Climate, Drought and Risk in the U.S

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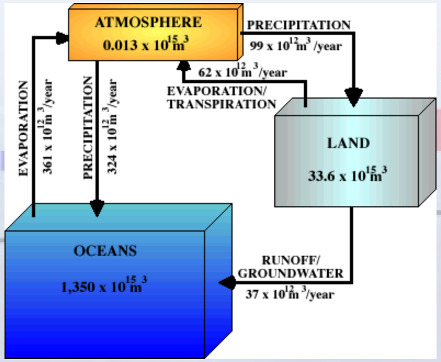
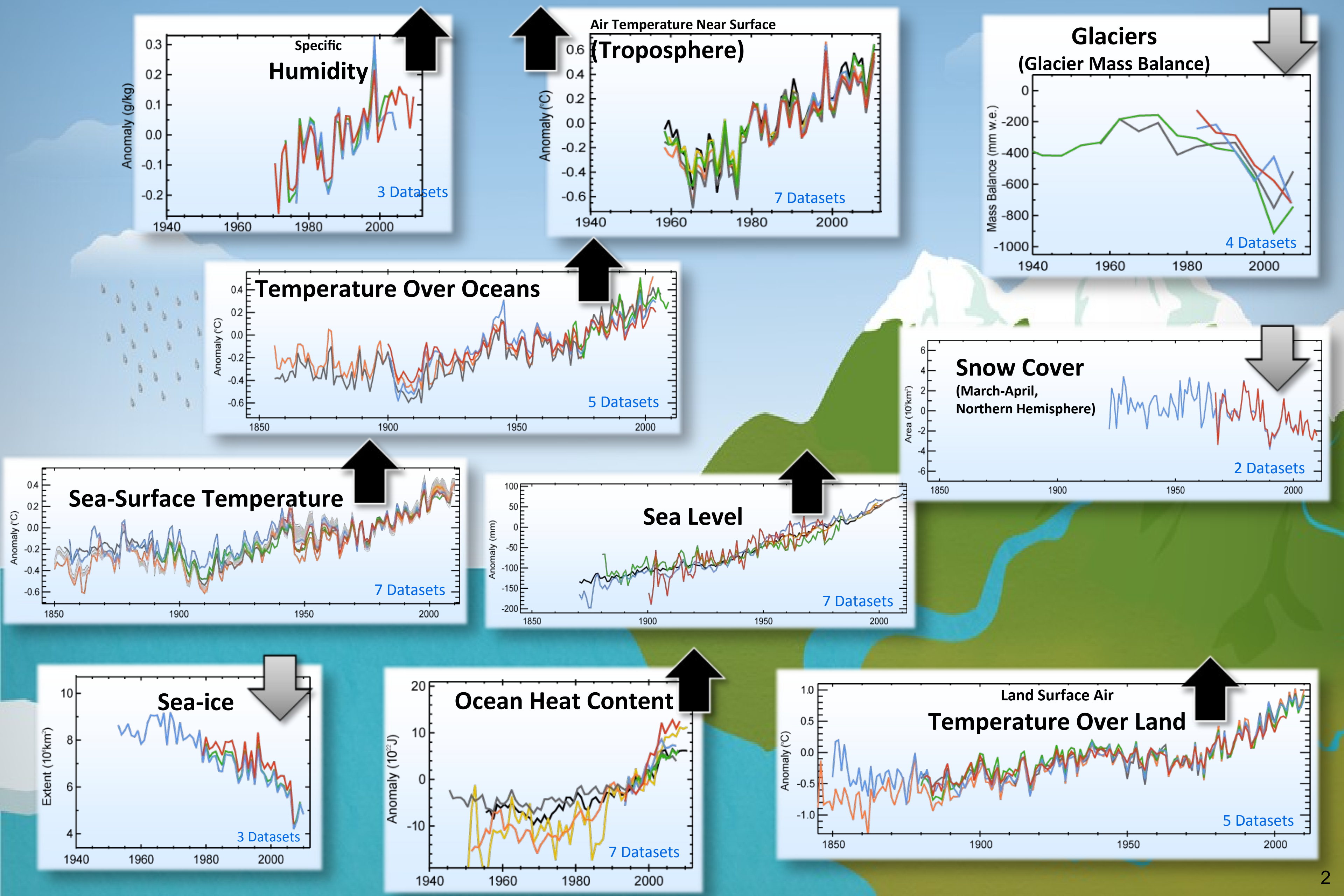
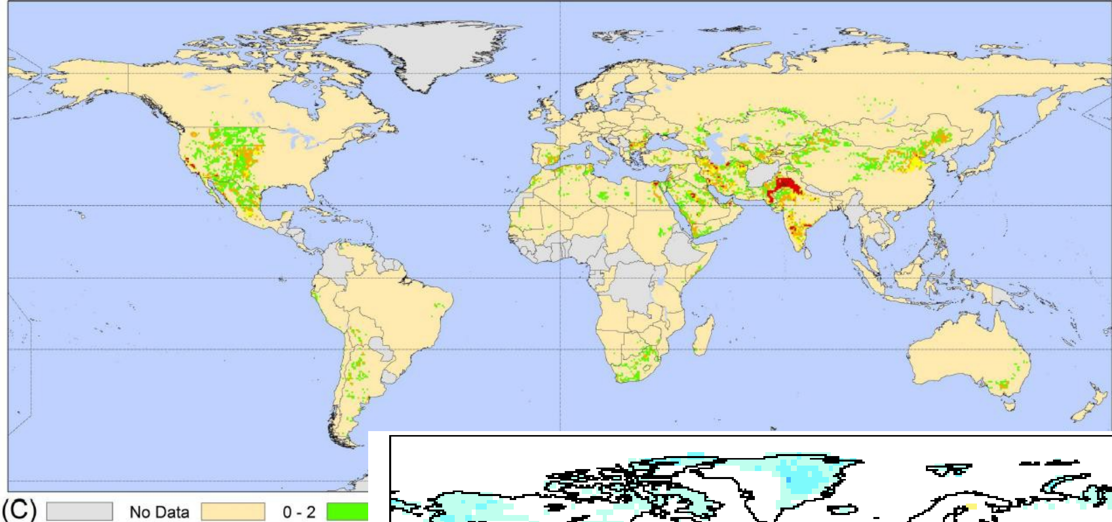
NDMC



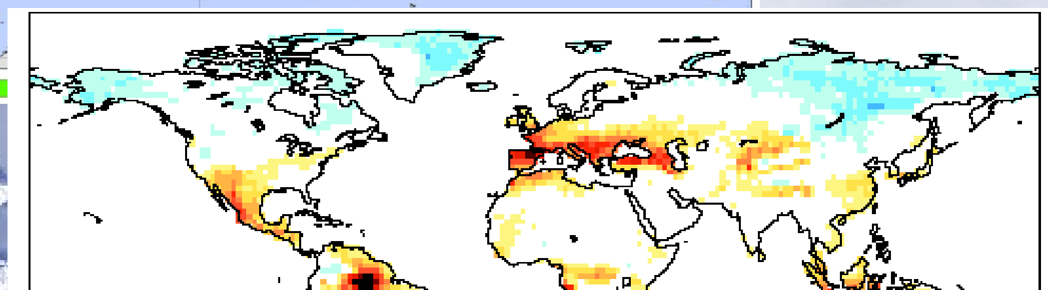
Is the climate changing ? -Observed Trends



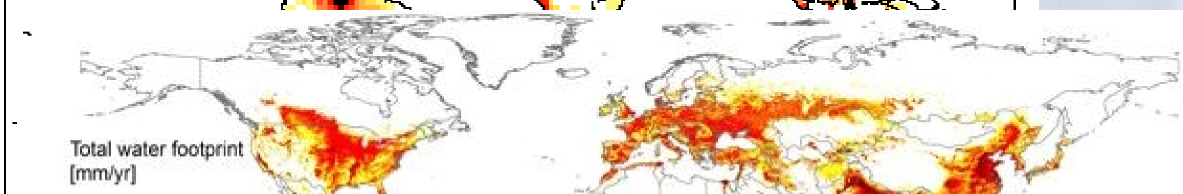


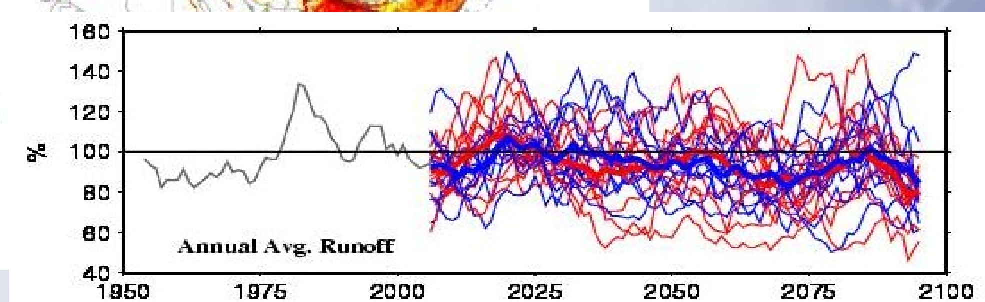
Ground water depletion

Model agreement (2050)



Water footprint





Many potential futures:

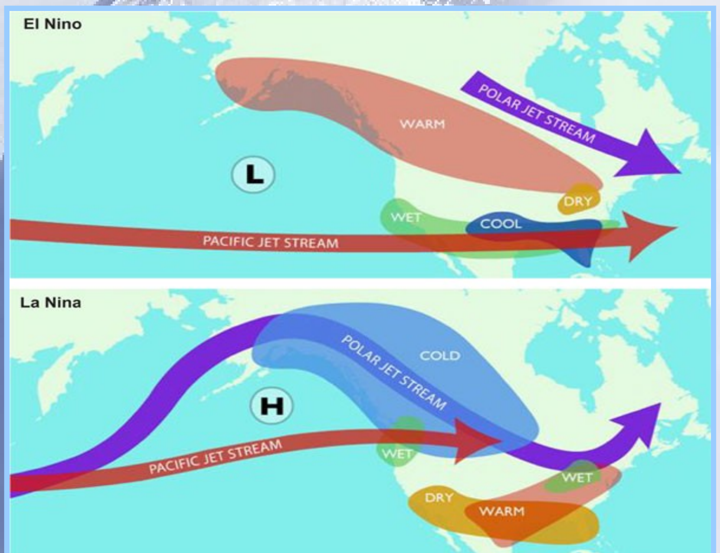
Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options

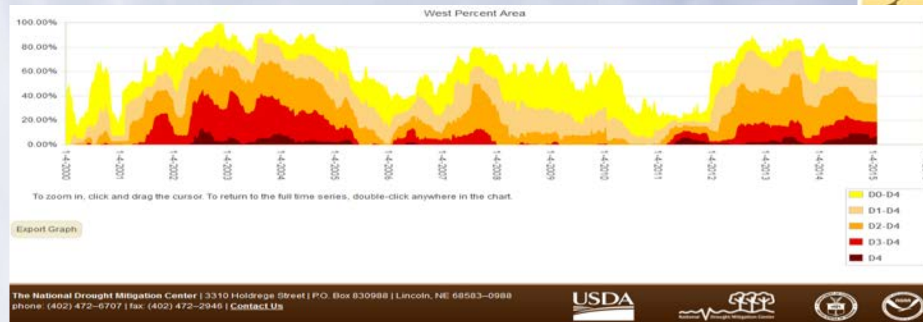
A changing climate leads to changes in extreme weather and climate events

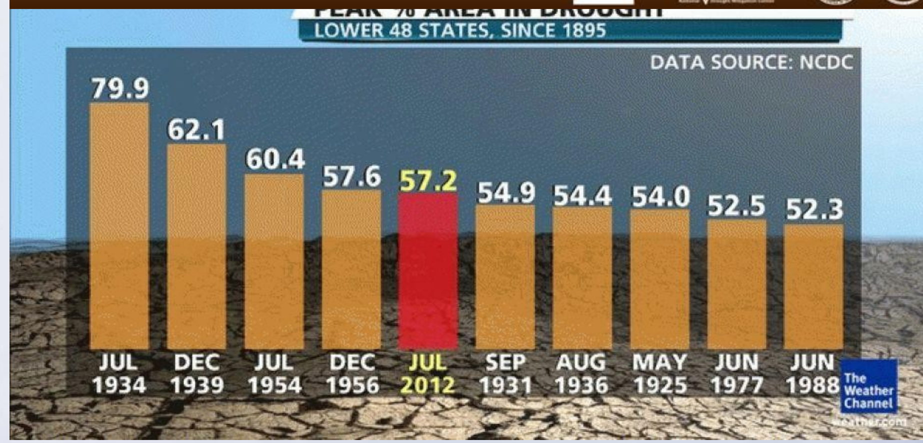
Changing Rain, Snow, and Runoff

- 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







6

Atmospheric chemistry

Marine Ecosystems

Ice sheets

Ocean surface upper full

Land

Atmosphere region global

1 DAY | 1 WEEK | 1 MONTH | 1 SEASON | 1 YEAR | 1 DECADE | 100 YEARS

Fronts, convective systems

Cyclones

Blocking

MJO

NAO

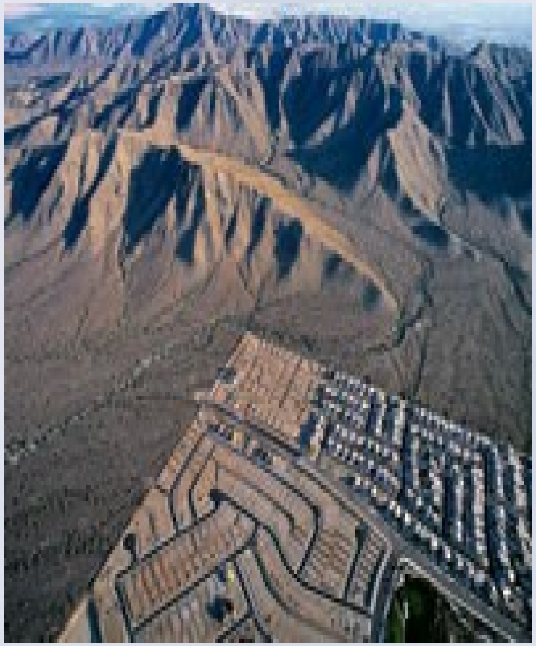
ENSO

QBO

PDO

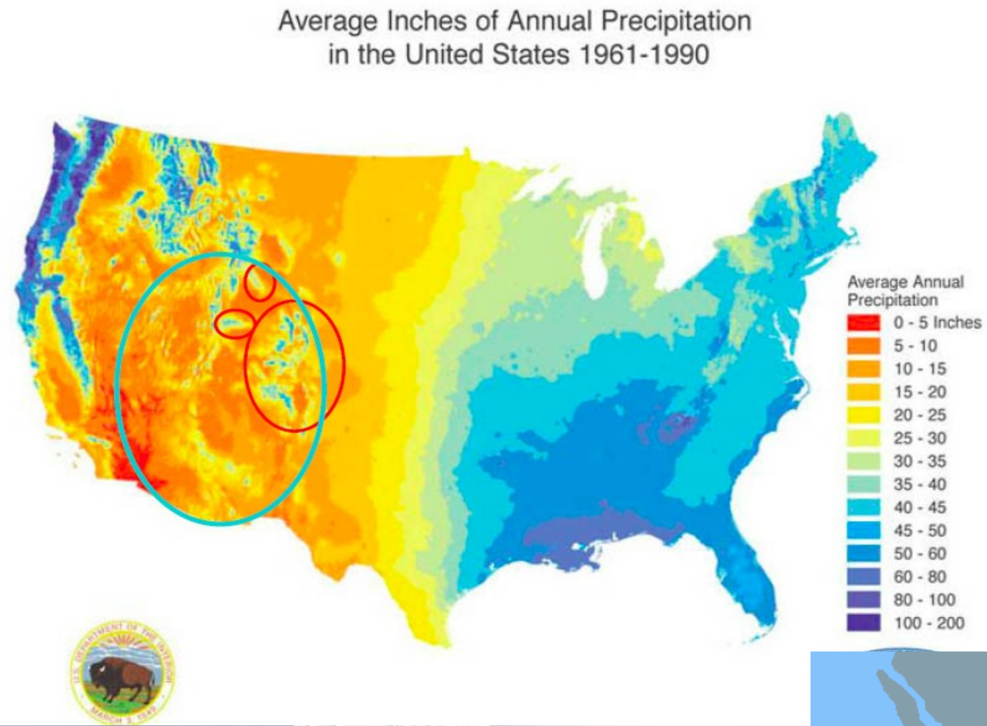
AMO

“If we are not careful we will end up where we are going”



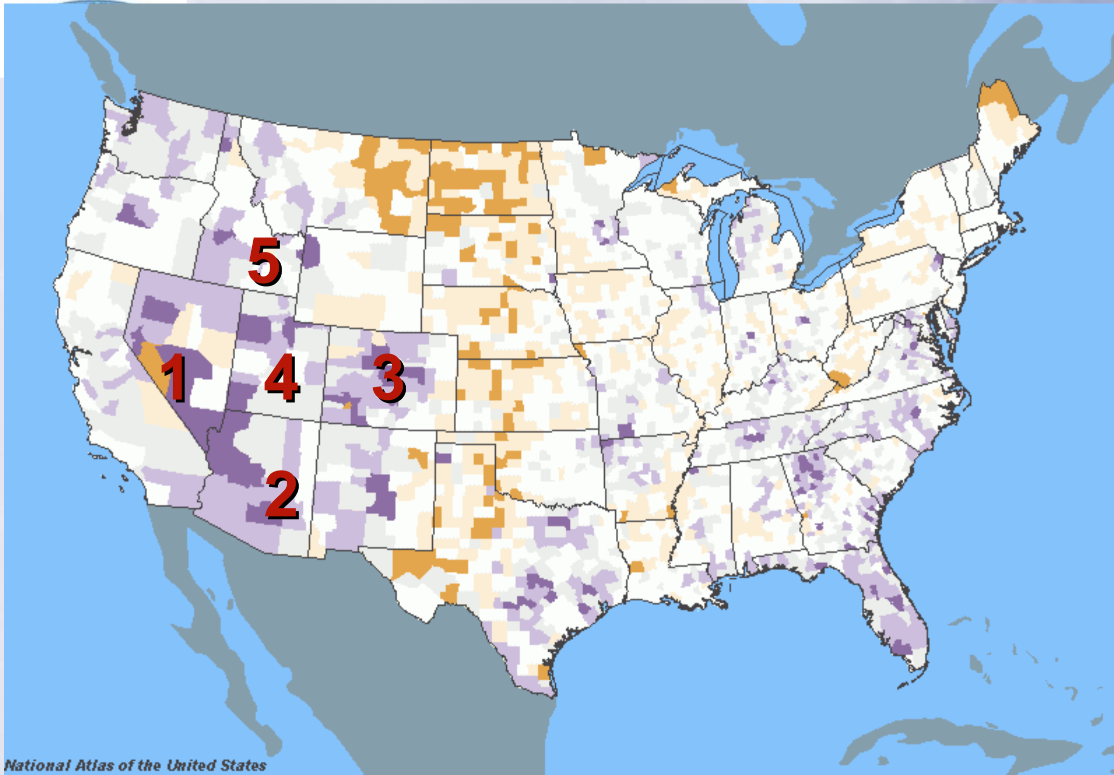
Central Arizona project
Late-1980’s

Development in Central
Arizona 20 years later



Average annual precipitation

Population growth



Impacts of a Changing climate

Climate Variability& change

Higher evaporation. More farm dams as surface water availability reduces?

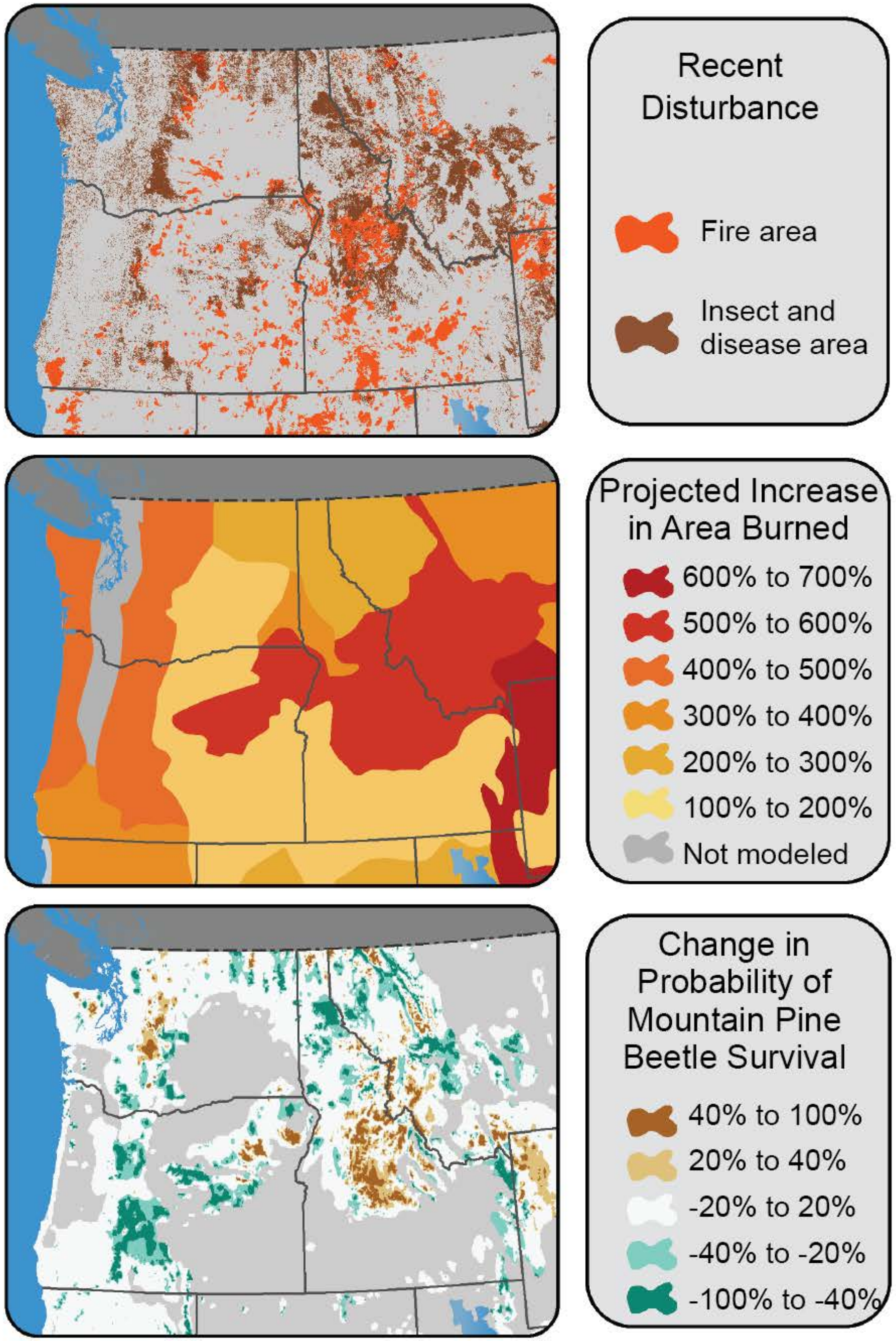
Increased demand for groundwater as surface water availability reduces?

Greater irrigation efficiency as surface water availability reduces?

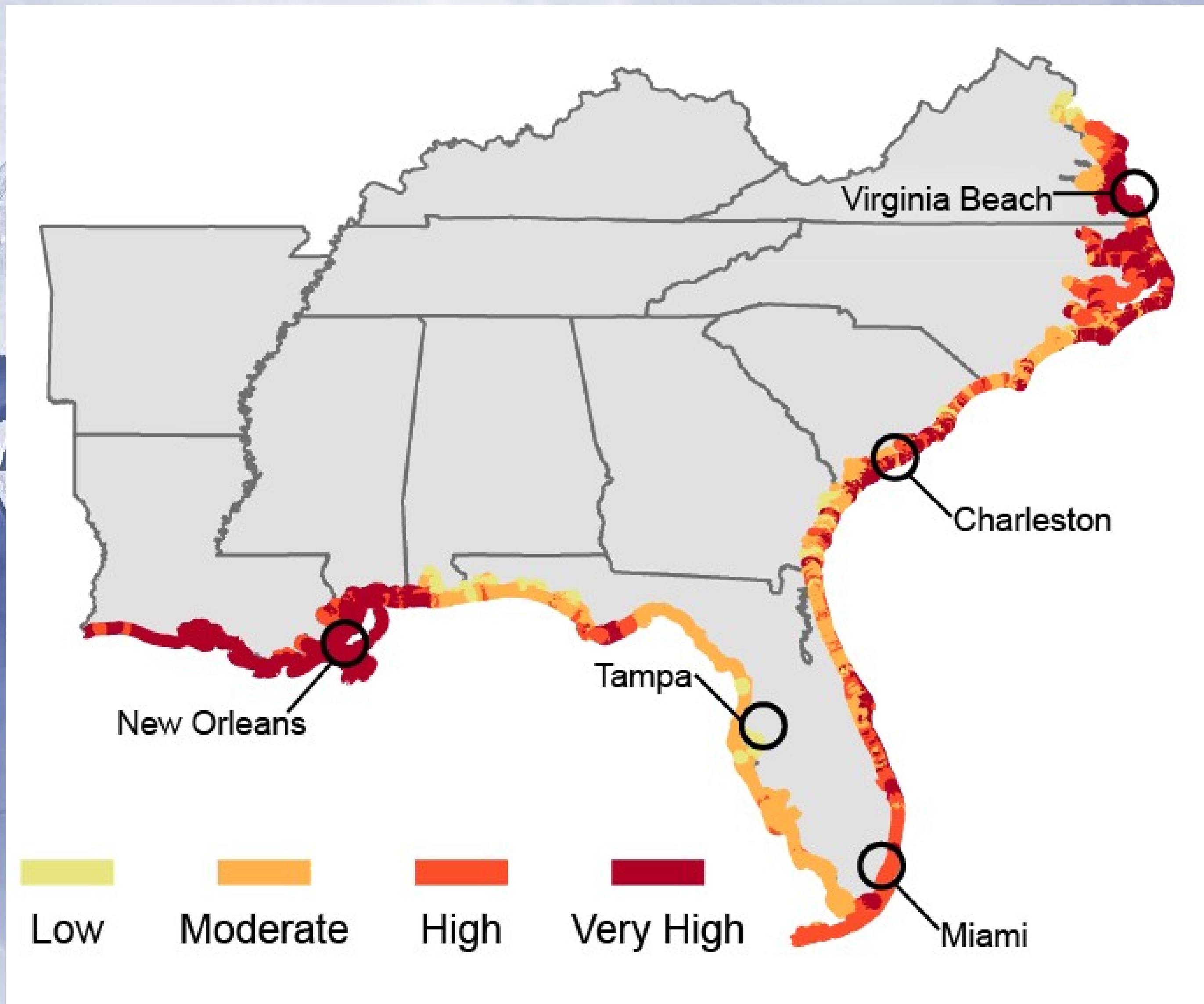
Increased evapo-transpiration due to higher temps?

Higher frequency and intensity of wildfires due to higher temps and droughts?

Insects, Fire in Northwest Forests

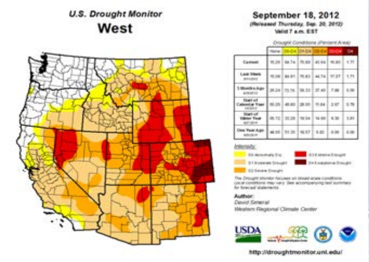


Rise

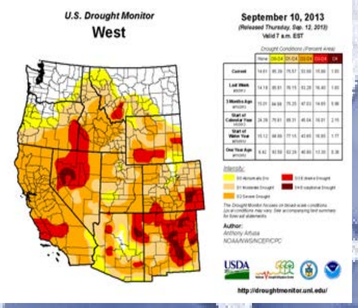


Data from Hammar-Klose and Thieler 2001

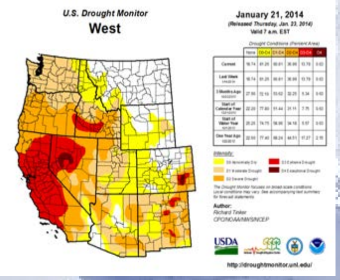
The California Drought Key Questions



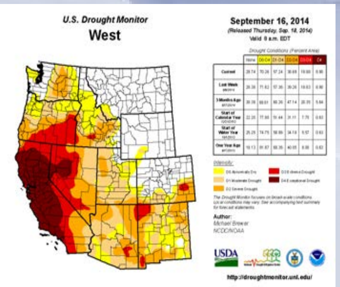
2011



2012

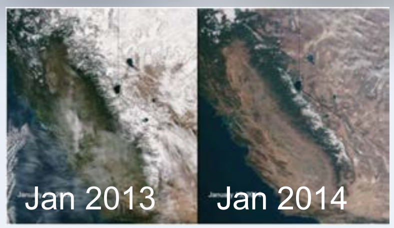


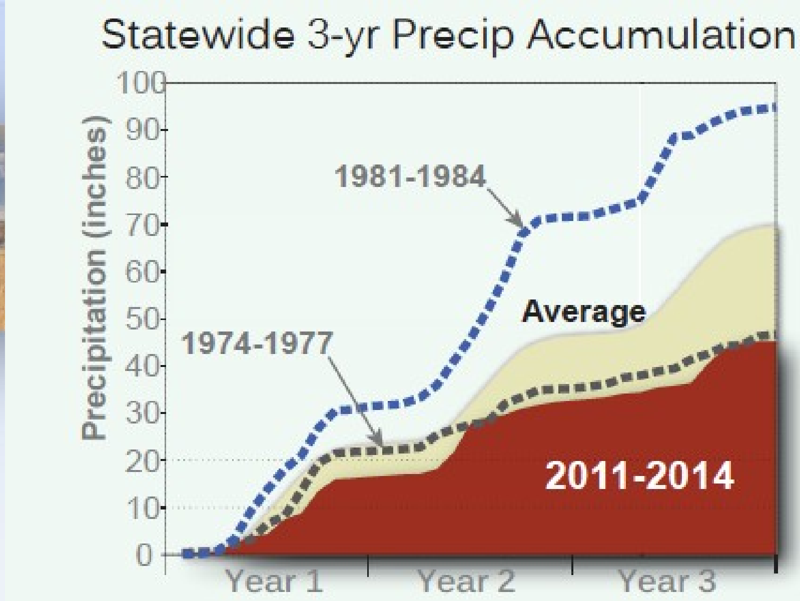
2013

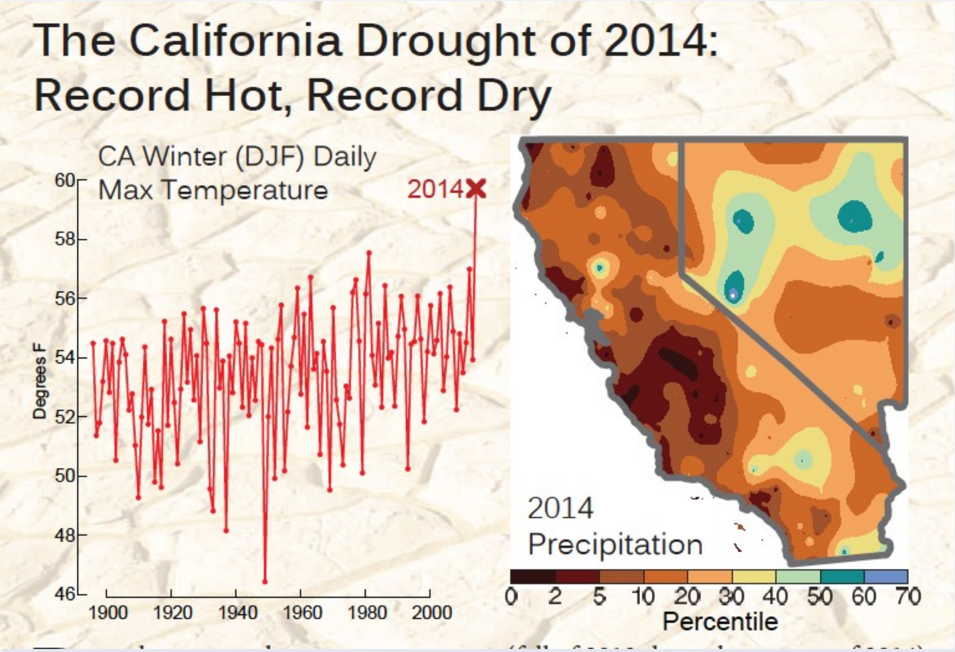


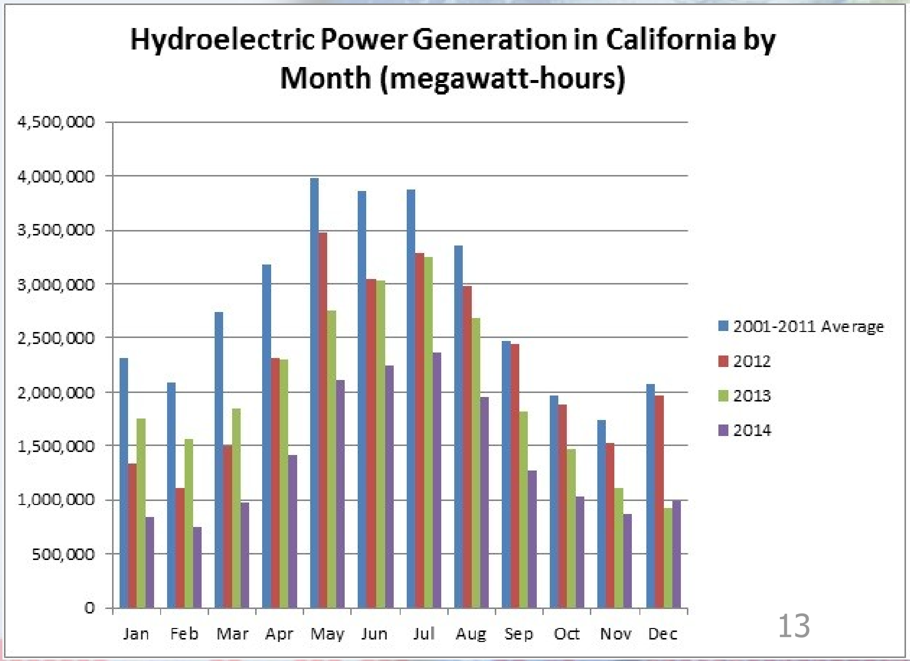
September 2014

- **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?**





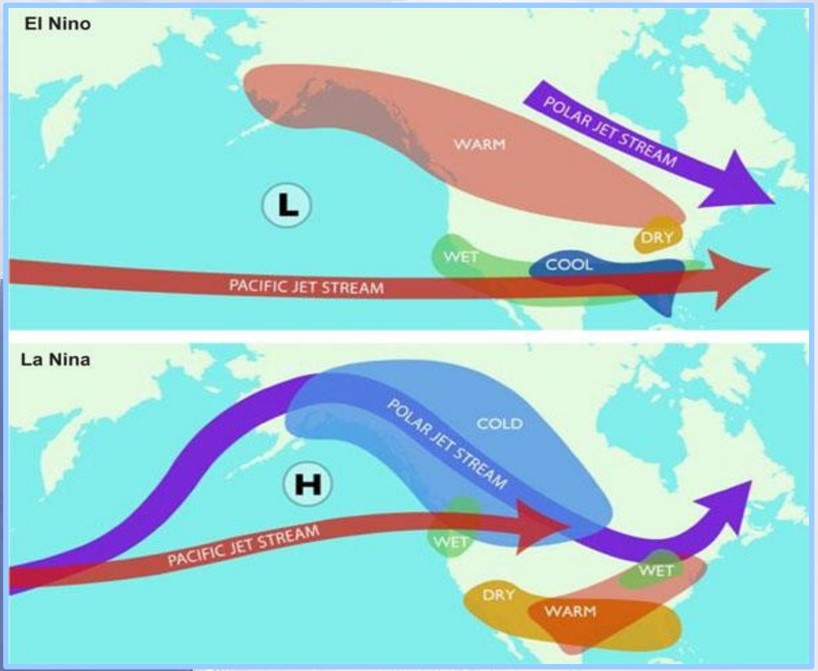




- Could “the” drought have been anticipated?

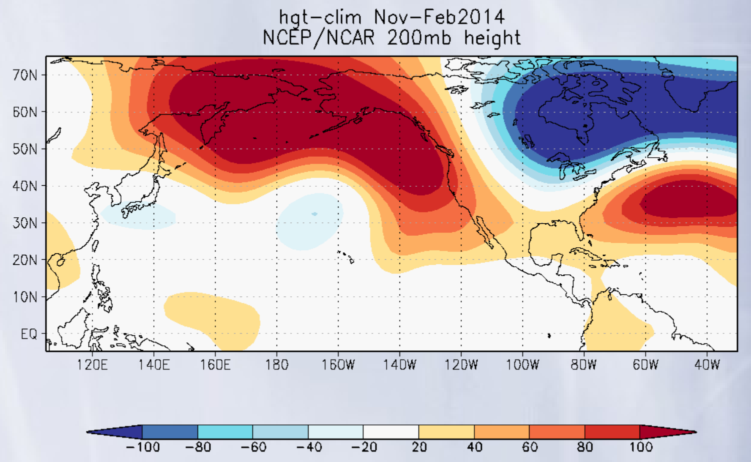
RISA California-Nevada Applications Program

Atmospheric Drivers of Drought Over the West

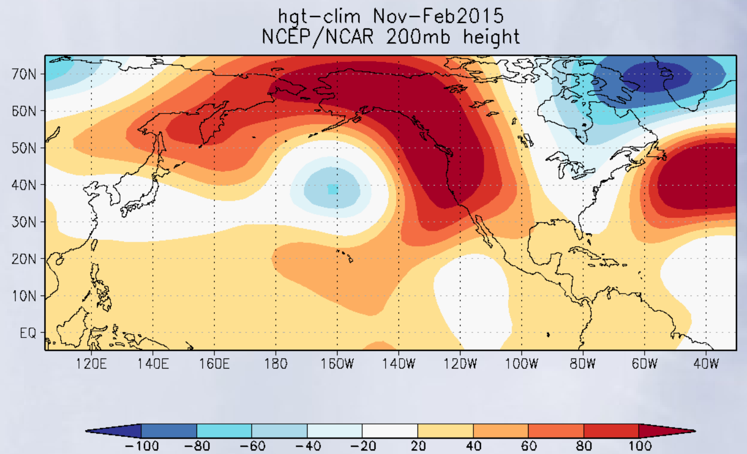


High Pressure conditions

November 2013-February 2014



November 2014 -February 2015

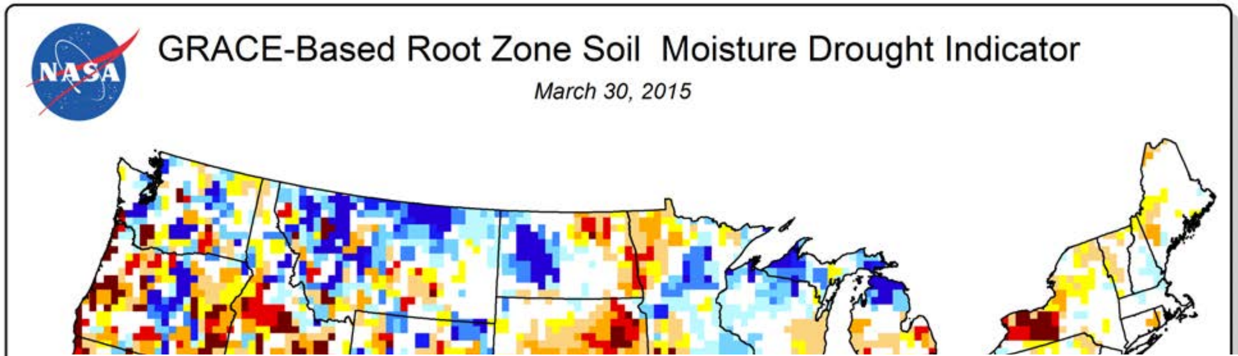


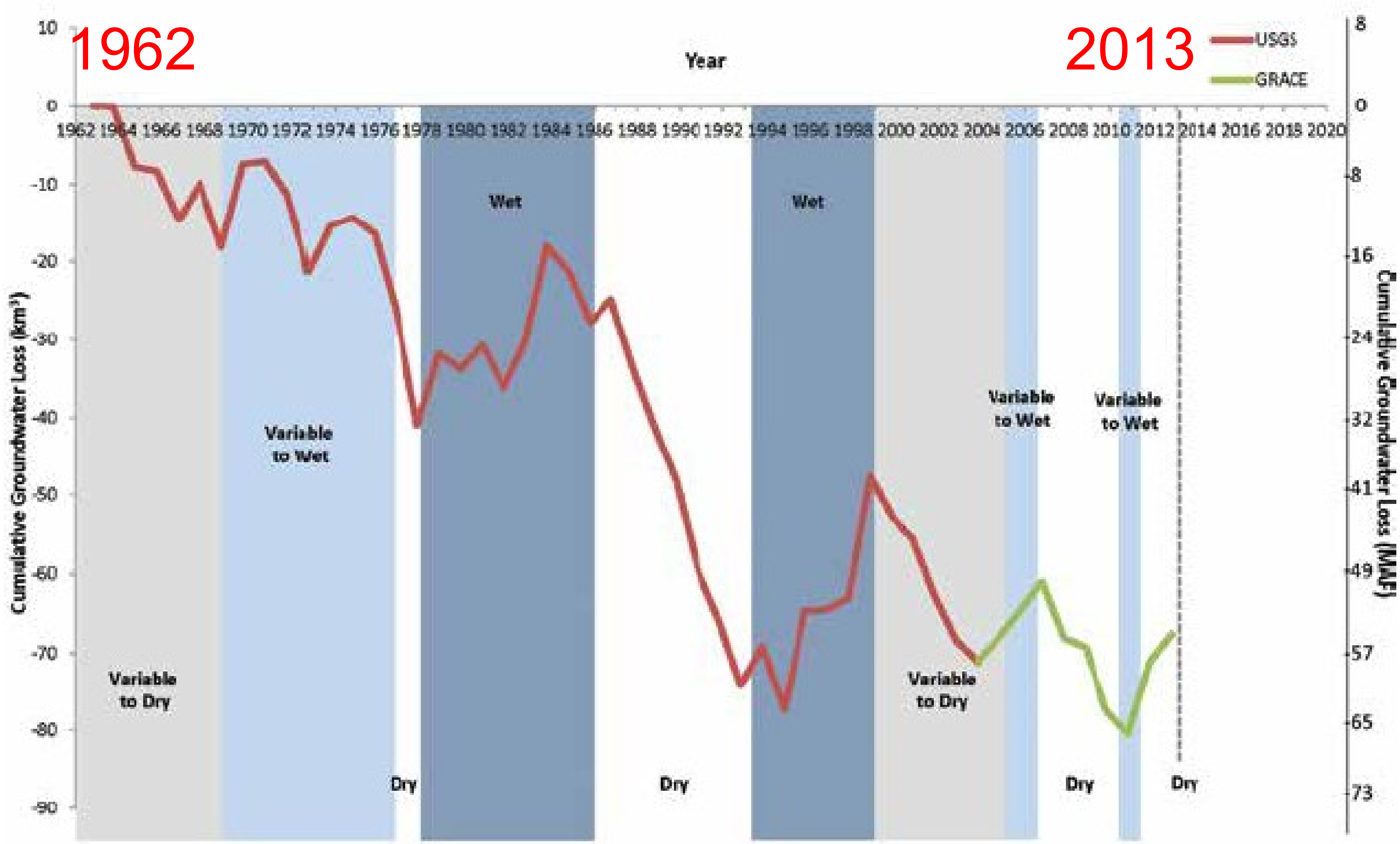
MAPP Modeling, Analysis, Predictions, and Projections

NIDIS National Integrated Drought Information System

Ground water conditions

Gravity Recovery And Climate Experiment (GRACE)





USGS

GRACE (Famiglietti et al)

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

2001

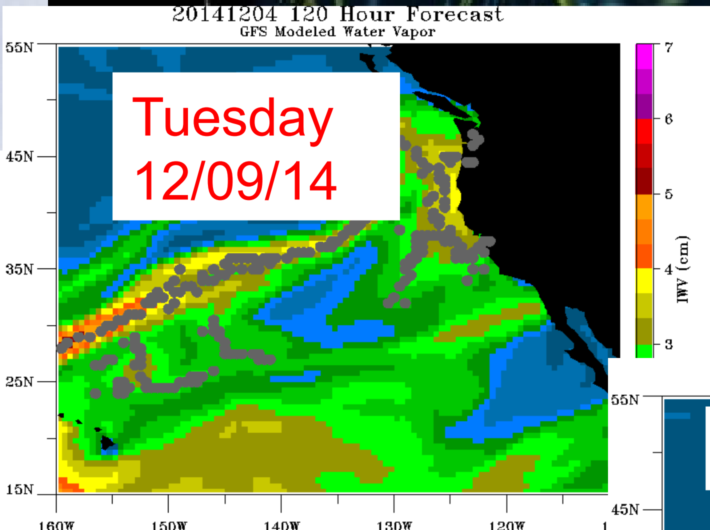
2014 January showing extensive areas of dryness

Outside of Cultivated Area Mask

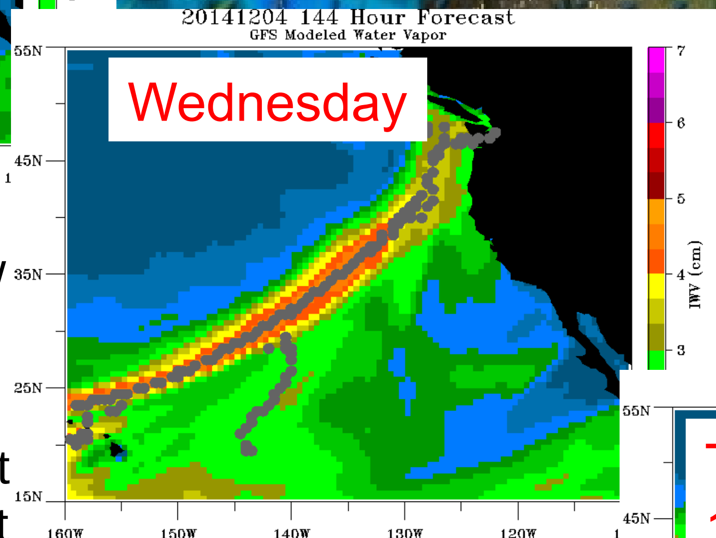
2014

NIDIS, NASA, USDA, USGS, NOAA and the California Department of Water Resources,

Atmospheric Rivers (ARs)

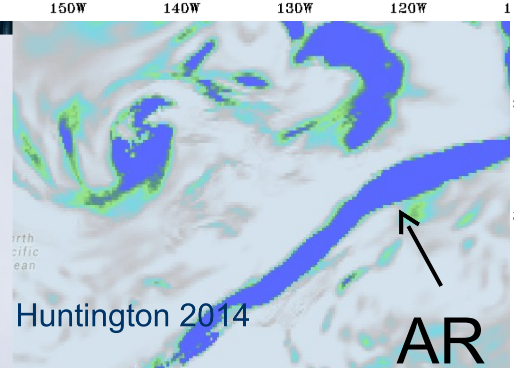


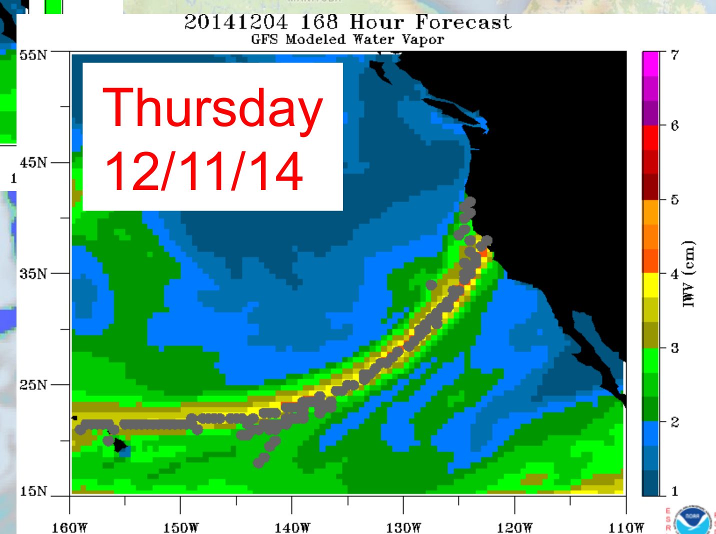
transport of water vapor at the boundary of a low pressure system

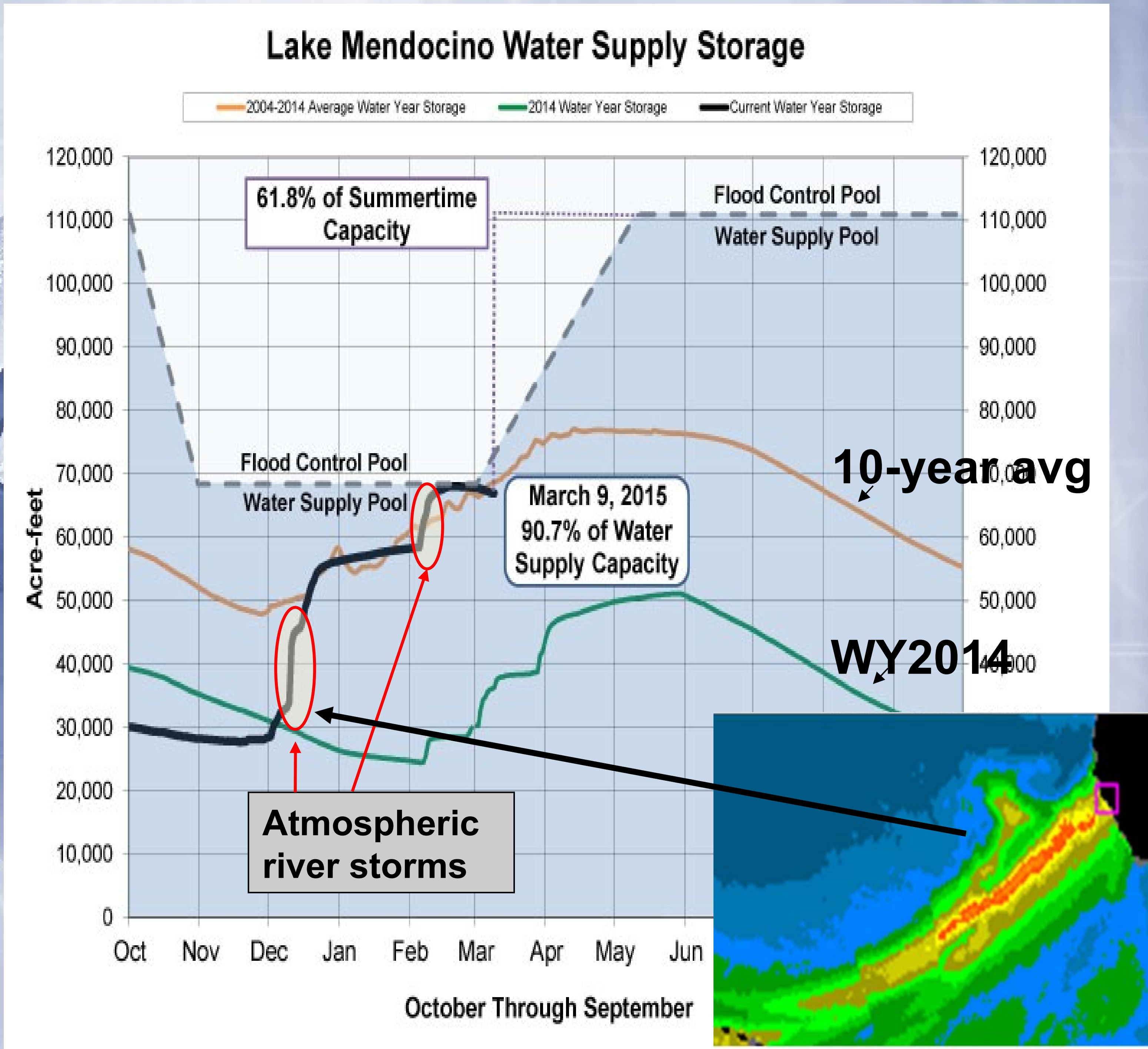


- ~ 40-70% of the drought breaks in the west coast since 1950 are due to ARs

- Large & slow moving ARs can cause flooding

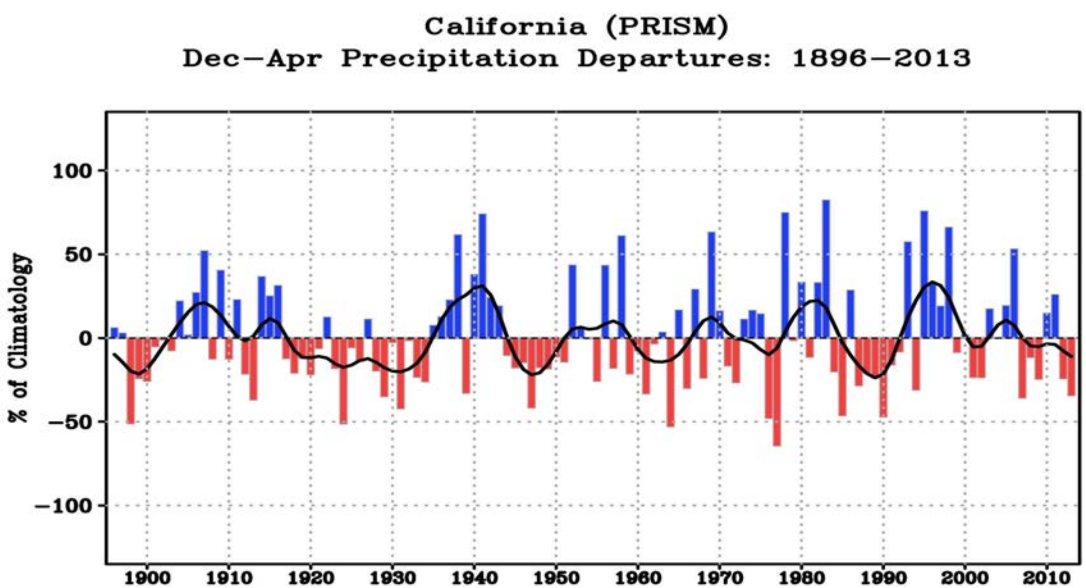


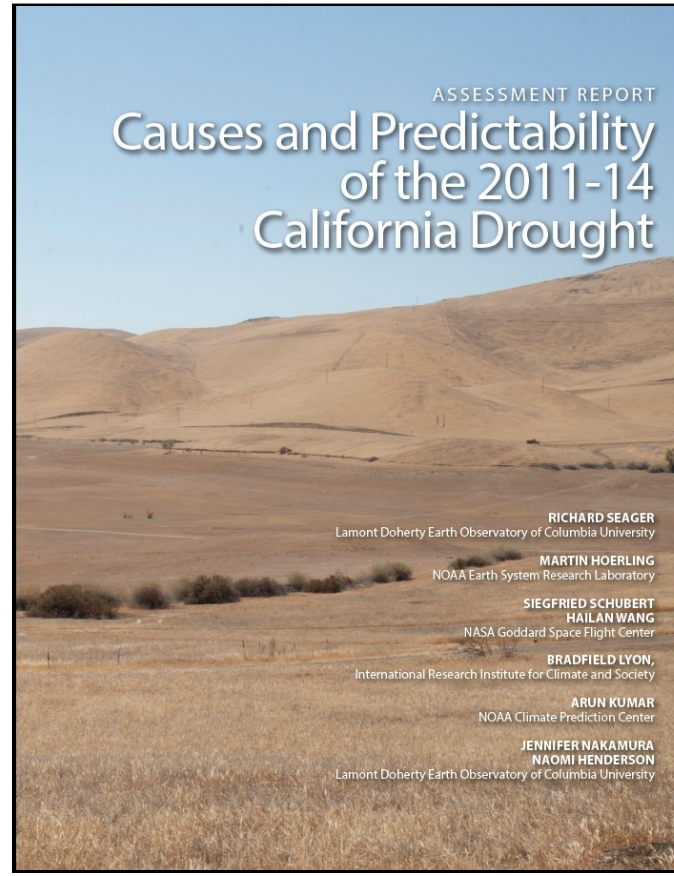



Lake Mendocino Water Supply Storage
2004-2014 Average Water Year Storage
2014 Water Year Storage
Current Water Year Storage
61.8% of Summertime Capacity
Flood Control Pool
Water Supply Pool
Flood Control Pool
Water Supply Pool
March 9, 2015 90.7% of Water Supply Capacity
10-year avg
WY2014
Atmospheric river storms
Acre-feet
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
October Through September

Could this drought have been anticipated?

Is this drought due to anthropogenic climate change?



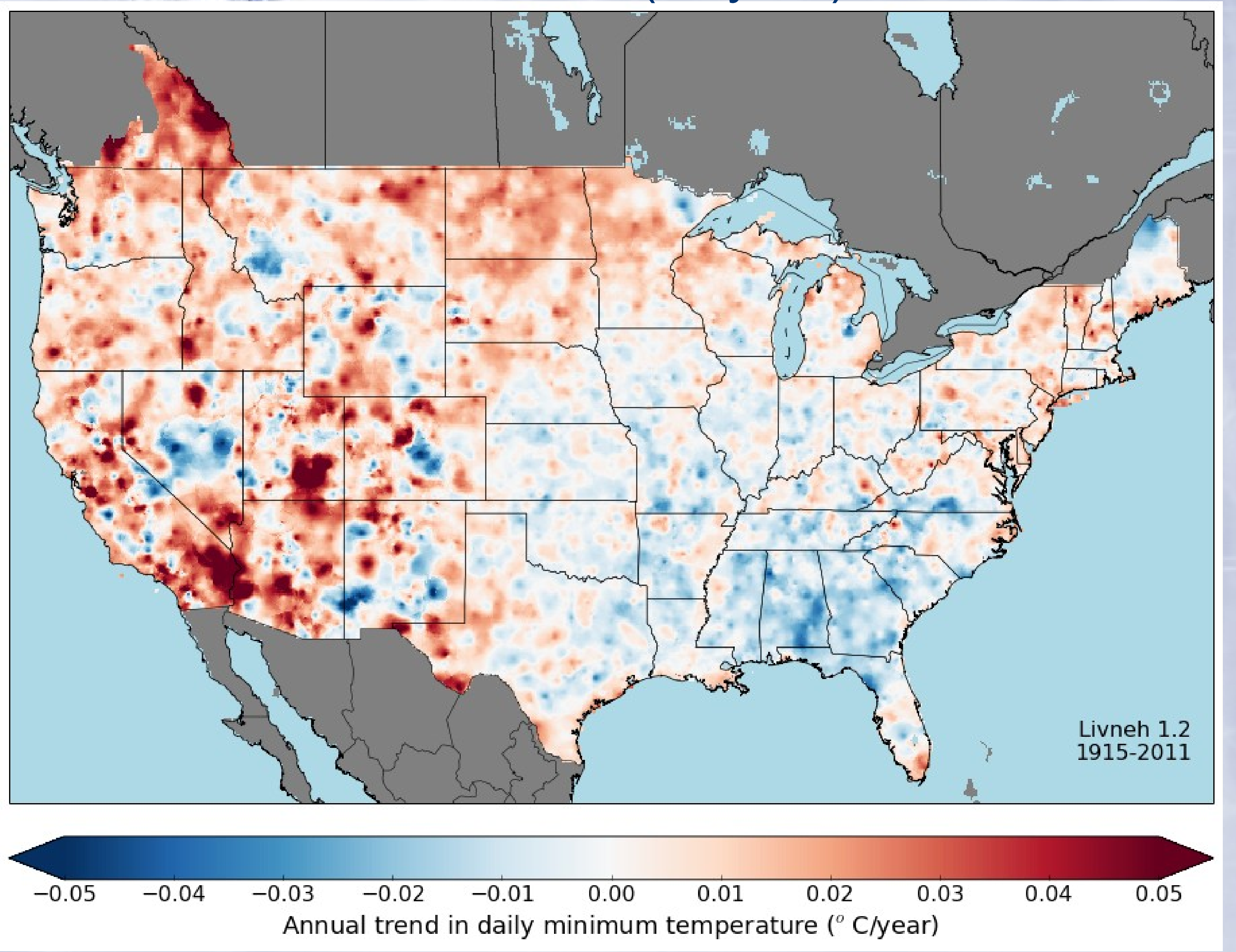


MAPP
Modeling, Analysis, Predictions, and Projections

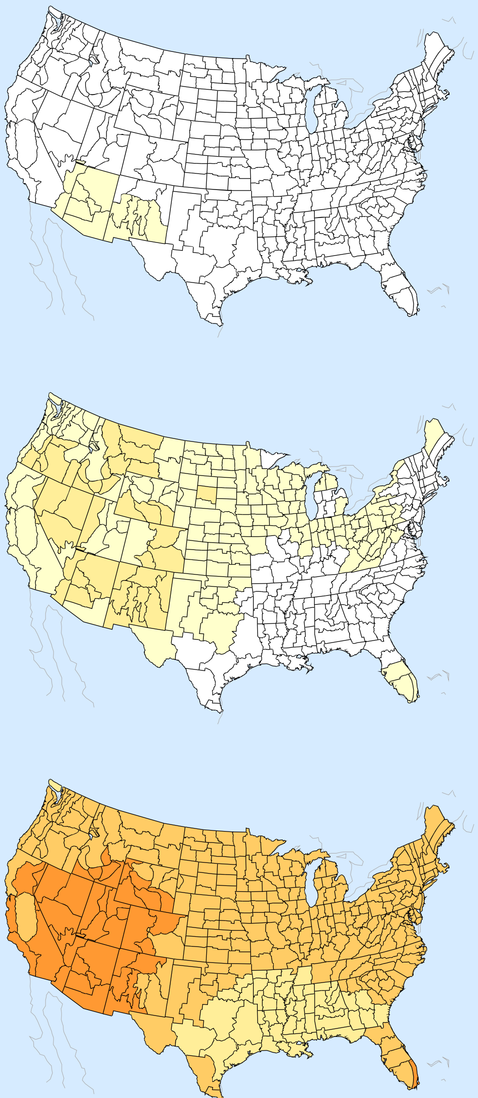
NIDIS

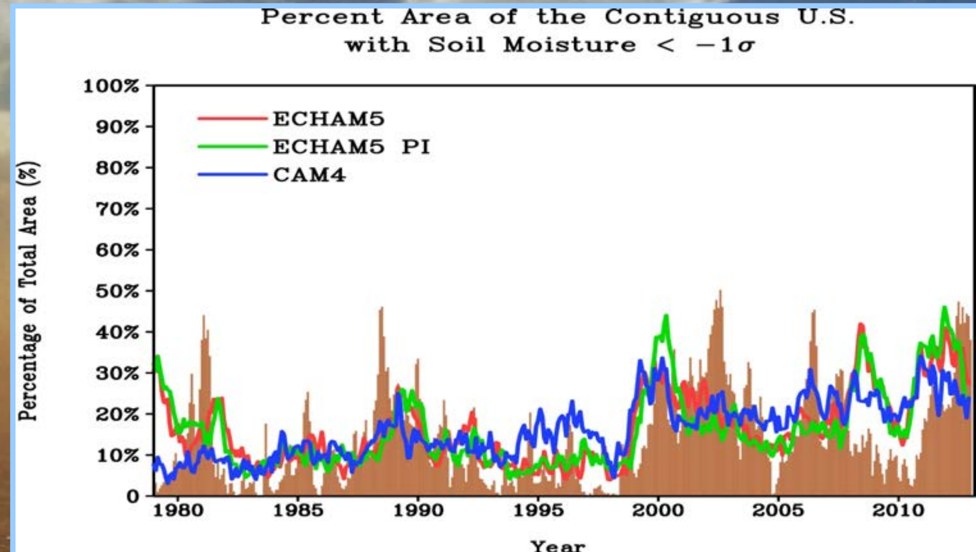
NOAA Drought Task Force

CONUS daily minimum temperature trend 1915-2011 (°C/year)

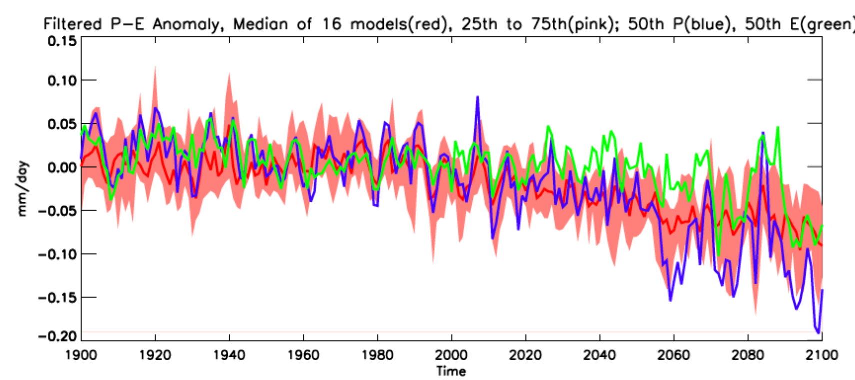


Are Transitions to Semi-Permanent Drought Imminent?





P, *E* and *P-E* averaged across all of SW North America in the IPCC AR5 global climate model simulations and projections for 1900 to 2100



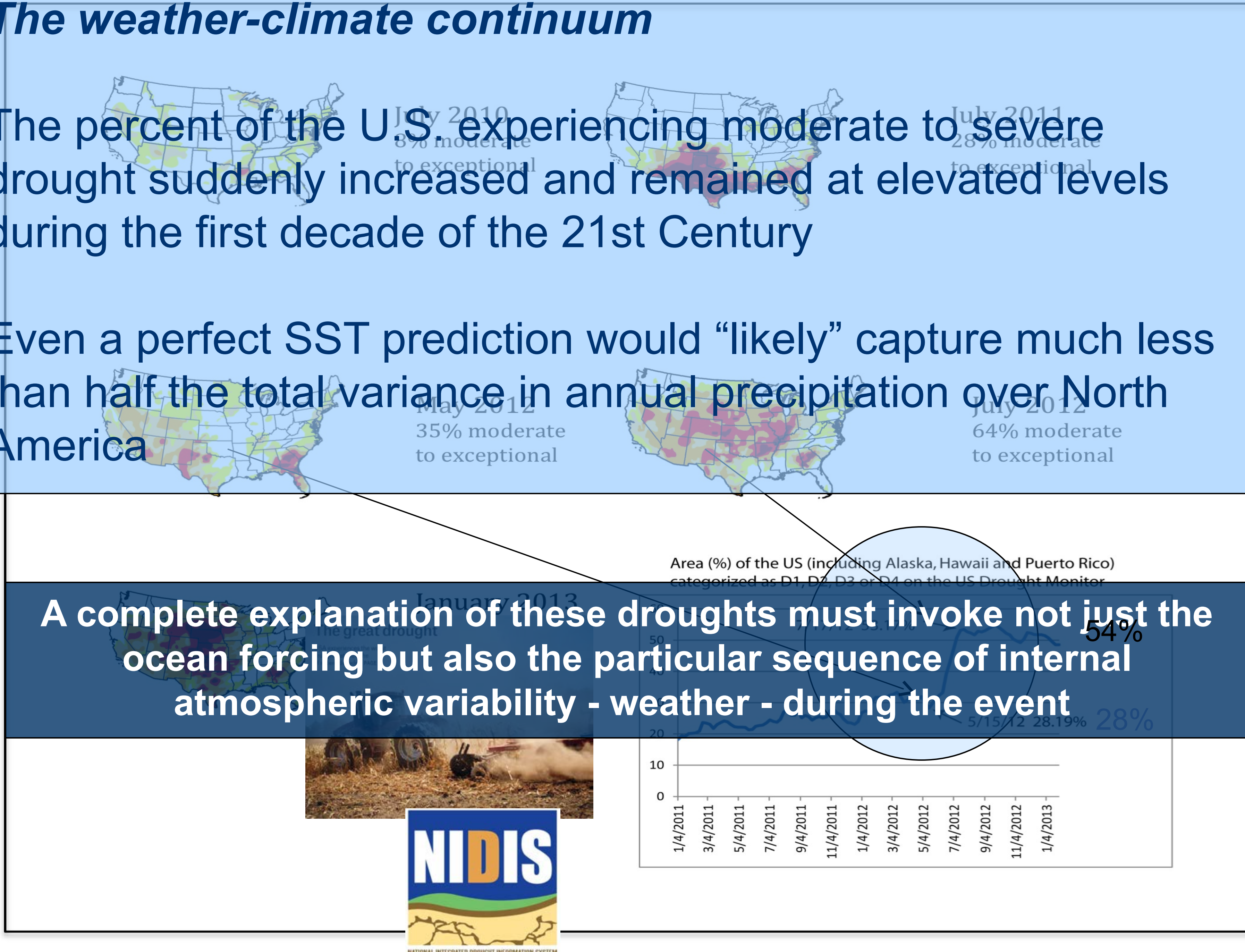
Ongoing transition to a drier climate driven by decreasing precipitation

Effect of Long Term Global Ocean Warming

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

Evaporative Demand Drought Index

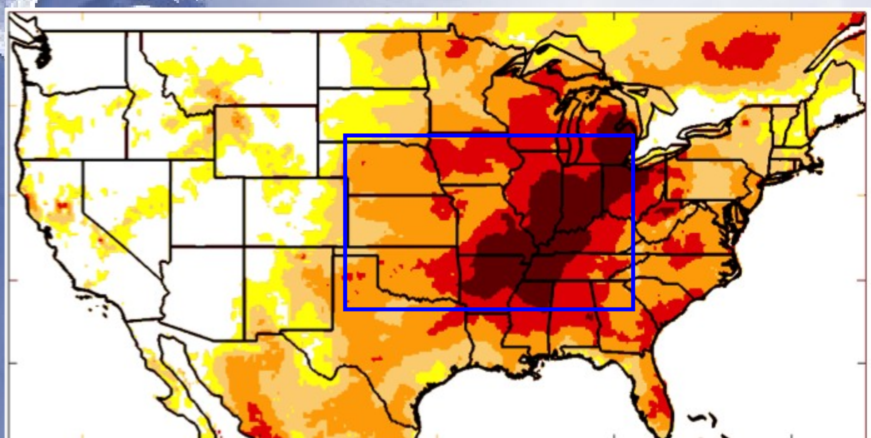
EDDI shows strong early warning potential-2012

August 7

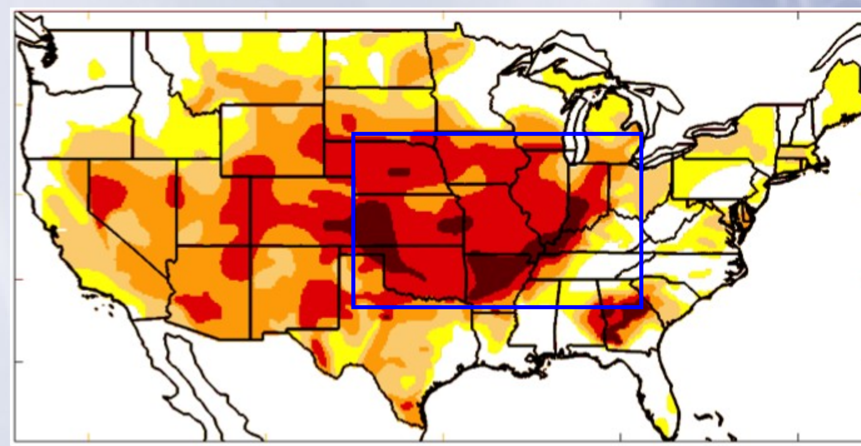
$$EDDI_j = \frac{\sum_{t=i}^{j}\left(ET_{0_t} - \overline{ET_{0_t}}\right)}{\sigma_{\overline{ET_{0_t}}}}$$

2-week *EDDI*

US Drought Monitor



[illegible] region
note little drought in western US



[illegible] much of region;
[illegible] 2 months after *EDDI*

- 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.

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

Recent Studies	Projected Annual Flow Reductions
Christensen et al., 2004	~18%
Christensen and Lettenmaier, 2007	~6%
Milly et al., 2005	10 to 25%
Hoerling and Eischeid, 2007	~45%
Seager et al., 2007	"an imminent transition to a more arid climate"
McCabe and Wolock, 2008	~17%
Barnett and Pierce, 2008	assumed 10-30%

Response One: These are so different, we can't trust any of them…

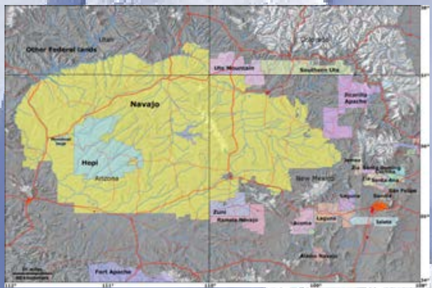
Response Two: We need to resolve these differences! Are the differences due to climate uncertainty or different models and methods?

Response Three: None of these studies show increasing flows. Any decrease is a source of concern.

Sand Dune Mobility = W/(P/PE)

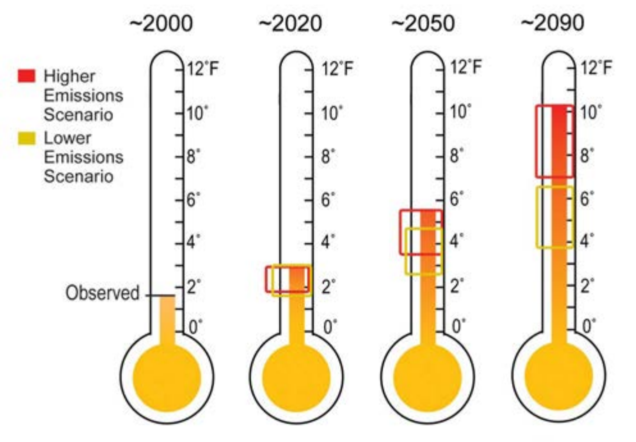
Four Corners Region

Stable Sand Dunes
= P/PE > 0.31

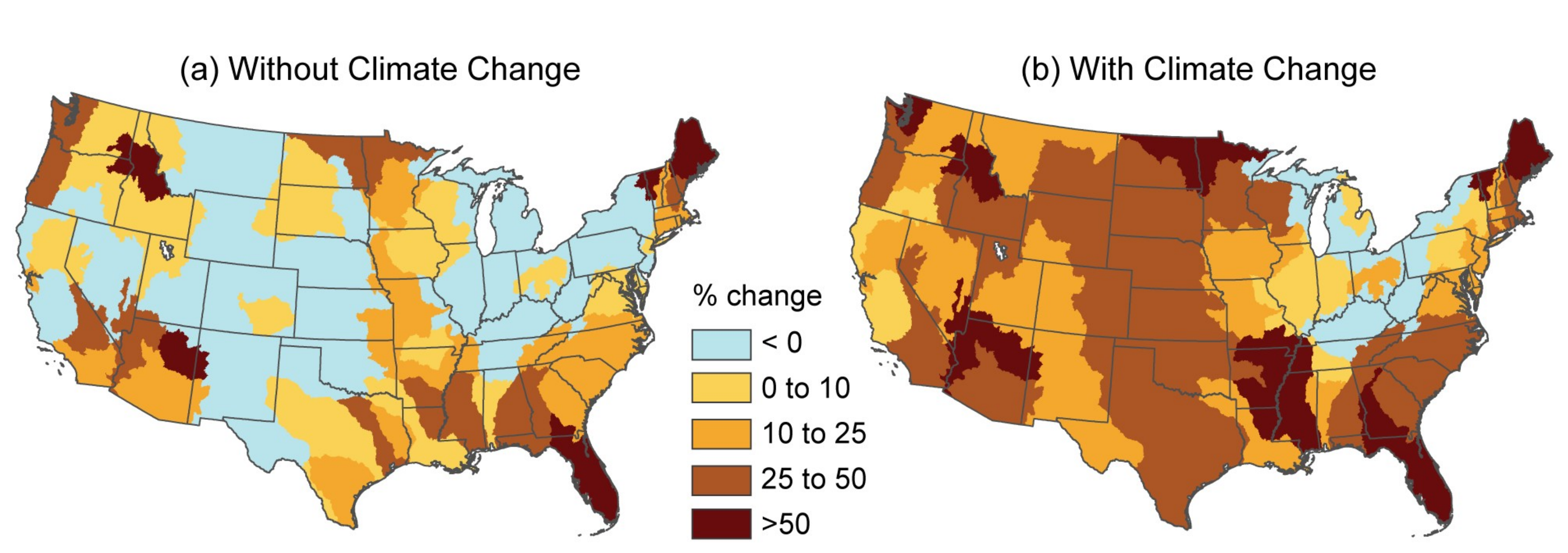


Partly Active Dunes

Fully Active Dunes
= P/PE< 0.125



Projected Changes in Water Withdrawals: Growth and demand 2005 to 2060



The Stakes on Climate Change:
US Water and Clean Water Sector Only (WUCA, 2012)

2011-2031: Without Adaptation

Drinking Water
Infrastructure Investment

$335 Billion [1]

OR $1 Trillion through 2035 [4]

Clean Water
Infrastructure Investment

$298 Billion [2]

By 2050: Potential Adaptation Costs

Drinking Water + Clean Water Sector:

$448 - 944 Billion [3]

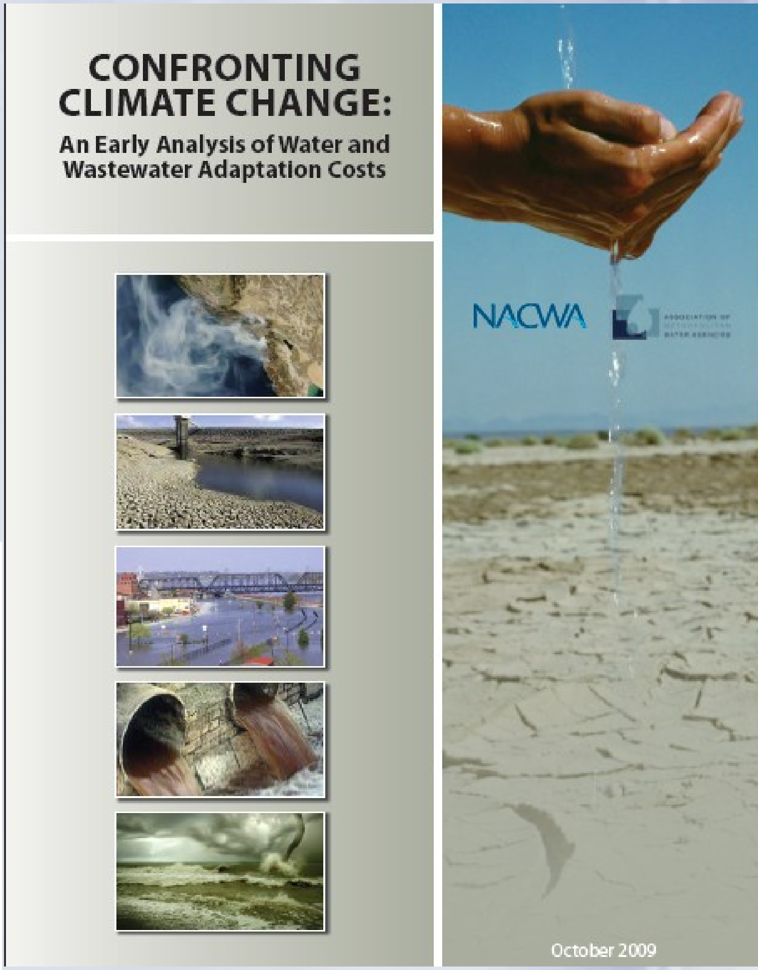
[1] "2009 Drinking Water Infrastructure Needs Survey and Assessment: Third Report to Congress." USEPA Office of Water, 2005.

[2] "Clean Watersheds Needs Survey 2008: Report to Congress." USEPA, May 2010.

[3] "Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs," Association of Metropolitan Water Agencies, National Association of Clean Water Agencies, 2009.

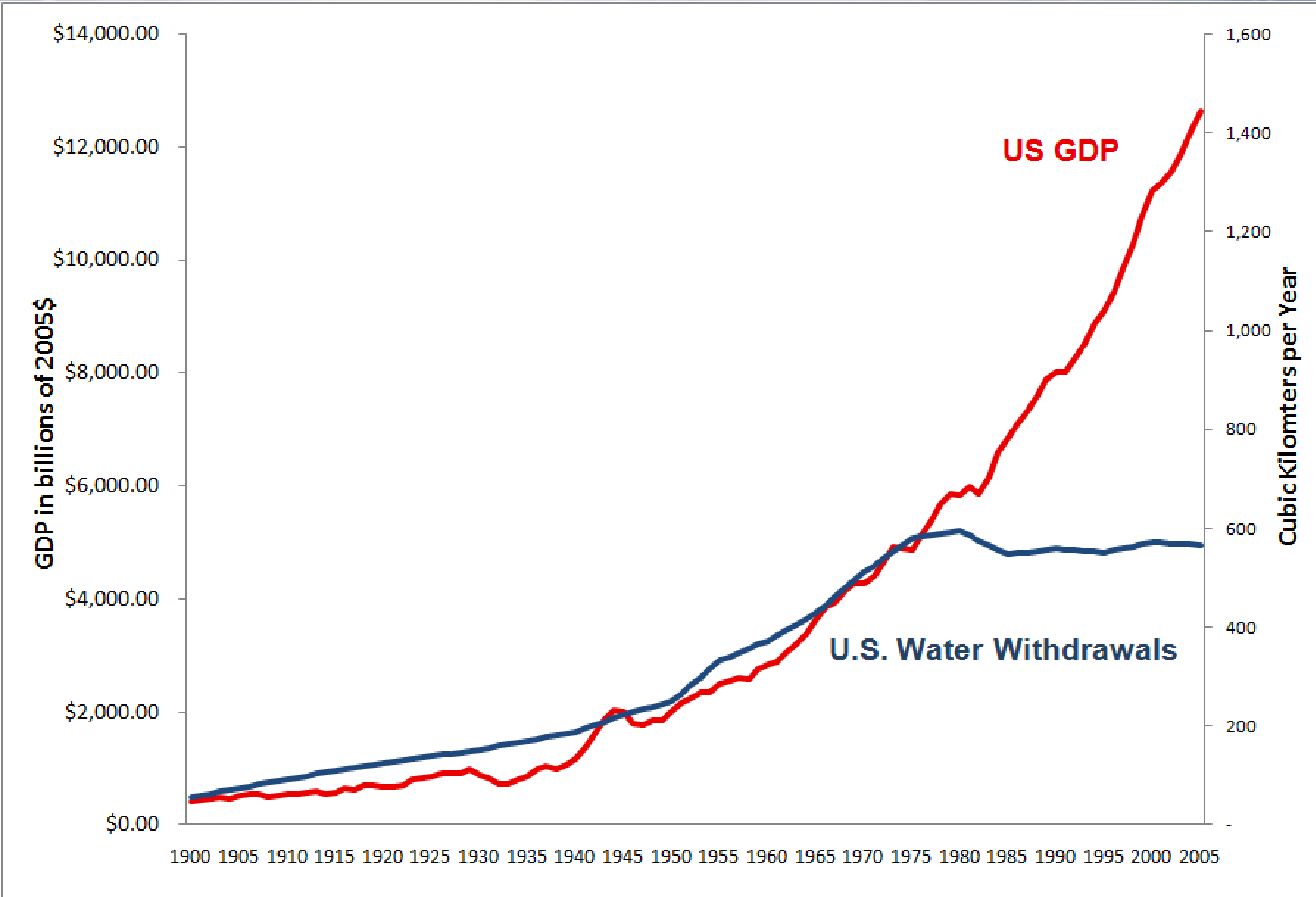
[4] "Buried No Longer: Confronting America's Water Infrastructure Challenge, American Water Works Association, 2012.

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



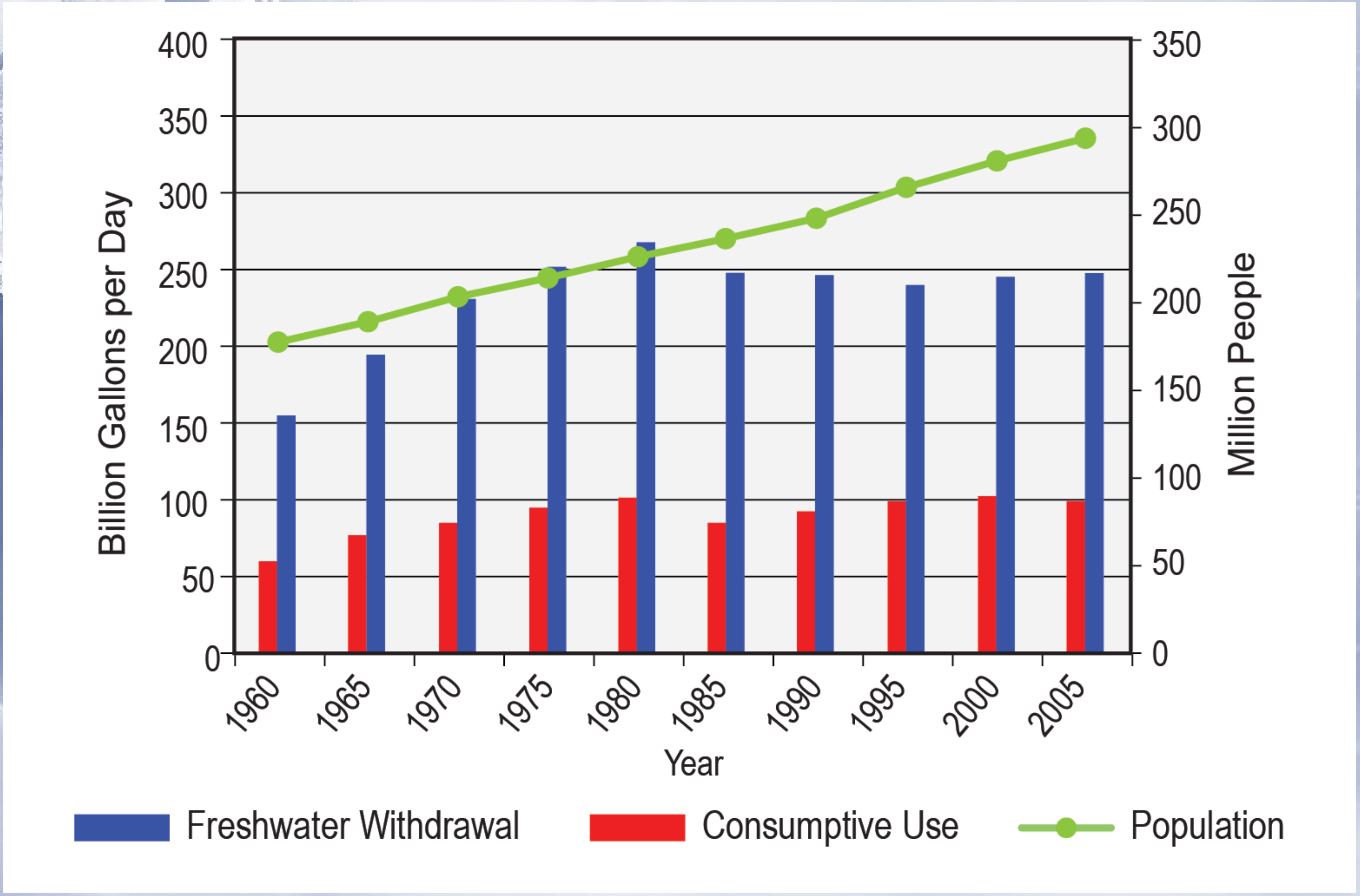
NACWA, AMWA

Is it all bad?

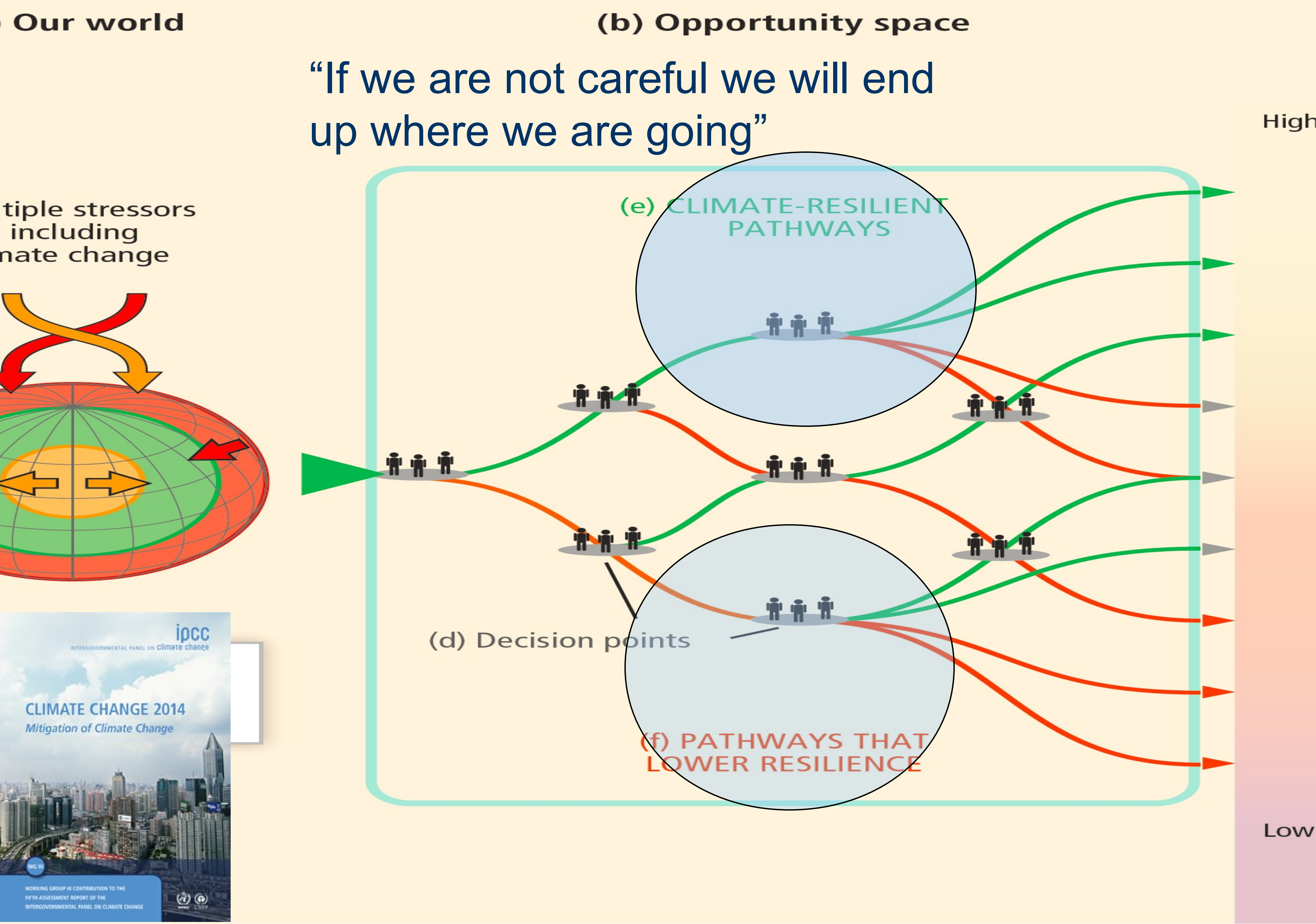


Source: Christian-Smith and Gleick 2012 “A 21st Century US Water Policy.” Oxford University Press.

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

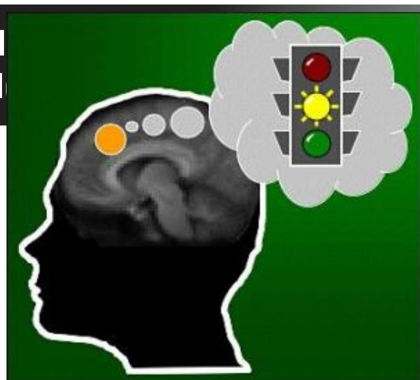
Sustainable and Resilient Energy in an Uncertain Water Future

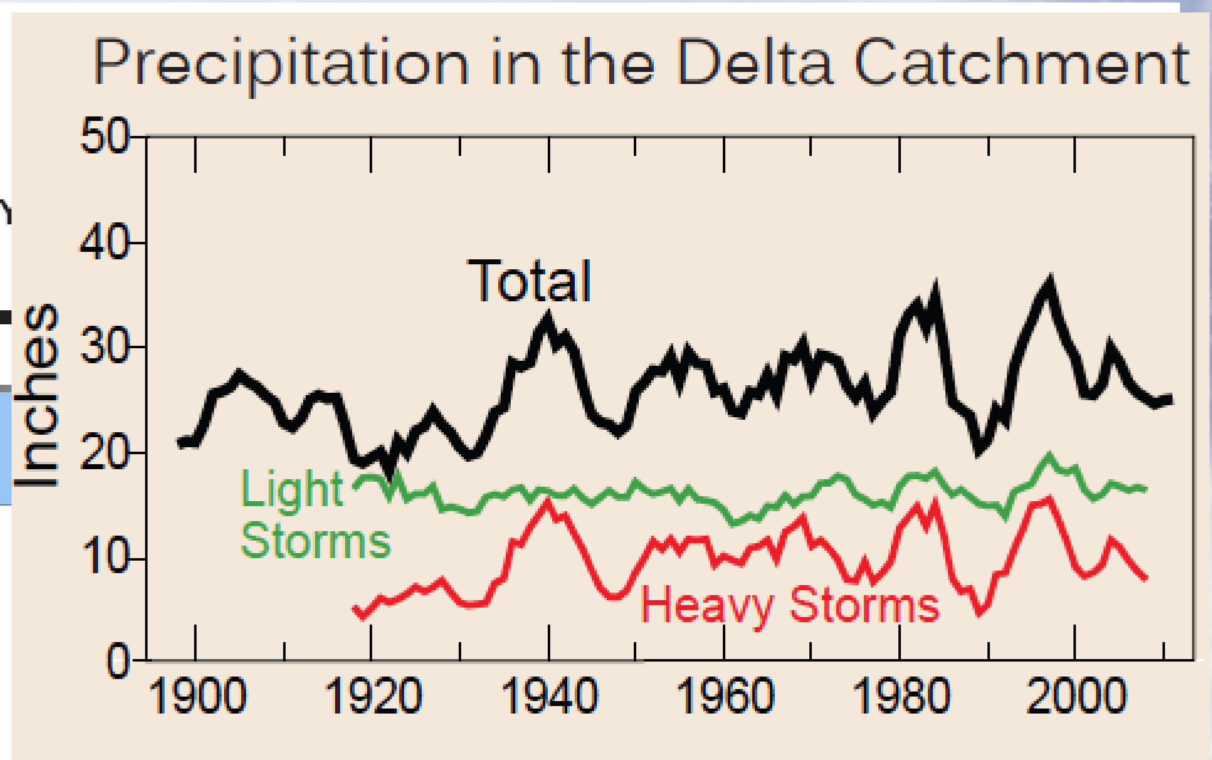
Optimize freshwater efficiency of energy	Optimize energy efficiency of water management	Enhance reliability and resilience of energy and water systems security	Increase safe and productive use of nontraditional water sources	Promote responsible energy options with respect to water	Exploit productive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

Dept. Energy/Vallario 2014)

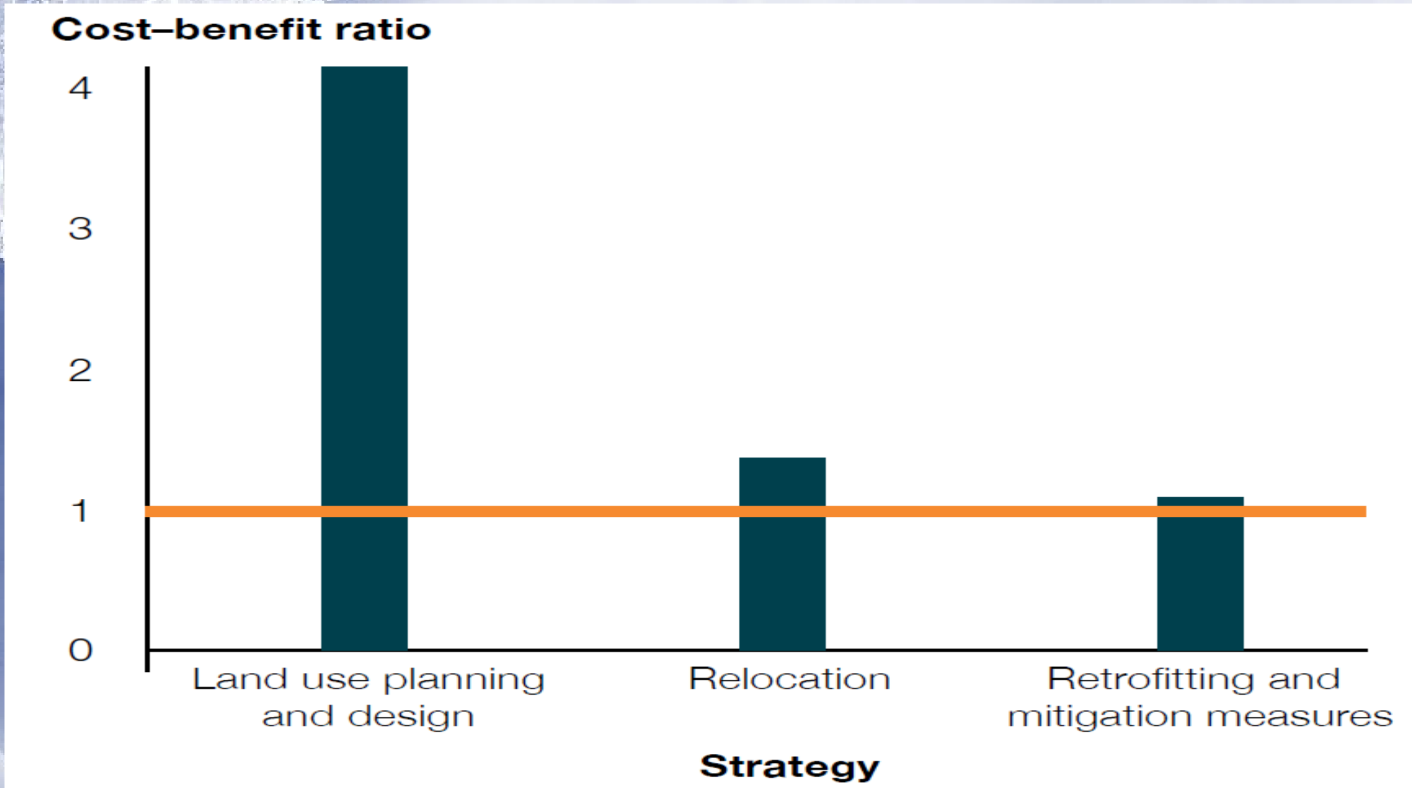
1. Acknowledge the cross-timescale nature of climate and of early warning information

Improved understanding of long-term variations of largest storms- dictate the occurrence of droughts in California



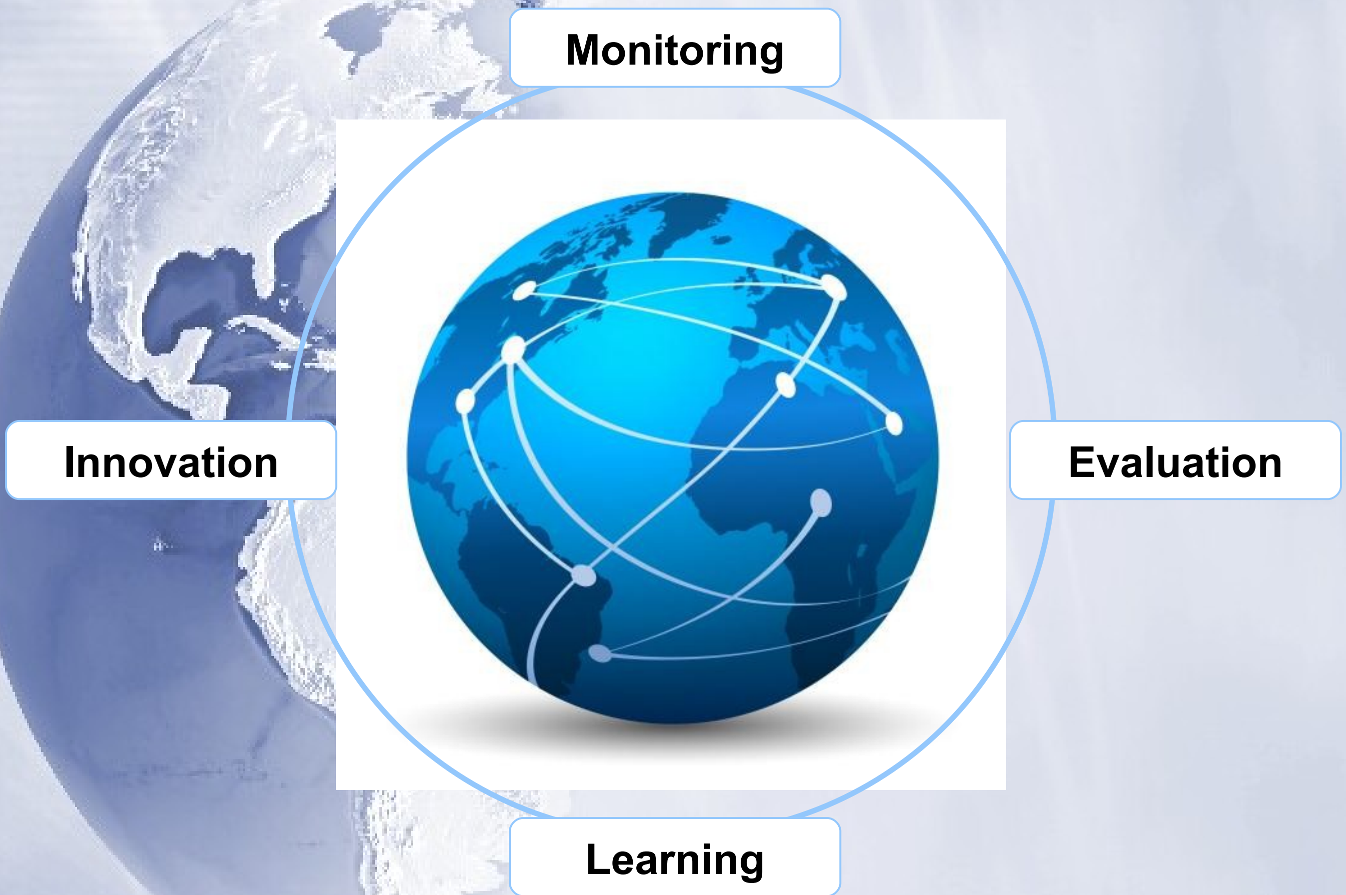


2. Recognize alternative means of addressing water security
Best adaptation practices may be novel configurations of land and water resources- and information to support those decisions



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



Are we doing and not learning?

1976-1977

1986 Coordinated Operations Agreement CVP and SWP

1987-1992

State Drought Water Bank

2007-2009

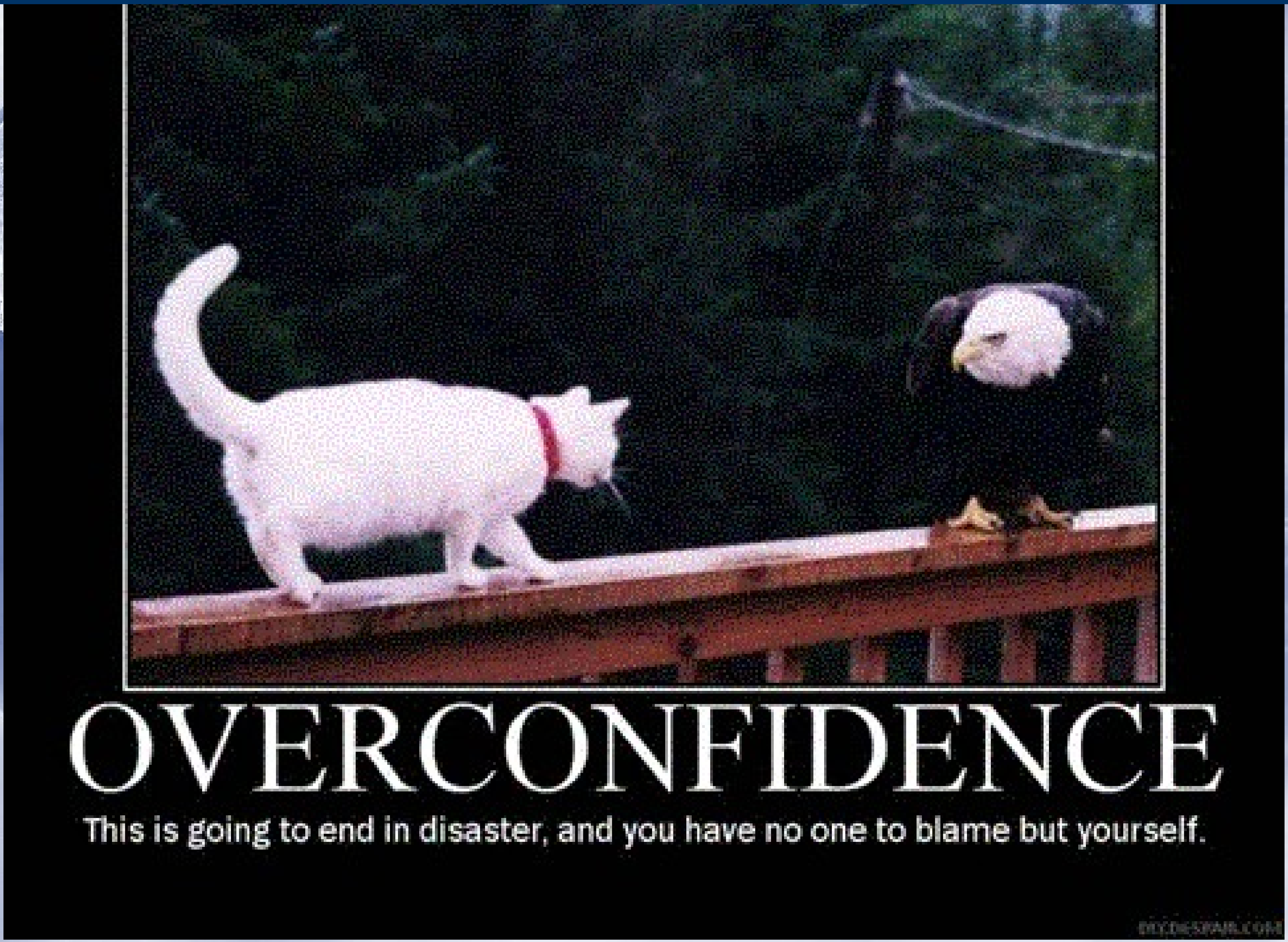
Regional Water Storage Projects Water Code Sect 85021 –reduced reliance on Delta water, emphasis on local reliance “the problem of water supplies not meeting human demands... **can be met in two ways: increase the supply or limit the demand.** Both are necessary. Methods of increasing the supply range 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?



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.

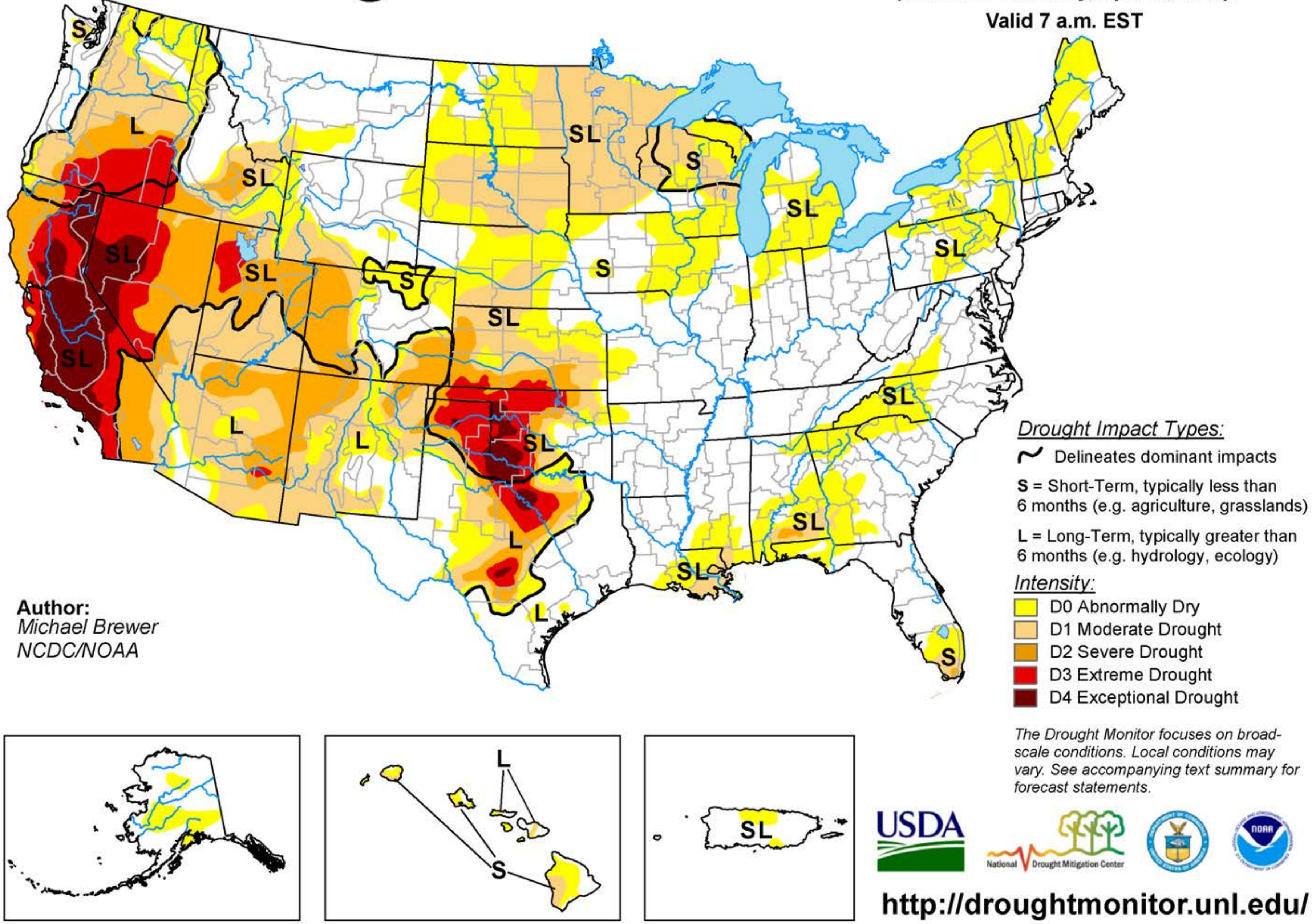
Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality- increases in sediment, nitrogen, and other pollutant loads.

U.S. Drought Monitor

April 14, 2015

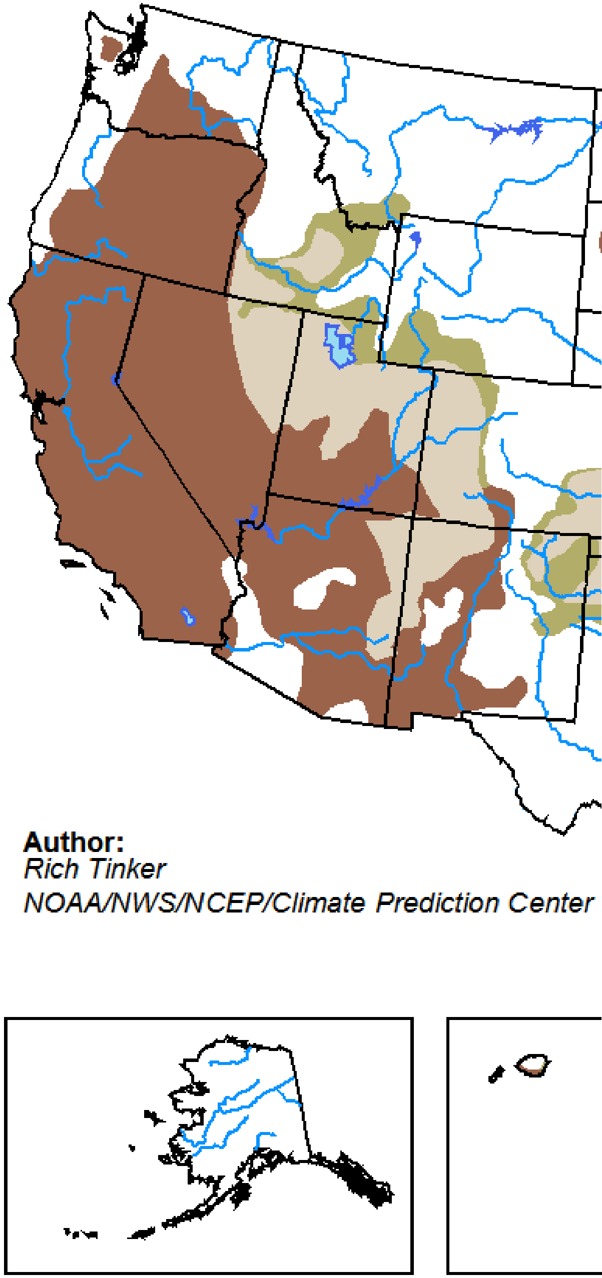
(Released Thursday, Apr. 16, 2015)

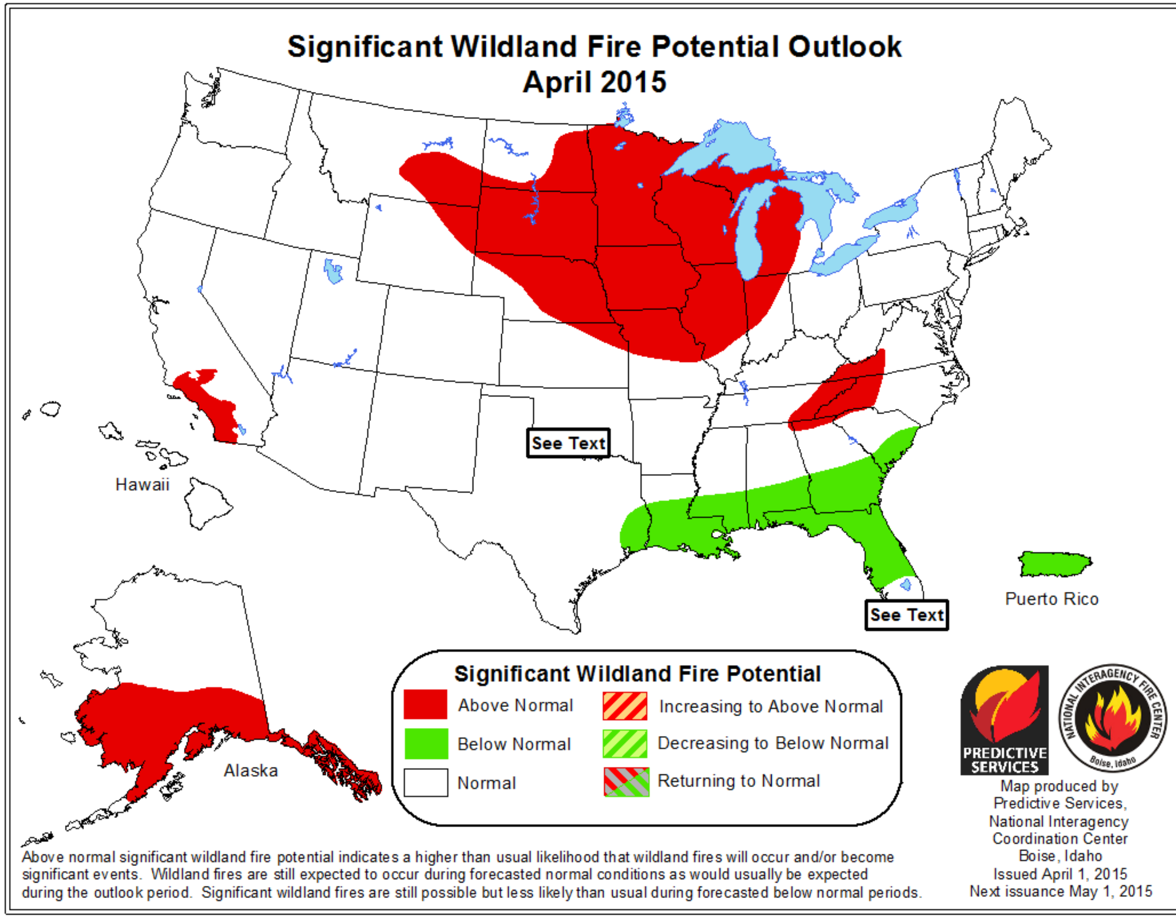
Valid 7 a.m. EST



U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period

Valid for April 16 - July 31, 2015
Released April 16, 2015

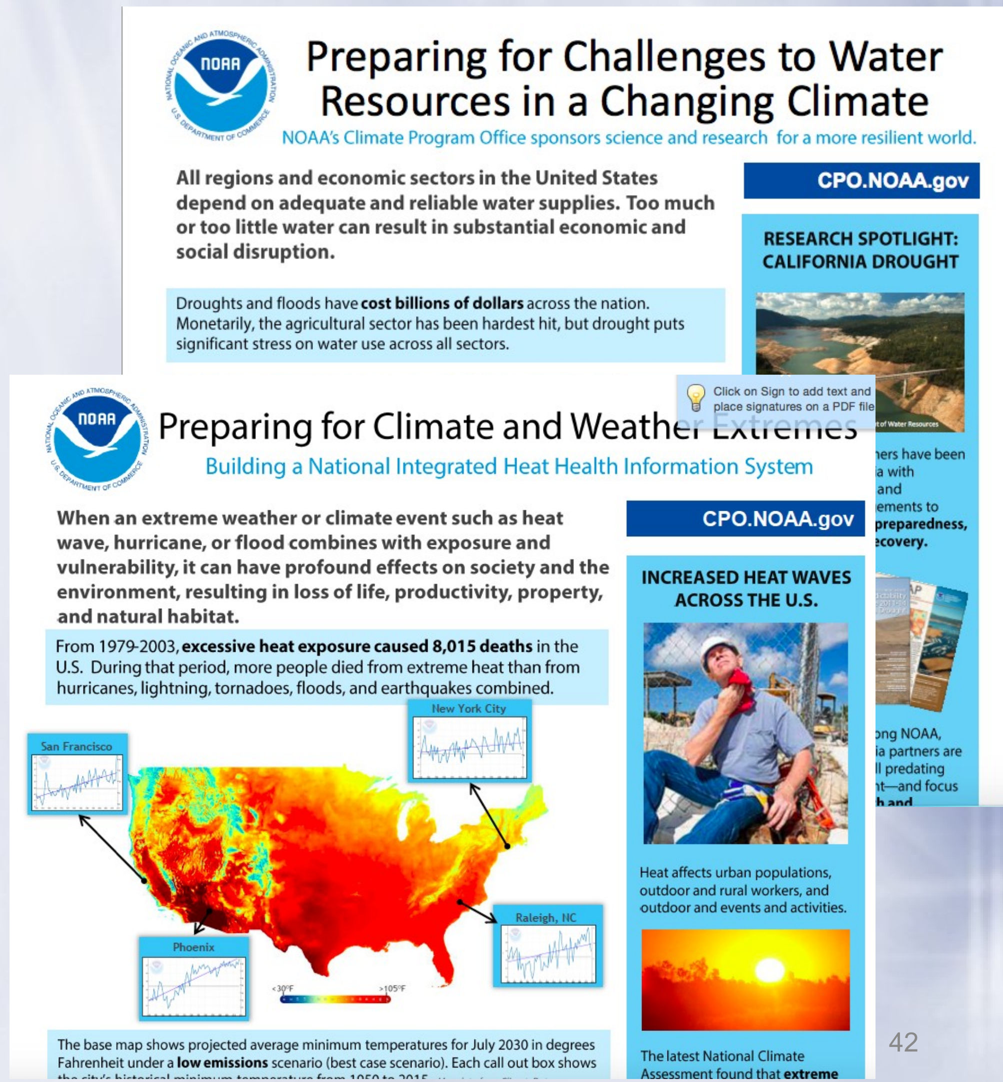




http://go.usa.gov/hHTe

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

drought.gov

City of Aurora, Colorado

2007

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

2010

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

2015

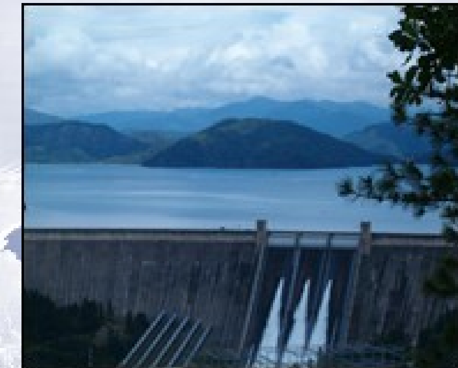
- Y2010 +
- Small Trans-basin
- Limited Ag Transfers
- Public Benefit Multi-Purpose

2025

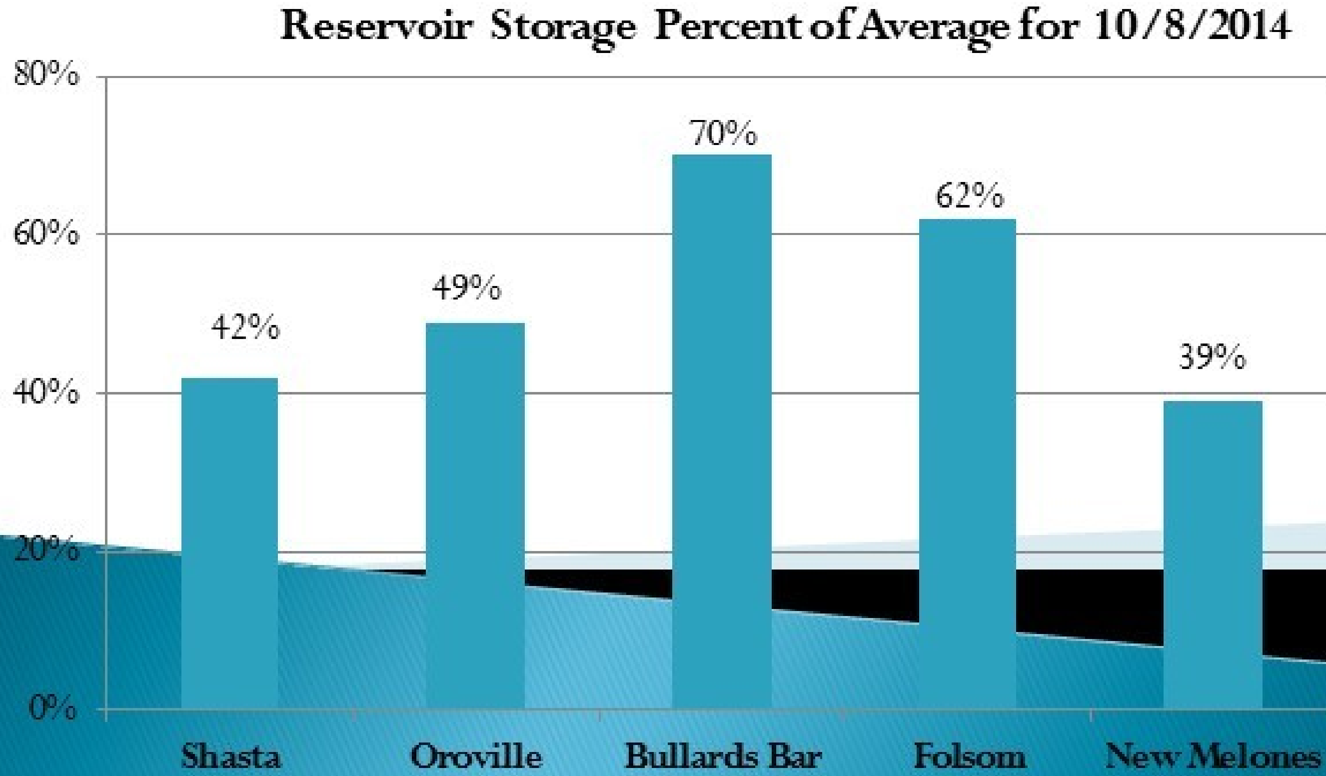
- Y2020 +
- One or Two Regional Trans-basin Projects
- System Integration
- Expanded Re-allocation of Ag Uses
- Planned Indirect Potable Projects

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.



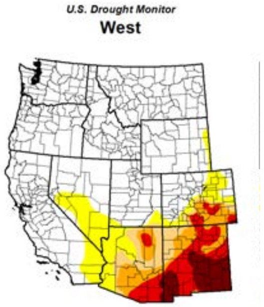
WATER STORAGE



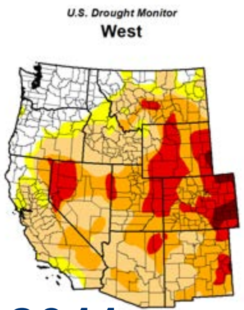
Hydrologic Data Courtesy of the California Department of Water Resources

Issued Thursday, Oct 9, 2014 at 10:44 am PDT

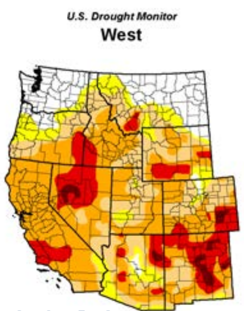
National Weather Service - Sacramento, CA



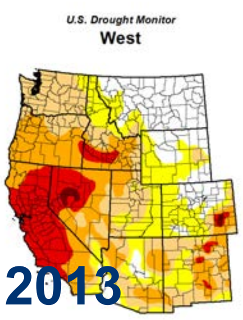
2010



2011



2012



2013

How did we get here? Status and antecedent conditions

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

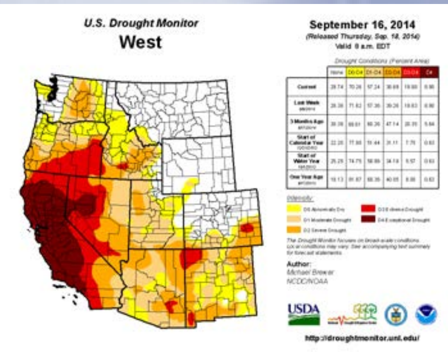
What are the impacts and where did they occur?

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?

September 2014



Climate Division CA Precipitation Anomaly
Winter (black) and Lowpass (magenta)

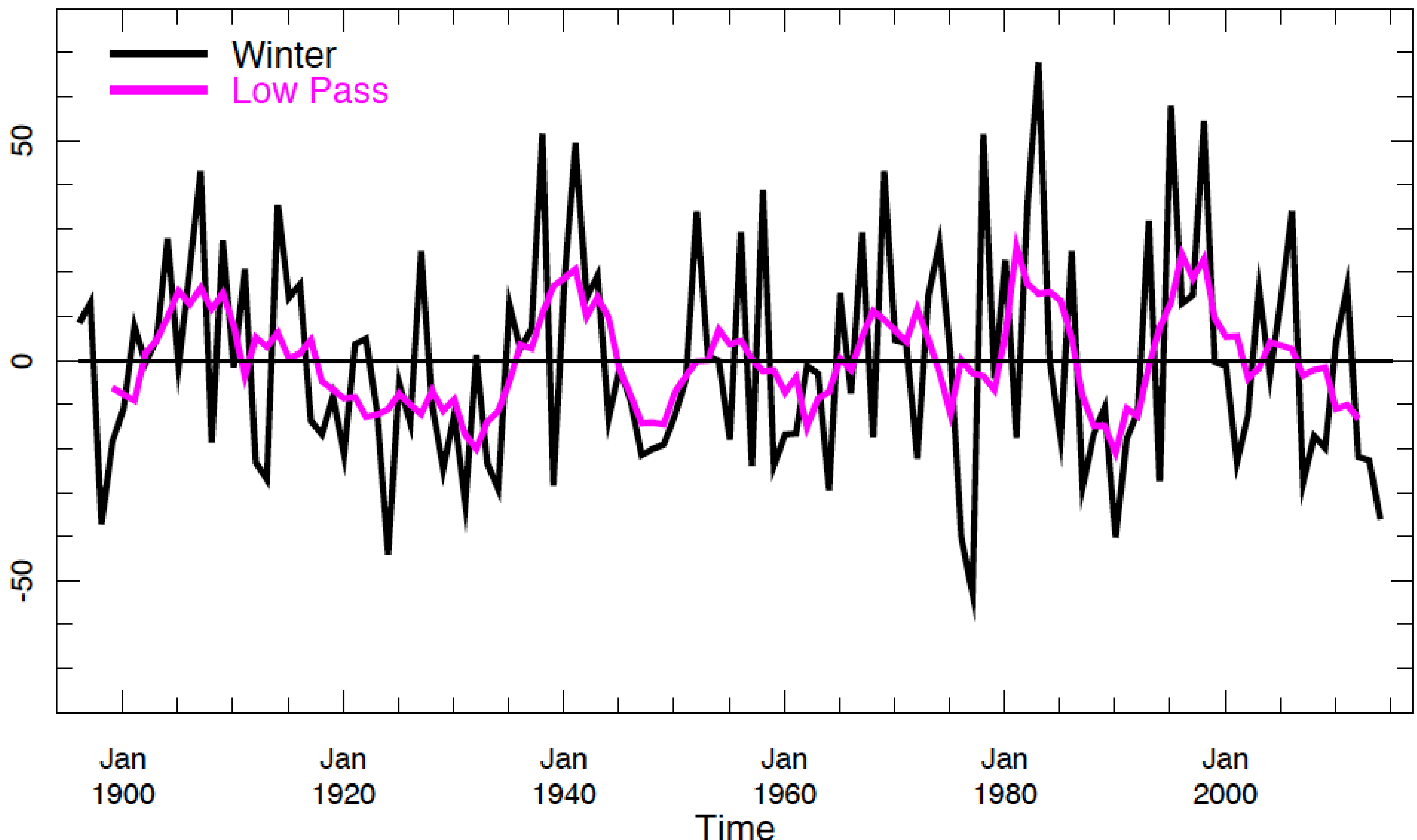


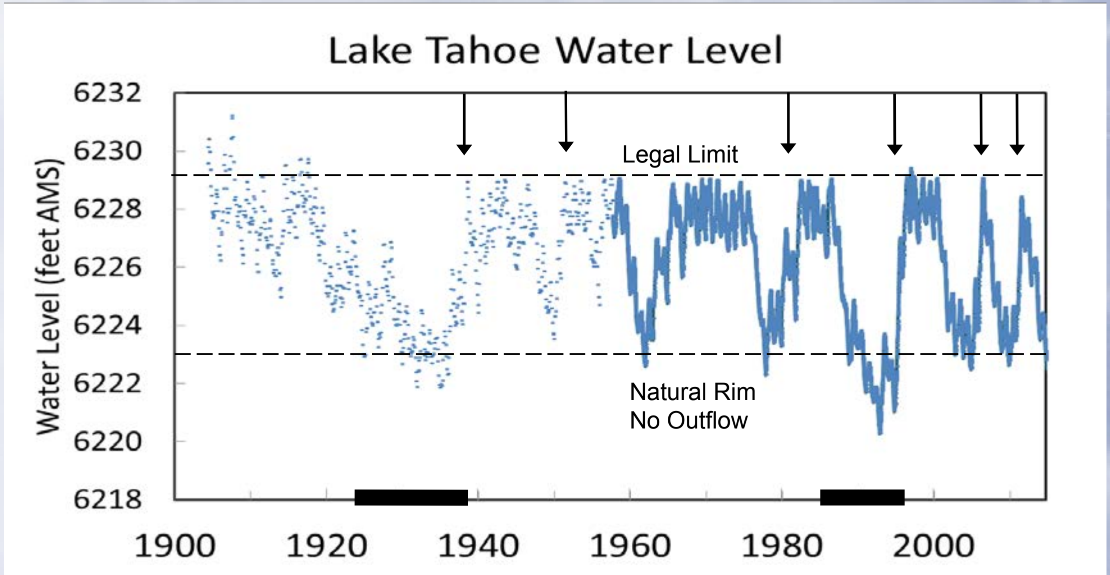
FIG. 2. Time series of all-California November to April winter precipitation for 1895 to 2014 and the same after low-pass filtering with .

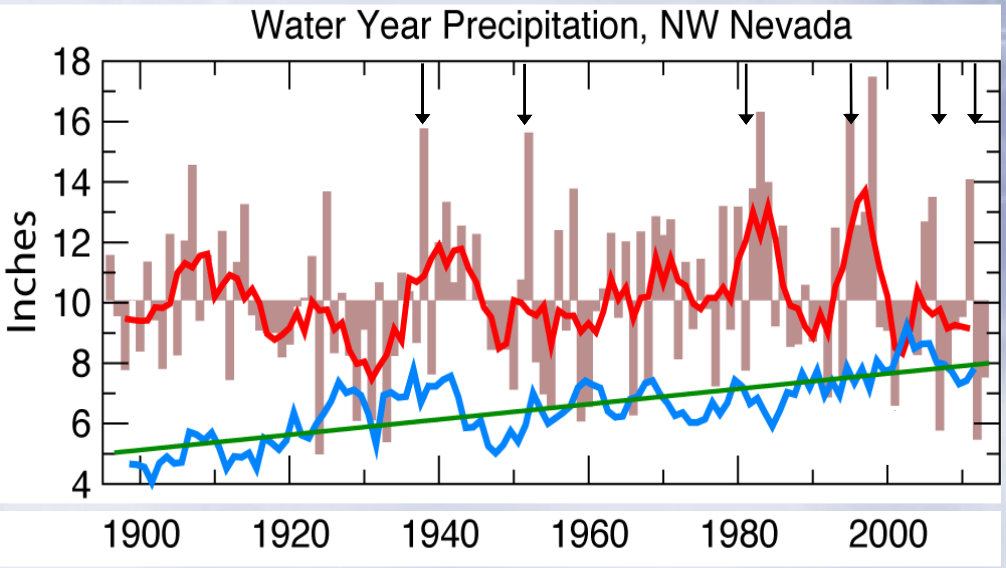
Modern

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)

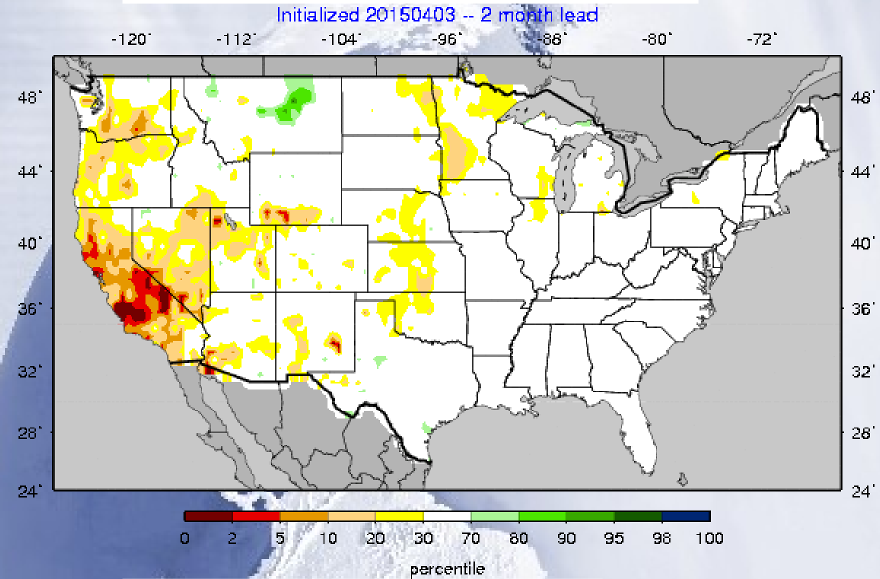




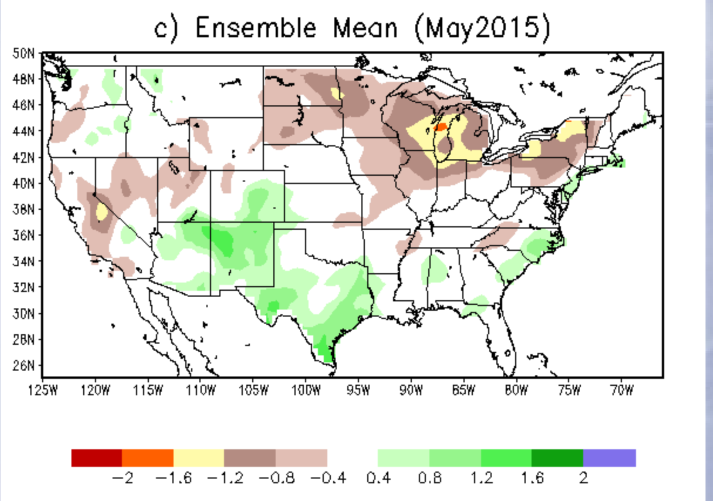
Huntington et al 2014

Forecasts for May 2015

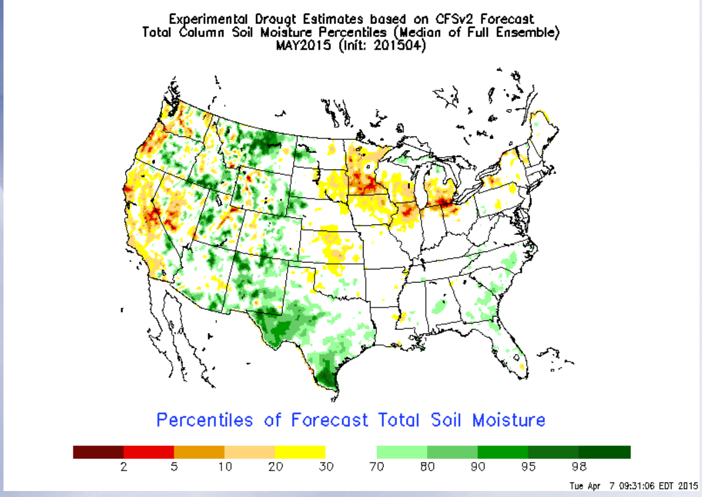
ESP UW



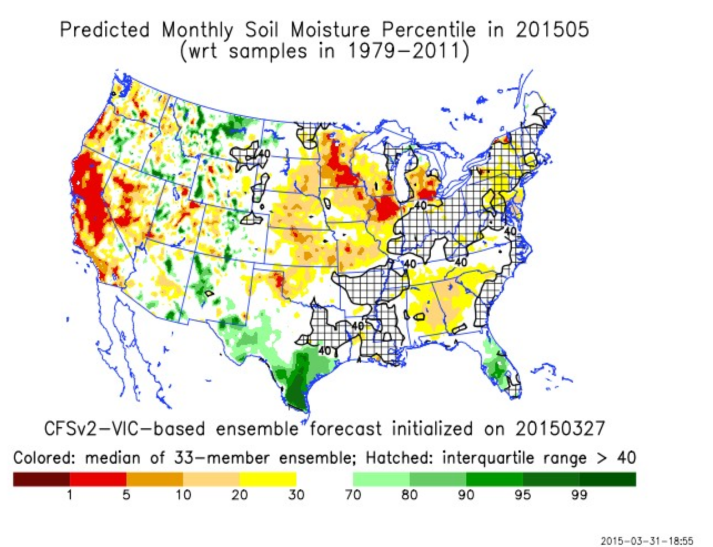
SPI6

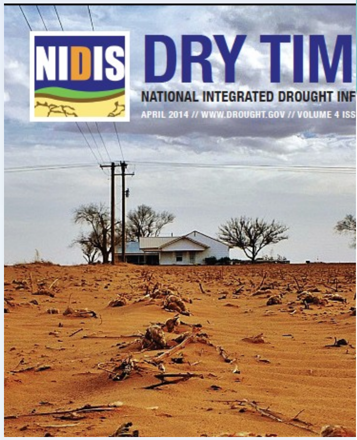


Princeton-MSU-EMC



MSU





Coordination

NDMC