enhance groundwater recharge & storage

Develop financing & implementation pathways

**Activities**

Verify water-balance & carbon-balance outcomes, establish other benefits

Communicate & engage, forge partnerships, develop risk-sharing mechanisms

Empower trusted brokers & champions

State (SNC, DWR), NGO (TNC), finance (BFC), local (RCD), UC

**Decision-Support**

Forest-water adaptation tools

**Thinned unit w/ control in background**

E. Knapp photo, Stanislaus-Tuolumne Experimental Forest, Sept 2011
ET reduction due to fires between 1990–2008 and recovery

Roche et al. 2018
Reducing forest density can improve forest resilience

Bart et al., in prep

Average measured ET (533 mm/year)
Conclusions:

• Climate-vegetation feedback will mediate future hydrologic response to climate change

• Our water sustainability in the future will largely depend on how forests respond to climate change

• Reducing forest biomass can help adapt to future climate, both in terms of enhance forest resilience and water supply
Funding Acknowledgements:
LPJ-GUESS – an ecosystem modelling framework

- Modelled area (stand) c. 10 ha - 2500 km²
- Replicate patches in various stages of secondary succession
- Average individual for PFT cohort in patch
- Tree and grass components:
  - Crown area
  - Leaves
  - LAI
  - Height
  - Stem diameter
  - Sapwood
  - Heartwood
  - Fine roots
  - 0-50 cm
  - 50-100 cm
  - Leaves/LAI
  - Fine roots
Decline in ET during the peak growing season but no change in Soil Moisture

We do not constrain our models for storage and evapotranspiration. Almost all hydrologic models treat vegetation as static. 

Big limitation
No change in ET, and even larger increase in Q

Safeeq et al., in prep