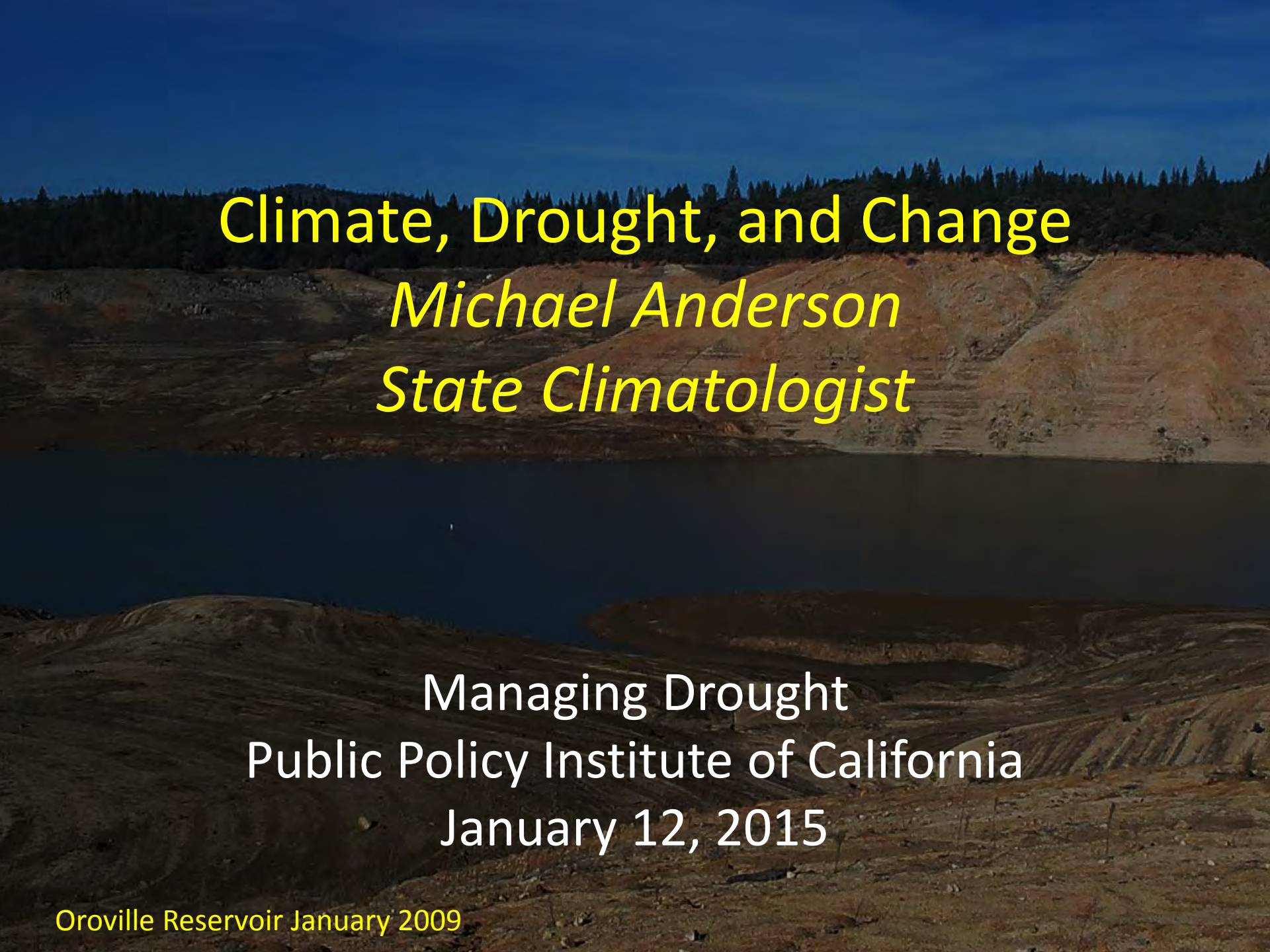


Climate, Drought, and Change

Michael Anderson
State Climatologist

Managing Drought
Public Policy Institute of California
January 12, 2015

Oroville Reservoir January 2009

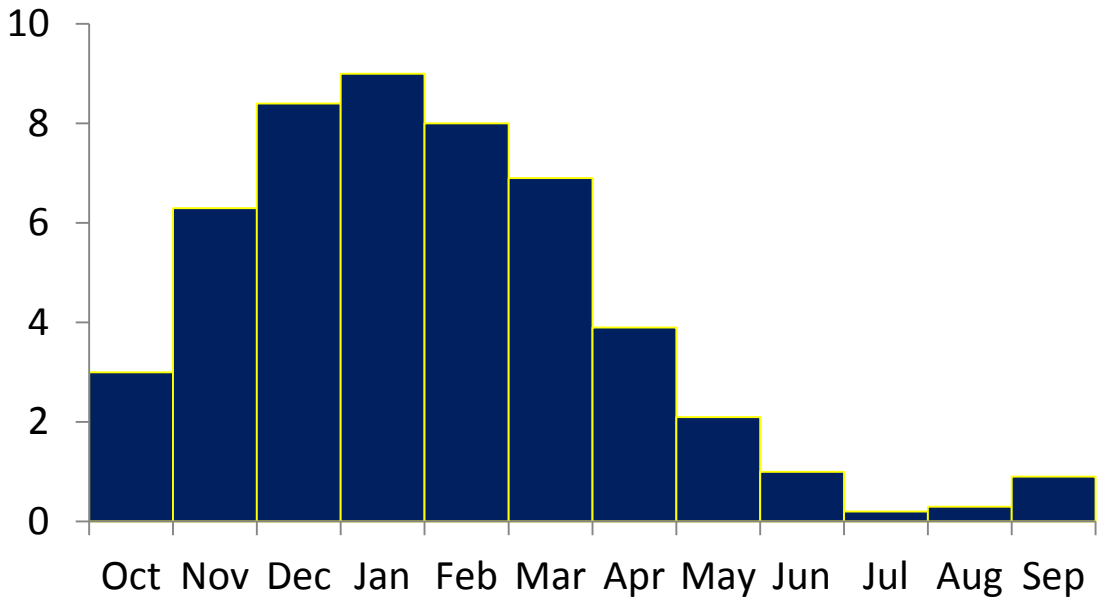
Presentation Overview

- The Rules
- What is Happening?
- Signs of Change

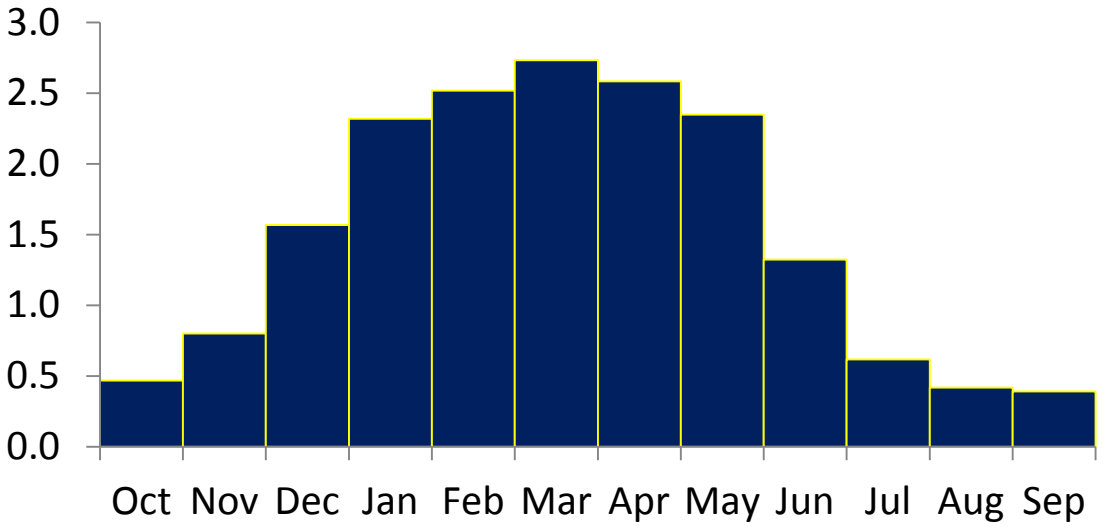
Folsom Reservoir January 2014

California's topography is important to our weather and climate

8 Station Precipitation Index (Inches)

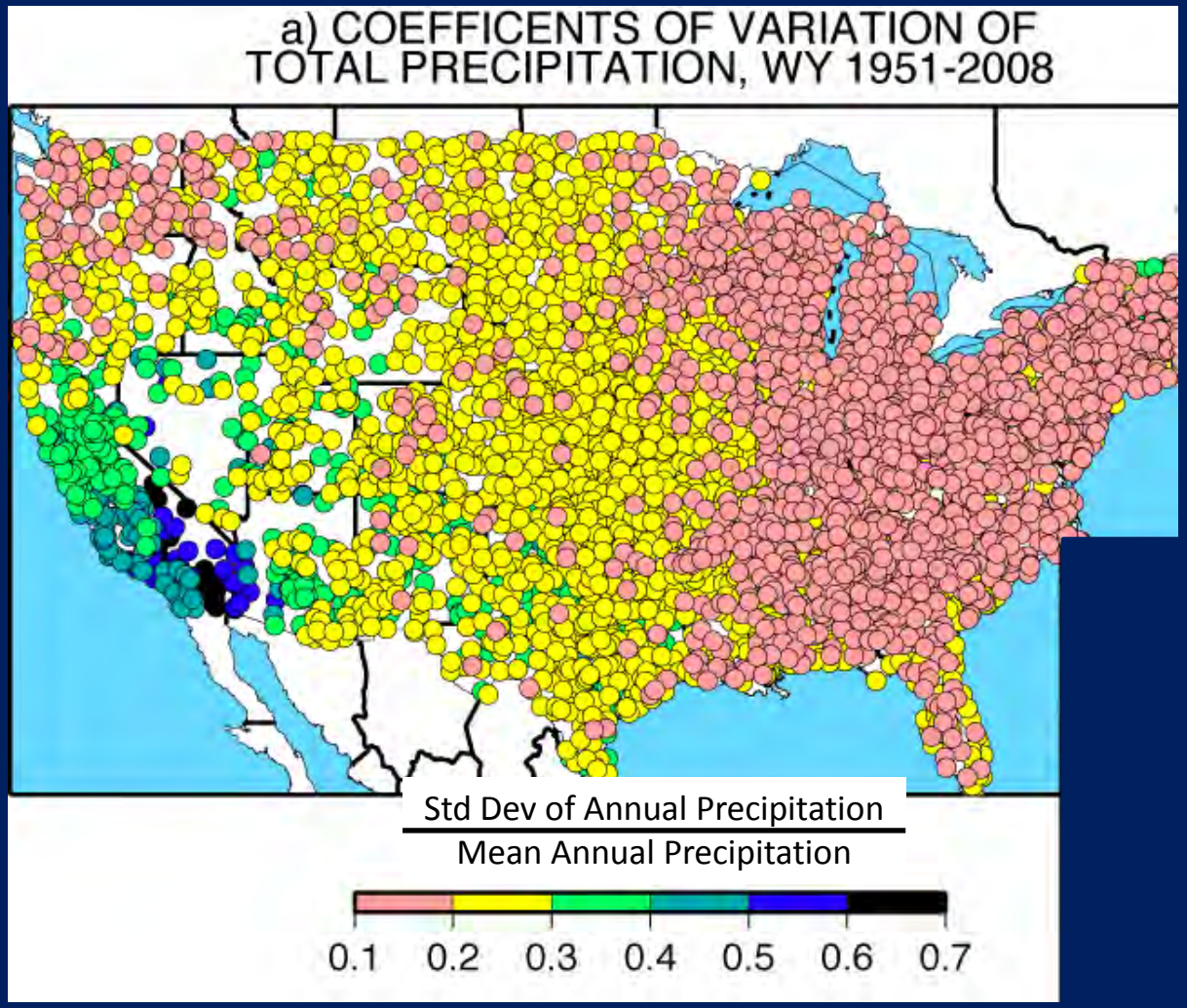


Sacramento River Flow (MAF)



Period of Record Monthly Averages

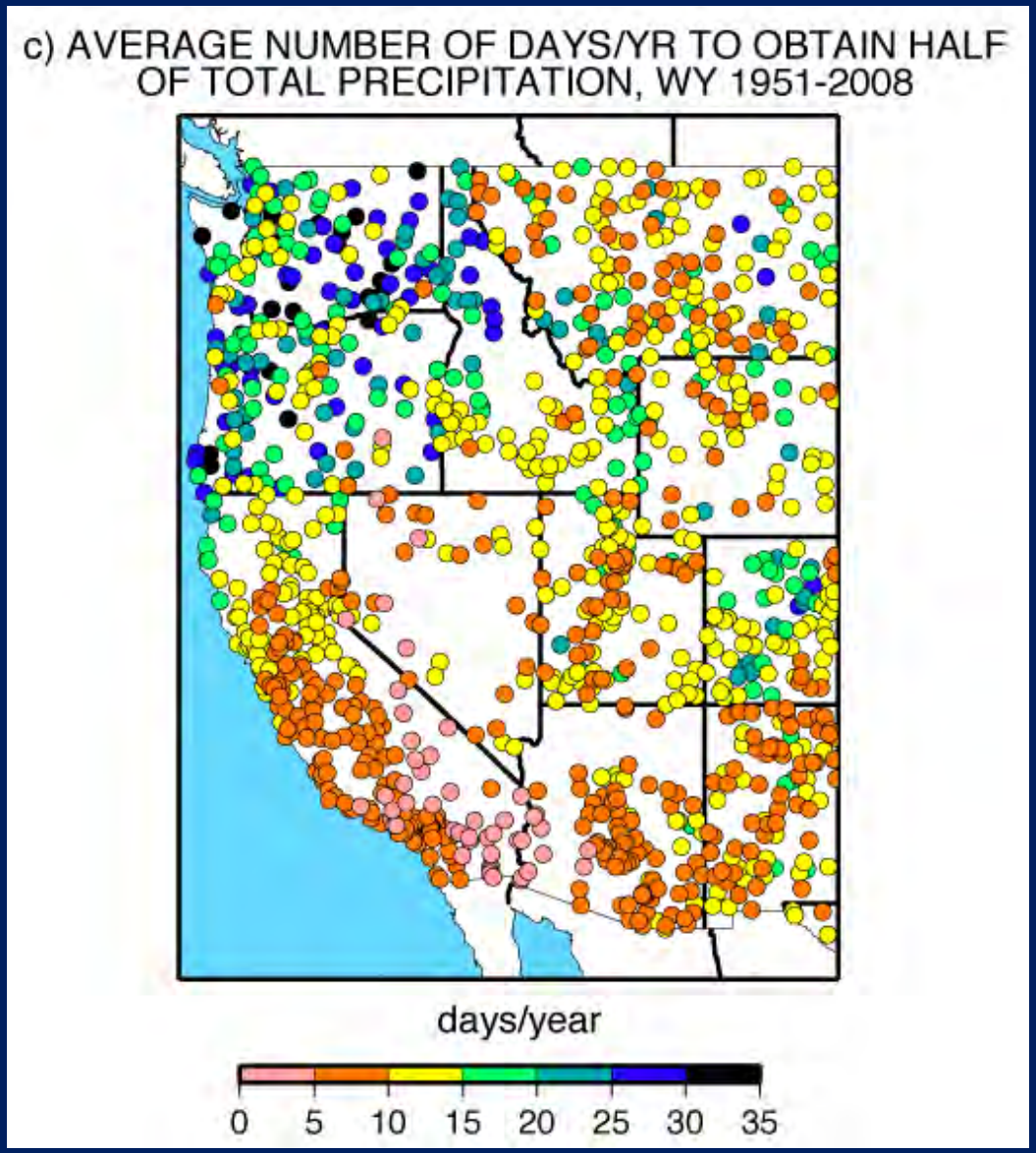
California's precipitation is uniquely variable



Higher values are higher variability

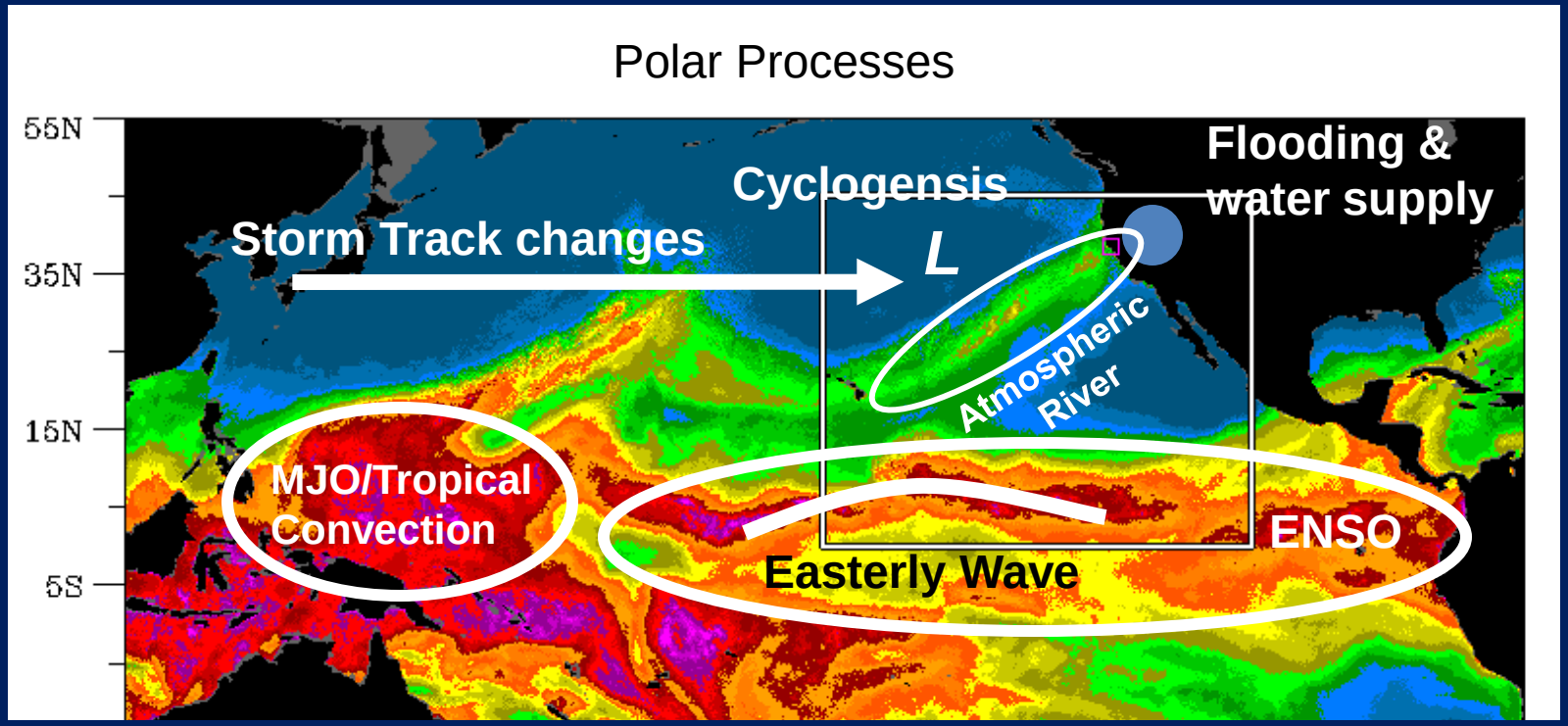
Source: Dettinger et al (2011)

Just a few storms each year are the core of California's water supplies



Source: Dettinger et al (2011)

Atmospheric rivers are a key phenomenon affecting water supply and flooding

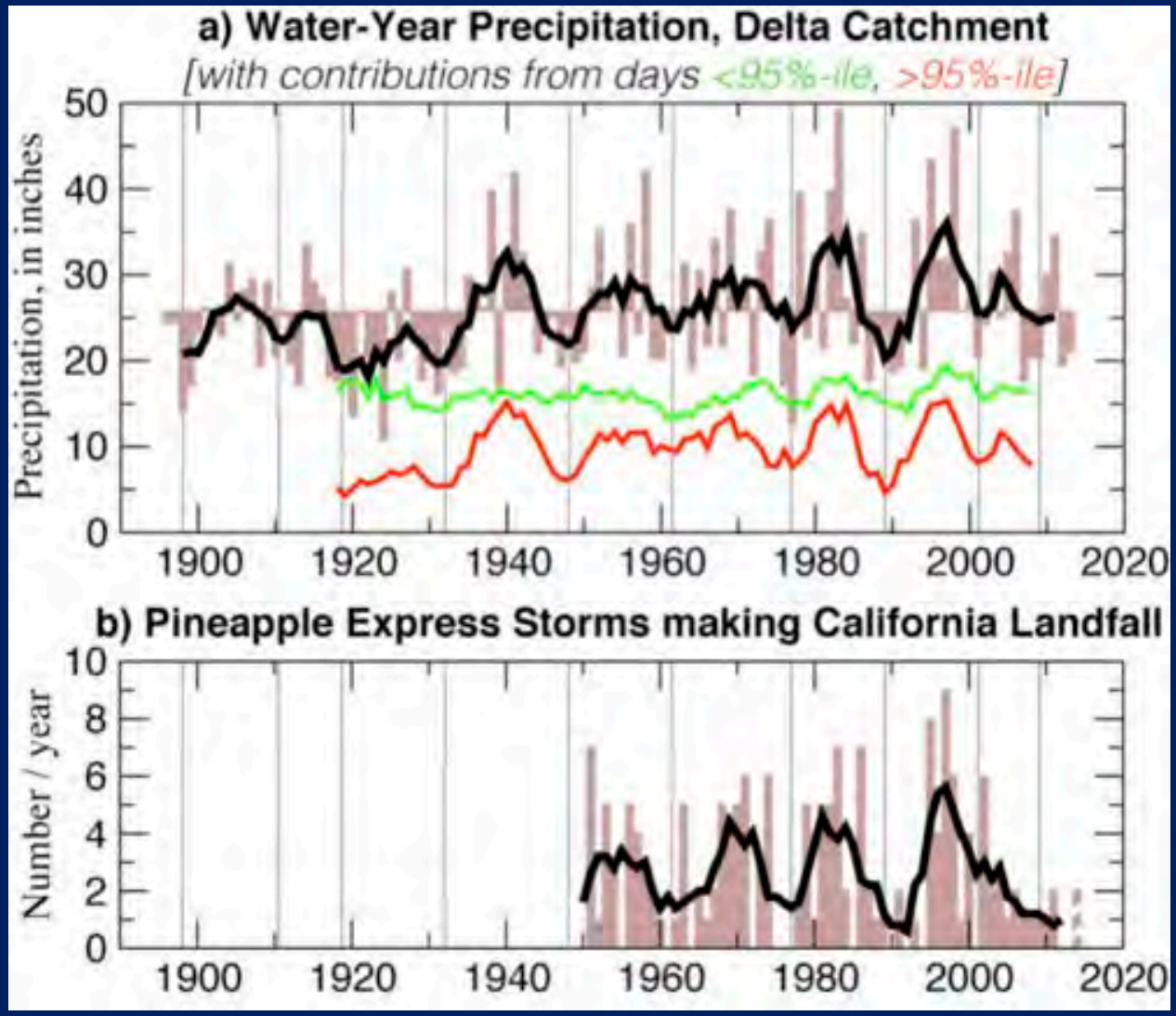


The size of an atmospheric river results from the alignment of key processes

The absence of atmospheric river activity important to drought (Dettinger and Cayan, 2014)

Slide adapted from M. Ralph

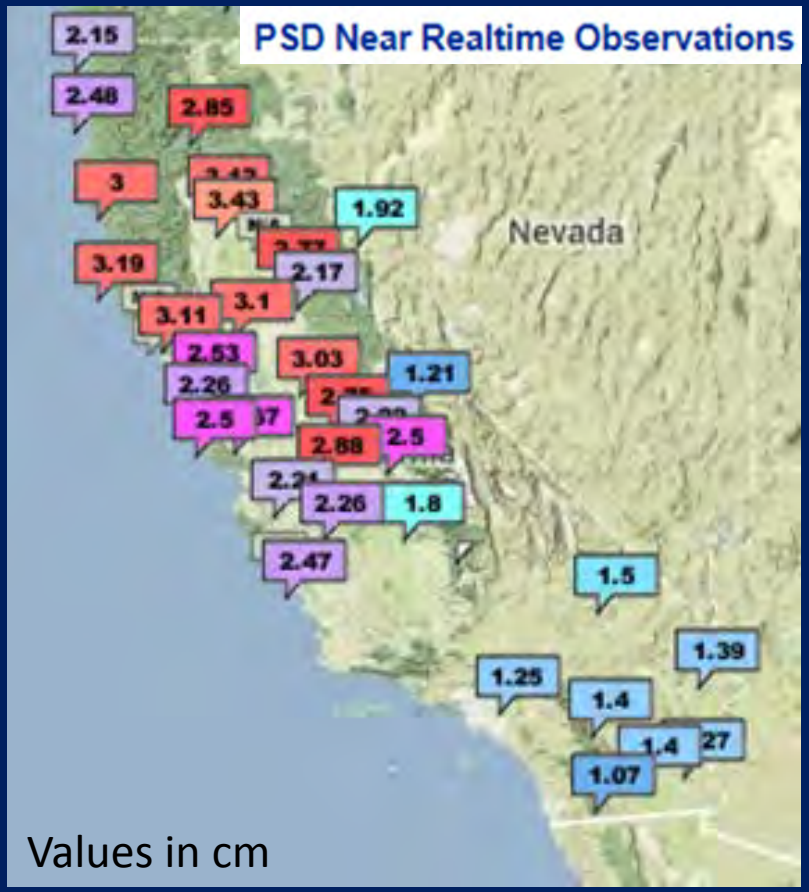
Decadal scale precipitation variability tied to atmospheric river landfall variability



Source: Dettinger and Cayan (2014)

Water vapor thresholds are important to precipitation processes

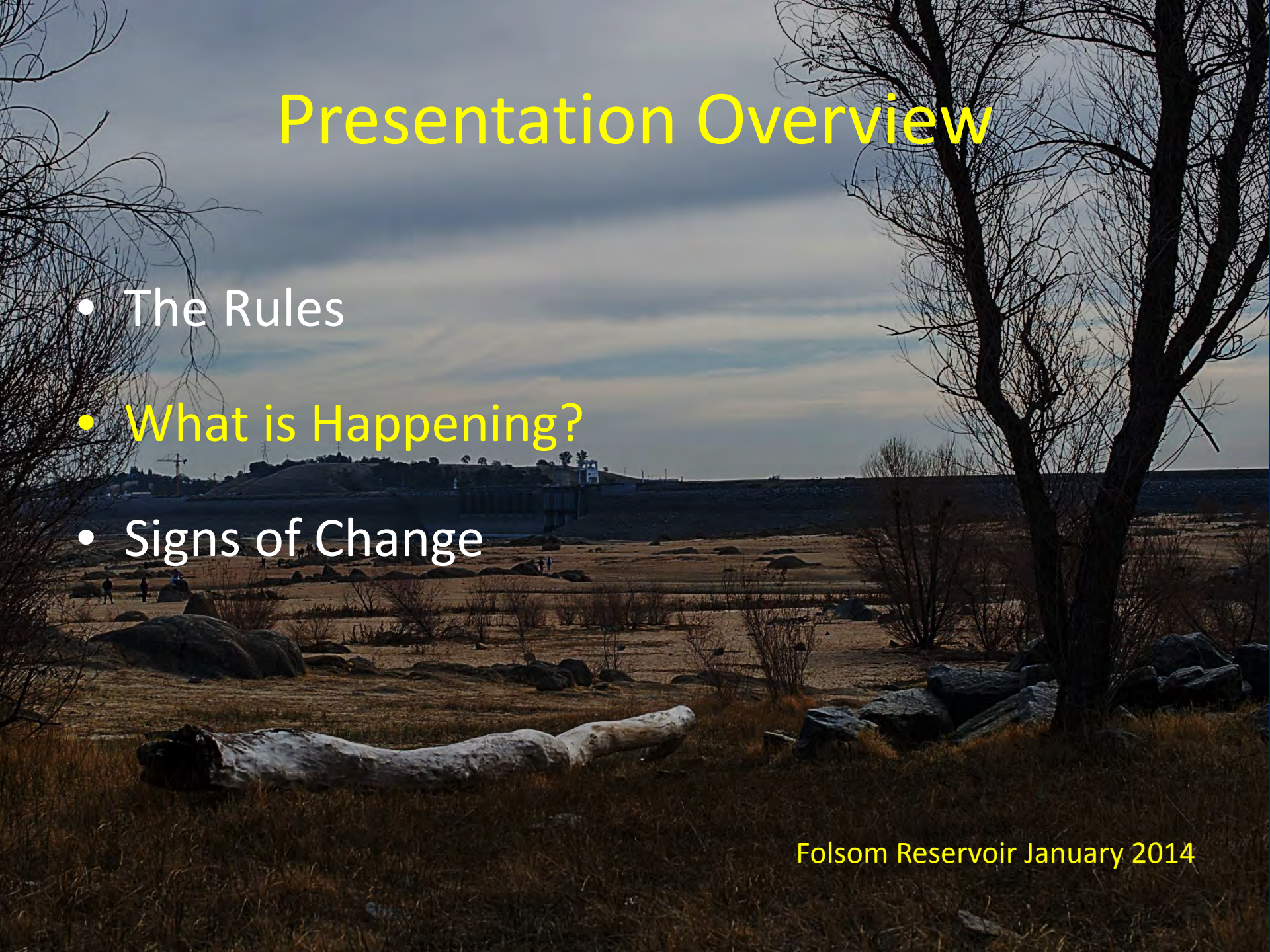
12/27/2013



1/29/2014

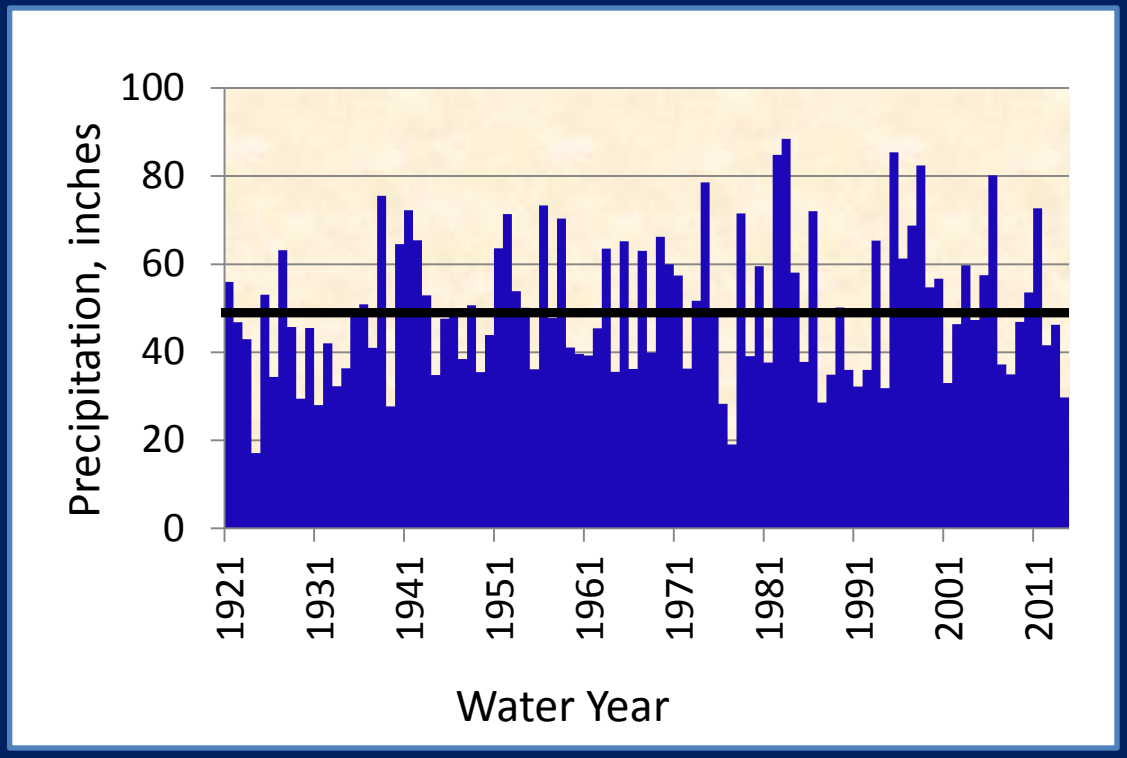
Presentation Overview

- The Rules
- What is Happening?
- Signs of Change



Folsom Reservoir January 2014

Using the Northern Sierra 8 Station Index



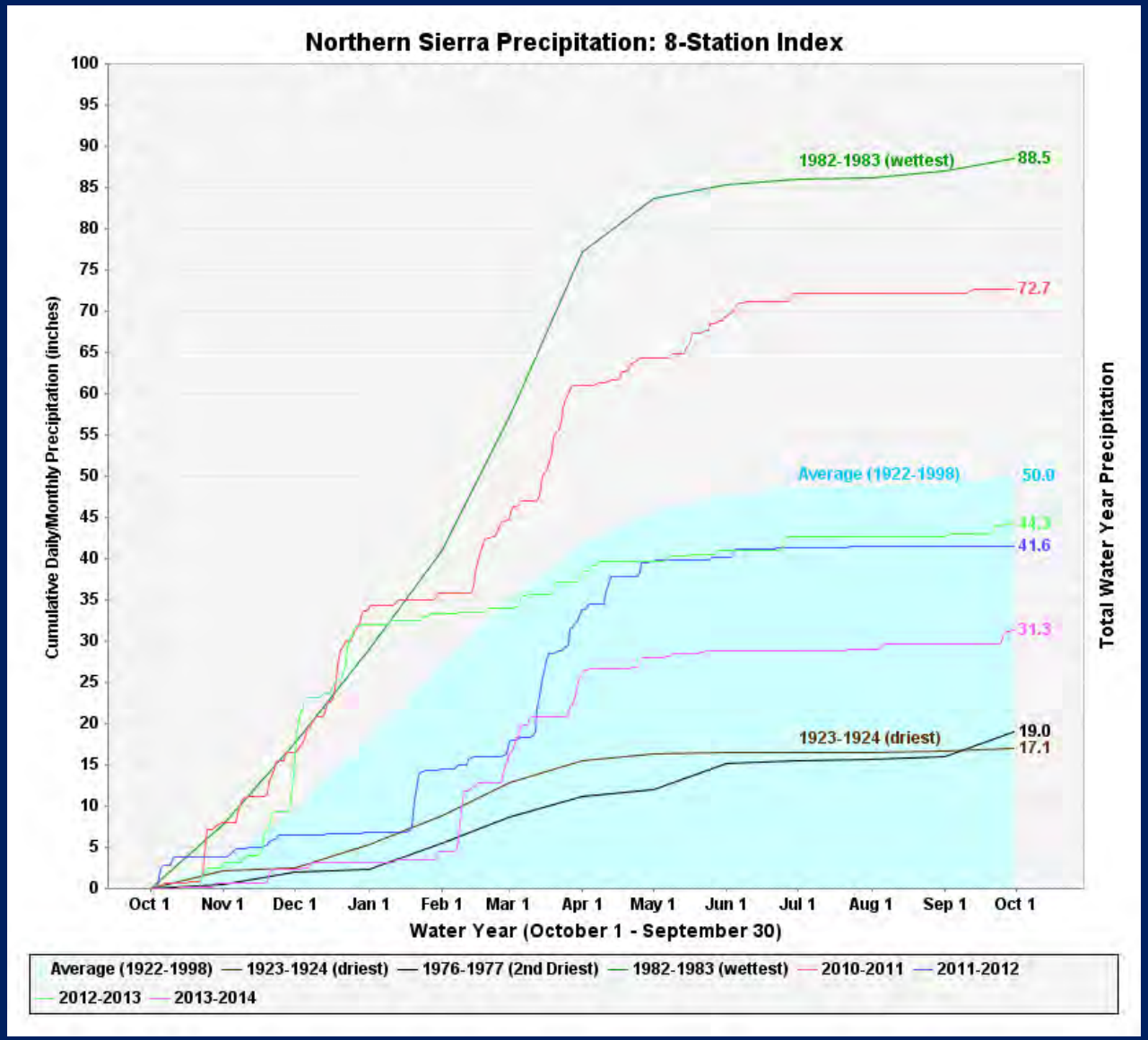
Annual Average: 50 inches
Maximum Year (1983): 88.5 inches
Minimum Year (1924): 17.1 inches
Period of Record 1921- Present

9 of 14 years of 21st Century below average

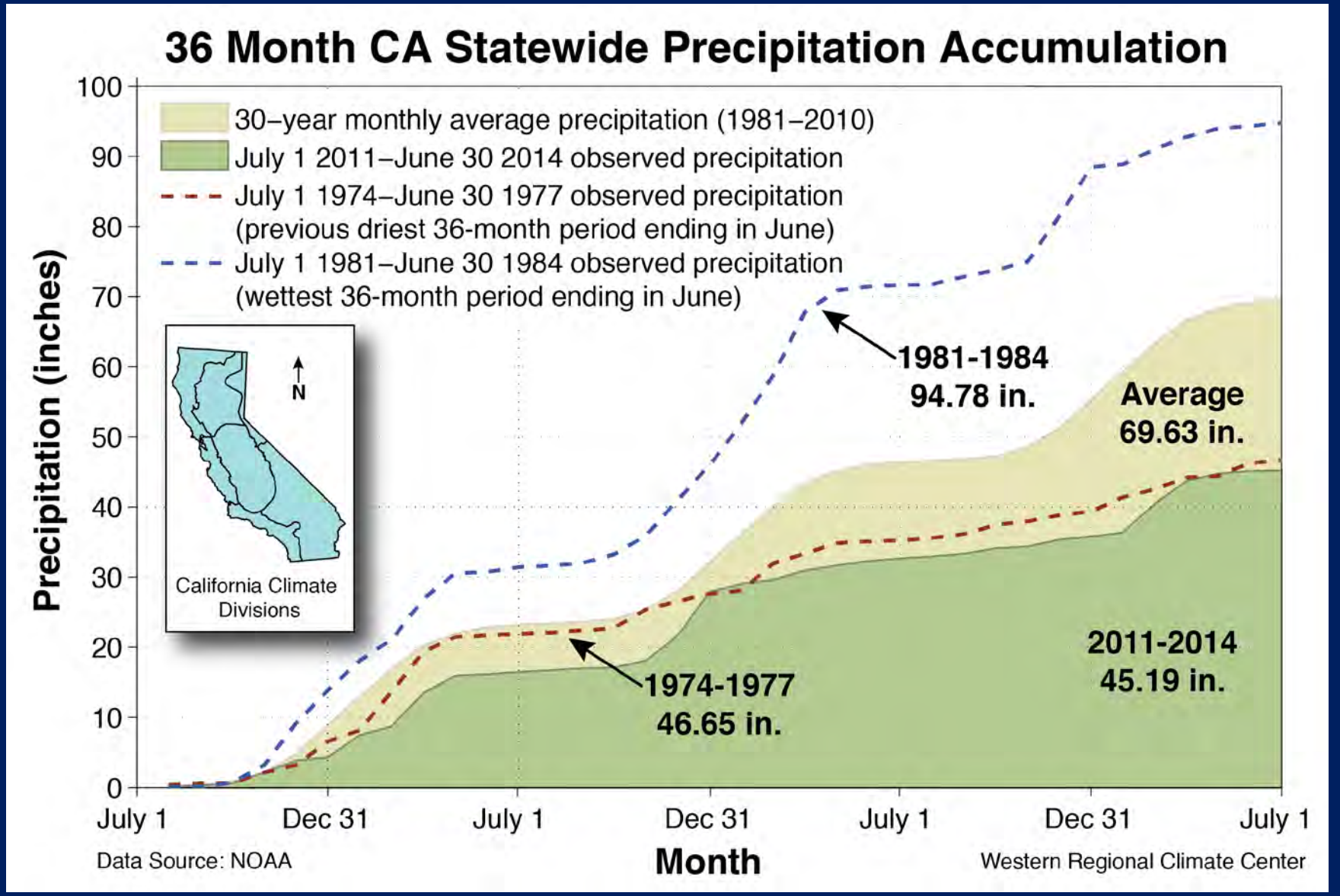
Average of:

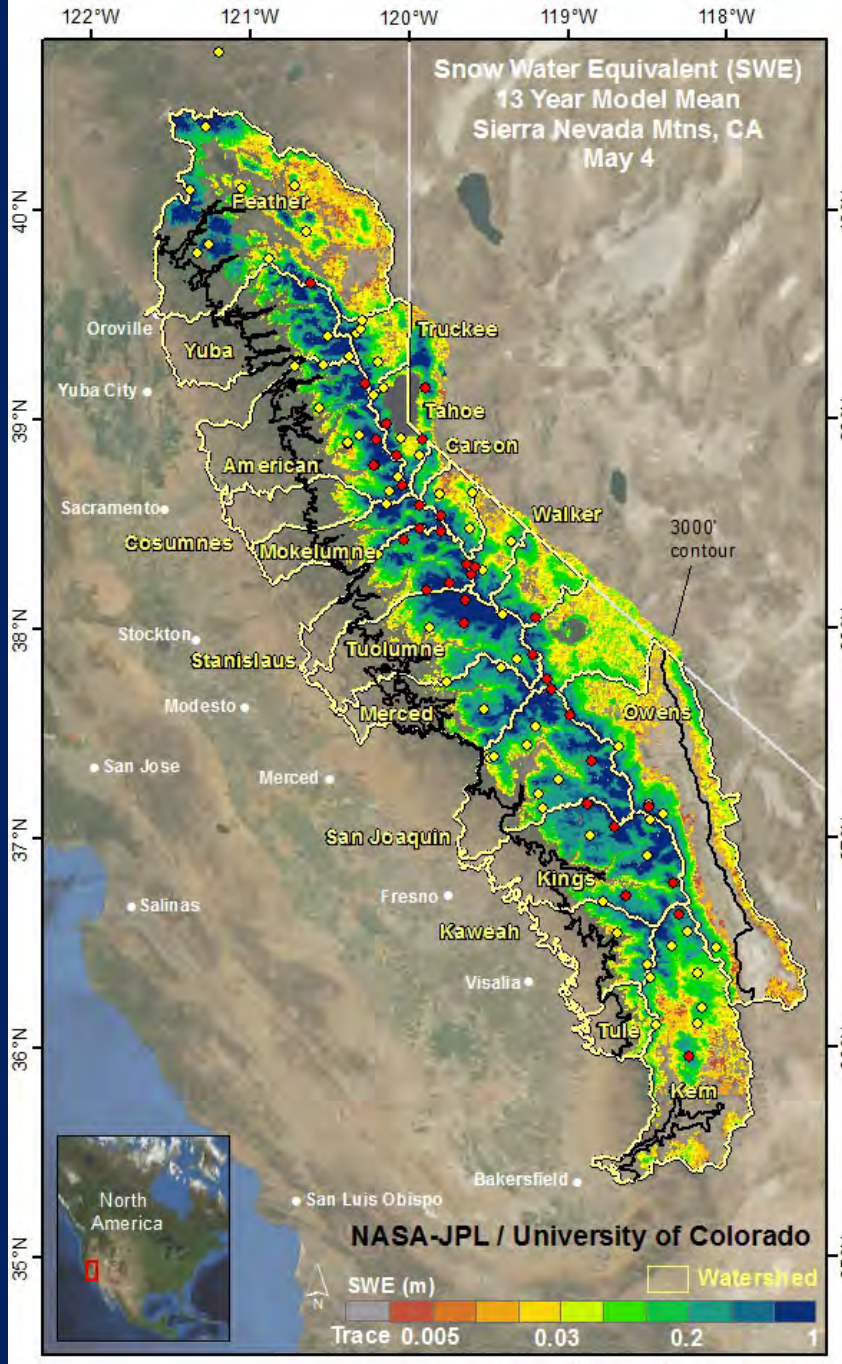
Mt. Shasta City	Quincy
Shasta Dam	Sierraville RS
Mineral	Pacific House
Brush Creek RS	Blue Canyon

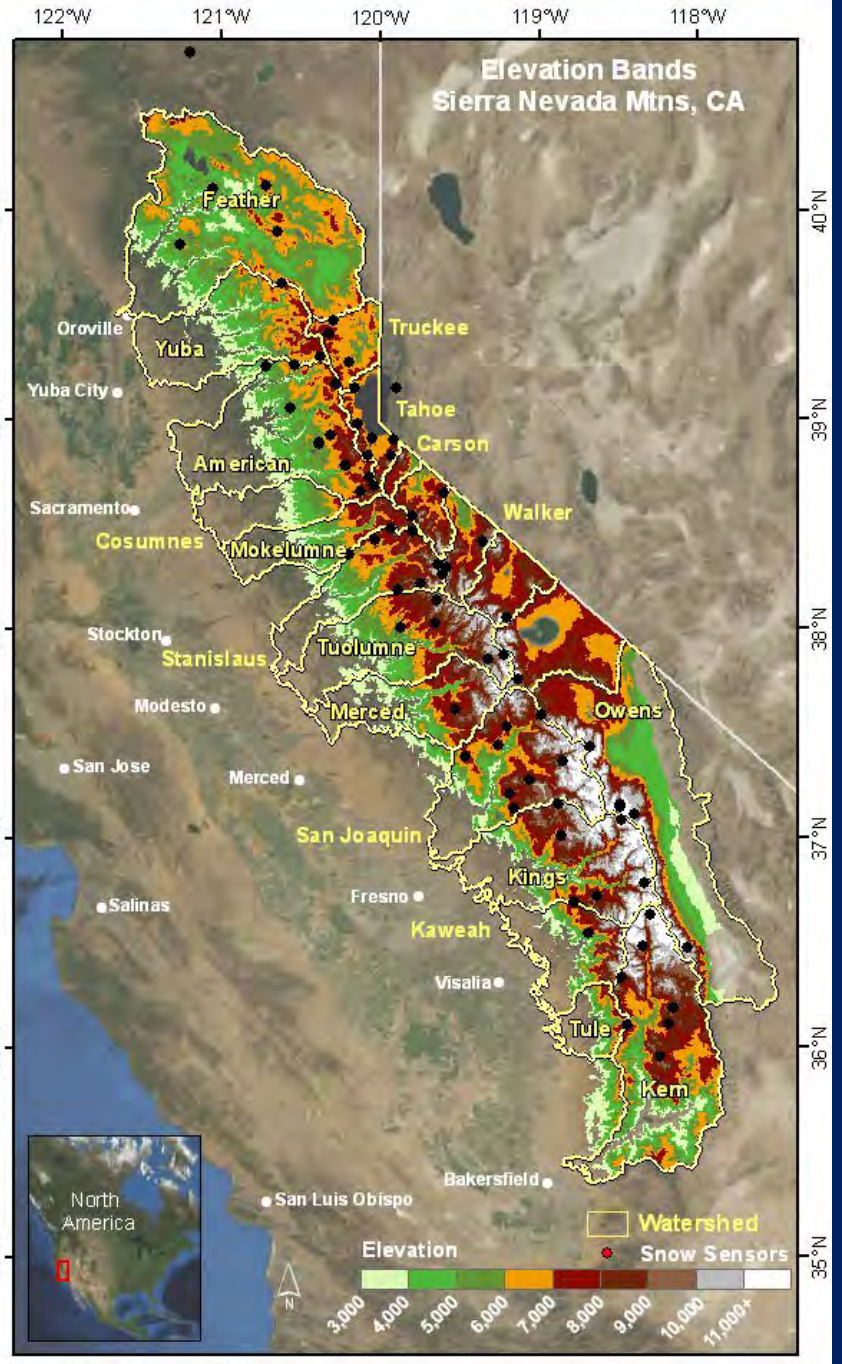
2013-14 was the 8th driest water year on record

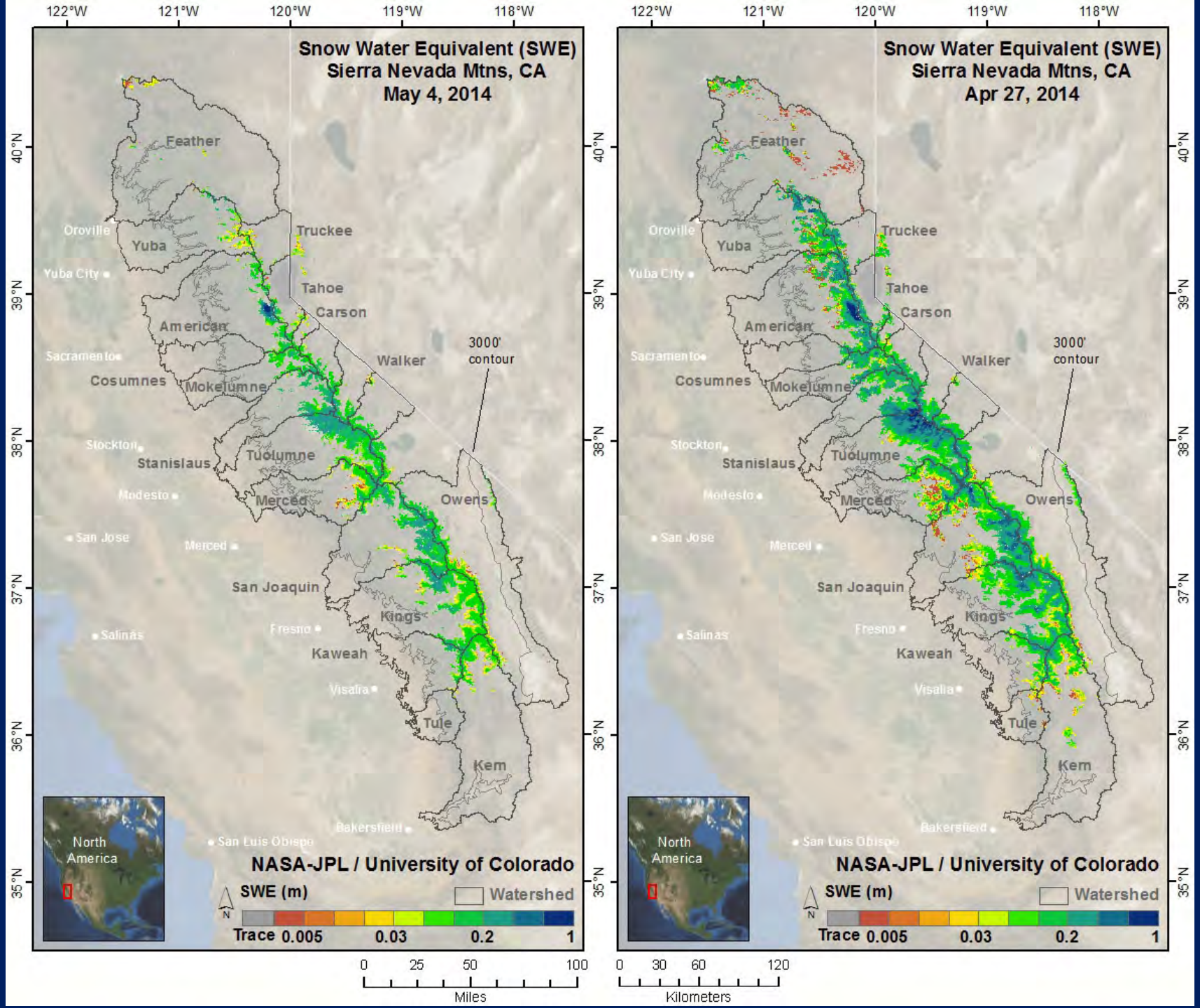


2011-2014 driest 3-Year period for CA




Snow Water Equivalent (SWE)
13 Year Model Mean
Sierra Nevada Mtns, CA
May 4
122°W
121°W
120°W
119°W
118°W
40°N
39°N
38°N
37°N
36°N
35°N
Feather
Oroville
Yuba
Yuba City
Truckee
Tahoe
Carson
American
Sacramento
Walker
Cosumnes
Mokelumne
3000' contour
Stockton
Stanislaus
Tuolumne
Modesto
Merced
Owens
San Jose
Merced
San Joaquin
Kings
Fresno
Salinas
Kaweah
Visalia
Tule
Kern
Bakersfield
San Luis Obispo
North America
NASA-JPL / University of Colorado
SWE (m)
Trace
0.005
0.03
0.2
1
Watershed
0
25
50
100
Miles


Elevation Bands
Sierra Nevada Mtns, CA
122°W
121°W
120°W
119°W
118°W
40°N
39°N
38°N
37°N
36°N
35°N
Feather
Oroville
Yuba
Yuba City
Truckee
Tahoe
Carson
American
Sacramento
Walker
Cosumnes
Mokelumne
Stockton
Stanislaus
Tuolumne
Modesto
Merced
Owens
San Jose
Merced
San Joaquin
Kings
Fresno
Salinas
Kaweah
Visalia
Tule
Kern
Bakersfield
San Luis Obispo
North America
Watershed
Snow Sensors
Elevation
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000+
0
30
60
120
Kilometers


Snow Water Equivalent (SWE)
Sierra Nevada Mtns, CA
May 4, 2014
Snow Water Equivalent (SWE)
Sierra Nevada Mtns, CA
Apr 27, 2014
122°W
121°W
120°W
119°W
118°W
40°N
39°N
38°N
37°N
36°N
35°N
Feather
Oroville
Yuba
Yuba City
Truckee
Tahoe
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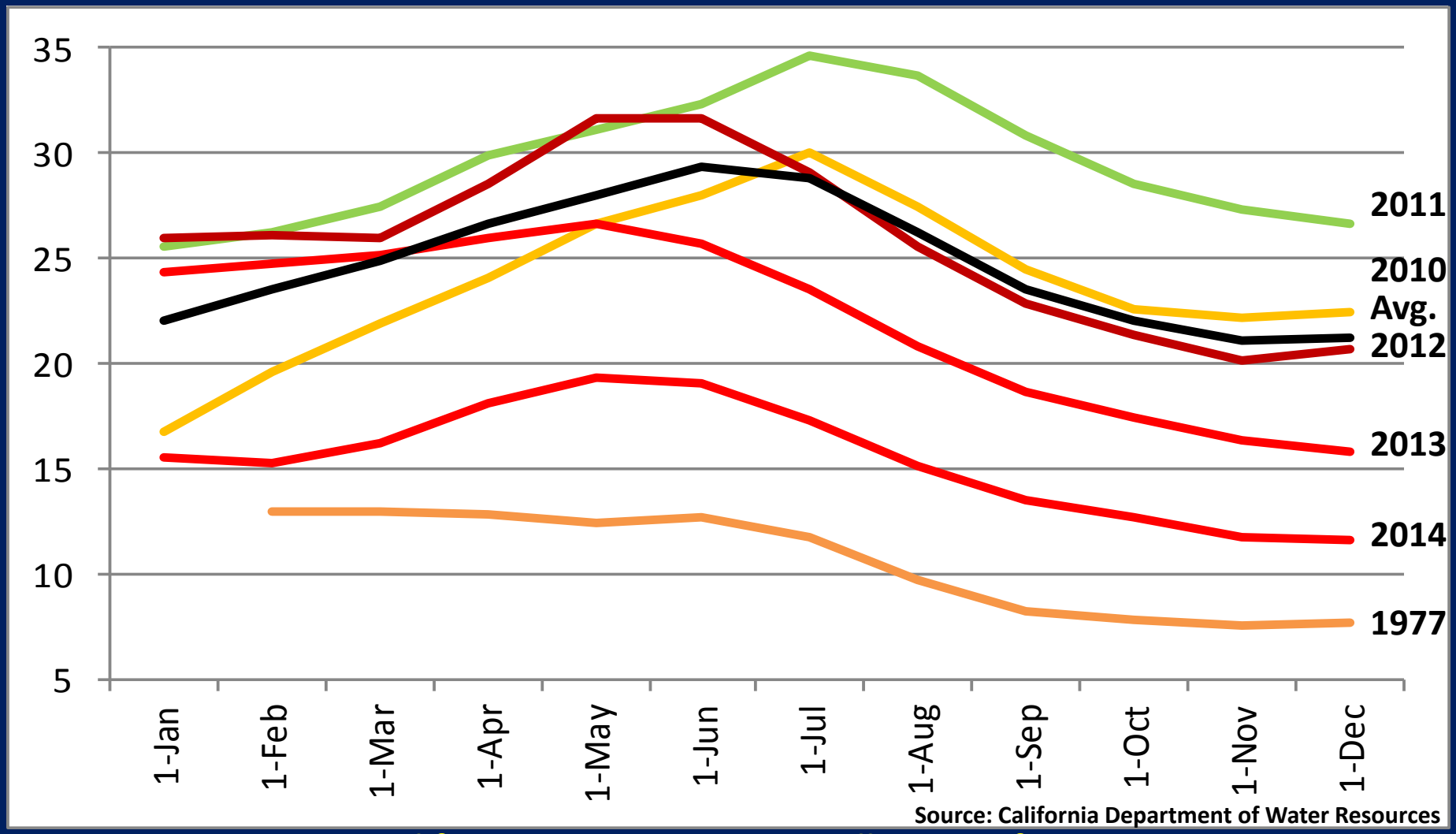
Kings
Fresno
Salinas
Kaweah
Visalia
Tule
Kern
Bakersfield
San Luis Obispo
North America
NASA-JPL / University of Colorado
SWE (m)
Watershed
Trace
0.005
0.03
0.2
1
0
25
50
100
Miles
0
30
60
120
Kilometers

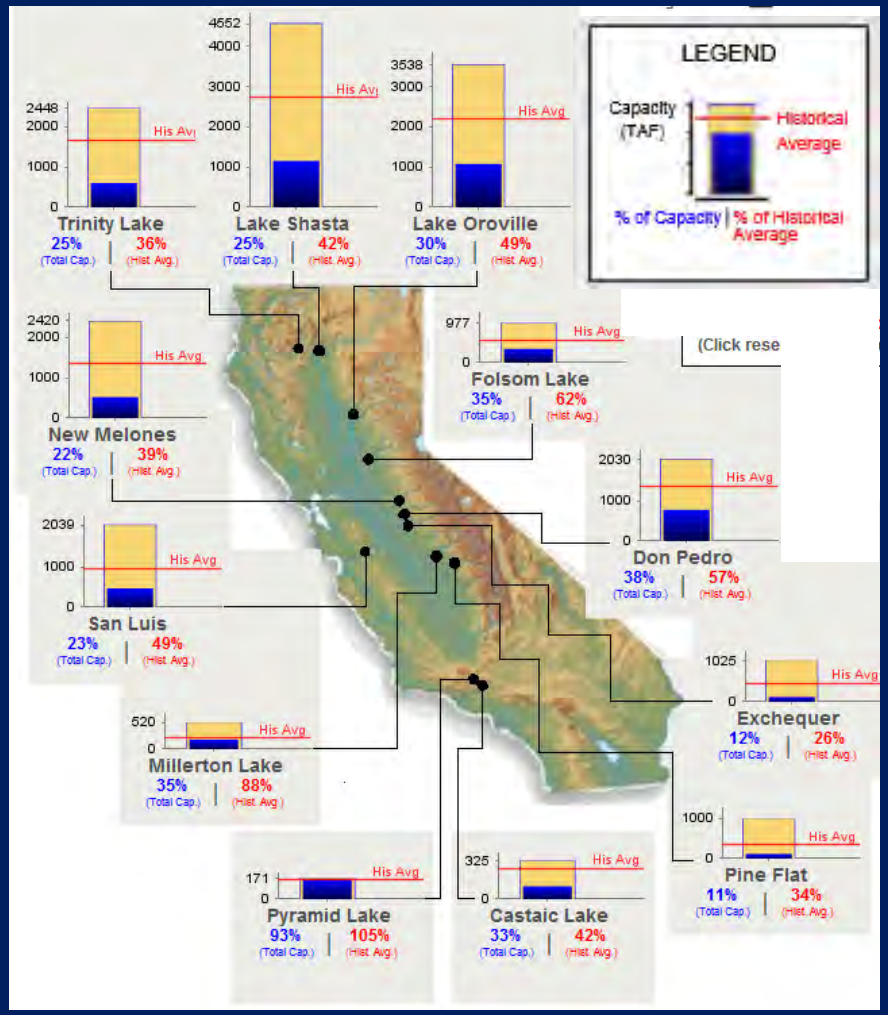
Surface reservoir storage since 2010



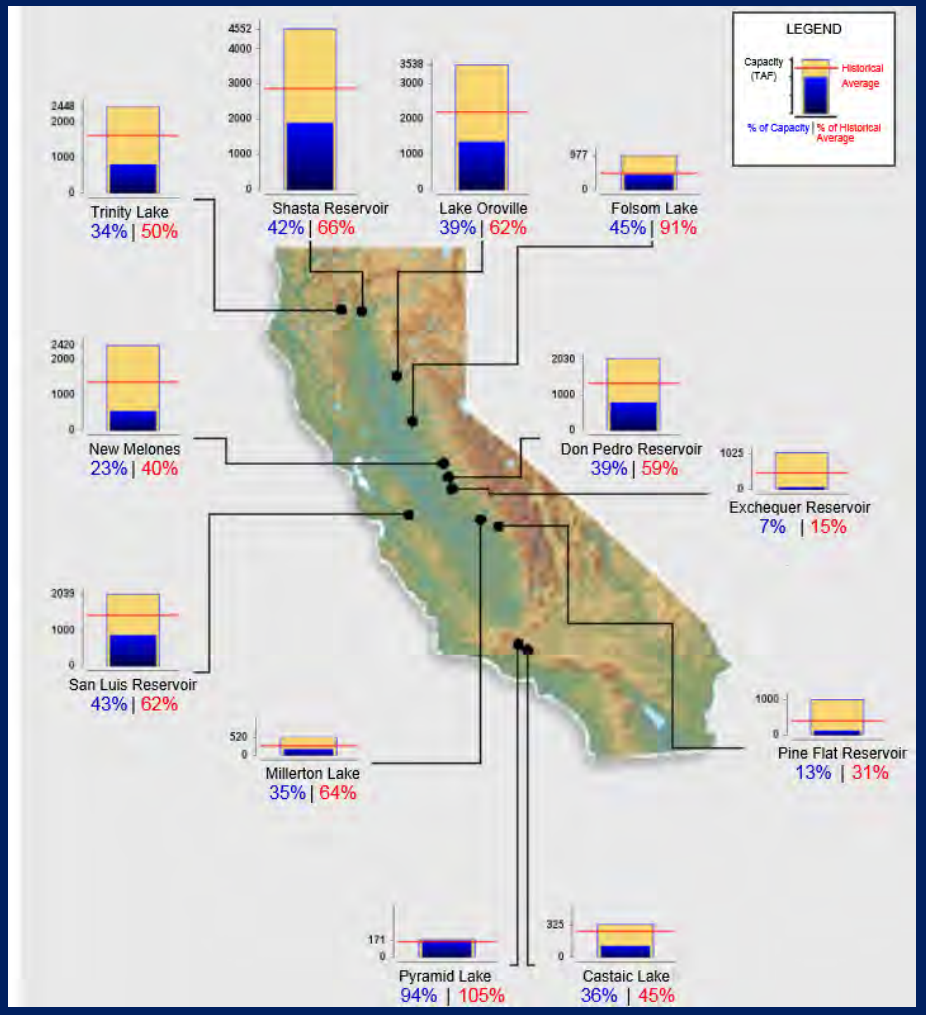
California reservoir storage, million acre-feet

Slide from B. Rippey, USDA

Recent rains have helped, but most reservoirs are still below average



October 2014



January 2015

Source: DWR, California Data Exchange Center

Presentation Overview

- The Rules
- What is Happening?
- Signs of Change

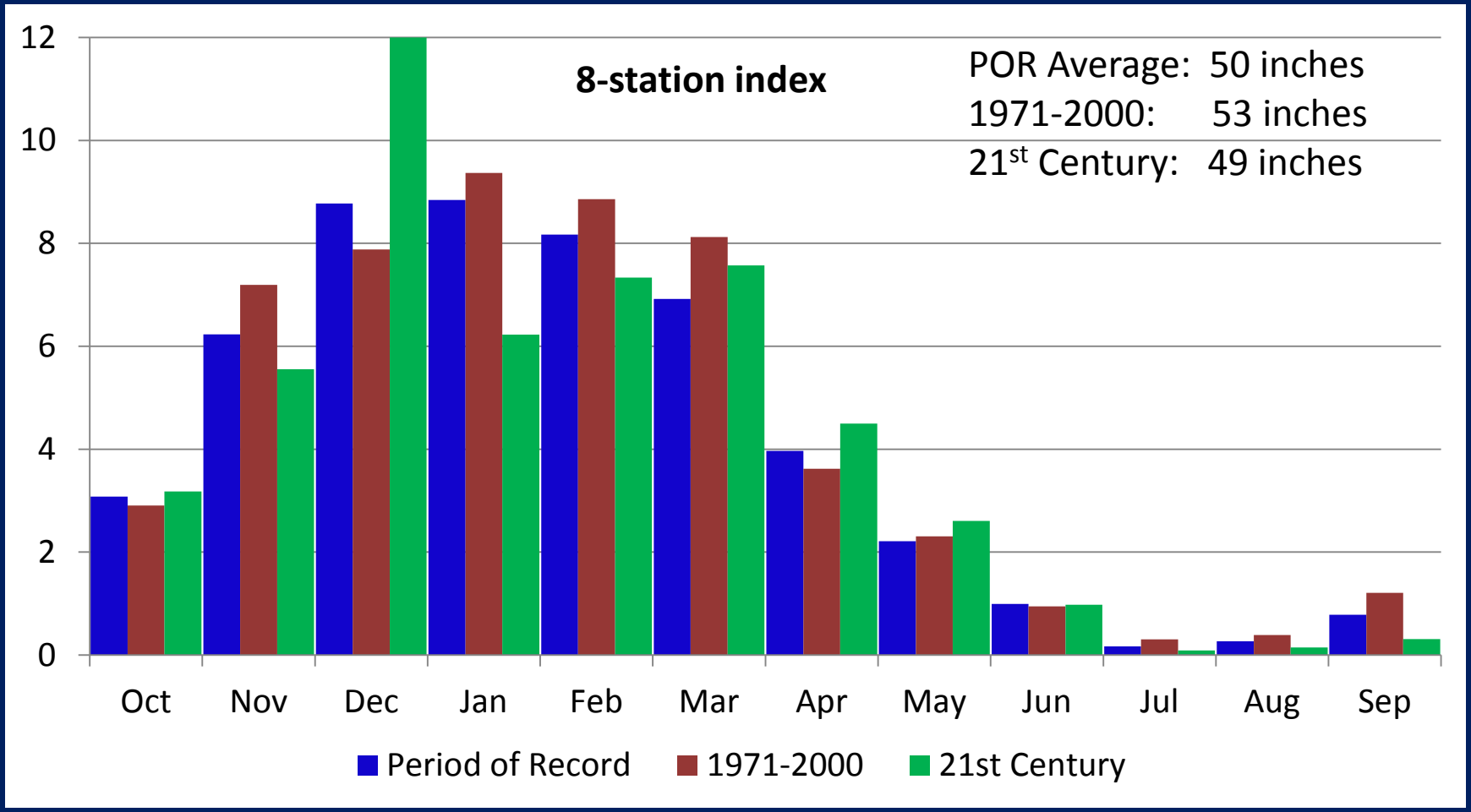
Tenaya Lake

Climate change expectations

- Warmer temperatures
- Smaller snowpack/more rain, less snow
- Earlier snowmelt onset
- More variability
- More extremes

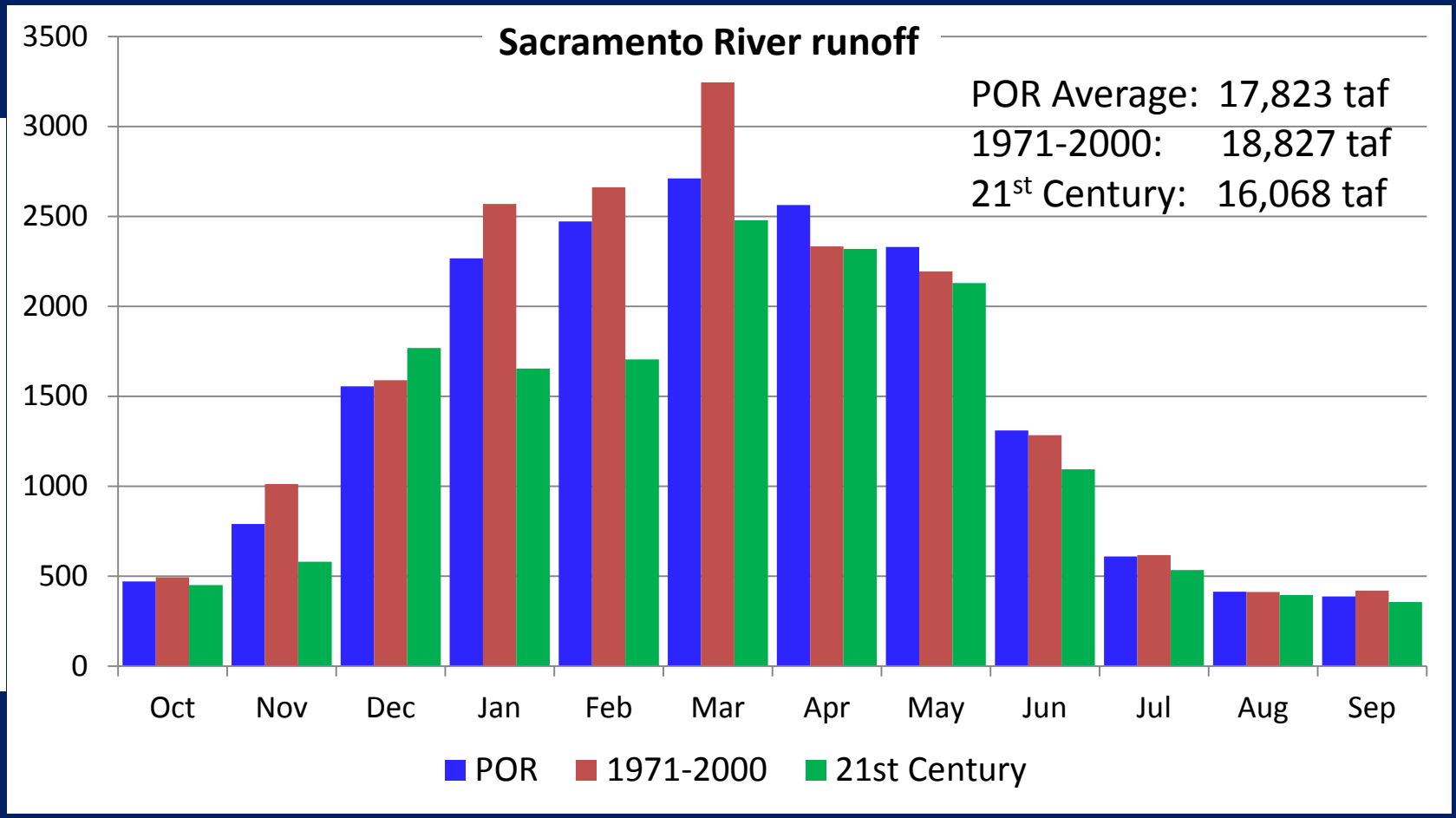
Are we seeing these already?

21st Century breakdown so far: A lot of variability

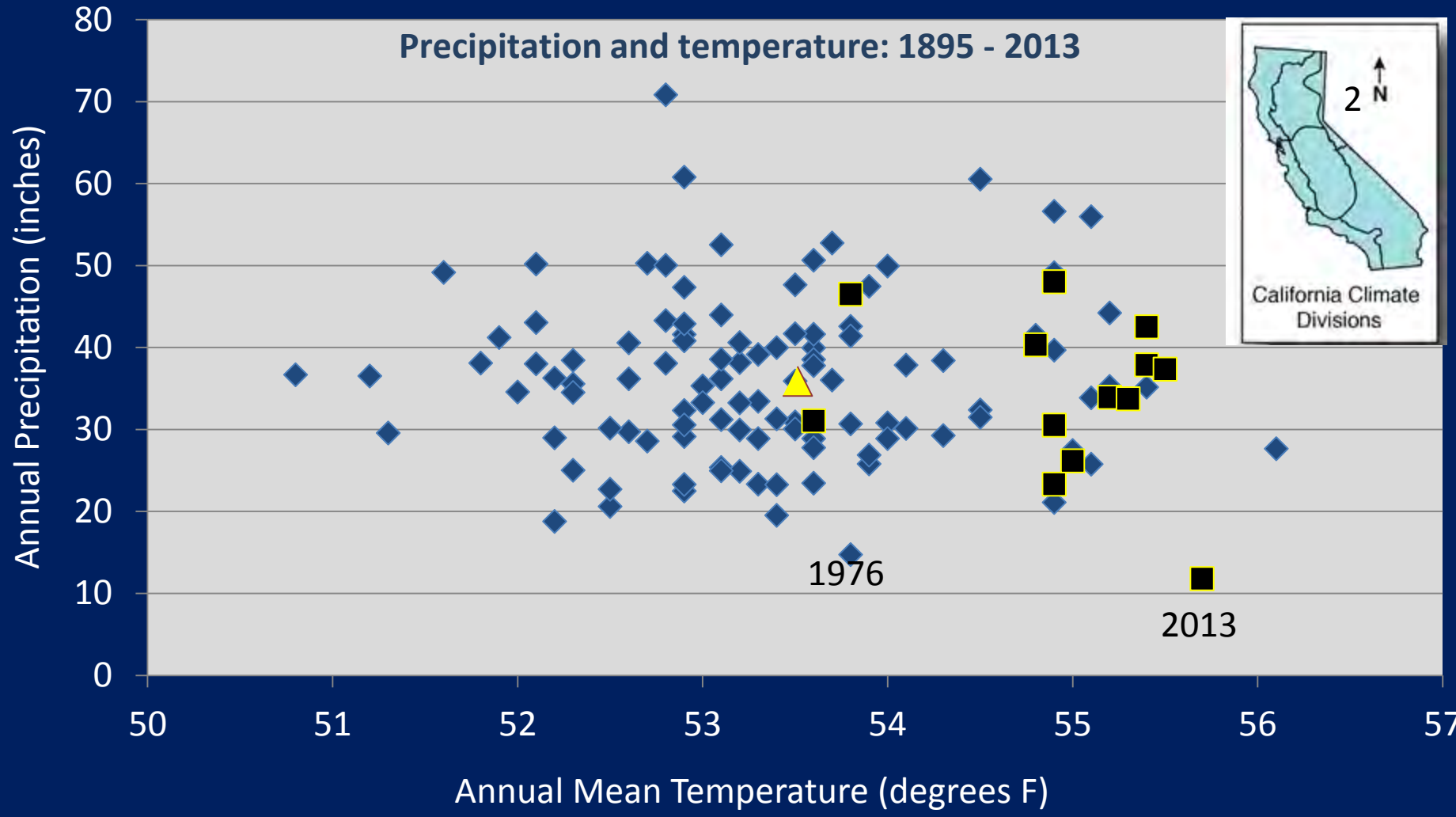


Note WY 2012 was 3rd driest December (0.34”) and WY2014 was 4th driest (0.80”)

Variability also evident in Sacramento River runoff

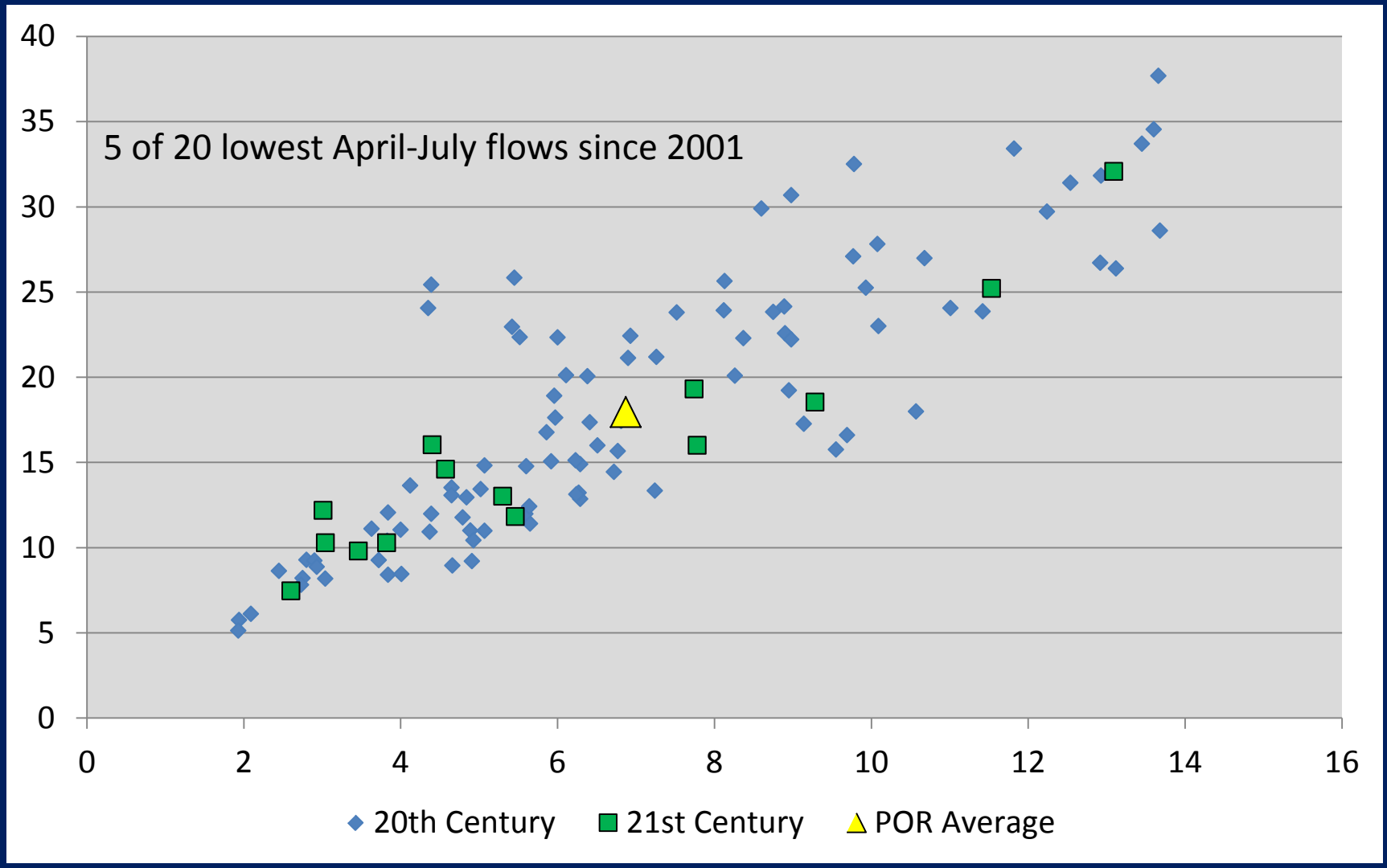


It's getting warmer, which increases the impact of droughts

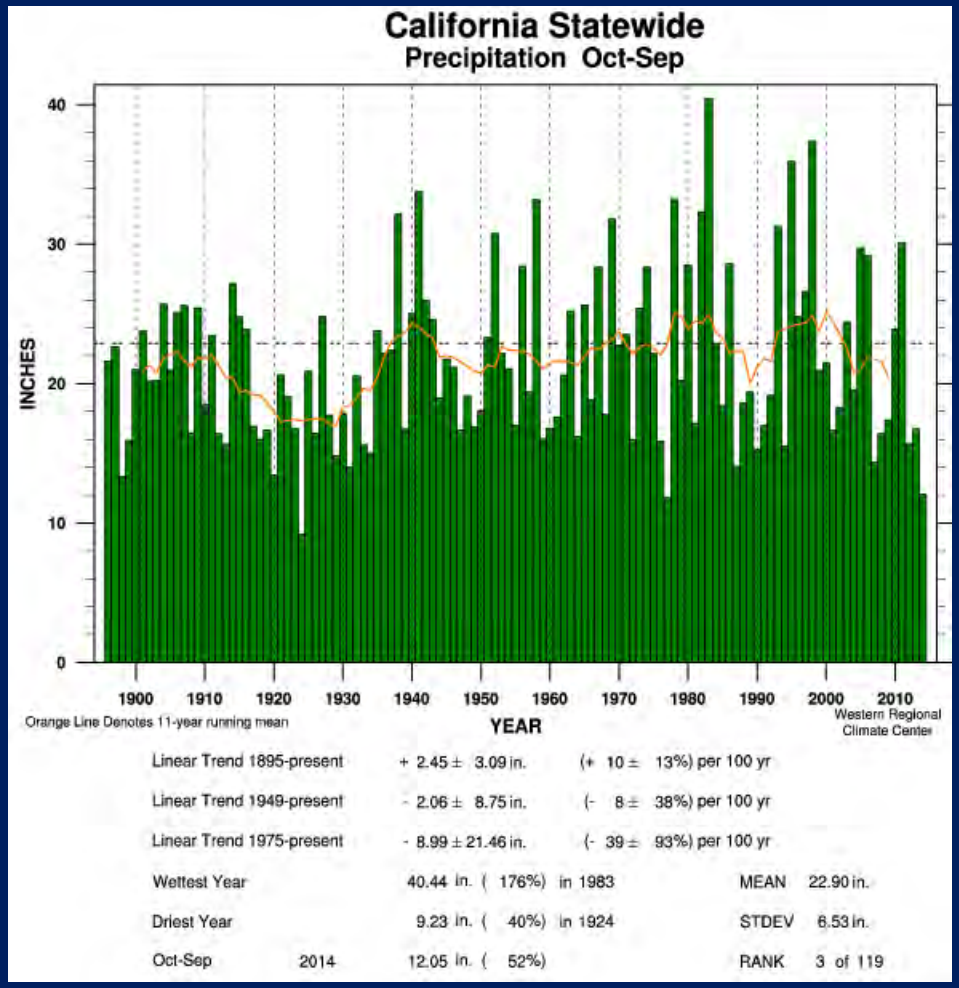


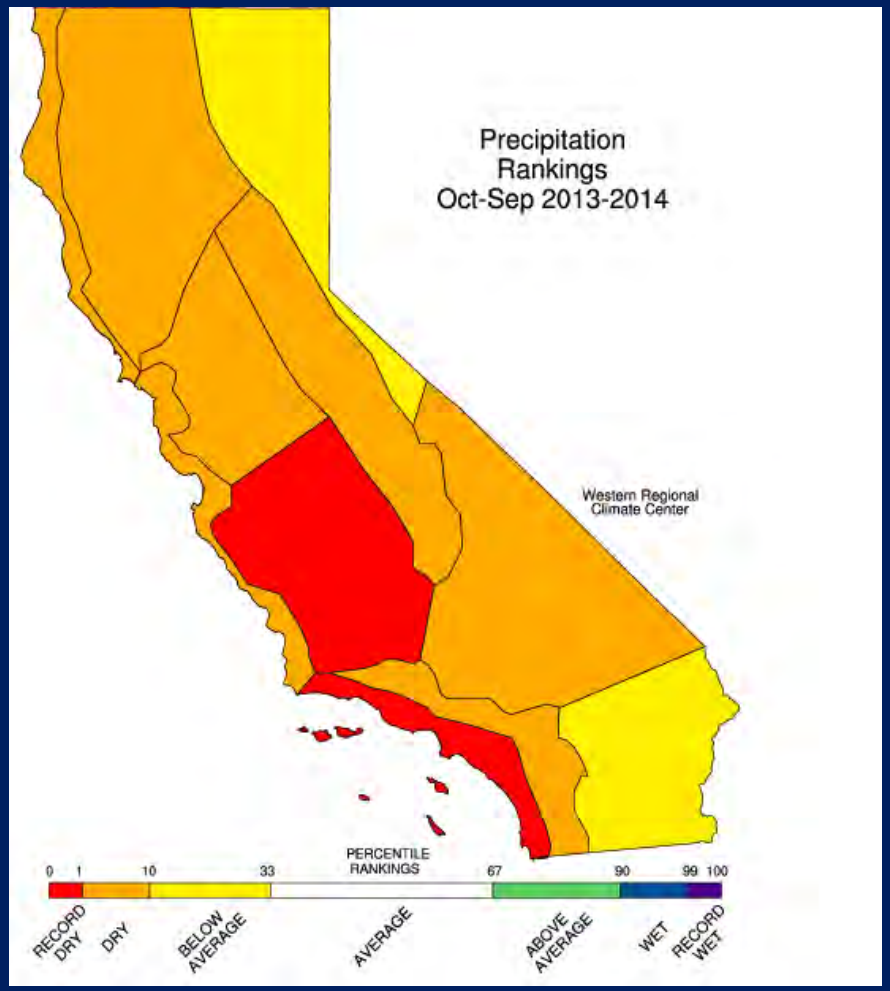
Source: NOAA Climate Division 2 Calendar Year Data

21st Century droughts on the Sacramento River



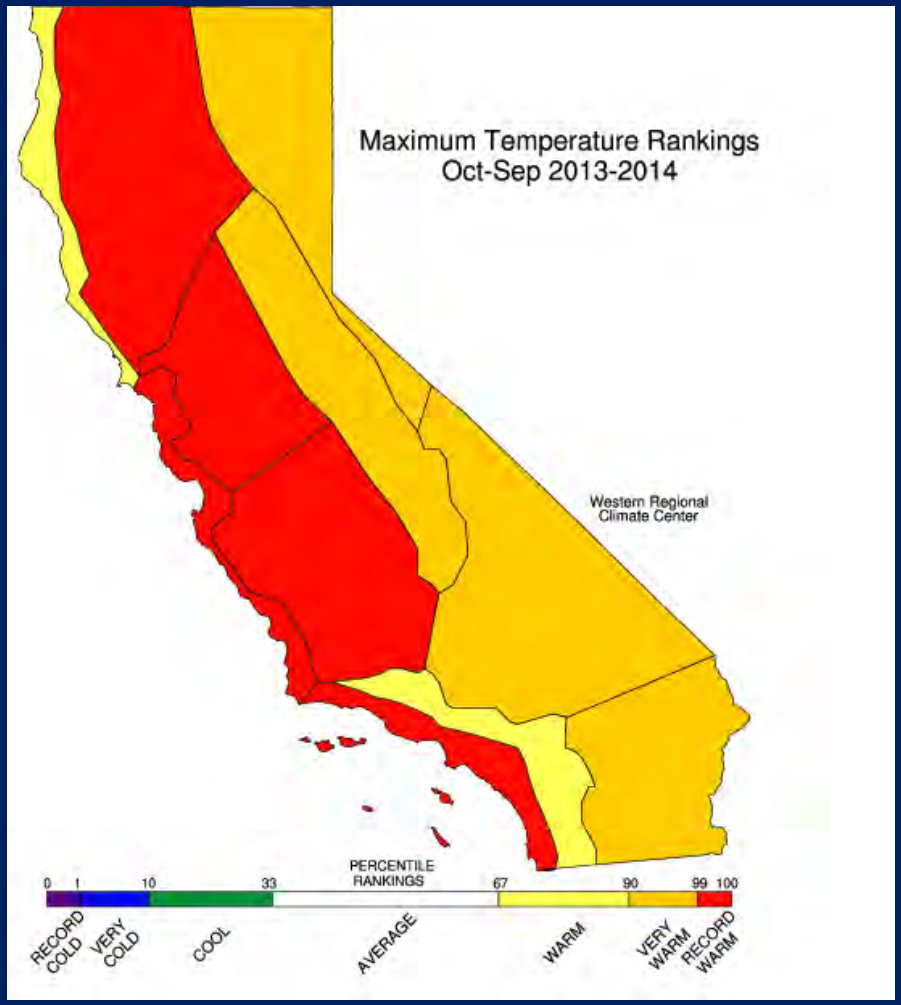
Western Region Climate Center's CA Climate Tracker: A way to track change

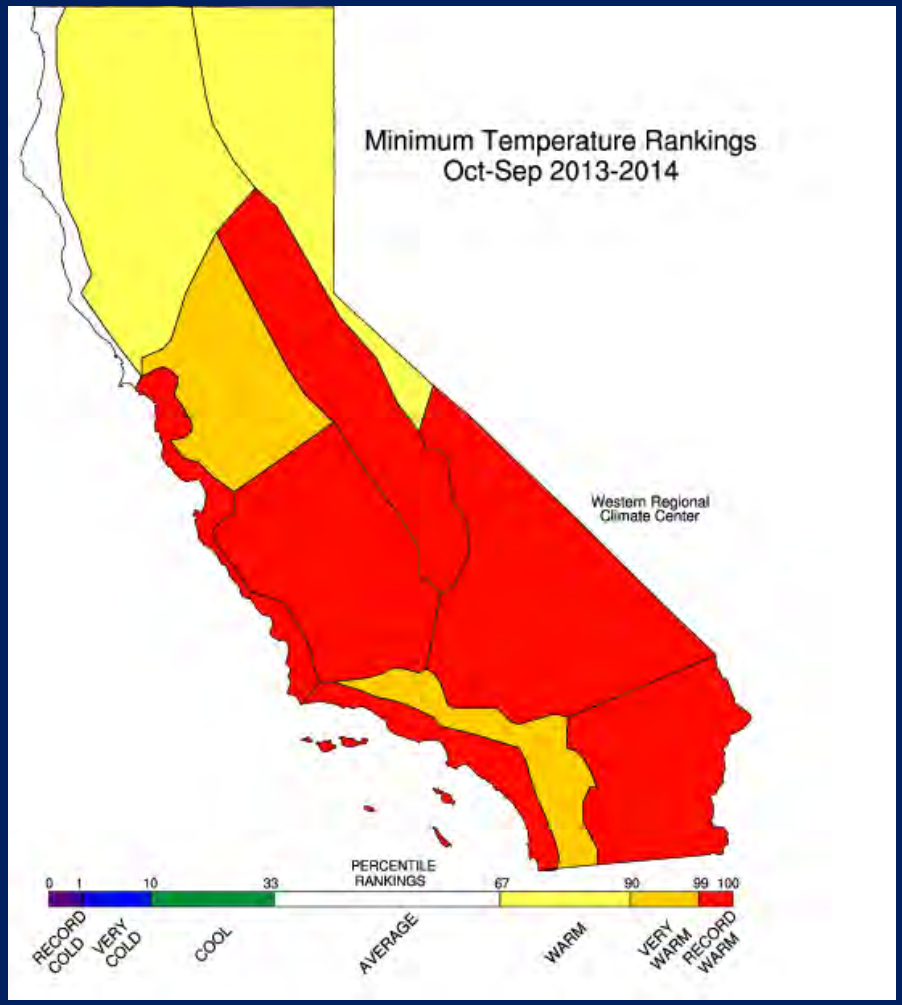




Source: California Climate Tracker - WRCC

Spatial representation of temperature rankings for water year 2014





Source: California Climate Tracker - WRCC

Summarizing thoughts

- Current drought and other 21st Century droughts have shown record-setting characteristics and are warmer than 20th Century counterparts.

- Atmospheric river events provide significant inputs into annual precipitation totals. There are fewer such events in drought years, and characteristics of atmospheric events will change with climate change.

Summarizing thoughts

- Planning for future droughts can take advantage of information in the historical record, including paleo reconstructions. The trick will be to increase our understanding of causal mechanisms and watershed condition/response over different time scales.

- Averages are not so useful anymore.
  We need to understand variability and process.

Lessons from Australia's Millennium Drought

National Water Commission

UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

Professor Jane M Doolan

Outline

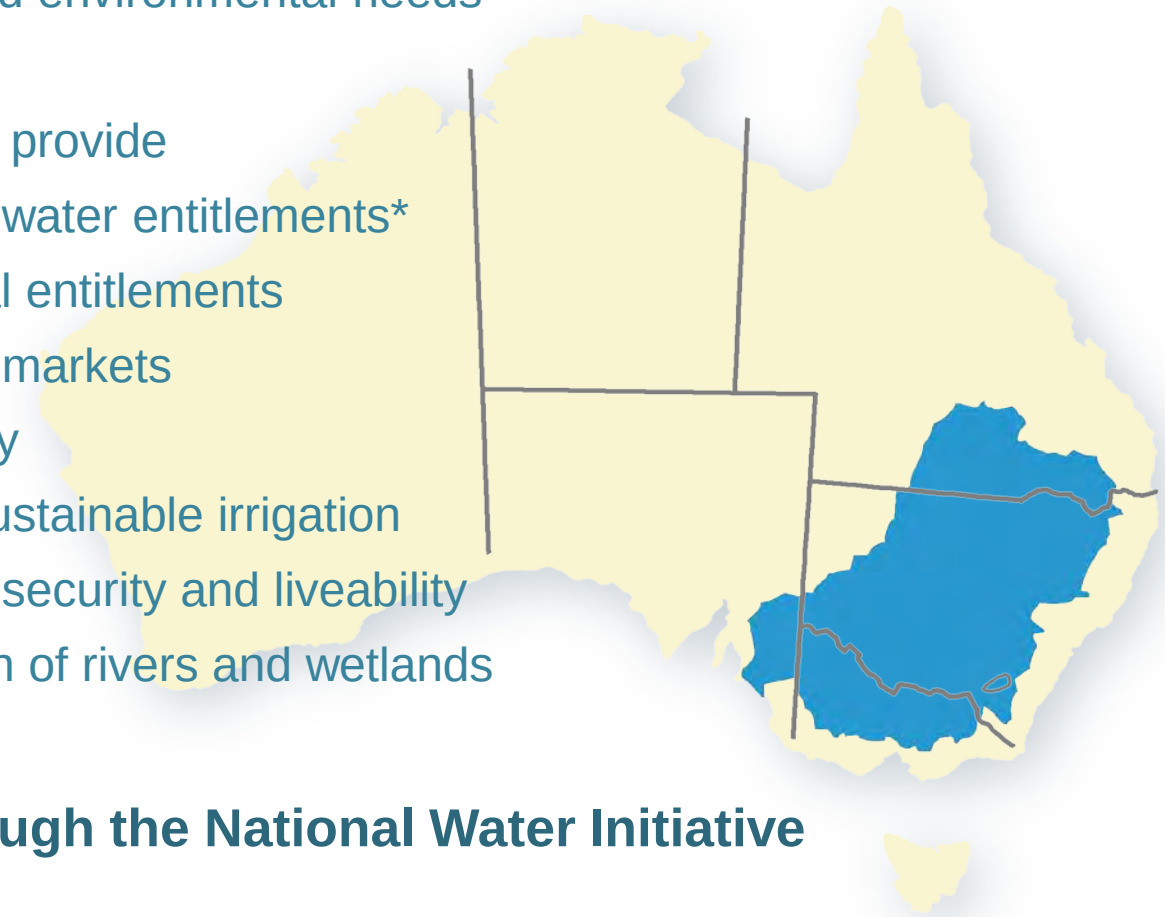
- Policy context
- Millennium Drought
  - The prospect of things to come
- Key policy responses
  - Water allocation
  - Urban
  - Rural
  - Environment
- After the drought

20 years of water reform in Australia

20 years of water reform in Australia

Goal: Effective management of water resources to meet future urban, rural and environmental needs

- Water planning to provide
  - Clear, secure water entitlements*
  - Environmental entitlements
- Functioning water markets
- Focus on efficiency
  - High-value, sustainable irrigation
  - Urban supply security and liveability
- Improved condition of rivers and wetlands



Implemented through the National Water Initiative

** water entitlements = water rights in California*

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Millennium Drought in SE Australia

- 1997 to 2009: Longest, most severe on record
- Equivalent to ‘worst case’ 2050 climate change scenario

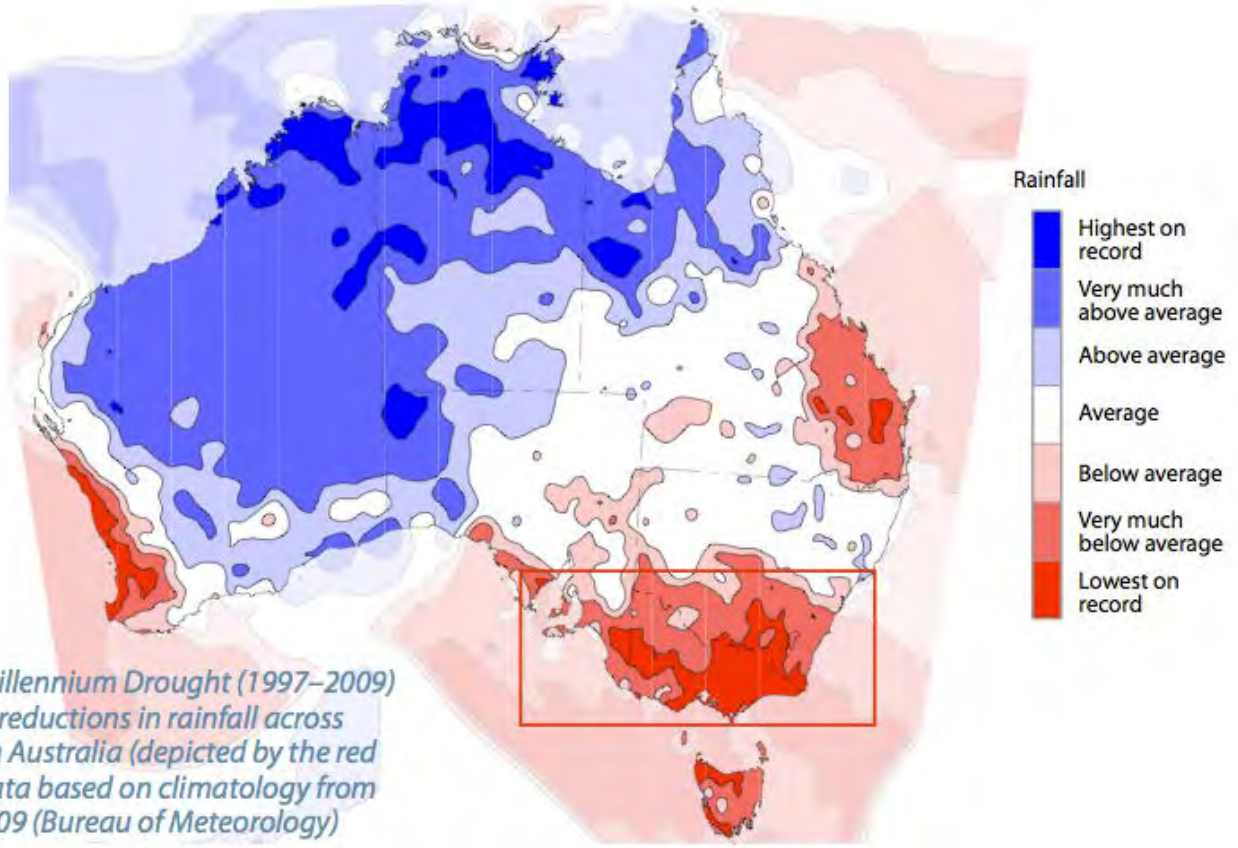
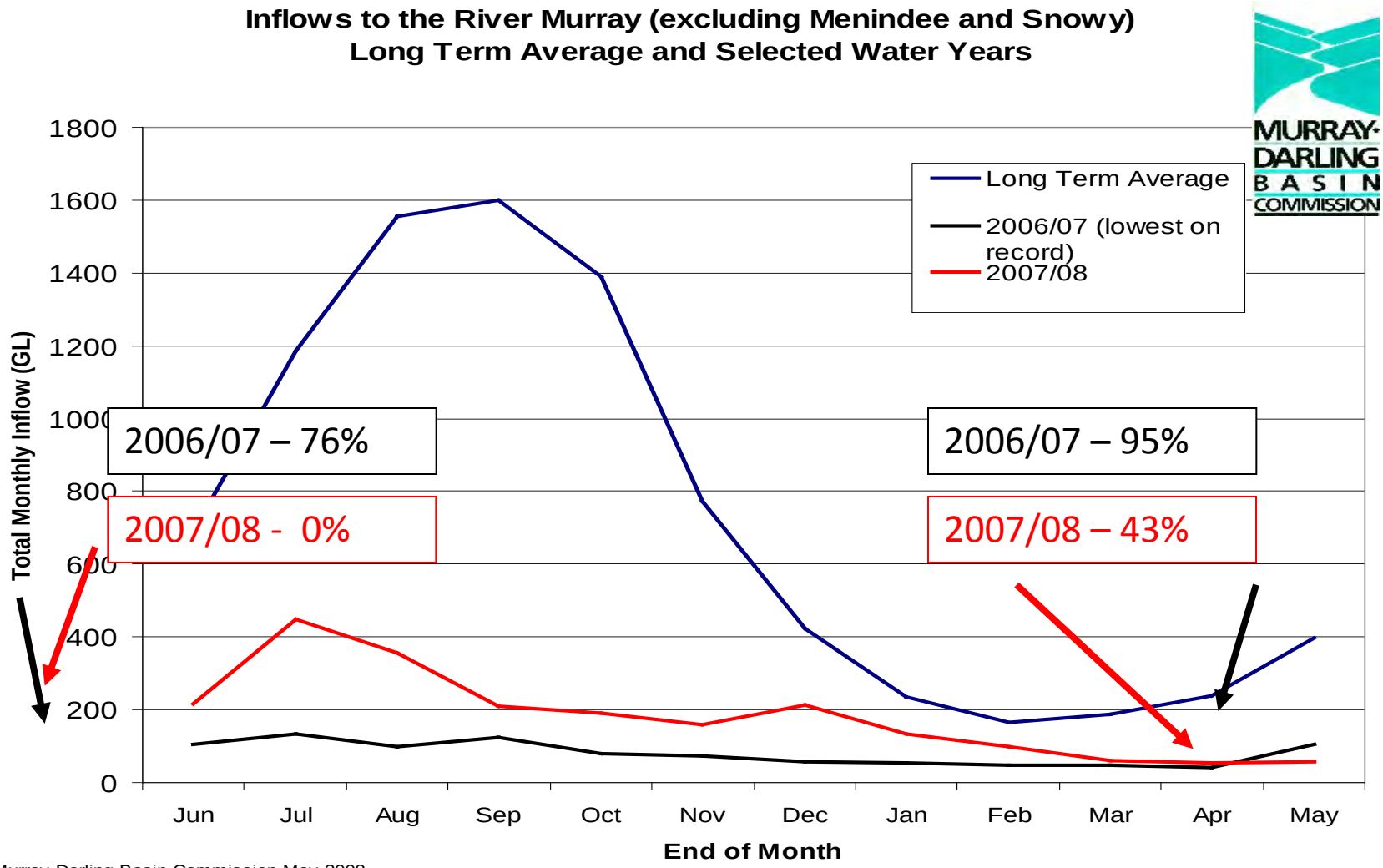


Figure 1. The Millennium Drought (1997–2009) saw major reductions in rainfall across south-eastern Australia (depicted by the red rectangle). Data based on climatology from 1900 to 2009 (Bureau of Meteorology)

Inflows and allocations in the Murray River



Urban and agricultural impacts

- Urban
  - Water restrictions limited to ***indoor only use***
  - Water carting to many small rural communities
- Irrigated Agriculture
  - Irrigation allocations: 0% -10%
  - 2002 – 2009
    - Rice 99% ↓
    - Cotton 84% ↓
    - 1/3 all vines sacrificed
  - Health impacts, foreclosures, suicides
- Economy
  - 2006-07: loss of ~1% of GDP
  - 2006-09: loss of 6,000 jobs in Murray region

Environmental impacts

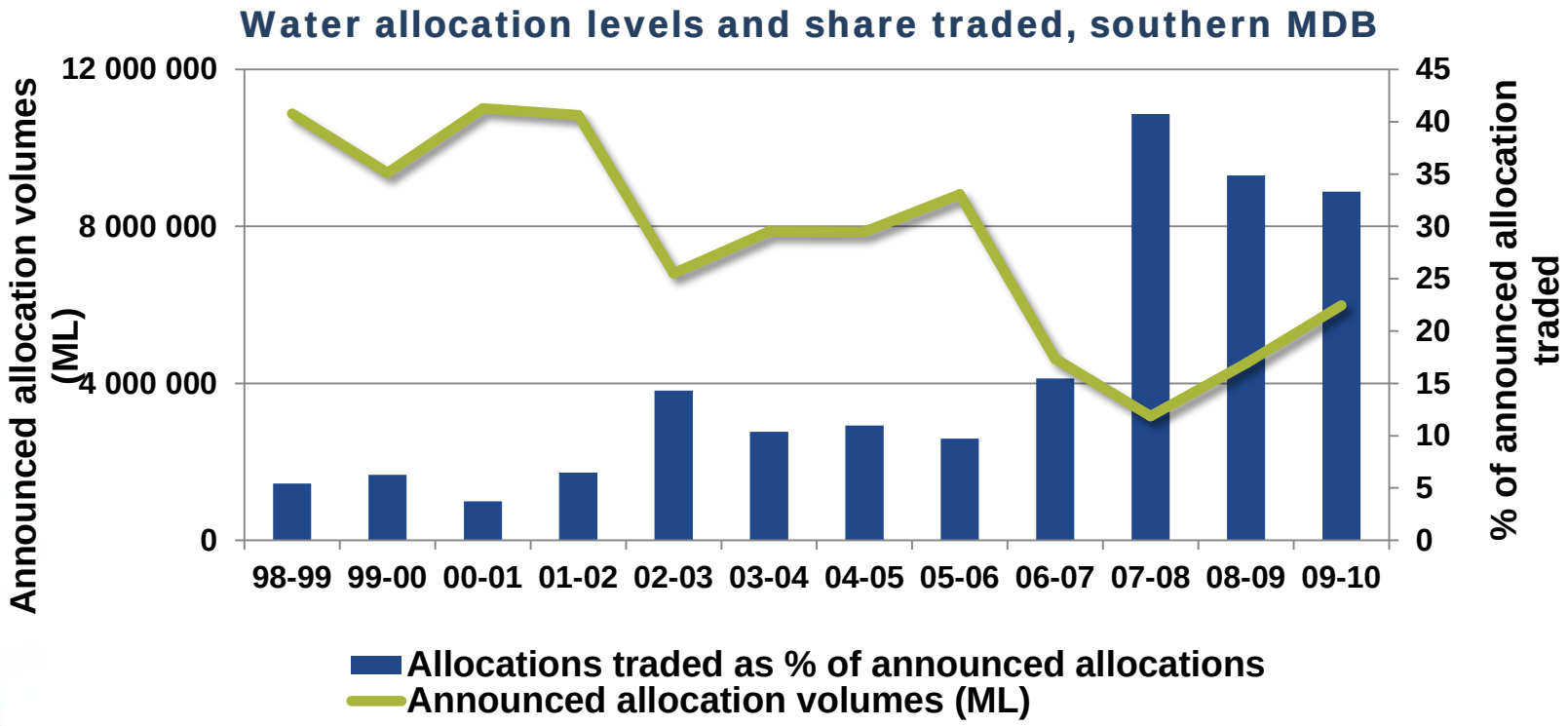
- Streamflows significantly reduced (some 5% of natural flow)
- Environmental flows restricted to provide for critical human needs
- Acidification of Lower Lakes
- Dying floodplain forests
- Multiple species at risk of extinction

Policy response and priorities

- Build on National Water Initiative reforms
- Balance economic, social, environmental outcomes
- Principles
  - Must work under drier/variable future climate
  - Improve efficiency and promote conservation
  - Entitlement (water right) holders manage risk
  - Facilitate water markets
  - Look for multi-benefit solutions
- New $13B Murray-Darling Basin (MDB) Plan

Water market - a critical element

- Needs some water to operate
- Needs it at the right time
- Systems need to be able to deliver



1 megalitre (ML) = .81 acre-foot

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Entitlements and markets

Entitlements protected, but improvements include

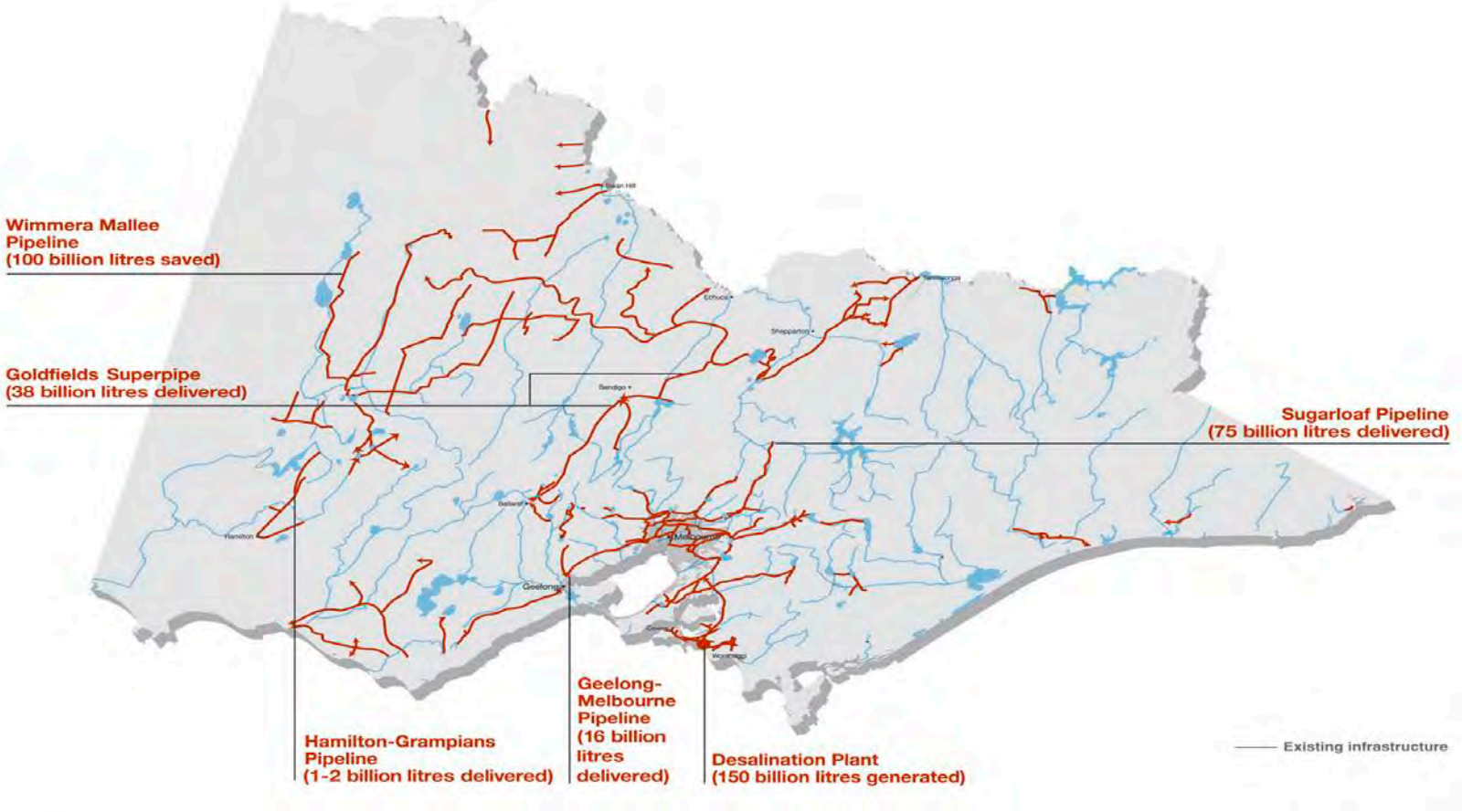
- Introduced carry-over
- Changed system reserve rules
  - Allows market to operate in all years
  - Provides certainty of delivery
- Clearer environmental entitlements with credit-for-return flows
- Improved Victorian water grid

Urban management

Goal: Supply minimum level of service with demand management and – where needed – new supply.

- Demand management
  - Per capita water usage down 43 %
  - In 2011/12, average residential use in Melbourne: 149 L (39 gallons) per person per day
- Alternative, new sources
  - Recycled water, stormwater
  - Groundwater
  - Trading
  - Desalination
  - Pipelines and interconnectors

Water grid additions 2007-2010



Some state-funded, many funded by customers

- ***Highly controversial***

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Agricultural irrigation

- Market, carryover and system reserves
- Significant investment in irrigation modernisation
- Whole-farm planning and on-farm efficiencies

Water use fell much more than farm revenue

	Water applied (estimate, GL)		Revenue* ($m, real)	
2005-06	7,370 (6.0 MAF)	53 %	5,522	21 %
2008-09	3,492 (2.9 MAF)		4,349	

Source: Australian Bureau of Statistics (for Murray-Darling Basin)
* Gross value of irrigated agricultural production

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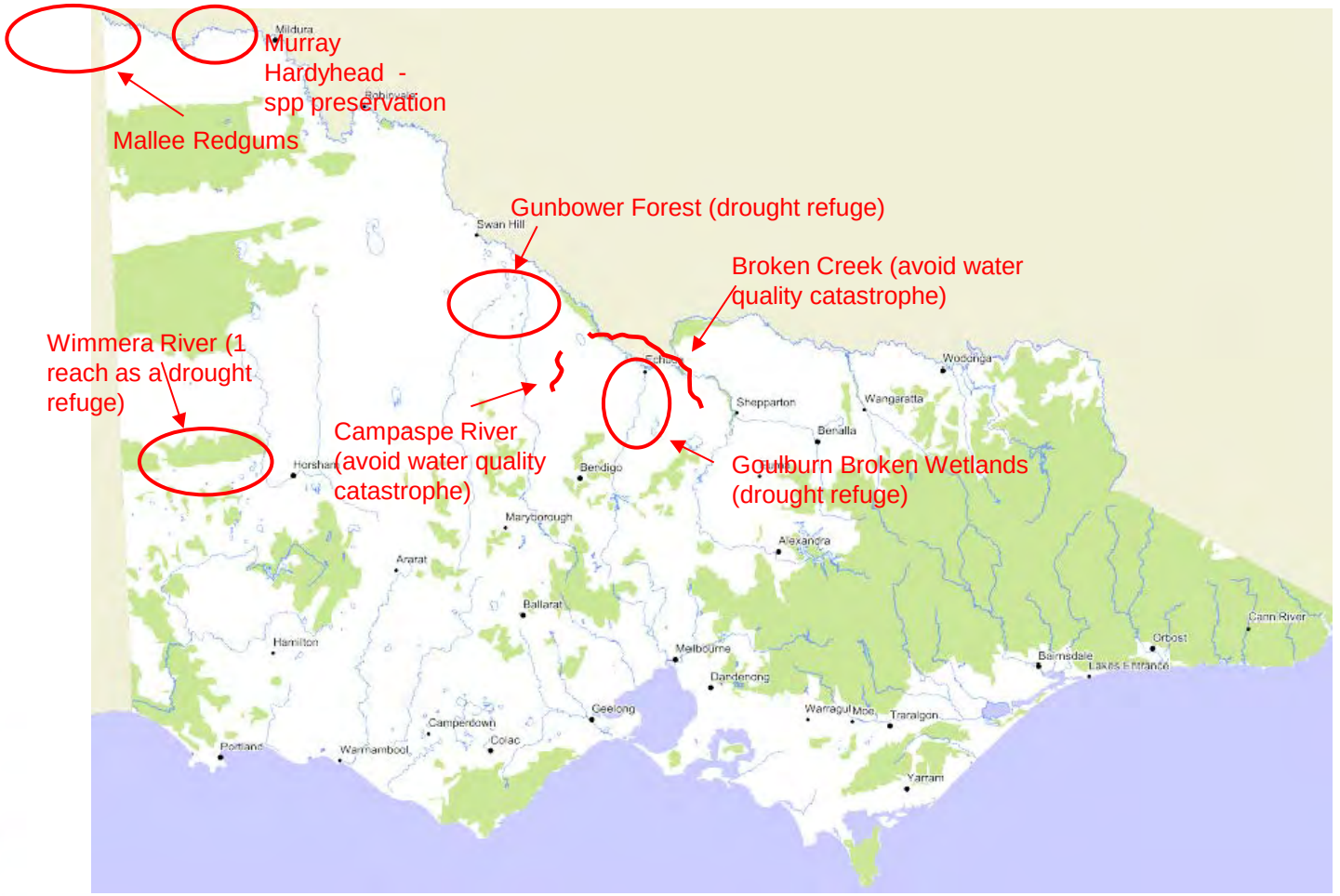
New ecological management approach for the environment

Goal: Ensure assets survive drought and recover

- Policy framework for reduction of river flows for critical human needs
- Improve environmental water use efficiency
  - Seasonally adaptive approach to environmental water use
  - Complementary use of supply infrastructure
  - Trade seasonal allocations
- Establish environmental water portfolio
- Improve governance
  - Environmental Water Holder

Strategic environmental watering in Northern Victoria 2007/08



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Red river gums saved by repeated watering using groundwater

August 2004

December 2004

May 2006

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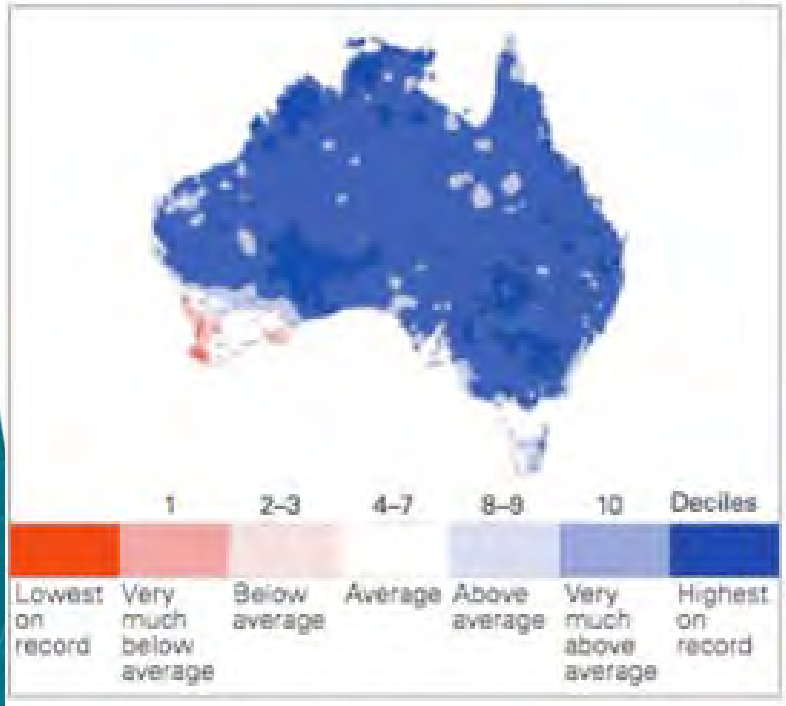
Goulburn Broken wetlands provide drought refuge

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

In summary

- Economic, social, environmental outcomes considered together
- ‘This is the future’ not ‘we need to get through this’
- Efficiency by all sectors
  - Water grid: moves water around
  - Urban: households, industry
  - Rural: on-farm and irrigation systems
  - Environment: infrastructure, smart river management
- Entitlement-holders given tools to manage their own risk
- Water market must be able to operate
- Supply augmentation when required
- Environment policy: practical, pragmatic, easily understood

And then the drought breaks



July 2010 to March 2012 rainfall deciles (based on climatology of gridded monthly rainfall analyses from 1900)

And you have to live with the consequences of reform

- Community backlash
- New government
- Water no longer a priority, but a nuisance
- Flood management and recovery becomes the new drought