Climate Change and Water: A View of the Future through a Cloudy Crystal Ball

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Both Globally and Close to Home …

Water is central to climate change impacts
All aspects of the human/water interface will be affected

Source: California DWR
We will need to adapt.

Crisis Response?
Forethought?
  - Pre-planning?
  - Adaptive Strategies?

-- but planning for adaptation is difficult in the face of inevitable uncertainties
What do we know?

- Greenhouse gas concentrations are increasing.
- Earth’s climate has warmed & warming will continue.
- Water resource impacts are inevitable.
Globally averaged, the planet is about 0.75°C warmer than it was in 1860.
2005 was the hottest year on record; the 13 hottest all occurred since 1990, 23 out of the 24 hottest since 1980.

J. Hansen et al., *PNAS* 103: 14288-293 (26 Sept 2006)
Warming accelerates the hydrologic cycle

- Surface temperature
- Water holding capacity
- Enhanced Greenhouse

**Atmospheric moisture**
- Evaporation
- Rain intensity
- Rain frequency

- Floods & Droughts
Water Resource Impacts

Most likely:

- Global precipitation $\uparrow \sim 1-2\%$ per $1^\circ C$
- Snow season shorter $\rightarrow$ earlier peak flow
- Glacial wastage $\rightarrow$ summer flow $\uparrow$ near-term, but $\downarrow$ long-term
- Sea level rise $\rightarrow$ saltwater intrusion, coastal flooding
- Intense precipitation $\rightarrow$ water quality impacts
Sea levels are rising & Northern Hemisphere snow cover is declining

Differences from 1961-1990 means shading represents confidence interval

Source: IPCC WG II FIGURE SPM-3.
Changes in snowpacks/ timing of runoff have occurred & will continue

Observed streamflow timing changes (Center of mass)

Large circles indicate sites with trends that differ significantly from zero at a 90% confidence level;

(Courtesy of Michael Dettinger, based on Stewart et al. 2005.)

Trends are projected to continue through the 21st Century…

with increased winter flood risks & lower summer low-flows in many rivers.
Big Wildfires – linked to earlier snowmelt & reduced summer soil moisture.

Less moisture—more fires. Between 1970 and 2003, spring and summer moisture availability declined in many forests in the western United States (left). During the same time span, most wildfires exceeding 1000 ha in burned area occurred in these regions of reduced moisture availability (right). [Data from (4)]
Wildfires:
watershed impacts / sediment transport

Hayman Fire burn area
(138,000 acres) 2002

Debris flow into Denver’s Strontia Springs Reservoir on July 12, 1996 as a result of the Buffalo Creek fire and flash flood.

(Photos courtesy of Denver Water).
Alaska's Toboggan Glacier is one of thousands in the state that have receded dramatically in the last century, as shown in this pair of photos from 1909 (top) and 2000 (bottom).

CREDIT: BRUCE MOLNIA/USGS
Future climate will depend on emissions of greenhouse gases.

**FIGURE SPM-6.** Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the Atmosphere-Ocean General Circulation multi-Model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming.
FIGURE SPM-7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}
Wet Get Wetter and Dry Get Drier?

NOAA Model Results

Historical

Future

Dry get drier

Wet Get Wetter

Courtesy of Brad Udall, Western Water Assessment
Mid-range climate scenario – Nine model average (2080-2099 relative to 1980-1999). Figure courtesy of Claudia Tebaldi
... and longer dry spells

*Index of change in number of consecutive dry days*

Mid-range climate scenario – Nine model average (2080-2099 relative to 1980-1999). Figure courtesy of Claudia Tebaldi
Projected Runoff Changes -- in %

Weighted ensemble mean end-of-century change  A1B Scenario
Based on: Nohara et al. 2006. J. Hydrometeorology 7:1076 -1089.
Currently stressed areas are vulnerable

Vulnerability and adaptability are complex

High variability in physical and socioeconomic settings affects vulnerability & adaptive capacity

Human ingenuity can solve some problems more easily than others

Ecological values may be especially vulnerable
Irrigation expansion increased water use & food availability

28% of Global harvested area
46% of Global value of agricultural output
Area equipped for irrigation ~ doubled 1960-2000

Unequal access to water = greater vulnerability for some

Irrigated agriculture accounts for 70% of global water withdrawals & > 90% of consumptive use

Irrigation solution

On a collision course with climate change?

- Reductions in usable water supplies
- Negative effects of irrigation may become worse
  - Damage to aquatic ecosystems
  - Impaired water quality
  - Aquifer depletion

Figure 2.7: The Living Planet Index shows that biodiversity is declining most rapidly in freshwater-dependent species.

Note: The index incorporates data on the abundance of 665 terrestrial species, 183 freshwater species, and 367 marine species around the world. While the index fell by some 40% between 1970 and 2000, the terrestrial index fell by about 50%, the freshwater index by about 50%, and the marine index by about 30%.

Source: MDA 2008b.
Global food markets move “virtual water” to offset scarcity.
Increasing human vulnerability to floods

The poor often live in vulnerable places

Mozambique, 2000

Homes destroyed by 1999 Flash Flood -- Venezuela
...and to droughts

African droughts:
Suffering compounded by other stressors -- setbacks for sustainable development

Sahel: rainfall decline
Reproduced by many models
Adaptation planning at the regional scale

- Current state of infrastructure; water use; water quality; aquatic ecosystem
- Policy issues and pressures
- How would these be affected by climatic extremes / prolonged trends
- Thresholds?
Hydrology, Biology & Human Use: Scale Matters

Continental Scale →

Different Scales
Different Issues
Different Stakeholders
Different Decisions

Watershed Scale →

But natural resource decisions occur here

Center for Hydrometeorology and Remote Sensing, University of California, Irvine
Climate Models circa early 1990s

Regional models

Global coupled climate models in 2006

Global models in 5-10 yrs?
Climate Change Predictions for Northern California Differ

Precipitation
Divergence in trend and magnitude

Air Temperature
Models agree that air temperature increases, but vary in the magnitude and rate of increase

(Source: D. Cayan, April 2003, ISAO Workshop)
Regional Climate Change “Probabilities”

**Statistical model of GCM output** (Mearns, Tebaldi et al.)

- What is the range of projected changes?
- 21 climate models; results weighted by:
  1. how well they reproduce the climate of the recent past.
  2. How much the models diverge amongst themselves in the future
- Suggests future changes as frequency distribution
Tebaldi, et al Bayesian analysis of regional climate change is available online.

http://rcpm.ucar.edu/
Uncertainty is nothing new

Develop response strategies that explicitly account for uncertainties. Decisions should be:

– Robust to foreseeable range of changes
– Adaptable to changing conditions and new information
– Resilient to surprise

“…nothing is certain but death and taxes” (Benjamim Franklin, 1789)
Awwa Research Foundation-NCAR

- Developing Decision Analysis tools that incorporate climate change information
- Risk-management approach to decision-making
- Working with a set of water utility partners from the very start

- CABY Regional Alliance, CA
- Inland Empire Utilities Agency, CA
- Colorado Springs, CO
- Boston, MA
- Raleigh/Durham, NC
- Palm Beach County, FL
Methods of Assessment

Traditional Scenario Approach

Top down:
- Emissions
- Climate
- Water

Assessment of impacts & adaptation options

Utility impacts

- Change in Resource
- Vulnerabilities

Bottom up:

Decision Analytic
Climate Change & Water Utility Planning

Goals:

- Articulate a structured process for analysis → template for future assessments

- Develop decision support tools – both:
  - Case specific
  - Applicable to other utility settings
Decision Analysis Approach

Problem Structuring

Deterministic Analysis

Uncertainty Analysis

Evaluation of Alternatives

Goals, alternatives, information, values

Model of the decision; Sensitivity analysis to identify key variables

Represent key variables with probabilities; Determine best plan under uncertainty

iterations
WEAP Models Hydrology and the Managed System Simultaneously

Land Cover Percentage

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<th>2005</th>
<th>2050</th>
<th>2100</th>
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<tr>
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<td>27</td>
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<tr>
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<td>28</td>
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<tr>
<td>Urban</td>
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<td>8</td>
<td>11</td>
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Precipitation

Evapotranspiration

Snow Accum/Melt

Alluvial Aquifer

Deep Aquifer

Groundwater Exchange with Stream
Adaptation under uncertainty

- Discard traditional assumption of climate stationarity.
- Integrated water resource management models to examine multiple climate, policy and resource use scenarios.
- Decision analysis – explicit attention to uncertainty & risk management options
Adaptation – an ongoing process

– First steps can be taken now

We know that:

- Global climate change may substantially change water supply and hazard characteristics
- It will create new uncertainties for water policy and planning.

What can we do?

- Risk management approach to water resource policy and planning – Engage stakeholders
- Develop tools to incorporate climate change information