Climate change & water planning: Tuolumne-Stanislaus IRWM

Roger Bales, UC Merced (and many collaborators)

Climate basics
Research findings – water balance
Water & forest management
Securing the future

Nov 19, 2014
Since 1895, annual average air temperatures in California have increased by 1.5°F, with minimum temperatures increasing at a rate double that for maximum temperatures (2°F/100 yr & 1°F/100 yr)
1\textsuperscript{st} assessment – 1990 – ... calculate with confidence that CO\textsubscript{2} has been responsible for over half the enhanced greenhouse effect. The unequivocal detection of the enhanced greenhouse effect is not likely for a decade or more.

5\textsuperscript{th} assessment – 2013 – ... increases the degree of certainty that human activities are driving the warming the world has experienced, from "very likely" or 90% confidence in 2007, to "extremely likely" or 95% confidence now.

Main point: plan on more warming as CO\textsubscript{2} rises
Climate warming scenarios for California

Projected Average Temperatures in California

<table>
<thead>
<tr>
<th>2005–2034</th>
<th>2035–2064</th>
<th>2070–2099</th>
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<tbody>
<tr>
<td>11°F</td>
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<td>0</td>
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</table>

California is expected to experience dramatically warmer temperatures during this century. The figure shows projected increases in statewide annual temperatures for three 30-year periods. Ranges for each emissions scenario represent results from state-of-the-art climate models.

Increase above 1961-1990 average

Source: CA Climate Change Center
Climate change impacts on the Sierra Nevada-San Joaquin Valley water cycle

Warming by 2–6°C (4–11°F) drives significant changes:
– rain-vs-snow storms *
– snowpack amounts *
– snowmelt timing *
– flood risk
– streamflow timing *
– low baseflows
– growing seasons *
– recharge
– drier soil in summer

Already observed (*)

Precipitation changes will further exacerbate these challenges

Plan for multi-year droughts – resiliency in water management

Water planning requires information developed from measurements and data not currently available

R. Bales, 11/19/14
Basic water balance

Precipitation = Evapotranspiration + Runoff

Evapotranspiration refers to evaporation, sublimation plus water use by vegetation
Evapotranspiration measurements

Oak savannah
E: 2000’
P_{ave}: 16”
ET: 20”

Pine/oak forest
E: 4000’
P_{ave}: 28”
ET: 33”

Mixed conifer forest
E: 7000’
P_{ave}: 33”
ET: 30”

Subalpine forest
E: 9000’
P_{ave}: 36”
ET: 18”

Evapotranspiration measurements
Water balance – Kings R. basin

Precipitation

Runoff

Evapotranspiration

Goulden & Bales, 2014
Runoff declines with higher temperature

- Longer growing season with temp. increase $\rightarrow$ more ET
- Average: 14% drop in runoff per 2°C
Evapotranspiration is currently lower in colder basins

![Graph showing current water fluxes across Sierra Nevada](image-url)
Some recurring questions around water & forests

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

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

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

Photos from G. Gruell
Water & Sierra Nevada forests

What we know
1. Vegetation removal generally results in more runoff, initially
2. Vegetation regrowth means less runoff
3. Clear cutting or wildfire means more sublimation & earlier snowmelt – runoff could go up or down
4. Less-dense forests (up to a point) can retain snow longer
5. Colder, snow-dominated areas produce more runoff that lower, rain-dominated areas

R. Bales, 11/19/14
Thinned unit w/ control in background

Stanislaus-Tuolumne Experimental Forest

Photo: Eric Knapp

R. Bales, 11/19/14
Three issues

1. Water use by vegetation
2. Interception losses
3. Timing of snowmelt & runoff

Also climate-warming context
Measuring forest effects on snow accumulation

1200 measurements

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SNAMP is a joint effort by the University of California, state and federal agencies, and the public to study management of forest lands in the Sierra Nevada.
SNAMP hydrology research

1. Hydrology (water quantity) research within SNAMP
   • Assessing SPLATS influence on water yield & timing
   • Expecting small hydrologic response from light treatments
   • Detailed water-balance measurements informing modeling
   • SNAMP goes well beyond a classical paired-watershed study and a modeling-only exercise
   • Drought is confounding some of the post-treatment hydrologic response

2. SNAMP addressing SPLATS; but knowledge gaps around “restoration” treatments & fire remain – i.e. effects of further vegetation removal

3. SPLATS treatments in this study limited by Sierra Nevada Framework

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SNAMP water-team approach

1. Measure water-balance: response to forest treatments

2. Model headwater processes: control, treatment & projected forest density

3. Transfer to large watersheds
SNAMP study sites
Field measurements

Research question:
Will forest treatments (SPLATs) increase water yield in response to reduced water demand by vegetation?

Hypothesis:
SPLATs will contribute to a small increase in water yield, most likely observed during summer baseflow.
Field methods

Upper, lower elevation met stations (4)
North, south facing sensor nodes: snow depth (62), soil moisture (164), temperature
Headwater synthesis & modeling

Research question:
1) What will be the modeled response in water yield to vegetation reduction from SPLATs and even more severe forest treatments?
2) How will the response in water yield change due to wildfire removal of vegetation as opposed to forest treatments?

Hypothesis:
1) The model will show an increase in water yield in response to forest treatments, the response will not be linear.
2) Vegetation reductions from wildfire will show even higher increases in water yield than forest treatments.

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Regional Hydro-Ecological Simulation System (RHESSys)
RHESSys key inputs & outputs

Met inputs
- Precipitation
- Temperature
- Relative humidity
- Vapor pressure deficit

Spatial inputs
- LiDAR/forest plot vegetation map
- Soils map
- LiDAR elevation

Outputs
- Snowpack
- Soil storage
- Water yield
Headwater model - calibration

Water Year Day 2011

Bear Trap Creek

Observed
Model

Snow cm
Soil Storage cm
Discharge cm

Oct Dec Feb Apr Jun Aug

30+ observations/site

2 observations/site

80+ observations/site

Work in progress – Phil Saksa

R. Bales, 11/19/14
Percent of precipitation converted to runoff

- **90% Soil Cover**
- **10% Soil Cover**

**Percent of precipitation converted to runoff**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Precipitation (191-cm, avg yr)</th>
<th>Runoff Current</th>
<th>Pre-fire suppression veg density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treatment</td>
<td>60%</td>
<td>51%</td>
<td>90% Soil Cover</td>
</tr>
<tr>
<td>33% vegetation removed</td>
<td>70%</td>
<td></td>
<td>10% Soil Cover</td>
</tr>
<tr>
<td>66% vegetation removed</td>
<td>80%</td>
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</tr>
</tbody>
</table>

**Decrease in biomass from thinning or fire**

- Thinned
- Burned

**Headwater model results – importance of soil cover (litter layer)**

*Work in progress – Phil Saksa*
Hypothesis:
1) The model will show an increase in water yield in response to forest treatments, the response will not be linear.
2) Vegetation reductions from wildfire will show even higher increases in water yield than forest treatments.

Preliminary results:
1) Model projections indicate a 50% decrease in vegetation could result in an average 10% increase in water yield
2) Model sensitivity to the forest litter layer shows wildfires may not increase water yield more than treatments.
Ongoing forest-watershed studies

SNAMP: 2 sets of paired catchments, Sierra Nevada Framework treatments

Stanislaus-Tuolumne EF: snow & soil moisture

KREW (USFS) watershed research site & CZO (NSF, UC): 8 headwater catchments; tree removal:
- 39% for <10 in
- 21% for 10-20 in
- 4% for 20-30 in

MODIS image
New studies – proposed to address knowledge gaps
<table>
<thead>
<tr>
<th>Name</th>
<th>acres</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>Rice 3</td>
<td>480</td>
<td>Restore</td>
</tr>
<tr>
<td>Rice 2</td>
<td>720</td>
<td>Control</td>
</tr>
<tr>
<td>Rice</td>
<td>1040</td>
<td>Control</td>
</tr>
<tr>
<td>Dolly</td>
<td>2320</td>
<td>Light</td>
</tr>
<tr>
<td>Chipmunk</td>
<td>350</td>
<td>Restore</td>
</tr>
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</table>
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.”
Making a water-secure world – the three I’s

**INFRASTRUCTURE**

- to store, transport & treat water

**INFORMATION**

- Stronger & more-adaptable INSTITUTIONS

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

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**Better & more-accessible INFORMATION**

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**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

R. Bales, 11/19/14
How can Stanislaus-Tuolumne benefit from better water information, to support decisionmaking?
Things to think about

– Are water utility leaders interested in being climate communication leaders?
– Can utilities develop long-term communication strategies that change how their communities respond to climate change?
Closing thoughts

1. Snowpack supports high evapotranspiration across a wide swath of mixed conifer forest – also sustains water yield
2. Sustained forest management can provide measurable benefits for water supply – will require both investment & verification
3. Groundwater storage can help offset some snowpack loss
4. Better information is a critical foundation for water security, especially in a warming & more-variable climate
   – The technology is readily available to accurately & routinely estimate water-balance components
   – Envision an accurate, timely, transparent water-accounting system for California
5. Climate change adaptation is a central responsibility of the IRWMs and their members