Climate, Drought and Risk in the U.S

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Experts say rainfall may lessen drought
DALLAS—Heavy rainfall that

SERIOUS DRIED TREATMENT

USA experiences the worst
drought catastrophe of recent decades. PAGE 14
Is the climate changing? - Observed Trends

- Specific Humidity
- Air Temperature Near Surface (Troposphere)
- Glaciers (Glacier Mass Balance)
- Temperature Over Oceans
- Snow Cover (March-April, Northern Hemisphere)
- Sea-Surface Temperature
- Sea Level
- Sea-ice
- Ocean Heat Content
- Land Surface Air Temperature Over Land

Datasets:
- Specific Humidity: 3 Datasets
- Air Temperature Near Surface: 7 Datasets
- Glaciers: 4 Datasets
- Temperature Over Oceans: 5 Datasets
- Snow Cover: 2 Datasets
- Sea-Surface Temperature: 7 Datasets
- Sea Level: 7 Datasets
- Sea-ice: 3 Datasets
- Ocean Heat Content: 7 Datasets
- Land Surface Air Temperature Over Land: 5 Datasets
Many potential futures:

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.
A changing climate leads to changes in extreme weather and climate events.
Changing Rain, Snow, and Runoff

- Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions.
- Very heavy precipitation events have increased nationally and are projected to increase in all regions.
- The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.
Drought: Weather-climate continuum and Adaptation deficits

- Atmospheric chemistry
- Ice sheets
- Marine Ecosystems
- Ocean surface

Atmosphere region: global

Ice sheets

- Fronts, convective systems
- Cyclones
- Blocking
- MJO
- NAO
- ENSO
- QBO
- PDO
- AMO

Days, weeks, months, years, decades, centuries
“If we are not careful we will end up where we are going”

Central Arizona project
Late-1980’s

Development in Central Arizona 20 years later
Impacts of a Changing climate

- Higher evaporation. More farm dams as surface water availability reduces?
- Greater irrigation efficiency as surface water availability reduces?
- Increased evapotranspiration due to higher temps?
- Increased demand for groundwater as surface water availability reduces?
- Higher frequency and intensity of wildfires due to higher temps and droughts?
Insects, Fire in Northwest Forests
Vulnerability to Sea Level Rise

Data from Hammar-Klose and Thieler 2001
The California Drought

Key Questions

• How did we get here? Status and antecedent conditions

• Why has it been dry/drier than normal? Is this drought like others?

• What are the impacts and where did they occur?

• What information is being provided and by whom?

• How bad might it get and how long will it last?

• How are we planning for this year and for longer-term risks and opportunities?
Could “the” drought have been anticipated?
Atmospheric Drivers of Drought Over the West

High Pressure conditions

November 2013-February 2014

November 2014 -February 2015
Ground water conditions

Gravity Recovery And Climate Experiment (GRACE)

USGS

GRACE (Famiglietti et al.)

1962

2013

GRACE-Based Root Zone Soil Moisture Drought Indicator

March 30, 2015
Cropland Greenness in January

A 35% (400,000 acre) increase in fallowing was observed in 2014 relative to 2011, a year of normal water availability-state resources for county food banks.

2014 January showing extensive areas of dryness

Outside of Cultivated Area Mask

NIDIS, NASA, USDA, USGS, NOAA and the California Department of Water Resources,
Atmospheric Rivers (ARs)

- Drought breaks in the western U.S. are often tied to ARs
- ARs are narrow corridors of enhanced winds and transport of water vapor at the boundary of a low pressure system
- ~40-70% of the drought breaks in the west coast since 1950 are due to ARs
- Large & slow moving ARs can cause flooding

February 8th, 2015

February 8th, 2014

Tuesday 12/09/14

Wednesday

Thursday 12/11/14
Atmospheric river storms

10-year avg

WY2014
Could this drought have been anticipated?

Is this drought due to anthropogenic climate change?

California (PRISM)
Dec–Apr Precipitation Departures: 1896–2013

NOAA Drought Task Force
CONUS daily minimum temperature trend
1915-2011 (°C/year)
Are Transitions to Semi-Permanent Drought Imminent?

Effect of Long Term Global Ocean Warming

- Precipitation
- Soil Moisture
- Temperature

Ongoing transition to a drier climate driven by decreasing precipitation
The weather-climate continuum

The percent of the U.S. experiencing moderate to severe drought suddenly increased and remained at elevated levels during the first decade of the 21st Century.

Even a perfect SST prediction would “likely” capture much less than half the total variance in annual precipitation over North America.

A complete explanation of these droughts must invoke not just the ocean forcing but also the particular sequence of internal atmospheric variability - weather - during the event.

Figure 1: How did we get here? Current conditions and status (Source: NIDIS and Drought.gov)
Evaporative Demand Drought Index

**EDDI** shows strong early warning potential-2012

\[
EDDI_j = \frac{\sum_{t=i}^{j} (ET_{0t} - \overline{ET_{0t}})}{\sigma_{ET_{0t}}}
\]

- Due to land-atmosphere feedbacks, evaporative demand \((E_0)\) reflects surface moisture conditions, *often before* ET does,
  - responds positively to both flash droughts and sustained droughts.

2-week EDDI

US Drought Monitor

May 7

- drought developing in entire region; note little drought in western US

June 5

- flash drought in MO, AR, KS, IL; drought expands; does not deepen

July 3

- persistent intense drought D3 edges into region

August 7

- intense drought persists;
  - new D4 and expanded D3 over much of region;
  - drought in NY, PA, and VA, 2 months after EDDI
Recent Studies of Mid-century Climate Change Impacts on Colorado River flows (Lee’s Ferry)

The future is already here. It’s just not very evenly distributed. -- William Gibson

<table>
<thead>
<tr>
<th>Recent Studies</th>
<th>Projected Annual Flow Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christensen et al., 2004</td>
<td>~18%</td>
</tr>
<tr>
<td>Christensen and Lettenmaier, 2007</td>
<td>~6%</td>
</tr>
<tr>
<td>Milly et al., 2005</td>
<td>10 to 25%</td>
</tr>
<tr>
<td>Hoerling and Eischeid, 2007</td>
<td>~45%</td>
</tr>
<tr>
<td>Seager et al., 2007</td>
<td>“an imminent transition to a more arid climate”</td>
</tr>
<tr>
<td>McCabe and Wolock, 2008</td>
<td>~17%</td>
</tr>
<tr>
<td>Barnett and Pierce, 2008</td>
<td>assumed 10-30%</td>
</tr>
</tbody>
</table>

Response One: These are so different, we can’t trust any of them...

Response Two: We need to resolve these differences! Are the differences due to climate uncertainty or different models and methods?

Response Three: None of these studies show increasing flows. Any decrease is a source of concern.
Sand Dune Mobility = $W/(P/PE)$

Four Corners Region

**Stable Sand Dunes**

$= P/PE > 0.31$

**Partly Active Dunes**

**Fully Active Dunes**

$= P/PE < 0.125$
Projected Changes in Water Withdrawals: Growth and demand 2005 to 2060

(a) Without Climate Change

(b) With Climate Change

% change
- < 0
- 0 to 10
- 10 to 25
- 25 to 50
- >50
The Stakes on Climate Change: US Water and Clean Water Sector Only (WUCA, 2012)

2011-2031: Without Adaptation

Drinking Water Infrastructure Investment
$335 Billion

Clean Water Infrastructure Investment
$298 Billion

OR $1 Trillion through 2035

By 2050: Potential Adaptation Costs

Drinking Water + Clean Water Sector:

$448 - 944 Billion

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Assess “Build-out”: Services provided, Avoided costs

DRINKING WATER COSTS
TOTAL: $326 - $692 billion

WASTEWATER COSTS
TOTAL: $123 - $252 billion

CONFRONTING CLIMATE CHANGE:
An Early Analysis of Water and Wastewater Adaptation Costs

NACWA, AMWA
Is it all bad?
U.S. Freshwater Withdrawal, Consumptive Use, and Population Trends
“If we are not careful we will end up where we are going”
Energy-Water Nexus: Strategic Pillars

- Enhance reliability and resilience of energy and water systems
- Increase safe and productive use of nontraditional water sources
- Promote responsible energy options with respect to water
- Exploit productive synergies among water and energy systems
- Optimize energy efficiency of water management
- Optimize freshwater efficiency of energy

Sustainable and Resilient Energy in an Uncertain Water Future

Dept. Energy/Vallario 2014)
1. Acknowledge the cross-timescale nature of climate and of early warning information.

Improved understanding of long-term variations of largest storms dictate the occurrence of droughts in California.
2. Recognize alternative means of addressing water security. Best adaptation practices may be novel configurations of land and water resources - and information to support those decisions.

SMART Growth Conservation costs - water obtained by conservation is still the cheapest option per AF for development (Kenney et al. 2010)
3. Managing drought-related risks in a changing climate: understanding (and learning) the lessons

- **1976-1977**: 1986 Coordinated Operations Agreement CVP and SWP
- **1987-1992**: State Drought Water Bank
- **2007-2009**: Regional Water Storage Projects
  - Water Code Sect 85021 – reduced reliance on Delta water, emphasis on local reliance

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Are we doing and not learning?
“the problem of water supplies not meeting human demands can be met in two ways: increase the supply or limit the demand. Both are necessary. Methods of increasing the supply range from experiments in saline water conversion, rain making……to bold and expensive projects to transport water great distances over the mountains from watersheds with surplus to areas of deficiency.

Limiting the demand for water has been less imaginative…..less prone to curb appetites than…. to invent new ways to satisfy them; hence, there have been few attempts to stretch the available water supply. Conservation and reclamation are viewed as a last resort.

“While this philosophy is responsible in part for a multi-billion dollar project to import water into thirsty areas, it is equally accountable for squandering the local supply”

(James Krieger and Harvey Banks, SDWR 1962)
The fundamental adaptation question: How often / when should we revise our assumptions?

OVERCONFIDENCE
This is going to end in disaster, and you have no one to blame but yourself.
What can we say about future drought intensity?

Droughts will intensify in the 21st century in some seasons and areas in the West due to reduced precipitation and/or increased evapotranspiration.

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality - increases in sediment, nitrogen, and other pollutant loads.
U.S. Drought Monitor

April 14, 2015
(Released Thursday, Apr. 16, 2015)
Valid 7 a.m. EST

Drought Impact Types:
- Delineates dominant impacts
- S = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
- L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

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

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

Author: Michael Brewer
NCDC/NOAA

http://droughtmonitor.unl.edu/
Developing Information Systems on Changing Weather and Climate Extremes

• Highlighting the role of rates of change trends, frequency, and magnitude of extremes in the context of planning and preparation
Thank you
City of Aurora, Colorado

- Wetter
- Demand Management
- Aquifer Mining
- Over-drafting
- Indirect Use
- Ag Leasing/Interruptible Supplies

2007

- Wetter
- Demand Management
- Aquifer Mining
- Over-drafting
- Planned Indirect Use/Maximization of Local Water
- Ag Leasing/Interruptible Supplies

2010

- Y2010 +
- Small Trans-basin
- Limited Ag Transfers
- Public Benefit Multi-Purpose

2015

- Y2020 +
- One or Two Regional Trans-basin Projects
- System Integration
- Expanded Re-allocation of Ag Uses
- Planned Indirect Potable Projects

2025
Elsewhere there is overall low confidence because of inconsistent projections of drought changes (dependent both on model and dryness index) due to…….

Definitional issues, lack of observational data, and the inability of models to include all the factors that influence droughts preclude stronger confidence than “medium” in drought projections.
WATER STORAGE

Reservoir Storage Percent of Average for 10/8/2014

Shasta 42%  Oroville 49%  Bullards Bar 70%  Folsom 62%  New Melones 39%

Hydrologic Data Courtesy of the California Department of Water Resources

Issued Thursday, Oct 9, 2014 at 10:44 am PDT
National Weather Service - Sacramento, CA
How did we get here? Status and antecedent conditions

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September 2014
FIG. 2. Time series of all-California November to April winter precipitation for 1895 to 2014 and the same after low-pass filtering with.
Modern

Medieval
Lake Tahoe Recent Drought History

- Water levels in Lake Tahoe are good indicators of persistent hydrologic droughts
- Many years in a row of no outflow into Truckee River (30s & 90s)
- Lower water levels in the 90s than in 30s due to increased demands
- **One very wet winter can break a persistent drought in the region**
  - Need many very wet winters for reservoirs with large storage deficits (i.e. Lake Mead)

Huntington et al 2014
Forecasts for May 2015

ESP UW

Rainfall Percentile

-120° -110° -100° -90° -80° -70°

Princeton-MSU-EMC

SPI6

Ensemble Mean (May 2015)

MSU

Predicted Monthly Soil Moisture Percentile in 201505

Colored: median of 33-member ensemble; Hatched: interquartile range > 40
<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Capacity (TAF)</th>
<th>% of Capacity</th>
<th>% of Historical Average</th>
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<tbody>
<tr>
<td>Trinity Lake</td>
<td>34%</td>
<td>50%</td>
<td></td>
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<tr>
<td>Shasta Reservoir</td>
<td>42%</td>
<td>66%</td>
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<tr>
<td>Lake Oroville</td>
<td>39%</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>Folsom Lake</td>
<td>45%</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td>New Melones</td>
<td>23%</td>
<td>40%</td>
<td></td>
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<tr>
<td>Don Pedro Reservoir</td>
<td>39%</td>
<td>59%</td>
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<tr>
<td>Exchequer Reservoir</td>
<td>7%</td>
<td>16%</td>
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<tr>
<td>San Luis Reservoir</td>
<td>43%</td>
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<td>Millerton Lake</td>
<td>35%</td>
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<td>Pyramid Lake</td>
<td>94%</td>
<td>105%</td>
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<td>Castaic Lake</td>
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<td>45%</td>
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<tr>
<td>Pine Flat Reservoir</td>
<td>13%</td>
<td>31%</td>
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