Climate Change implications for California’s Water & Food

Michael Hanemann
California Climate Change Center
UC Berkeley
Topics

• View in US versus Europe
• Climate change and agriculture
• Climate change and water
• The California Scenarios Study
The US vs Europe
Conventional view in Washington

• The conventional view in DC is that
  – Climate change poses relatively little risk to the US in the near term, and may even be beneficial.
  – The cost of any large reduction in US emissions would be economically harmful.
  – Hence the notion of setting a modest price on carbon and seeing what happens.
Stern Review

- Review of economics of climate change commissioned by the Chancellor of the Exchequer, conducted by Sir Nicholas Stern Head of the UK Government Economic Service, released in November 2006.

- Calls for “prompt and strong action….If we don’t act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever.”
Reception of Stern

- Nordhaus (2006): The Stern Review results are “dramatically different” from existing economic analyses.
- He finds that optimal economic policy for climate change involves modest rates of emissions reductions in the near term. 6% emissions reduction in 2005; 14% in 2050; and 25% in 2100.
Why the different conclusions?

• Choice of interest rate used for balancing future damage avoided versus present costs of abatement.
  – Stern uses a much lower interest rate, Also, Stern takes damages through 2200, not 2100.

• Assessment of future damages
  – Stern’s assessment of these is much greater

• Assessment of costs of emission reduction
  – Stern’s assessment of these is lower

• Treatment of uncertainty
  – Stern includes allowance for risk aversion, views climate policy as partly a matter of insurance
Climate Change and Agriculture

• The most heavily analyzed sector in climate economics literature.
• Also the most divergent range of estimates e.g., from loss of 25% in value of US ag output to gain of 20%.
Interactions between climate & crop growth

Complex, non-linear, not unidirectional, and multidimensional:

• Temperature
  – Effects on yield
  – Effects on quality

• CO$_2$ fertilization

• Crop ET (crop water need)

• Weeds, pests

• Ozone
• Existing literature focuses just on temperature and CO2 fertilization; focuses on crop yield, not quality, especially major grain crops.
• Other effects largely ignored so far.

• When attention is thus restricted, estimated, climate change impact on yield can well be positive:
  – Fertilization effect is positive
  – Cooler areas benefit from warming
Three factors

• Characterization of temperature change
  – Annual, seasonal, monthly, daily
  – Global, US, California, Central Valley

• Assumed shape of relationship between temperature and yield
  – Symmetric, hill-shaped
  – Asymmetric, mesa-shaped

• Allowance for economic adaptation
Characterization of temperature change

<table>
<thead>
<tr>
<th>HOW TO CHARACTERIZE THE CHANGE IN TEMPERATURE, 2070-2099, USING HADCM3</th>
<th>EMISSION SCENARIO**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1fi</td>
</tr>
<tr>
<td>Change in global average annual temperature</td>
<td>4.1</td>
</tr>
<tr>
<td>Change in statewide average annual temperature in California*</td>
<td>5.8</td>
</tr>
<tr>
<td>Change in statewide average winter temperature in California*</td>
<td>4</td>
</tr>
<tr>
<td>Change in statewide average summer temperature in California*</td>
<td>8.3</td>
</tr>
<tr>
<td>Change in LA/Sacramento average summer temperature</td>
<td>~10</td>
</tr>
</tbody>
</table>

*Change relative to 1990-1999. Units are °C
Schlenker & Roberts (2006)
Relation of Temperature and Crop Yield

- Relationship is not symmetrical; it is distinctly asymmetric, fairly flat at first and then sharply declining beyond an upper threshold.
Economic adaptation

• The extent to which a physical change in yield translates into a corresponding change in output supplied depends on
  – Supply and demand in market for product and in related markets
  – Other responses and adaptations
    • Change planting/harvest dates
    • Change cropping pattern
    • New seed varieties
    • Change land use
    • etc
Two approaches to incorporating adaptation

• Combine crop yield model with some model of economic market behavior.
  – Led to estimates of loss to US agriculture ranging from $1.1 billion to $17.5 billion.

• Ricardian Approach (Mendelsohn, Nordhaus and Shaw, 1994) [MNS]. Regress farmland value directly on climate variables. In theory, allows for adaptation to a greater extent.
  – Gain of $2.5 billion, $24 billion.
• The difference was widely attributed to the economic effect of adaptation.

• In fact, it arises from some flaws in MNS’s statistical analysis of their data involving their failure to control adequately for irrigation (Schlenker, Hanemann and Fisher 2005).

• Irrigation breaks the link between precipitation where crop is grown and the amount of plant growth.
  – In Iowa, 22” of growing season precip, 100% of crop water need for corn
  – In California, 1.5” of growing season precip, 5% of crop water need for cotton.
Implication

• Need to analyze irrigated areas separately from rain fed areas.
• When MNS analysis is repeated just for rain fed areas of US, instead of a gain for these areas of $2.3 billion, there is a loss of $11 billion.
• Irrigated areas need individual analysis based on a measure of their water supply; but there clearly is a net loss:
  – Increased crop demand for water
  – Reduced supply of water
Climate change and water

• Most existing economic analyses assume either no economic cost to water sector, or some gain.

• This is based on the assumptions that:
  – For water, precipitation is the key climate variable
  – “Wetter is better”

• Both assumptions are wrong, especially in the US West
Importance of change in temperature versus precipitation

• Climate change will affect patterns of both precipitation and temperature. But, there are important differences in the nature and significance of these effects.

• First, precipitation is much harder to predict than temperature because it is inherently cyclical (El Niño/La Niña), and the precise starting and ending of a cycle are harder to model.
Striking difference in degree of consensus among projections of temperature and precipitation

Not certain about precipitation

Clearly warmer

Dettinger, 2004
Importance of spatial and temporal details for water supply

- 2/3 of precipitation occurs north of Sacramento.
- About 2/3 of all water use occurs south of Sacramento.
- 80% of precipitation occurs October-March.
- 75% of all water use occurs April – September.
- Snow pack holds the equivalent of ~1/3 of our major storage capacity.
• In California, changes in winter precipitation are far less significant economically than changes in temperature.
  – Water is not a scarce resource in the winter.
  – To make winter precipitation an economically valuable asset requires an investment in some form of storage. This becomes cost of climate change.
  – Unlike precipitation, changes in winter temperature directly affect spring and summer water supply.
• Economically, it is the change in temperature that is especially significant for California.
The Scenarios Study of Climate Change Impacts on California


• Governor’s Report on climate change [link](http://www.climatechange.ca.gov/climate_action_team/reports/index.html)
# Impact reports

## Research Papers

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dan Cayan et al.</td>
<td>Climate Scenarios for California</td>
</tr>
<tr>
<td>Dan Cayan et al.</td>
<td>Projecting Future Sea Level</td>
</tr>
<tr>
<td>Dennis Baldocchi et al.</td>
<td>An Assessment of Impacts of Future CO₂ and Climate on Agriculture</td>
</tr>
<tr>
<td>Brian Joyce et al.</td>
<td>Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley</td>
</tr>
<tr>
<td>Josue Medellin et al.</td>
<td>Climate Warming and Water Supply Management in California</td>
</tr>
<tr>
<td>Department of Water Resources</td>
<td>Progress on Incorporating Climate Change into Management of California's Water Resources*</td>
</tr>
<tr>
<td>Andrew Paul Gutierrez</td>
<td>Analysis of Climate Effects on Agricultural Systems</td>
</tr>
<tr>
<td>Timothy Caragnano et al.</td>
<td>Climate Change: Challenges and Solutions for California Agricultural Landscapes</td>
</tr>
<tr>
<td>James Lonihan et al.</td>
<td>The Response of Vegetation Distribution, Ecosystem Productivity, and Fire in California to Future Climate Scenarios Simulated by the MC1 Dynamic Vegetation Model</td>
</tr>
<tr>
<td>Anthony Westerling and Benjamin Bryant</td>
<td>Climate Change and Wildfire in and Around California: Fire Modeling and Loss Modeling</td>
</tr>
<tr>
<td>Jeremy Fried et al.</td>
<td>Predicting the Effect of Climate Change on Wildfire Severity and Outcomes in California: A Preliminary Analysis</td>
</tr>
<tr>
<td>Max Moritz and Scott Stephens</td>
<td>Fire and Sustainability: Considerations for Califormia Altered Future Climate</td>
</tr>
<tr>
<td>John Battles et al.</td>
<td>Climate Change Impacts on Forest Resources</td>
</tr>
<tr>
<td>Deborah Drozdowski et al.</td>
<td>Public Health-Related Impacts of Climate Change for California</td>
</tr>
<tr>
<td>Amy Lynd Luers and Suzanne Meier</td>
<td>Preparing for the Impacts of Climate Change in California: Opportunities and Constraints for Adaptation</td>
</tr>
</tbody>
</table>

## Technical Notes

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sebastian Vizcaya et al.</td>
<td>Climate Change Impacts on High Elevation Hydropower Generation in California’s Sierra Nevada: A Case Study in the Upper American River</td>
</tr>
<tr>
<td>Guido Franco and Alan Sandstad</td>
<td>Climate Change and Electricity Demand in California</td>
</tr>
<tr>
<td>Sebastian Vizcaya</td>
<td>Predictions of Climate Change Impacts on California Water Resources Using CalSim-II: A Technical Note</td>
</tr>
</tbody>
</table>
The new impact ("Scenario") analyses

The new analyses contrast two global emission scenarios: (i) business as usual with continuing high rate of growth in greenhouse gas (GHG) emissions; and (ii) sustained global effort to reduce GHG emissions by 2100.

The analyses use statistical downscaling to translate the larger scale global climate model results to California with finer resolution (grid scale = 12 km).
Global Climate Models compute Climate on a coarse grid

So, a “downscaling” procedure was used to provide temperature and precipitation over a finer mesh that is more commensurate with the California landscape.

A hydrologic model is used to simulate streamflow, soil moisture and other hydrologic properties.
Structure of the Overall Study

Global Climate Models

Statistical Downscaling and Hydrological Modeling: common set of scenarios

Water  Costal Impacts  Agriculture  Forest Sector  Public Health  Electricity
IPCC Emission Scenarios
How are the new versions of these climate models different?

• The new versions of both models are somewhat more pessimistic with regard to precipitation than the previous two versions.
• The new versions are substantially more pessimistic with regard to the increase in summer-time temperature.
• The latter result may be due to improved modeling of the linkage between surface temperature and ambient air temperature.
Temperatures in California are predicted to rise significantly.
Time Lags

- The temperature trajectories for the two emission scenarios remain fairly intertwined until about 2045.
- They illustrate the fact that California’s future climate for next 40 years is already determined by past emissions.
- Emission reductions initiated now show a significant effect after about 2045, with their impact increasing over time.
Rising Temperatures
California statewide
Projected average summer temperature changes
Patterns of Temperature Change
2070-2099 relative to 1961-1990
Summer

LOWER EMISSIONS    HIGHER EMISSIONS

PCM lower    HadCM3 lower    PCM higher    HadCM3 higher
Diminishing Sierra Snowpack
% Remaining, Relative to 1961-1990
The shrinking of the snow pack

• Higher winter temperatures mean that more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier in the spring.
• Consequently, the amount of water stored in the snow pack on April 1st will be dramatically reduced.
• Full effect of these changes depends on whether reservoirs can be managed to capture earlier snowmelt and maintain water supply without losing flood control and hydropower capacity.
Droughts become more frequent, longer, more severe
Water deliveries

• In the Sacramento Valley over the period 2070–2099, almost no change in the amount of surface water available to agricultural users about 50% of the time; in the worst 15% of the years, there is a reduction which amounts on average to 53%.

• In the San Joaquin Valley, half the time there is a reduction in surface water availability which averages about 10%; in the next 35% of years, the reduction averages 48%; and in the worst 15% of years it averages 68%.

• Over all years combined, the average reduction in surface water availability amounts to 12% in the Sacramento Valley and 32% in the San Joaquin Valley.
CVP South of Delta Annual Deliveries under climate change scenarios
PCM B1-A2 and GFDL B1-A2 for 2070-2099

![Graph showing annual deliveries under climate change scenarios.](chart)
Impact on water supply: Less streamflow

• Spring and summer streamflow declines by 10-20% before mid-century under low emissions scenario, and 20-25% under high emissions.

• By 2100, streamflow declines by 40% under low-emissions scenario, and 45-55% under high emissions.

• This will disrupt many existing water rights since these are specific to a particular time period for withdrawal.
Some other impacts on water supply

- With higher sea level, there is greater potential for sea water intrusion into Delta.
- Also, some potential for sea water intrusion into coastal aquifers.
- Increased evaporation from surface storage.
- Greater chance of fires in watershed areas.
- More groundwater overdraft due to more frequent dry spells.
- Climate changes also affects Colorado River.
Impact on water demand

• Climate change not only affects water supply: it also affects the demand for water.
• Higher temperatures mean increased ET demand for agriculture and urban outdoor water use.
• These effects are combined with, and exacerbate, the effects of population growth
Economic impacts – water supply

• By 2085, in an average year, 9% loss of net revenue in Central Valley agriculture; 26% reduction in lowest 15% of years.
• By 2085, loss to urban users in Southern California includes about $300 million/yr.
• Urban droughts occur twice as frequently and are about twice as severe; in about 35% of the years, rationing would cause loss averaging $5 + billion/yr for water users.
Agricultural pests

Figure 8. Cotton/pink bollworm (PBW): Predicting areas of favorableness
Vegetation

(Lomax et al. 2009)

Figure 9. Vegetation distribution under historical conditions and multiple climate change scenarios at end of century
Forest fires

Figure 10. Percent change in the expected minimum number of large fires per year in California

(Source: Westerling and Bryant 2006)
Heat waves

(Source: Drechsler et al. 2006)

Figure 11. Projected increase in the number of extreme heat days relative to 1961–1990. Extreme heat is defined as the average temperature that is exceeded less than 10% of the days during the historical period (1961–1990), or approximately 36 days a year.
Air pollution

(Source: Kleeman and Cayan 2006)

Figure 13. Projected days at Riverside meteorologically conducive to exceedances of the 1-hour California ambient air quality standard for ozone of 0.09 ppm.
Modesto Hourly Load/Temp (Aufhammer)
Extreme events

• With extreme events (heat waves, floods, coastal storms) the consequences spill over to the larger economy, not just climate-sensitive sectors (agriculture, forestry, water, energy).
  – There is property damage
  – There is disruption of normal production
Severe threats of flooding

- Coastal flooding from sea level rise combined with winter storms
- Flooding in the Sacramento Valley from increased winter runoff
- Flooding of Delta from sea level rise
Coastal flooding

- Extreme event are where the hourly sea level height lies above the historical 99.99% level for the period 1960-1978 (i.e., sea levels higher than this occurred one hour per year then).
- Such extreme events tend to occur when heavy winter storms coincide with high tides, as happened in 1982-83 and 1997-98.
- By 2000, with about 5-6 cm of sea level rise since 1978, these waves occurred 15-20 hours per year on average.
Coastal flooding, continued

• If the mean sea level at San Francisco rises by 20 cm between 2000 and 2100, an extreme hourly event would occur about 150-200 times per year in San Francisco.
• If it rises by 40 cm, an extreme hourly event would occur about 1,500 times per year.
• If it rises by 60 cm, an extreme hourly event would occur about 7,000 times per year.
• If it rises by 80 cm, an extreme hourly event would occur about 20,000 times per year.
Flooding in Delta

• The threat of from seismic events is well known.
• Less attention has been paid to the threat from sea level rise combined with extreme winter events.
• Even if no earthquake occurs, it seems unlikely that the Delta will continue to exist in its present state by the end of the century – probably by the middle of the century – due to the effects of sea level rise if not also to flooding of the Sacramento River from winter storms.
How the Delta islands became bathtubs
Flood Risk in the Sacramento Valley

- Even without accounting for climate change, Sacramento faces a very high risk of flooding – and much more so with climate change.
• For further information, contact
  
  • hanemann@are.berkeley.edu

• See
  
  • http://calclimate.berkeley.edu