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Implications of Extreme Climate Events for Water Management and Policy

November 10, 2015

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Talk Overview

- Introductory Comments
- National Climate Assessment "Big Picture"
- Challenges in Forecasting Extremes
- Challenges in Managing Water Resources
- Shifts in Planning Paradigms
- Hope for the Future, Reasons for Concern
- Final Comments

Introductory Comments

- Pleased to be included in this group of outstanding climate scientists ("weather nerds"), hoping to learn
- My research interests have included drought management and exploring impacts of climate change
- Climate Impacts Group (University of Washington)
- Northeast Climate Science Center
- Managers typically ask for precise forecasts, not trends
- Long been a fan of Don Wilhite and NDMC

Comparing weather to what you know

National Climate Assessment "Big Picture"

What managers might (possibly) have read)

- The Northern Plains will remain vulnerable to periodic drought because much of the projected increase in precipitation is expected to occur in the cooler months while increasing temperatures will result in additional evapotranspiration.
- Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs

National Climate Assessment "Big Picture"

- Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.
- A key uncertainty is the exact rate and magnitude of the projected changes in precipitation, because high inter-annual variability may either obscure or highlight the long-term trends over the next few years.

The Midwest region includes the states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. The Highlights section below offers a high-level overview of climate change impacts on this region, including the six Key Messages and selected topics

Extreme heat, heavy downpours, and flooding will affect infrastructure, health, agriculture, forestry, transportation, air and water quality, and more. Climate change will also exacerbate a range of risks to the Great Lakes.

Source: http://nca2014.globalchange.gov/report/regions/midwest


I THOUGHT I WAS
INTERESTED IN UNCERTAINTY
BUT NOW I'M NOT SO SURE
TOSHIO

Challenges in Forecasting Extremes

Challenges in Forecasting Extremes

- Our ability to forecast extreme events (without even considering climate change) is still limited
- Probable Maximum Precipitation - Maximum Probable Flood
- Statistical approach used to calculate return periods of floods of interest (Weibull, Gumbel, Fréchet)
- We have yet to solve problem of estimating accurately flood events at ungaged sites

Challenges in Forecasting Extremes

- Droughts have complex characteristics presenting unique challenges (slow onset, spatial variability, temporal variability, termination unclear)
- Characterizations complicated by existence of infrastructure
- Approaches include weather generators, paleo-analysis, synthetic streamflows, among others
- Regardless of challenges, engineers will have to design, operate and manage

Shifts in P

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was

Stationarity is Dead

1. Why did it die?

   Substantial anthropogenic change of Earth's climate and landscape

2. Why now?

   Time to move beyond "wait and see"

3. What is the successor?

   Very challenging because changes are complex, uncertainties are large, and our understanding is evolving

   Adapt existing techniques (Harvard Water Program) including economics, OR, statistics, trade-offs of costs, risks, and benefits OR new approaches?.

Shifts in Planning Paradigms

- Many of today's existing water resources systems were designed for a future that never occurred.
- The services demanded by consumers and their priorities have changed dramatically over time
- Our measures of performance are outdated (safe yield, reliability)

Shifts in Planning Paradigms

- “we may have to face up to the fact that skillful prediction of variables of interest to decision makers may simply not be possible…. it may be time to rethink how we make decisions in the face of not simply uncertainty, but fundamental and irreducible ignorance. Rather than focus on optimal decisions guided by prediction, we may need instead to focus on robust decisions guided by recognition of the limits of what can be known.” Pielke (2009)

Shifts in Planning Paradigms

- "Reliability is dead." Brown (2009)
- Decision Scaling – describe what conditions determine system failure, then determine likelihood of those circumstances occurring
- Managers are looking for "actionable science"
  - David Behar - Working directly with resource managers to produce science and tools to address effects of climate change on the nation's biological resources should remain the core focus of the Interior Department's Climate Science Centers, according to a federal advisory committee report released today.

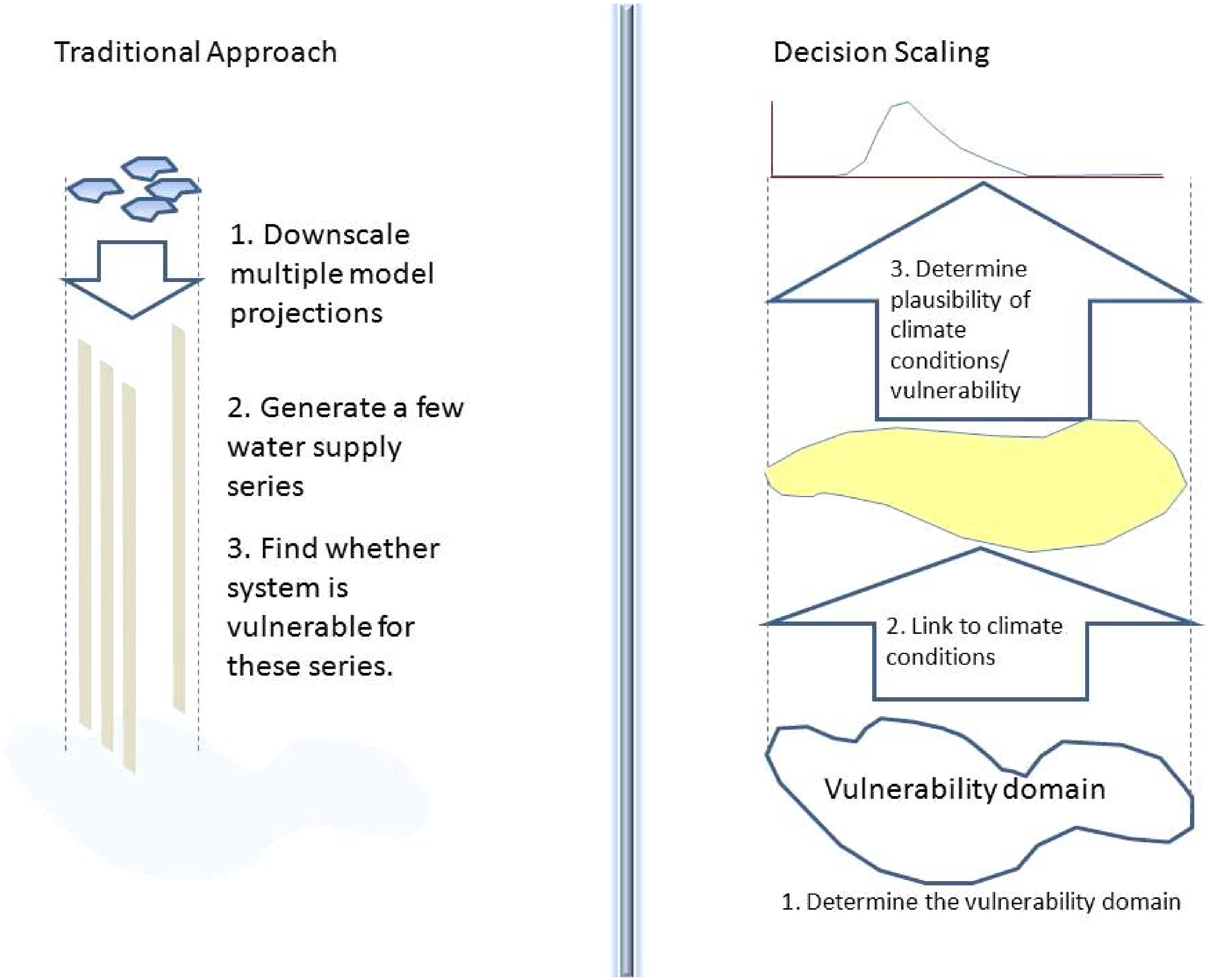


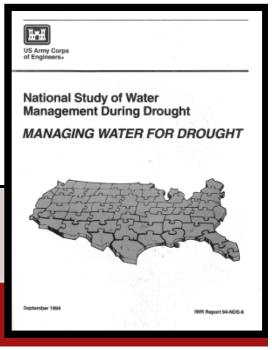
Figure 1 Steps in decision scaling vs. traditional approach

Rational Water Resources Planning (Generic)

1. Engage stakeholders in defining problems and opportunities
2. Create an inventory (physical, policy, financial)
3. Forecast the future and status quo
4. Define performance metrics
5. Identify alternatives
6. Explore promising alternatives
7. Evaluate alternatives relative to performance metrics
8. Select the best alternatives
9. Implement the plan
10. Re-examine the plan periodically

Lessons Learned

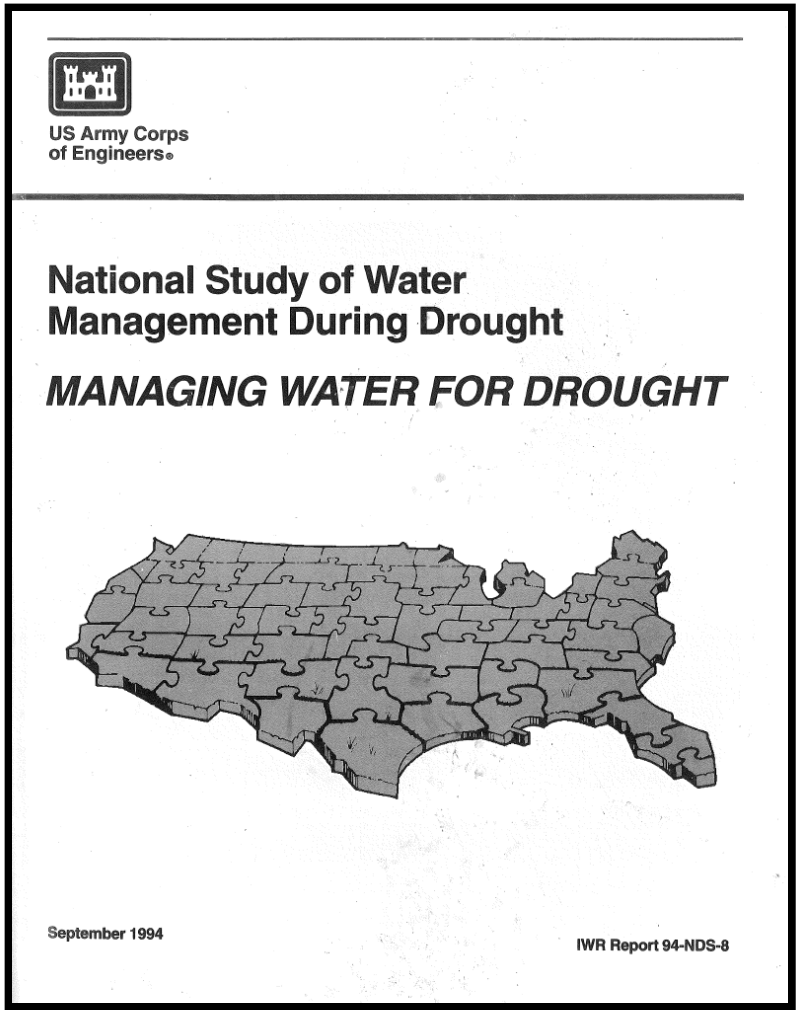
1) Water utilities must have strategic, tactical and emergency drought planning
2) The public should be involved in the development of drought plans (transparency, collaborative planning, co-generation of plans)
3) Plans need to have drought indicators, drought triggers and drought actions clearly stated (like risk aversion curves)



Lessons Learned

4) Accurate and full explanation of the drought likelihood and impact are essential
5) Drought plans work best if they are practiced (Virtual Drought Exercises)
6) Collaboration between water providers and citizens always makes planning and responses more success

National Drought Study


US Army Corps of Engineers

National Study of Water Management During Drought

MANAGING WATER FOR DROUGHT

September 1994

IWR Report 94-NDS-8

- Early 1990’s the US Army Corps of Engineers conducted the National Drought Study
- 34 Findings (Lessons) from the report designed to improve drought planning
- We will focus on 6

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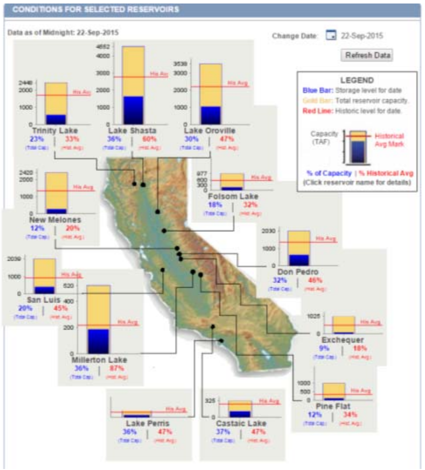
Reasons for Hope

California is entering the 5th year of drought

Driest and hottest 4 year period in California recorded history (who could have planned for this – Well, California did)



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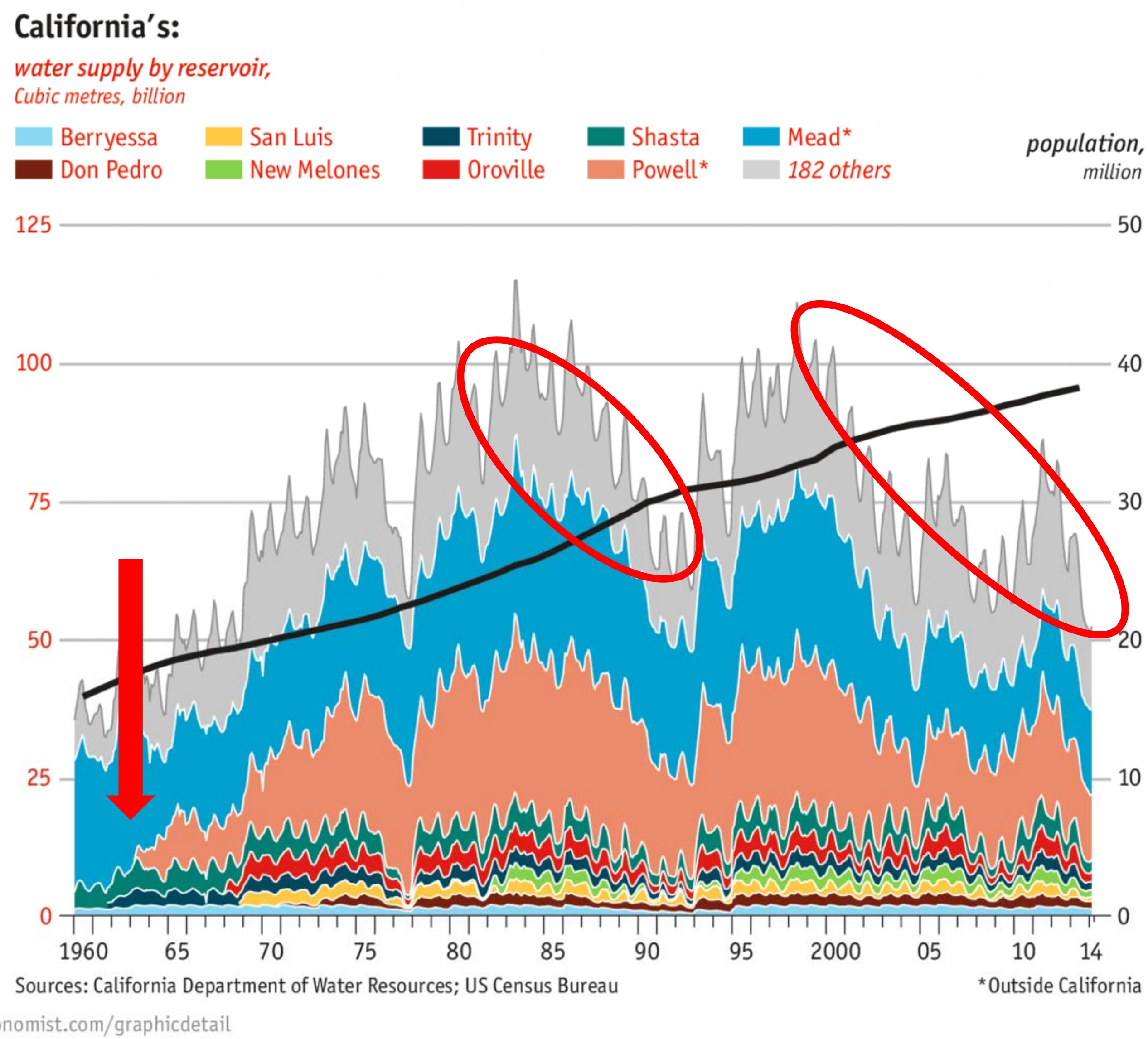
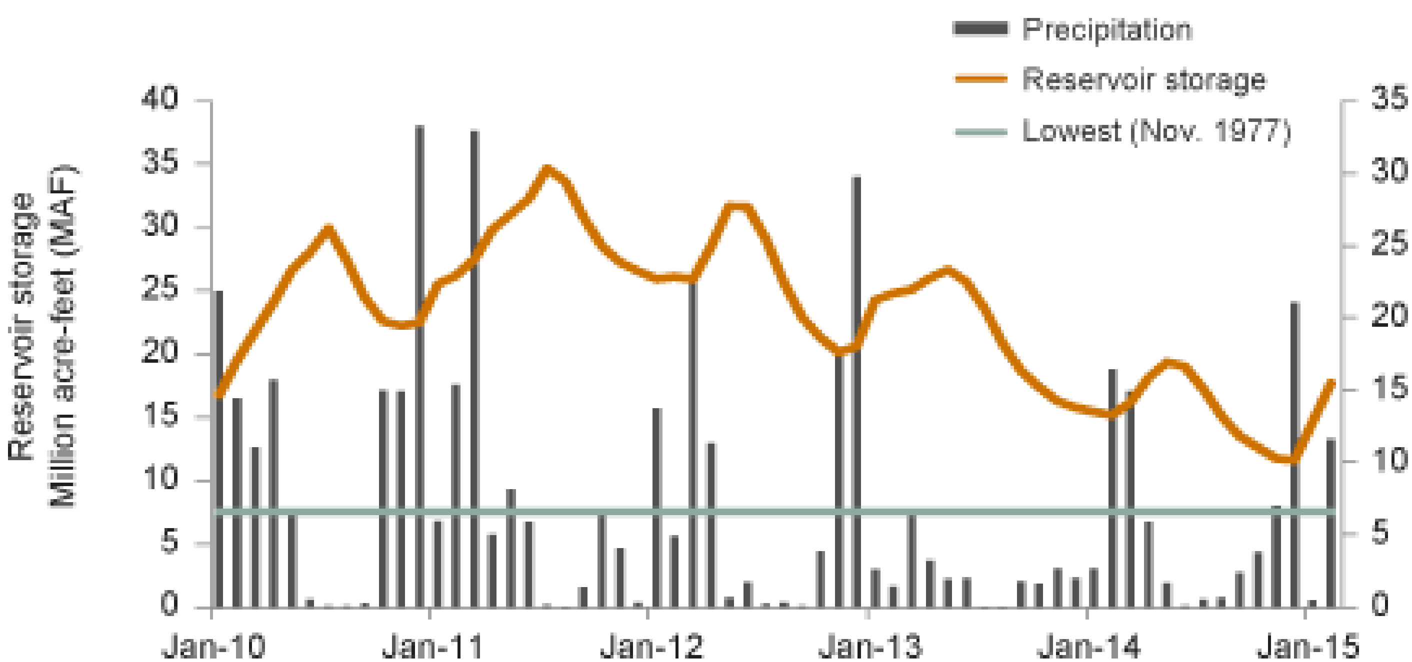
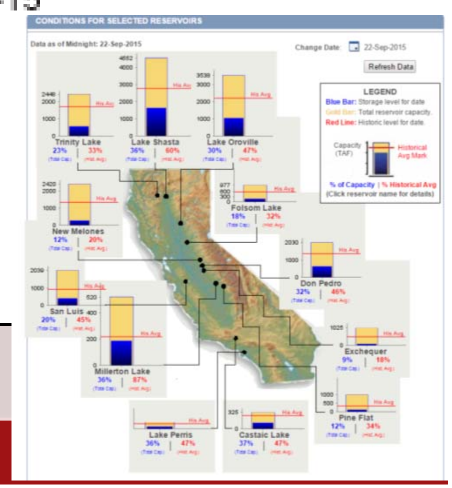


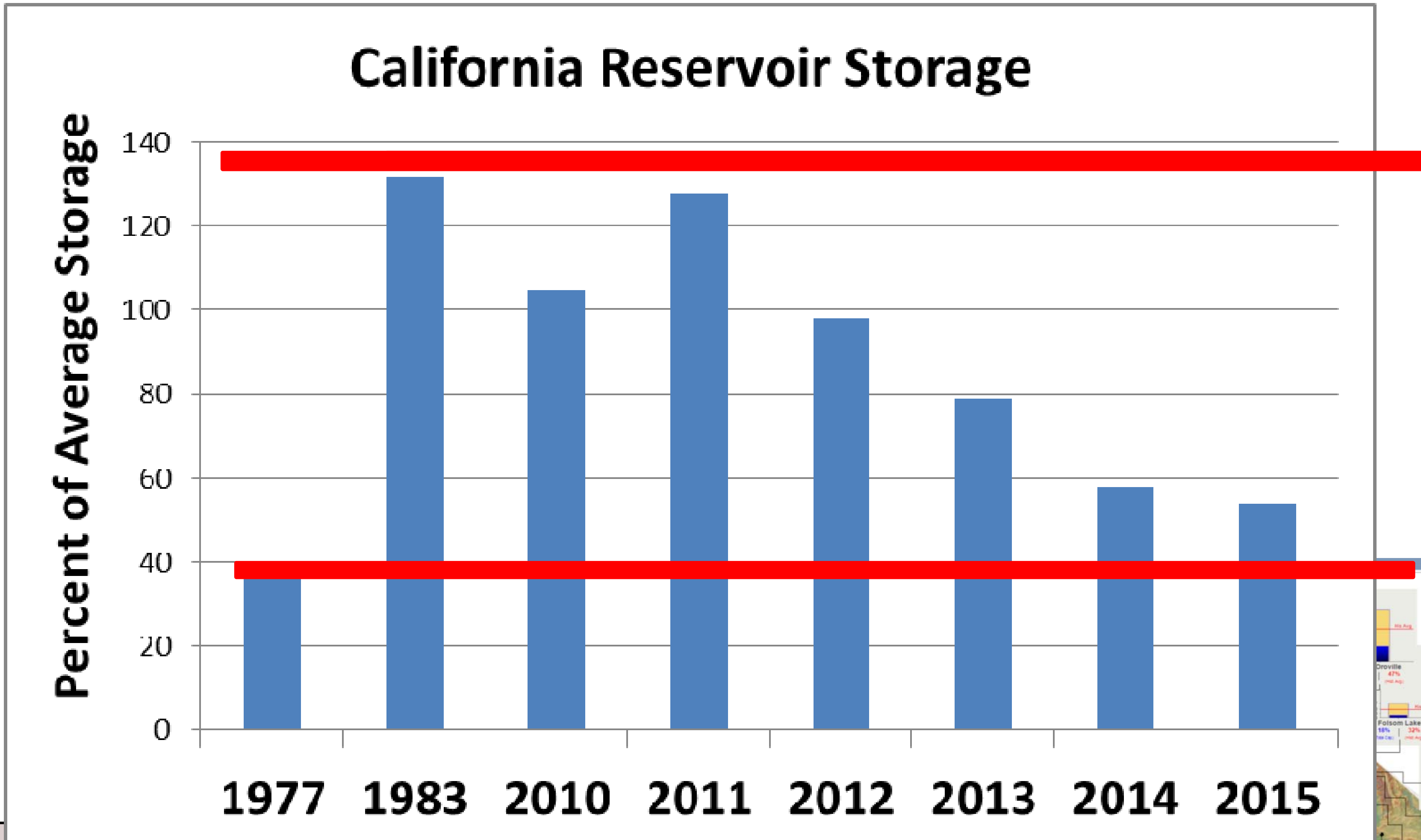
- California is facing one of its most significant droughts in 100 years

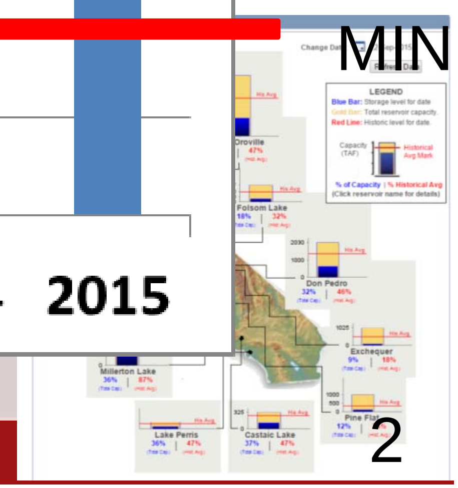


Precipitation
Reservoir storage
Lowest (Nov. 1977)
Reservoir storage
Million acre-feet (MAF)
Precipitation (inches)
40
35
30
25
20
15
10
5
0
35
30
25
20
15
10
5
0
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



Past and Recent Storage History





California Drought Experience

- California is entering the 5th year of drought
- Driest and hottest 4 year period in California recorded history (who could have planned for this – Well, California did)
- During this period, California's economy has grown faster than the nation's average
- Agricultural production has remained almost constant
- California is weathering the drought with remarkable resilience (not in terms of forest fires)

How has California done this?

- California has been preparing for 20 years.
  - Broad and effective public engagement and communication (excellent stakeholder engagement)
  - Water conservation
    - 39% of all irrigation is drip irrigation
    - Per capita water demands down 25%
  - Response to droughts that integrates Drinking water with Surfacewater/Groundwater/Storm and Wastewater
  - Bold leadership demonstrated during the drought

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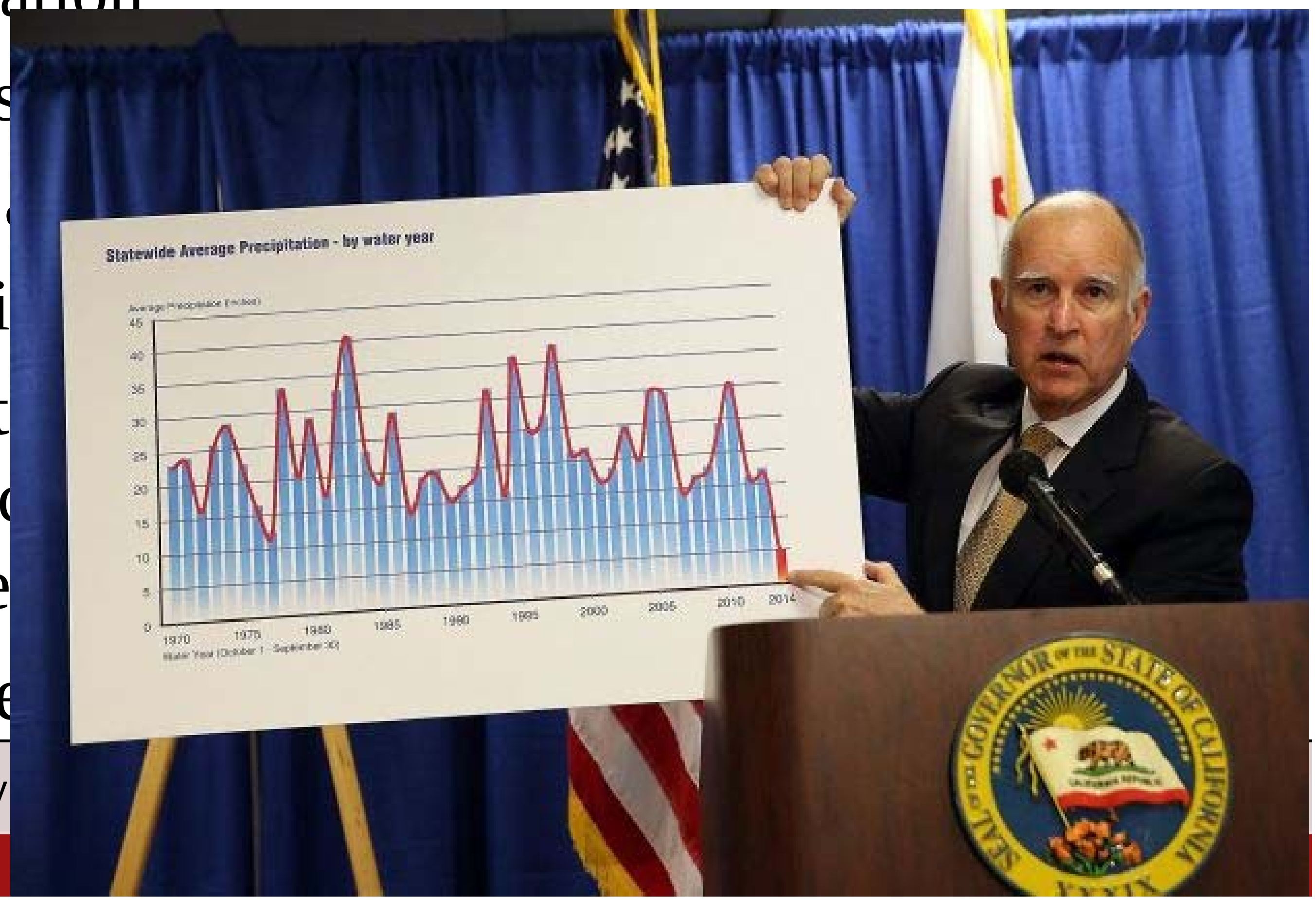
    - 39% of
    - Per capi
  - Response t with Surfac Wastewate
  - Bold leade



Bold Leadership Current Drought

On the following Dates, Governor Brown took bold actions:

May 20, 2013 - Executive Order

January 17, 2014 - State of Emergency

April 25, 2014 - Continued State of Emergency

May 1st, 2015 - Announced new actions to require 25% reduction in water use by all cities

Today's "State of the Art" of Drought Preparedness in the US

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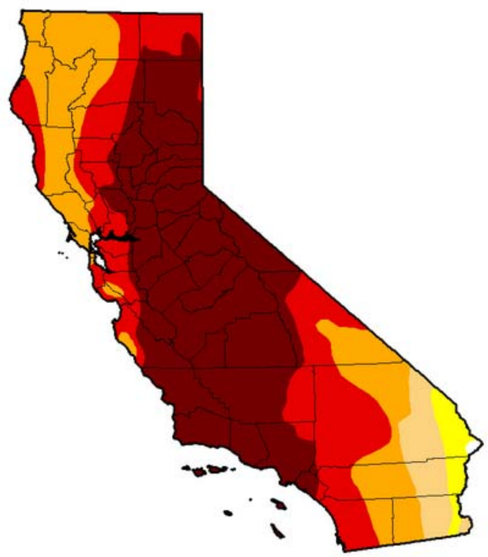
California



August 11, 2015

(Released Thursday August 13, 2015)

Valid 8 a.m. EDT

Statistics type: Traditional Percent Area

Export table: PNG CSV XLS

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current 2015-08-11	0.14	99.86	97.35	92.36	71.08	46.00
Last Week 2015-08-04	0.14	99.86	97.35	94.59	71.08	46.00
3 Months Ago 2015-05-12	0.14	99.86	98.28	93.91	66.60	46.77
Start of Calendar Year 2014-12-30	0.00	100.00	98.12	94.34	77.94	32.21
Start of Water Year 2014-09-30	0.00	100.00	100.00	95.04	81.92	58.41
One Year Ago 2014-08-12	0.00	100.00	100.00	99.80	81.92	58.41

Population Affected by Drought: **36,664,526**

View More Statistics

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(s):

Brian Fuchs, National Drought Mitigation Center

Download: PNG PDF JPG

View drought planning resources

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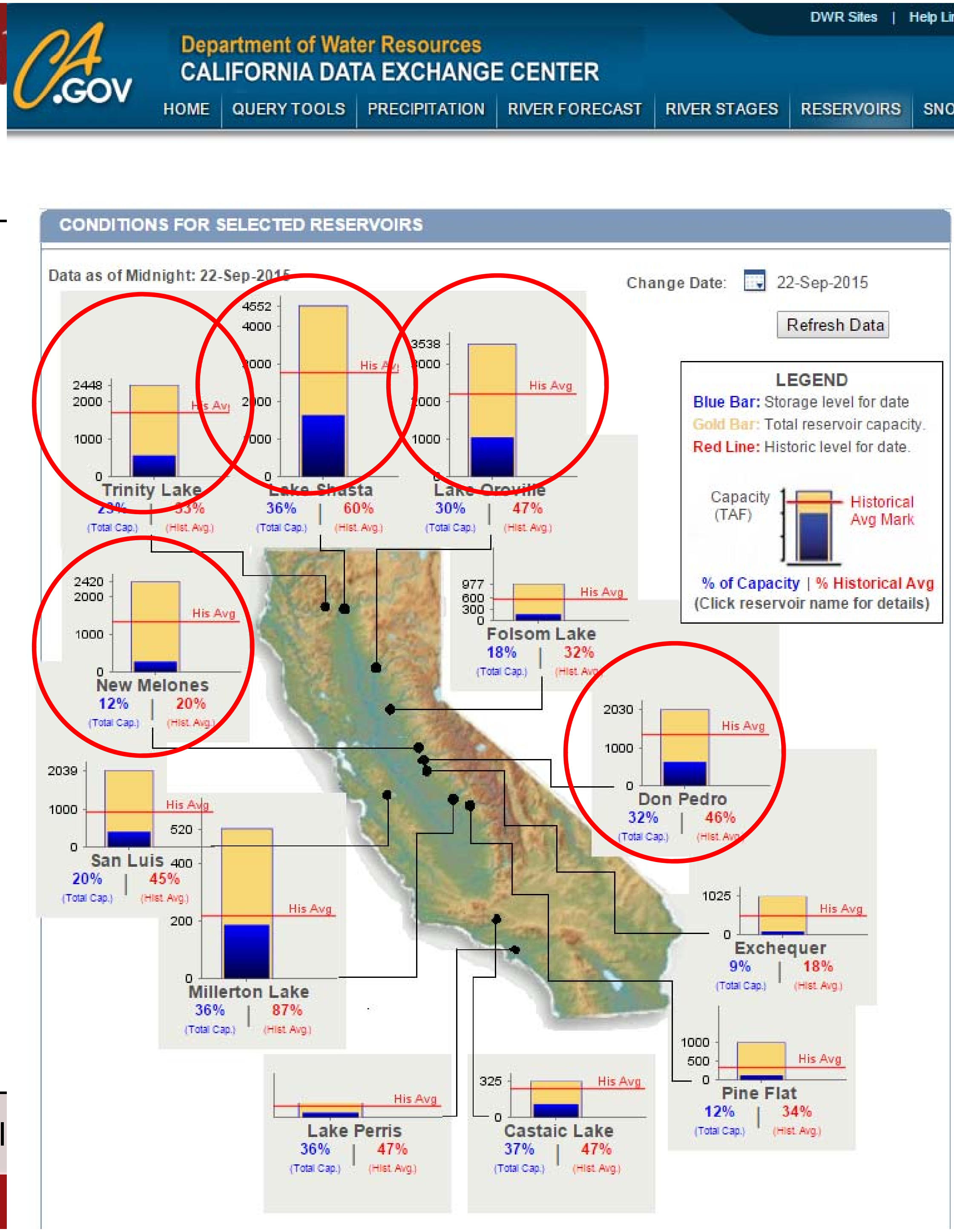

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Department of Water Resources
CALIFORNIA DATA EXCHANGE CENTER
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QUERY TOOLS
PRECIPITATION
RIVER FORECAST
RIVER STAGES
RESERVOIRS
SNO
CONDITIONS FOR SELECTED RESERVOIRS
Data as of Midnight: 22-Sep-2015
Change Date: 22-Sep-2015
Refresh Data
LEGEND
Blue Bar: Storage level for date
Gold Bar: Total reservoir capacity.
Red Line: Historic level for date.
Capacity (TAF)
Historical Avg Mark
% of Capacity | % Historical Avg
(Click reservoir name for details)
Trinity Lake
Lake Shasta 36% | 60%
Lake Oroville 30% | 47%
Folsom Lake 18% | 32%
New Melones 12% | 20%
Don Pedro 32% | 46%
San Luis 20% | 45%
Millerton Lake 36% | 87%
Exchequer 9% | 18%
Pine Flat 12% | 34%
Lake Perris 36% | 47%
Castaic Lake 37% | 47%
His Avg
(Total Cap.)
(Hist. Avg.)

Planning 〉 Drought Plans 〉 State Planning   Login

California State Drought Planning

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State Climatologist
Michael Anderson
California State Climate Office
(916) 574-2830

State Drought Plan
California Drought Contigency Plan

Released in 2010
California Department of Water Resources

See more state and local plans

State Drought Websites
California Department of Water Resources: Drought Page

California Department of Food and Agriculture Drought Resources

The California Drought, from the Pacific Institute

California Drought Resources from the California Institute for Water Resources

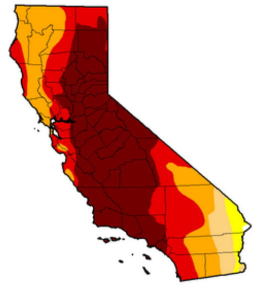
California Governor's Office of Planning and Research Drought Clearinghouse

California Drought, from the Office of the Governor

Status of Response to 2014 Drought, Association of California Water Agencies

Lead Agency
California Governor's Office

Current U.S. Drought Monitor
August 11, 2015



Estimated Population Affected by Drought
36,664,526

State-wide Agencies and Organizations | Monitoring and Data | Local Organizations | Tribal | Farmers and Ranchers | Water

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Breaking News

NASA Report: Drought Causing Valley Land to Sink
August 19, 2015

SACRAMENTO, CA — As Californians continue pumping groundwater in response to the historic drought, the Department of Water Resources today released a new NASA report showing land in the San Joaquin Valley is sinking faster than ever before, nearly two inches per month in some locations.

Read more ...

$30 Million in Rebates Available to Help Replace Old Toilets and Turf
August 12, 2015

Two new rebate programs can help Californians replace inefficient toilets and tear out water-guzzling lawns, further conserving water during the state's historic drought.

The "turf and toilet" rebate program is financed by the Proposition 1 water bond approved by voters in 2014. The program will help carry out Governor Brown's April 1 Executive Order on drought to further reduce water use in homes by replacing more than 10 million square-feet of lawn and upgrading more than 60,000 water-wasting toilets.

DWR will oversee the two rebate programs, which provide a $100 consumer rebate to replace one old toilet per household and up to $2 per square foot for lawn replacement. Californians can visit www.SaveOurWaterRebates.com to apply for the rebates.

» Breaking News
» Drought Background
» Emergency Drought Barriers
» Governor's Drought Declaration
» Publications
» Rebate Programs
» Upcoming Events
» Water Conditions

RESOURCES

» 2015 Drought Operations Plan
» Ag and Urban Water Management Plans
» California's Drought website
» Daily Hydrologic Overview - *interactive*
» Groundwater Information Center
» Turf Replacement Initiative
» Toilet Retrofit

FEATURED INFORMATION

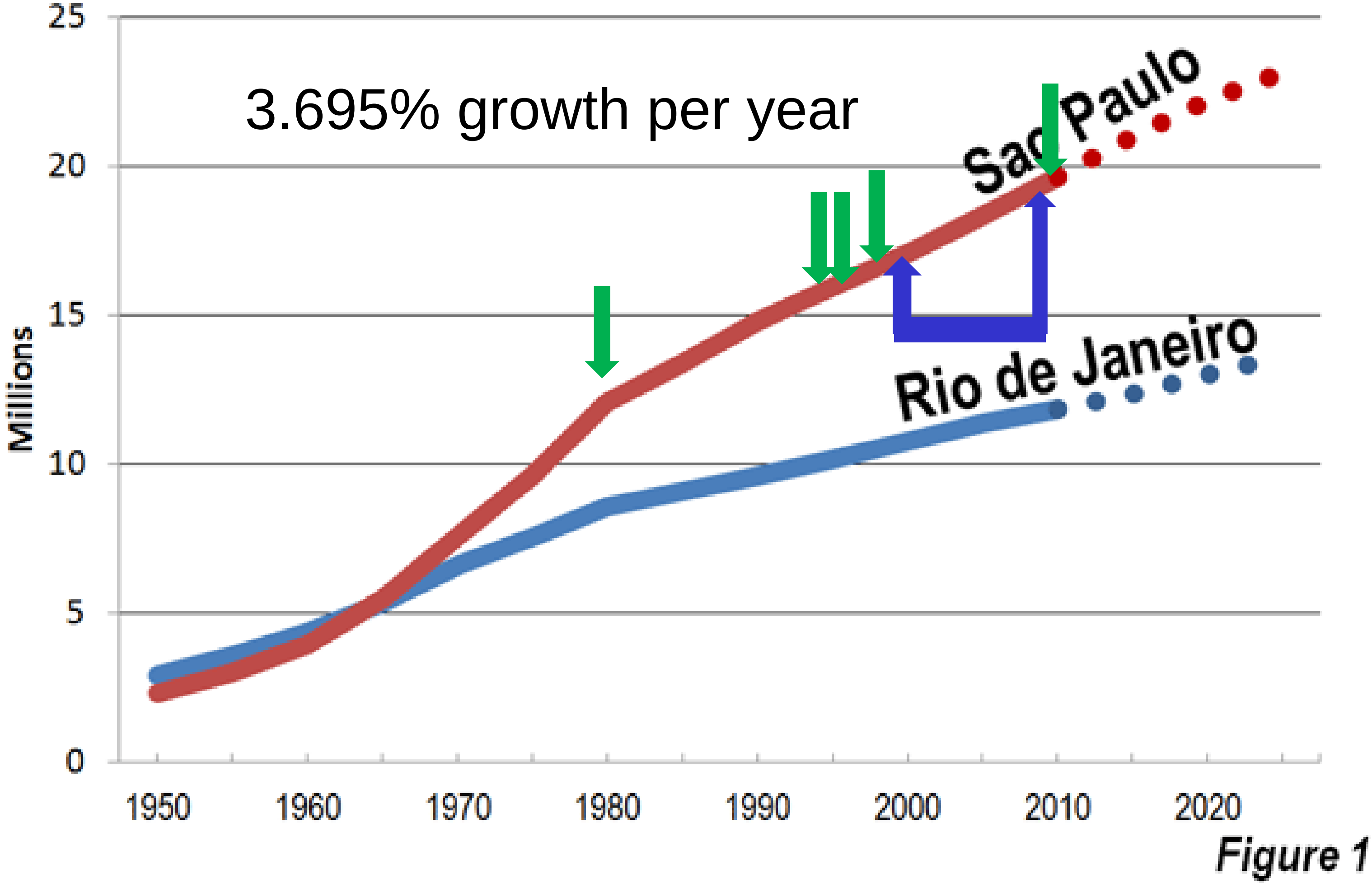
» California Drought – U.S.

Reasons for Concern

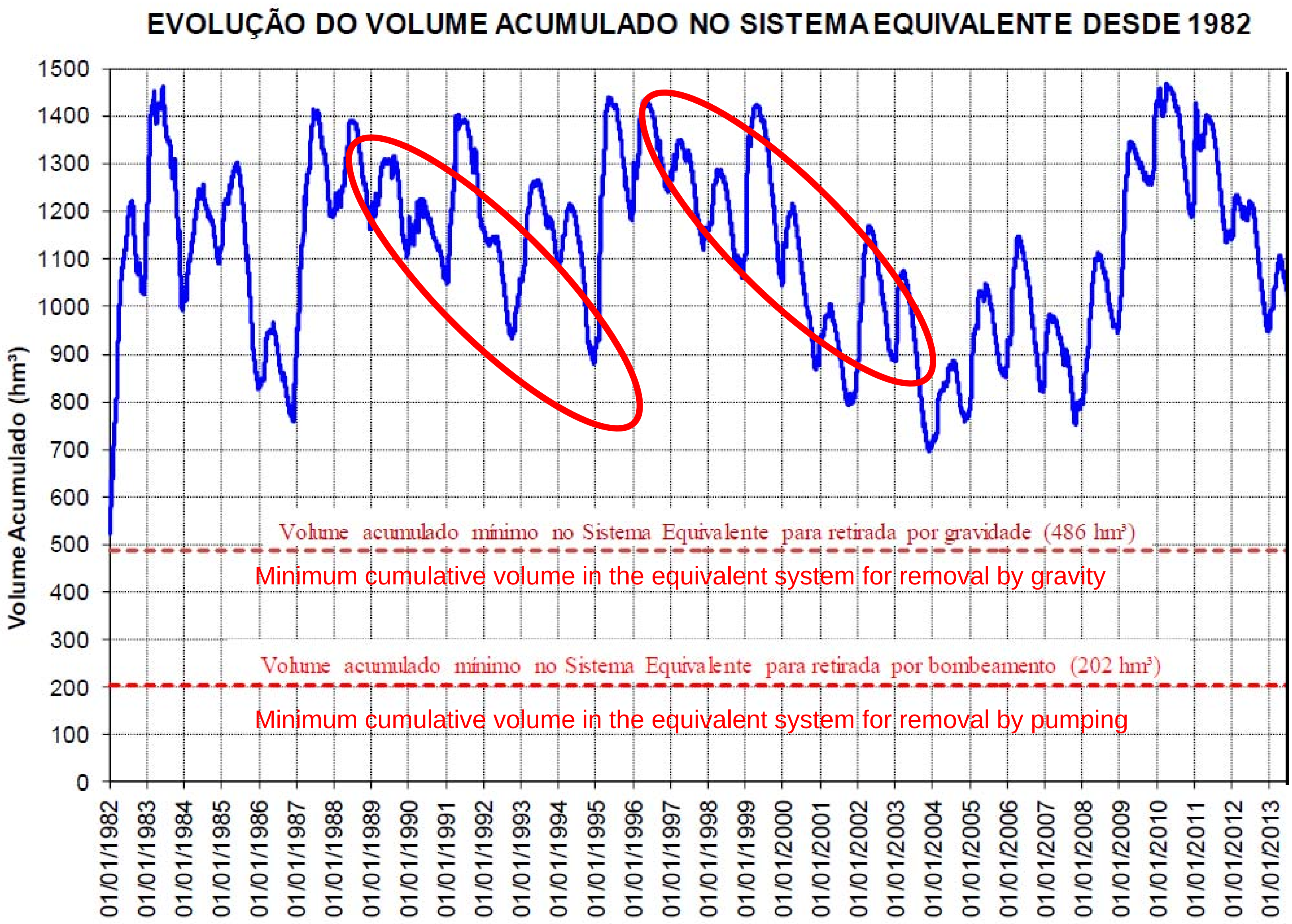
The drought in São Paulo

Sao Paulo & Rio Urban Areas Population

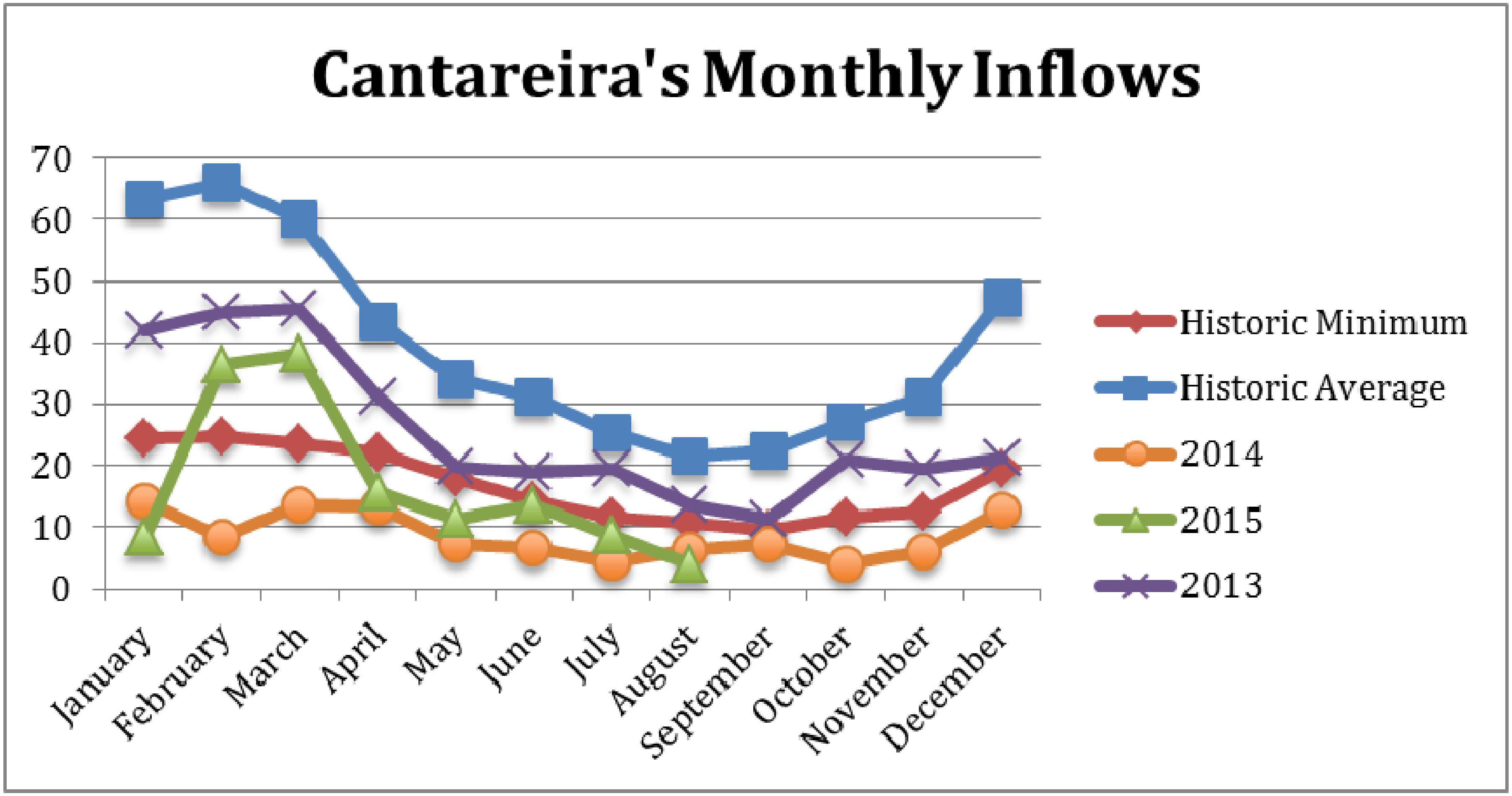
1950-2010 WITH PROJECTIONS TO 2025



Sistema Cantareira



Sao Paulo Current Drought



Sao Paulo Current Drought

- October 31, 2010 – Presidential Election, Dilma Rousseff (won with 56.0% of votes), Reservoirs full
- August 2013, Continuation of Meteorological Drought
  - Record low rainfall for each month
- BAU - SABESP releases 31m^3/s to São Paulo
  - Justify by a reserve known as Water Banks
- Jan 30th, 2014- First Public Comment
  - Openly accept Water Banks are virtual-they don't physically exists
  - No need for further planning
- Report "Rodizio do Sistema Cantareira 2014"
  - Discarded by high level administrators of SABESP and SP Governor

Sao Paulo Current Drought

- February 2014
- "Anti-crisis" group created (GTAG), represented by:
  - National Water Agency (ANA)-Federal
  - Department of Water and Energy (DAEE)-State
  - Utility company (SABESP)—1/2 State (PPP)
  - PCJ Basin committee (CBH-PCJ)
  - Alto Tietê Basin committee (CBH-AT)

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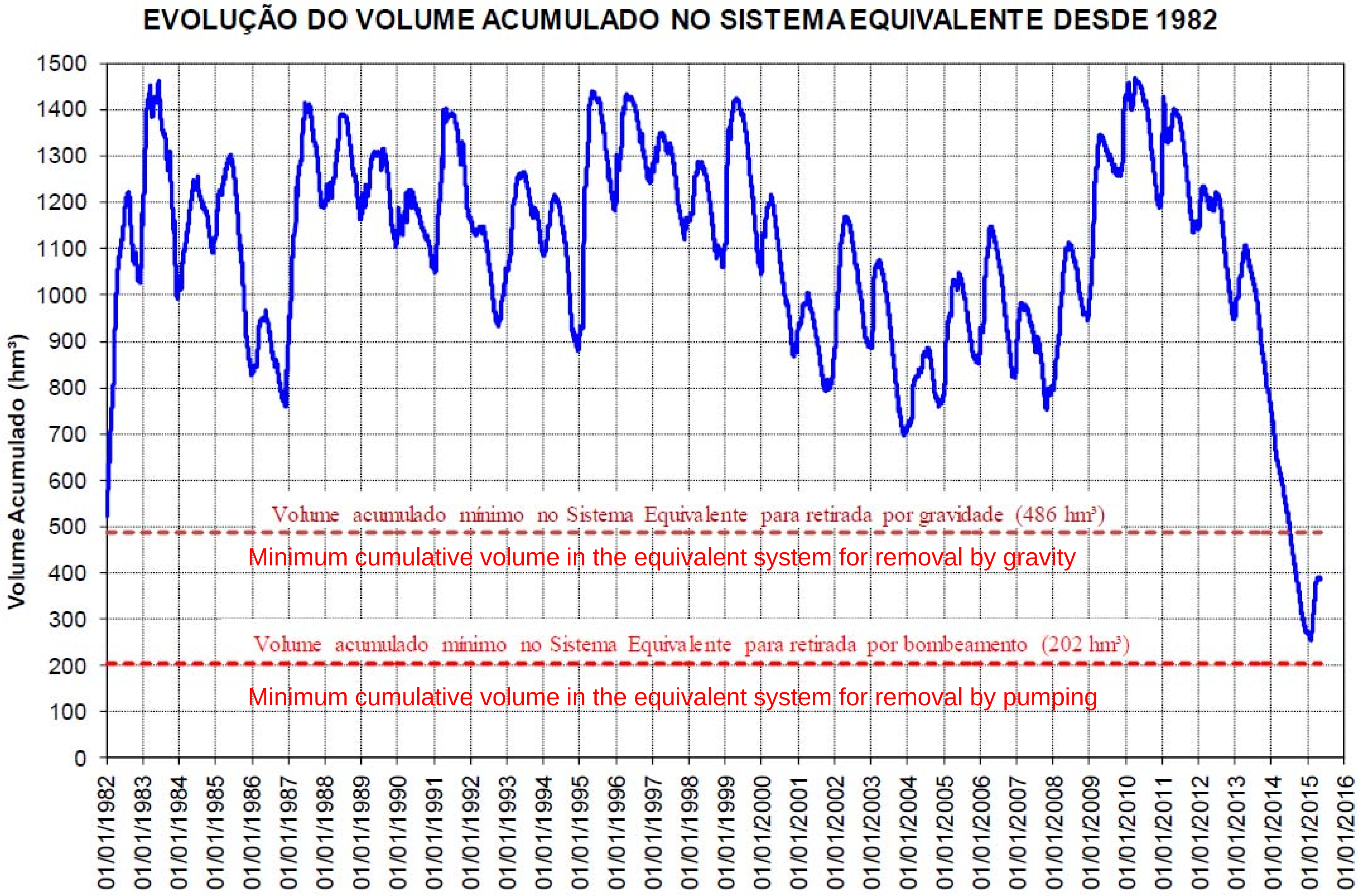
Sao Paulo Current Drought

- Pre-Election - “Don’t worry, we are entering the rainy season…”
- March 17, 2014 - Projects to install floating pumps begin
- March 2014, First reduction to 21.09 m3/s to supply São Paulo, What is a reduction?
- October 26, 2014 - Presidential Election, Dilma Rousseff (51.6%), Reservoirs 20% full
- June 2015 - World Cup in São Paulo, New definition of full, Reservoirs 8% full
- August 2015 – Drought ordinance identifies Drought in São Paulo
- July 2016 – Olympics in Rio

Sistema Cantareira

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Final Comments

- Forecasts are for warming temperatures, more precipitation, but not in seasons most needed
- Our ability to predict extremes with current models is limited
- Clear recognition that new water resources and drought planning paradigms needed
- Past structure planning approaches still valuable
- Well managed droughts suggest reason for hope

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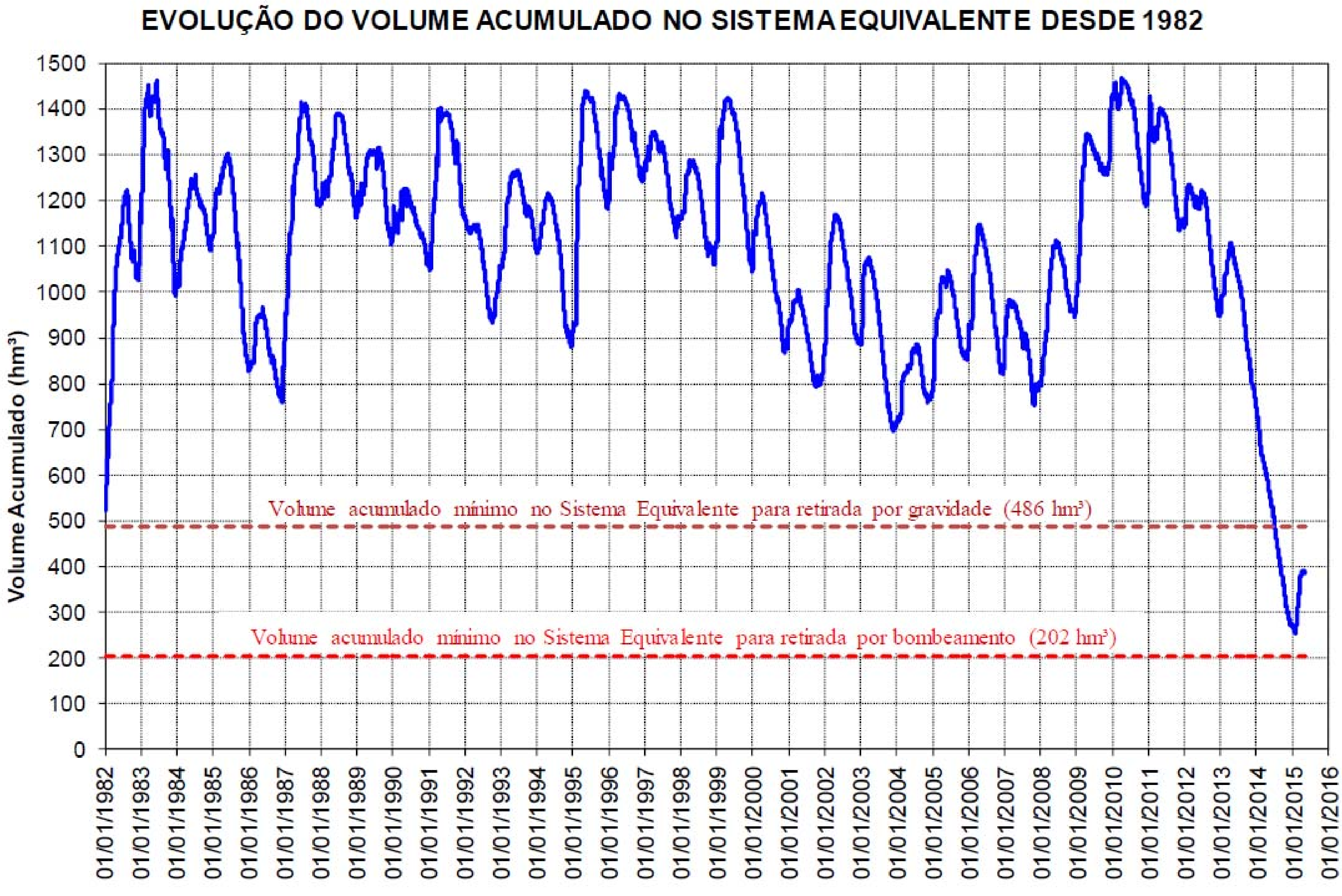
Sistema Cantareira



- California is facing one of its most significant droughts in 100 years

National Drought Mitigation Center