Climate change, Sierra Nevada snowpack & California's water supply

Roger Bales, Sierra Nevada Research Institute
April 1 snowpack was 3rd largest in last 10 years

Source: NWS-NOHRSC
Sierra Nevada snow depth, April 13, 2008

2008 was a “dry” year

Source: NWS-NOHRSC
Sierra Nevada snow depth, April 13, 2009

2009 was an average year

Source: NWS-NOHRSC
Sierra Nevada snow depth, April 13, 2010

2010 was an average but late year

Source: NWS-NOHRSC
Sierra Nevada snow water equivalent
April 13, 2008

Source: NWS-NOHRSC
Sierra Nevada
snow water equivalent
April 13, 2009

Source: NWS-NOHRSC
Snow cover in the Western U.S.

- exhibits considerable interannual variability
- occurs on only a small fraction of the landscape
- yet it sustains the streamflow & groundwater recharge of much of the west
Most runoff & recharge comes from snowmelt

Serreze et al., 1999
Much of the semi-arid west derives its water supply from intensively managed mountain ranges

News Focus

In a region already prone to water shortages, researchers now forecast that rising temperatures threaten the American West’s hidden reservoir: mountain snow

As the West Goes Dry

20 FEBRUARY 2004 VOL 303 SCIENCE www.sciencemag.org
Having 10+ years of drought focused attention on western water. It made scientists & decision-makers alike push for new measurements & understanding of mountain hydrology to close critical knowledge gaps. This understanding is needed for longer-term sustainable water management.
Drought, snow cover & climate change

U.S. Drought Monitor
August 26, 2008
Valid 8 a.m. EDT

Intensity:
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:
- Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm

Released Thursday, August 28, 2008
Authors: Jay Lawrimore/Liz Love-Brotak, NOAA/NESDIS/NCDC
Drought, snow cover & climate change
Drought, snow cover & climate change

Conditions have fluctuated in California & the Southwest, and the West currently shows limited evidence of a drought – but one wet year does not end a drought.
Southwest water balance

CA
108 billion gallons/day
62.7%

NV
48 billion gallons/day
95.8%

AZ
67 billion gallons/day
98.5%

NM
73 billion gallons/day
97.3%

Water balance component
- Evapotranspiration
- Precipitation

Data in billion gallon/day

Source: USGS Water Use Report 1990
Climate outlooks

- Is the drought over?
- A warm winter to follow a warm summer?
- Will it be wet or dry?
Forecasts vs. projections
What is the relationship between climate change & weather?

Climate is average weather; thus climate change & weather are intertwined. Observations & statistics of changes in weather over time identify climate change.

Common confusion: how can scientists predict climate 50 years from but only predict the weather a few days out. *The chaotic nature of weather.*

Projecting changes in climate (i.e., long-term average weather) due to changes in atmospheric composition or other factors is a very different and much more manageable issue.

As an analogy, while it is impossible to predict the age at which any particular man will die, we can say with high confidence that the average age of death for men in industrialized countries is about 75.
Weather forecast – 6 days out

### Forecast at a Glance

<table>
<thead>
<tr>
<th>Overnight</th>
<th>Monday</th>
<th>Monday Night</th>
<th>Tuesday</th>
<th>Tuesday Night</th>
<th>Wednesday</th>
<th>Wednesday Night</th>
<th>Thursday</th>
<th>Thursday Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing Clouds</td>
<td>Becoming Sunny</td>
<td>Sunny</td>
<td>Mostly Clear</td>
<td>Sunny</td>
<td>Clear</td>
<td>Sunny</td>
<td>Clear</td>
<td></td>
</tr>
<tr>
<td>Lo 56°F</td>
<td>Hi 80°F</td>
<td>Lo 56°F</td>
<td>Hi 80°F</td>
<td>Lo 50°F</td>
<td>Hi 81°F</td>
<td>Lo 51°F</td>
<td>Hi 85°F</td>
<td></td>
</tr>
</tbody>
</table>

### Detailed 7-day Forecast

**Overnight:** Increasing clouds, with a low around 56. Northwest wind between 8 and 11 mph.

**Monday:** Cloudy through mid morning, then gradual clearing, with a high near 83. Northwest wind between 7 and 11 mph.

**Monday Night:** Clear, with a low around 55. North northwest wind between 5 and 11 mph.

**Tuesday:** Sunny, with a high near 83. West northwest wind between 5 and 7 mph.

**Tuesday Night:** Mostly clear, with a low around 50. West northwest wind between 5 and 9 mph.

**Wednesday:** Sunny, with a high near 81.

**Wednesday Night:** Clear, with a low around 51.

**Thursday:** Sunny, with a high near 85.

**Thursday Night:** Clear, with a low around 54.

**Friday:** Sunny, with a high near 87.

**Friday Night:** Clear, with a low around 55.

**Saturday:** Sunny, with a high near 88.

**Saturday Night:** Clear, with a low around 56.

**Sunday:** Sunny, with a high near 91.

### Current Conditions

- **Fresno, Fresno Air Terminal**
  - Last Update on 19 Sep 22:53 PDT
- **Humidity:** 66%
- **Wind Speed:** NW 14 MPH
- **Barometer:** 29.85 in (1013.50 mb)
- **Dewpoint:** 58°F (14°C)
- **Visibility:** 10.00 Miles
- **70°F (21°C)**
- **3 Day History**
Outlooks beyond one week are expressed as probabilities of being above or below normal/median, i.e. relative to past 30-year period.
One-month & three-month outlooks are expressed as probability of being in upper or lower tercile of climatological values, i.e. relative to past 30-year period.

Deviations from normal are based largely on ENSO conditions.
Nov 2004

Developing El Niño
Lack of anomaly
Sept 2010

Developing La Niña
Snow cover & climate change

- Western snowpacks hold less water than 50 years ago
- They are also melting earlier
- Result is earlier runoff & drier summer soil
- These trends should continue as climate warms further
Climate change

There are 3 important points on which the science community agrees:

- global warming is occurring
- fossil fuel consumption contributes to the warming
- if we fail to act now to reduce greenhouse gases it will get worse

Many government & private sector planners consider climate change in:

- planning infrastructure
- evaluating investments
- protecting public health, welfare & natural resources
California has been warming in recent decades, following the global trend.

Land surface temperatures
5-yr average departure from 1901-2000 mean
20th century temperature trends

Positive trends of 2-3°C (3-5°F) per century over much of the West

Kart et al., 1996
Northern Hemisphere temperature estimates from tree rings and other sources relative to 1961-90 mean

Recent temperature changes are unprecedented

Data from 10 studies, with darker colors representing greater consensus.

The so-called “hockey stick” curve
The Anthropogenic Impact

- Atmosphere CH₄ (ppbv)
- Atmospheric CH₄
- Atmospheric CO₂
- Atmospheric N₂O
- World Population (billions)
- World Population
- Direct Measurements

Calendar Years (AD)
Observed changes in water cycle go beyond historical levels

TRENDS (1950-97) in April 1 snow-water content at western snow courses

Elevation

-2.2 std devs LESS as snowfall
+1 std dev MORE as snowfall

less snow more rain

less spring snowpack

Related effects:
- Earlier greenup, Cayan 2001
- Greater fire severity in warm/dry years, Westerling 2006
- Increasing forest mortality, van Mangten 2009
- Reduced summer streamflows, Stewart 2006

TRENDS

earlier snowmelt

Stewart et al., 2005

Mote, 2003

Knowles et al., 2006
The combined effects of climate change, population growth, land-use change & landcover changes are placing increasing stresses on mountain environments & on the imbalance between water demand & supply.