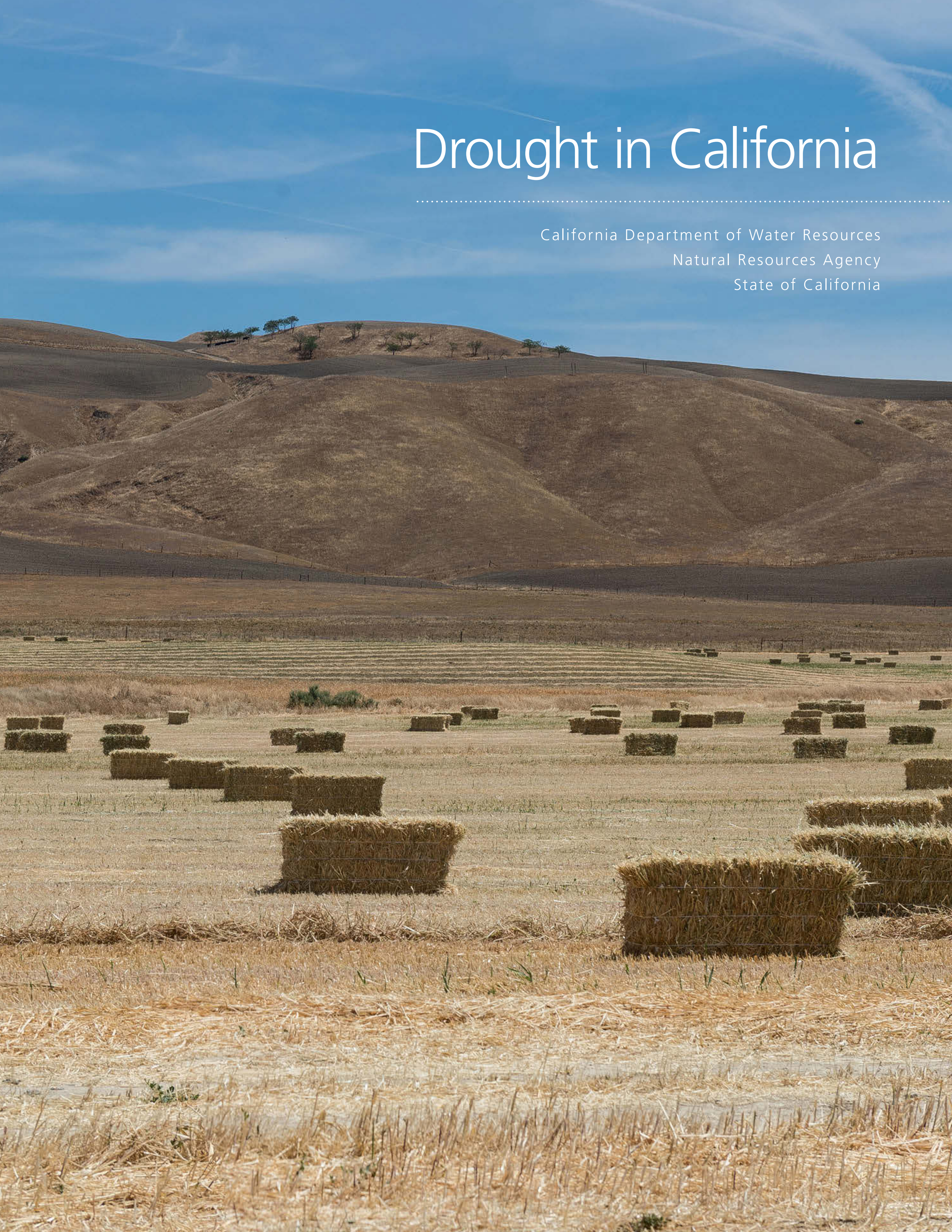
Drought in California

California Department of Water Resources
Natural Resources Agency
State of California

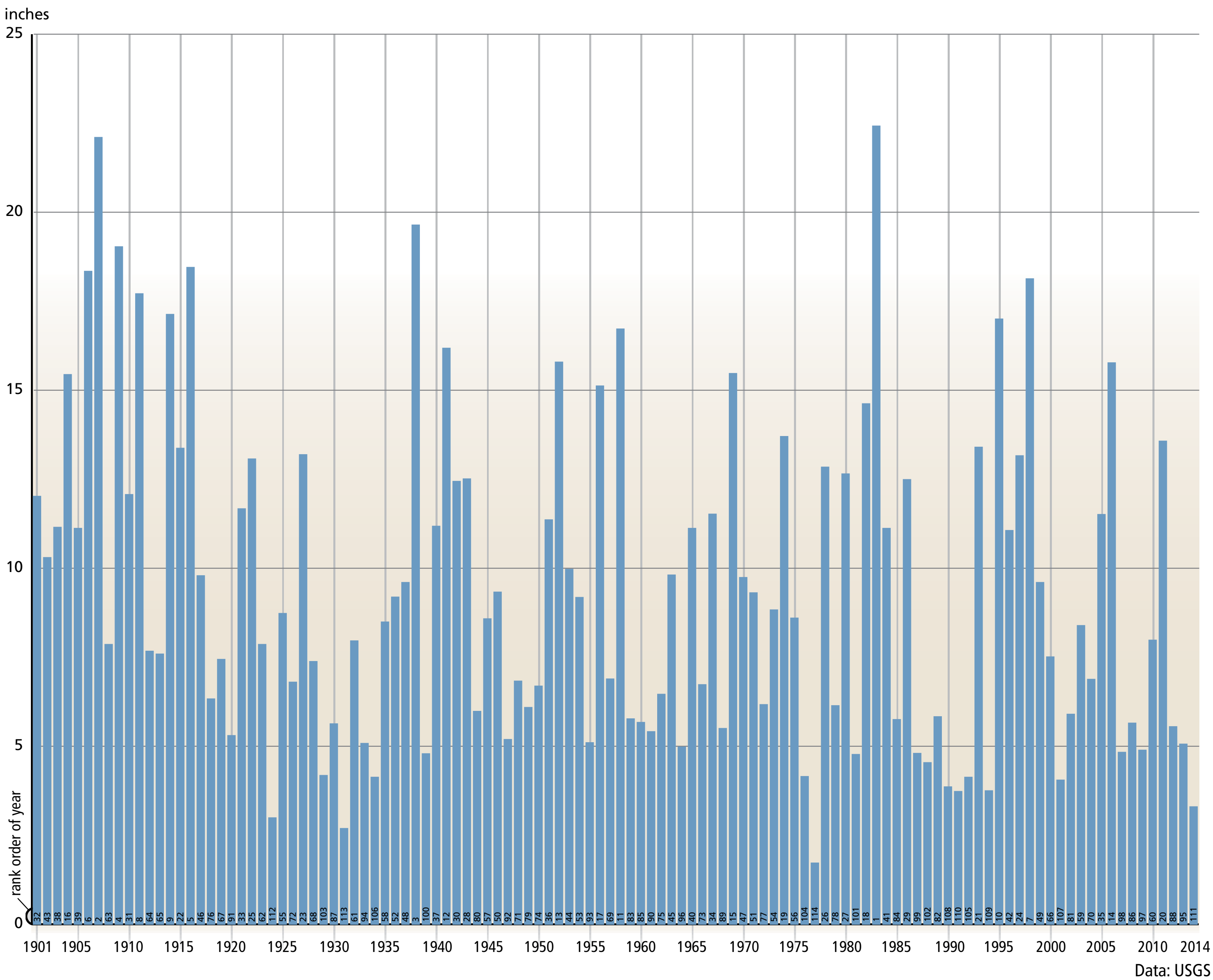


DEFINING DROUGHT

There are many ways that drought can be defined. Some ways can be quantified, such as meteorological drought (period of below normal precipitation) or hydrologic drought (period of below average runoff), others are more qualitative in nature (shortage of water for a particular purpose). There is no universal definition of when a drought begins or ends, nor is there a state statutory process for defining or declaring drought, other than through proclamation of emergency conditions pursuant to the California Emergency Services Act. California's annual water supply conditions are highly variable, and droughts are a recurring feature in the state's water budget.

Drought is a gradual phenomenon. Impacts of drought are typically felt first by those most dependent on annual rainfall, such as ranchers engaged in dryland grazing or rural residents relying on wells in low-yield rock formations. Drought impacts increase with the length of a drought, as carry-over supplies in reservoirs

Calculated statewide runoff



Major rivers and facilities

Colorado River inflow to Lake Powell has been below average in 12 of the past 15 water years (2000-2014), resulting in reduced storage levels in Lakes Powell and Mead. This 15-year period is the lowest in more than 100 years of record-keeping. The Colorado River has historically been a highly reliable water supply for Southern California despite prolonged drought, thanks to the basin's large reservoir storage capacity. Interim guidelines adopted in 2007 for Lower Basin shortages and coordinated operations of Lakes Mead and Powell have helped reduce the risk of shortages to California.

Collecting a tree-ring sample near Ebbetts Pass. Data from multiple trees at one site are combined into a single record representative of the site.

are depleted and water levels in ground water basins decline. Hydrologic impacts of drought to any individual water supplier may be exacerbated by other factors such as regulatory requirements to satisfy the rights of senior water right holders or to protect environmental resources.

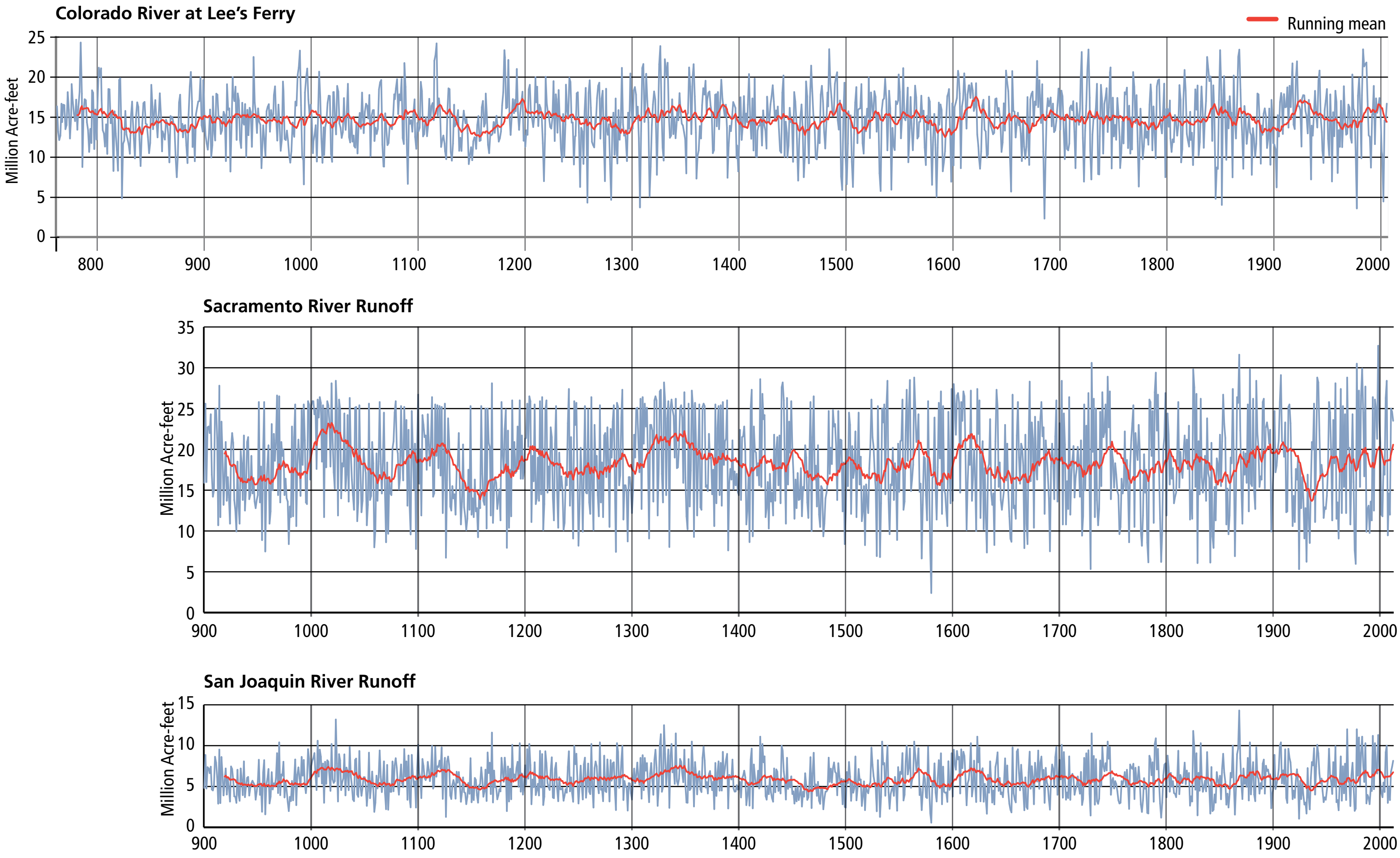
From a water use perspective, drought is best defined by its impacts to a particular class of water users in a particular location. In this sense, drought is a very local circumstance. Hydrologic conditions constituting a drought for water users in one location may not constitute a drought for water users in a different part of the state or with a different water supply. California's extensive system of water supply infrastructure— reservoirs, managed groundwater basins, and inter-regional conveyance facilities—mitigates the effect of short-term (single year) dry periods. Individual water suppliers may use criteria such as rainfall/runoff, amount of water in storage, decline in groundwater levels, or expected supply from a water wholesaler to define their water supply conditions. Criteria used to identify statewide drought conditions—such as statewide runoff and reservoir storage—do not address these localized circumstances. And although California's water supply infrastructure provides a means to mitigate impacts for some water users, other types of impacts (increased wildfire risk, stress on vegetation and wildlife) remain.

DROUGHTS IN CALIFORNIA

Drought played a role in shaping California's early history, as the so-called Great Drought in 1863-64 contributed to the demise of the cattle rancho system, especially in Southern California. Subsequently, a notable period of extended dry conditions was experienced during most of the 1920s and well into the 1930s, with the latter time including the Dustbowl drought that gripped much of the United States. Three twentieth century droughts were of particular importance from a water supply standpoint – the droughts of 1929-35, 1976-77, and 1987-92. More recent multi-year droughts are 2007-09 and 2012-15.

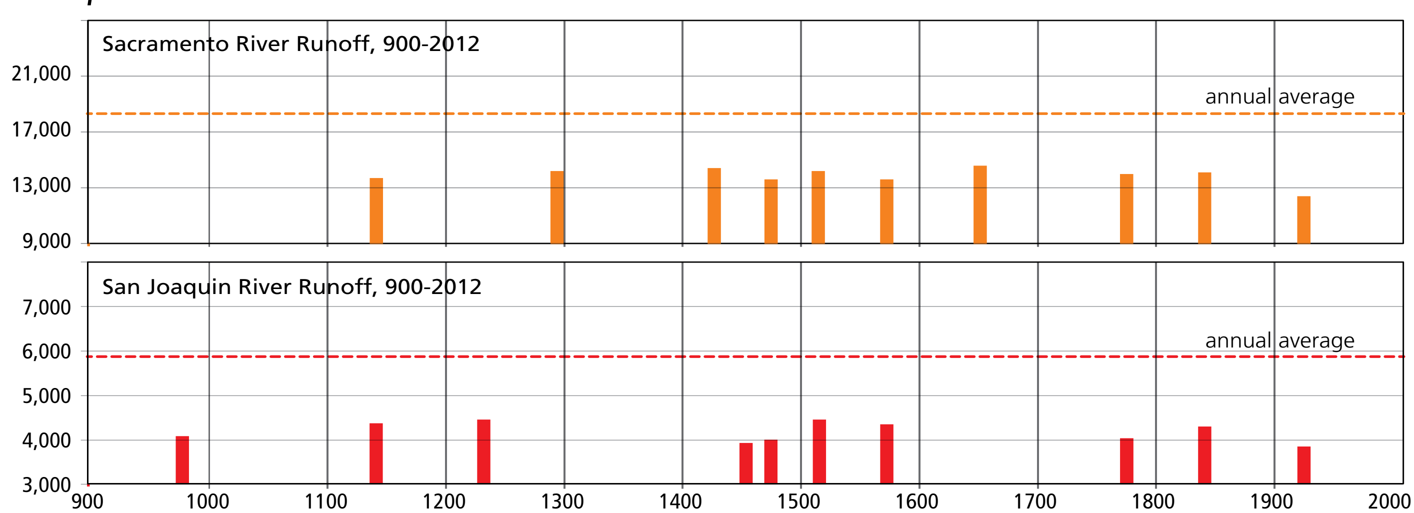
The 1928-34 drought was notable not only for its duration but also for its occurrence within a longer period of very dry hydrology. This drought's hydrology was subsequently widely used in used in evaluating and designing storage capacity and yield of large Northern California reservoirs. The 1976-77 drought, when statewide runoff in 1977 hit an all-time low, served as a wake-up call for California water agencies that were unprepared for major cut-backs in their supplies. Forty-seven of the State's 58 counties declared local drought-related emergencies at that time. Probably the most iconic symbol of the 1976-77 drought was construction of an emergency pipeline across the San Rafael Bridge to bring water obtained through a complex system of exchanges to Marin Municipal Water District in southern Marin County. The 1987-92 drought stands out because of its six-year duration. Twenty-three counties declared local drought emergencies then. Santa Barbara experienced the greatest water supply reductions among the larger urban areas. In addition to adoption of measures such as a 14-month ban on all lawn watering, the city installed a temporary emergency desalination plant and an emergency pipeline was constructed to make

Reconstructed flows in major rivers



Data courtesy of Dave Meko, University of Arizona

Driest 10-Year periods in reconstructed records



Sacramento River runoff is the sum of the unimpaired flow at the Sacramento River above Bend Bridge, Feather River at Oroville, Yuba River near Smartville, and American River below Folsom Lake.

San Joaquin River runoff is the sum of the unimpaired flow at the Stanislaus River below Goodwin Reservoir, Tuolumne River below La Grange, Merced River below Merced Falls, and San Joaquin River inflow to Millerton Lake.

Figure provided courtesy of Connie Woodhouse, University of Arizona

Dry periods in combined reconstructed and instrumental periods: periods of four or more consecutive years with flows below median

Sacramento River Runoff		San Joaquin River Runoff	
Years	Length, years	Years	Length, years
921-924	4	946-950	5
945-950	6	977-981	5
975-981	7	1072-1075	4
1072-1075	4	1143-1148	6
1130-1136	7	1155-1158	4
1143-1148	6	1172-1177	6
1150-1158	9	1210-1213	4
1170-1177	8	1233-1239	7
1233-1239	7	1294-1301	8
1292-1301	10	1395-1402	8
1390-1393	4	1407-1410	4
1395-1400	6	1425-1428	4
1407-1410	4	1450-1461	12
1425-1432	8	1463-1466	4
1451-1457	7	1471-1483	13
1475-1483	9	1505-1508	4
1515-1521	7	1518-1523	6
1540-1543	4	1540-1545	6
1569-1572	4	1569-1572	4
1578-1582	5	1578-1582	5
1592-1595	4	1592-1595	4
1636-1639	4	1629-1632	4
1645-1648	4	1645-1648	4
1652-1655	4	1652-1655	4
1753-1760	8	1688-1691	4
1780-1783	4	1753-1757	5
1783-1846	4	1780-1783	4
1856-1859	4	1793-1796	4
1917-1922	6	1843-1846	4
1926-1935	10	1855-1859	5
1946-1951	6	1928-1931	4
1959-1962	4	1946-1950	5
1987-1992	6	1959-1962	4
		1987-1992	6
		2000-2004	5

Data courtesy of Dave Meko, University of Arizona

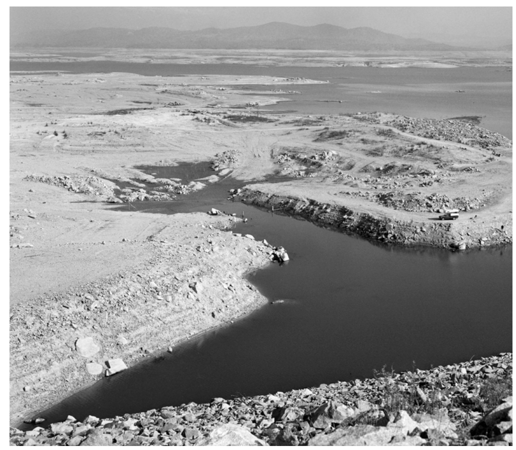
State Water Project supplies available to southern Santa Barbara County.

However, a period of historically recorded hydrology of little more than a century does not represent the full range of the climate system's natural variability. Paleoclimate information, such as streamflow reconstructions based on tree-ring data, shows that natural variability can be far greater than that observed in the historical record. These reconstructions have identified droughts prior to the historical record that were more severe than today's water institutions and infrastructure were designed to manage, although one period in the historical record – that of the 1920s-30s – ranks among the driest events of the extended record.

DROUGHT CAUSATION AND PREDICTION

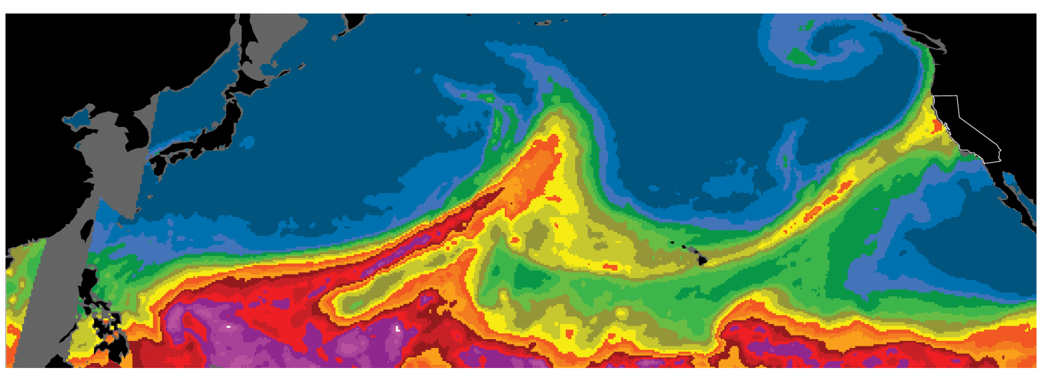
Most of California's moisture originates from the Pacific Ocean. During the wet season, the atmospheric high pressure belt that sits off western North America shifts southward, allowing Pacific storms to bring moisture to California. On average, 75 percent of the state's average annual precipitation occurs

Folsom Lake in water year 1977 (an El Niño year) and in water year 2014 (an ENSO-neutral year).



(Below) Satellite image of atmospheric river reaching West Coast. Atmospheric river storms – storms fueled by concentrated streams of water vapor from the Pacific Ocean – are big contributors to annual water supply conditions. A few major storms more or less shift the balance between a wet year and a dry one.

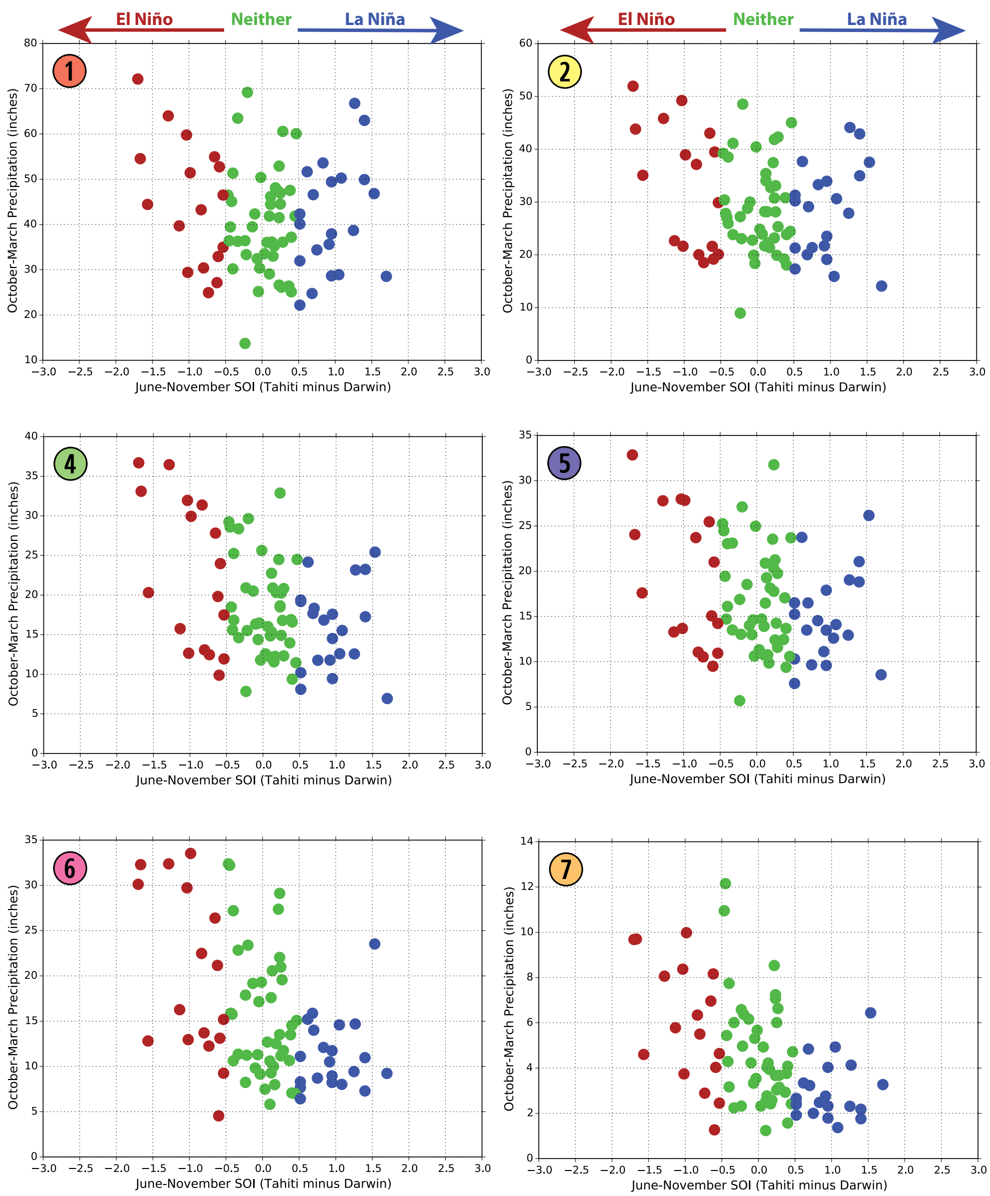
Image courtesy NOAA Hydrometeorology Testbed.



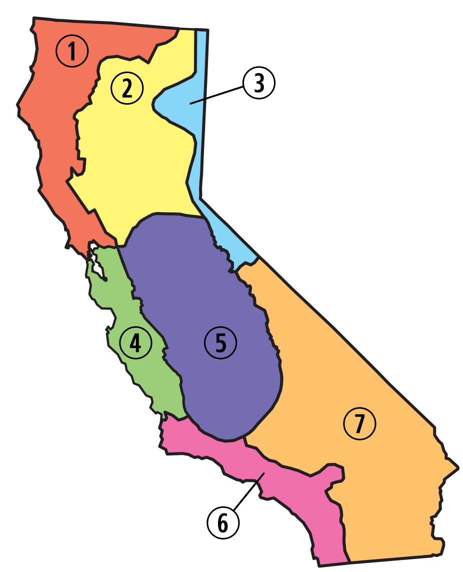
between November and March, with half of it occurring between December and February. A few major storms more or less shift the balance between a wet year and a dry one. A persistent high pressure zone over California during the peak winter water production months predisposes the water year to be dry.

The ability to reliably predict precipitation conditions at seasonal or annual timescales is very limited. The status of the El Niño-Southern Oscillation (ENSO) is presently the only factor that offers limited predictive capability for precipitation in California. ENSO is a periodic shifting of ocean-atmosphere conditions in the tropical Pacific that ranges from El Niño (warm phase) to neutral to La Niña (cold phase). La Niña conditions tend to favor a drier outlook for Southern California, but do not typically

ENSO and California precipitation



California climate divisions



SOI - Southern Oscillation Index

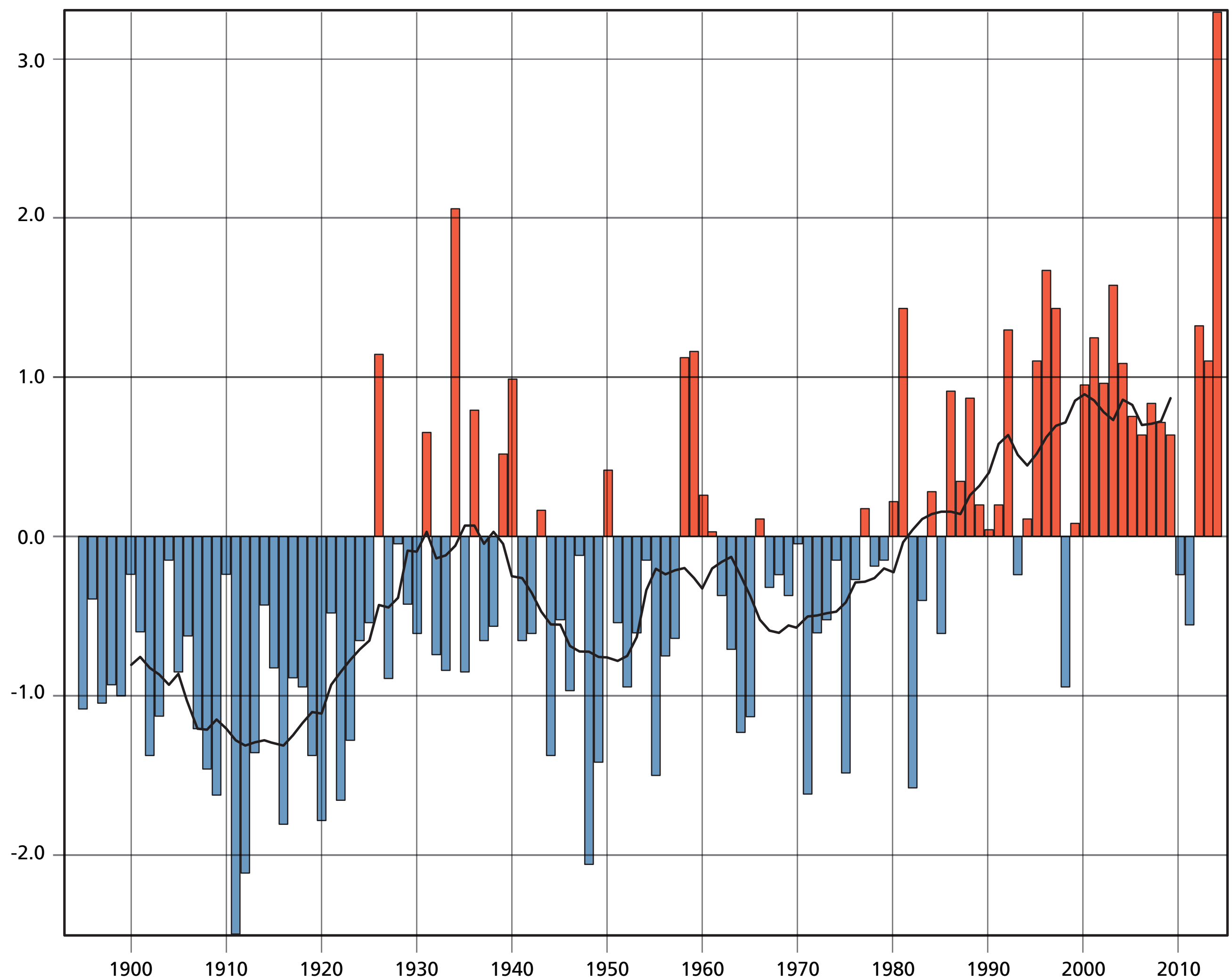
Data courtesy of Western Regional Climate Center

Historically California's largest directly quantifiable economic impacts of drought have been associated with loss of timber resources and wildfires.

show significant correlation with water year type for Northern and Central California. The predictive capabilities provided by ENSO events are related to the strength of an event; stronger events yield better predictive signals. In any individual year, interactions with other climate patterns or forcings may affect the outcome that might otherwise be expected from ENSO conditions alone.

Over the long-term climate change is expected to affect California's water supply conditions, with one of the most significant impacts being reduction in mountain snowpack due to warmer temperatures. Climate change models show very pronounced impacts – such as loss of half or more of Sierra Nevada snowpack – by the end of the century, with noticeable impacts occurring by mid-century. Even though climate models predict that Northern California may be slightly wetter by century's end, the loss of winter storage capacity in mountain snowpack will exacerbate drought conditions. The record warm temperatures California experienced in the winters of water years 2014 and 2015 illustrate how

California statewide mean temperature departure



Source: Western Regional Climate Center

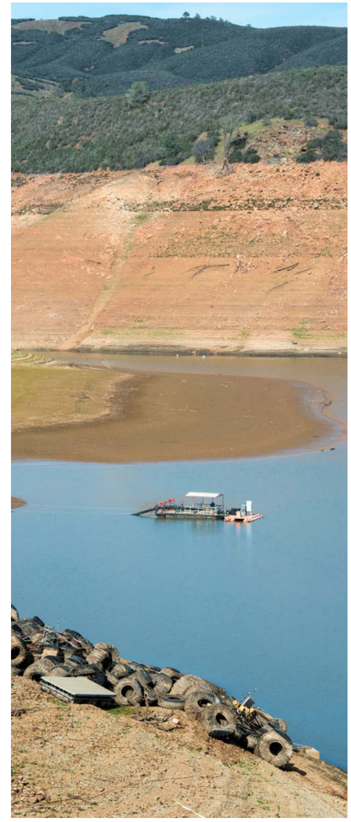
Droughts pose risks for shallow private residential wells. Emergency deliveries of bulk and bottled water were used to respond to dry private wells in parts of Tulare County in 2014 and 2015.

future droughts may unfold, with greatly reduced spring runoff into major reservoirs and water temperatures too warm to support critical fish populations. California's statewide snowpack water content normally peaks in early April; a record low for April 1st was set in 2015, surpassing calculated values that date back to 1950.

DROUGHT IMPACTS

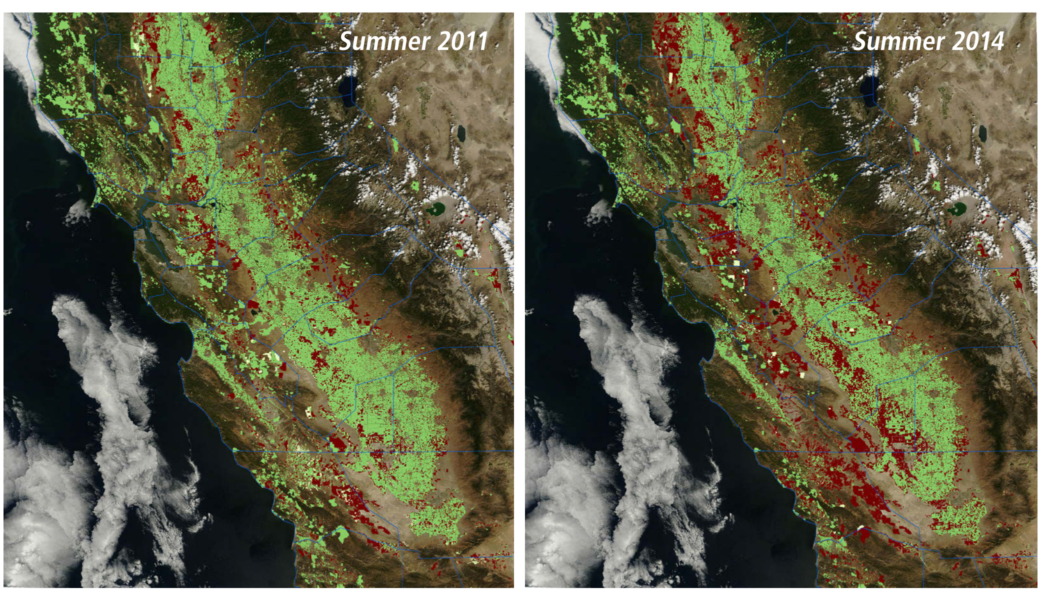
Even a single dry year can pose problems for activities that are wholly dependent on unmanaged water supplies, such as dryland farming or livestock grazing. Single dry year impacts to the natural environment can often be seen in the form of increased wildfire risk, a risk that increases in multiple dry years. Damages associated with wildfires and loss of timber resources can be one of the largest economic impacts of drought, and California faces increasing risk of damages as urban development encroaches on the urban/wildland interface. California's most devastating urban/wildland fire episodes (Oakland hills in 1991, Southern California in 2003, Southern California in 2007) occurred during a drought or in a year immediately following a multi-year drought, when dry vegetation created conditions favorable for massive fire outbreaks.

Multiple dry years predictably create



An emergency temporary pumping plant for the Lake Don Pedro Community Services District floats on a depleted Lake McClure in early 2015.

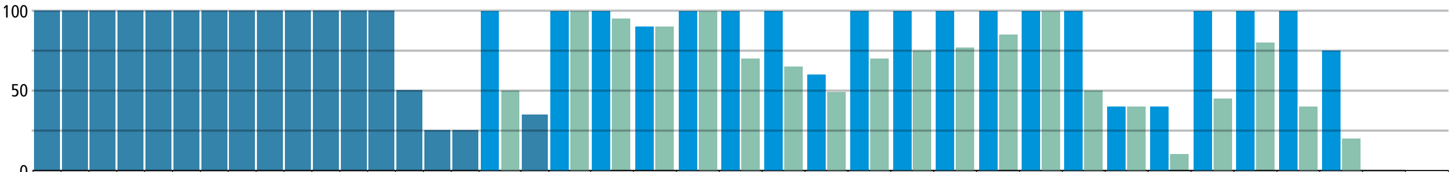
Summer satellite imagery of the Central Valley in 2011 (wet year) and 2014 (drought year)



False color image. Estimated idled acreage shown in red. *Image courtesy of NASA*

Cumulative effects of changing conditions on California water project allocations

Historical Central Valley Project allocations to agricultural contractors



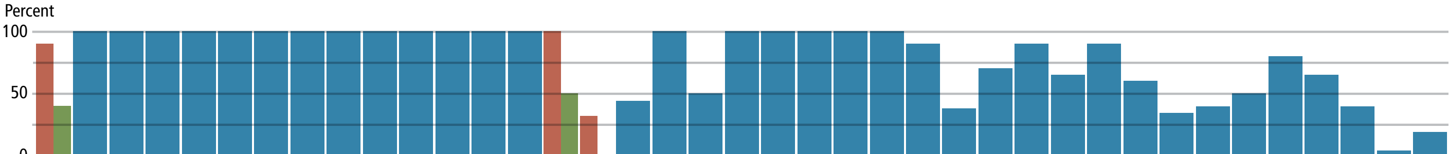
100	100	100	100	100	100	100	100	100	100	100	100	100	50	25	25
1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992

100/50	35	100/100	100/95	90/90	100/100	100/70	100/65	60/49	100/70	100/75	100/77
1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004

100/85	100/100	100/50	40/40	40/10	100/45	100/80	100/40	75/20	0/0	0/0
2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015

No differentiation made between North of Delta and South of Delta contractors prior to 1993 | North of the Delta | South of the Delta

Historical State Water Project allocations to project contractors



90/40	100	100	100	100	100	100	100	100	100	100	100	100
1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989

100	100/50	30/0	45	100	50	100	100	100	100	100	90	39
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002

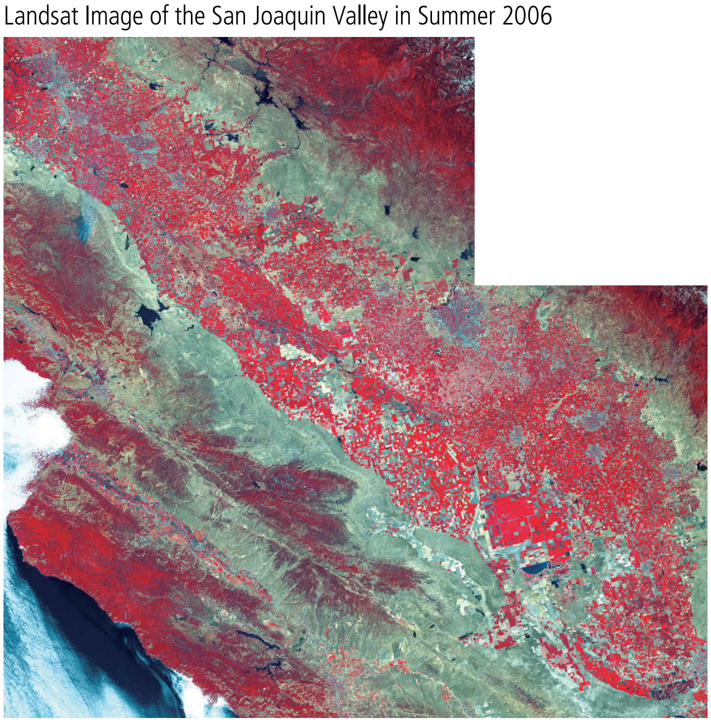
70	90	65	90	60	35	40	50	80	65	40	5	20
2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015

Urban Allocation | Agricultural Allocation | Same allocation to all contractors

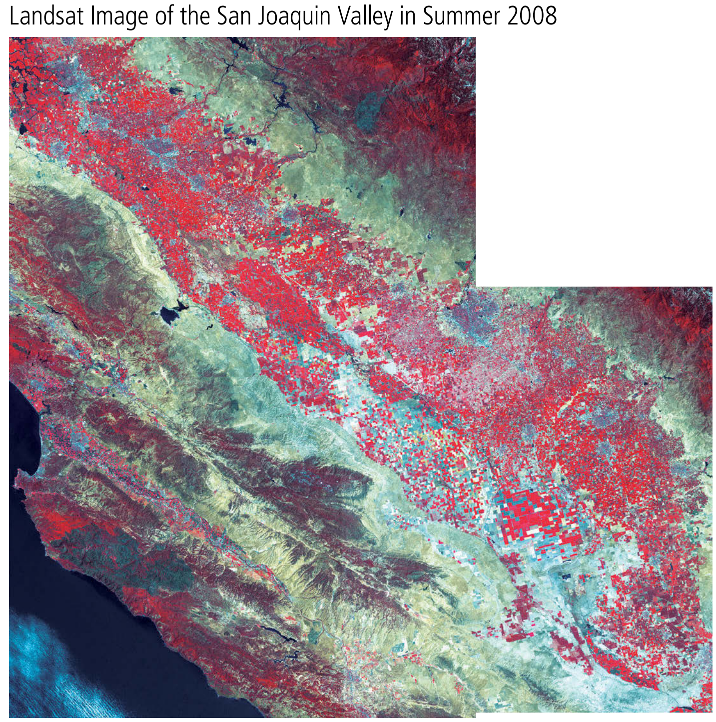
Prior to 1994, differential allocations could be made for urban and agricultural contractors. The few years for which separate allocations were made are highlighted in contrasting colors.

Comparing extent of irrigated acreage at the end of a wet water year and a dry one

Landsat Image of the San Joaquin Valley in Summer 2006



Landsat Image of the San Joaquin Valley in Summer 2008



USGS Landsat Image. False-color infrared, irrigated areas in red.

problems for small water systems in at-risk areas. Urban water suppliers, particularly those serving larger metropolitan areas, normally provide reliable supplies for their customers, as they have the resources and the revenue base to prepare for and respond to drought impacts. The majority of serious water supply problems during droughts (e.g. inability to maintain fire flows, need for truck haulage of water) are experienced by small water systems. Although small systems serve a low percentage of California's total population, they constitute the majority of the state's public water systems. Small systems tend to be located outside the state's major metropolitan areas, often in lightly populated rural areas where opportunities for interconnections with another system or water transfers are minimal. Small systems also have limited financial resources and rate bases that constrain their ability to undertake major capital improvements. Most small system drought problems stem from dependence on an unreliable water source, commonly groundwater in fractured rock systems or in small coastal terrace groundwater basins.

Historically, particularly at-risk geographic areas have been foothill areas of the Sierra Nevada, Coast Range, and inland Southern California mountains, and the North and Central Coast regions.

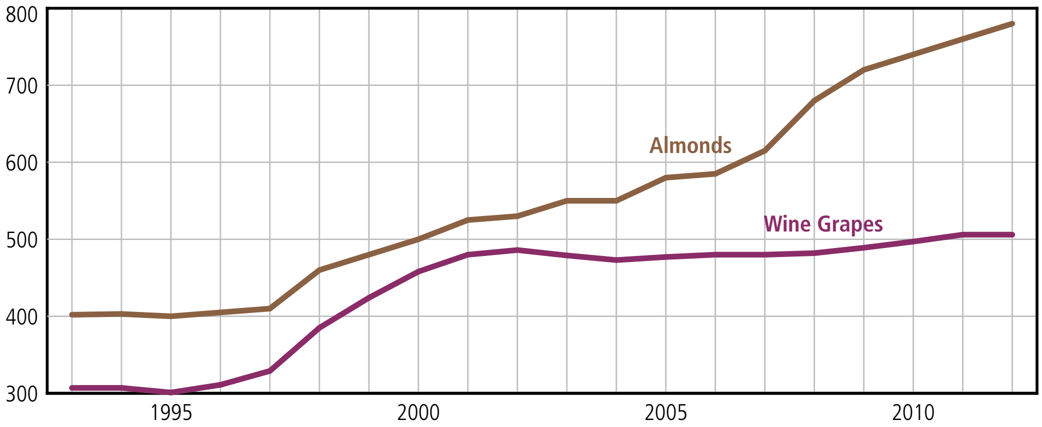
In the irrigated agriculture sector, the largest at-risk area has historically been the west side of the San Joaquin Valley, particularly the area supplied by Central Valley Project (CVP) south-of-Delta exports. For example, CVP contractors in this area received zero supplies in water years 2014 and 2015; these years were also the first in which CVP contractors in the Friant Division on the east side of the valley received zero supplies from the project. Although groundwater and water transfers may make up for some of the lost surface water supplies, cuts of this magnitude result in abandonment of permanent plantings such as orchards and vineyards, large-scale land fallowing, and job losses in rural communities dependent on agricultural employment.

Drought impacts can change over time due to factors such as increases in population, changes in agricultural cropping patterns, or changes in institutional

Orchard on the Westside of the San Joaquin Valley abandoned during the 2007-09 drought.

Example of increased acreage in permanent plantings

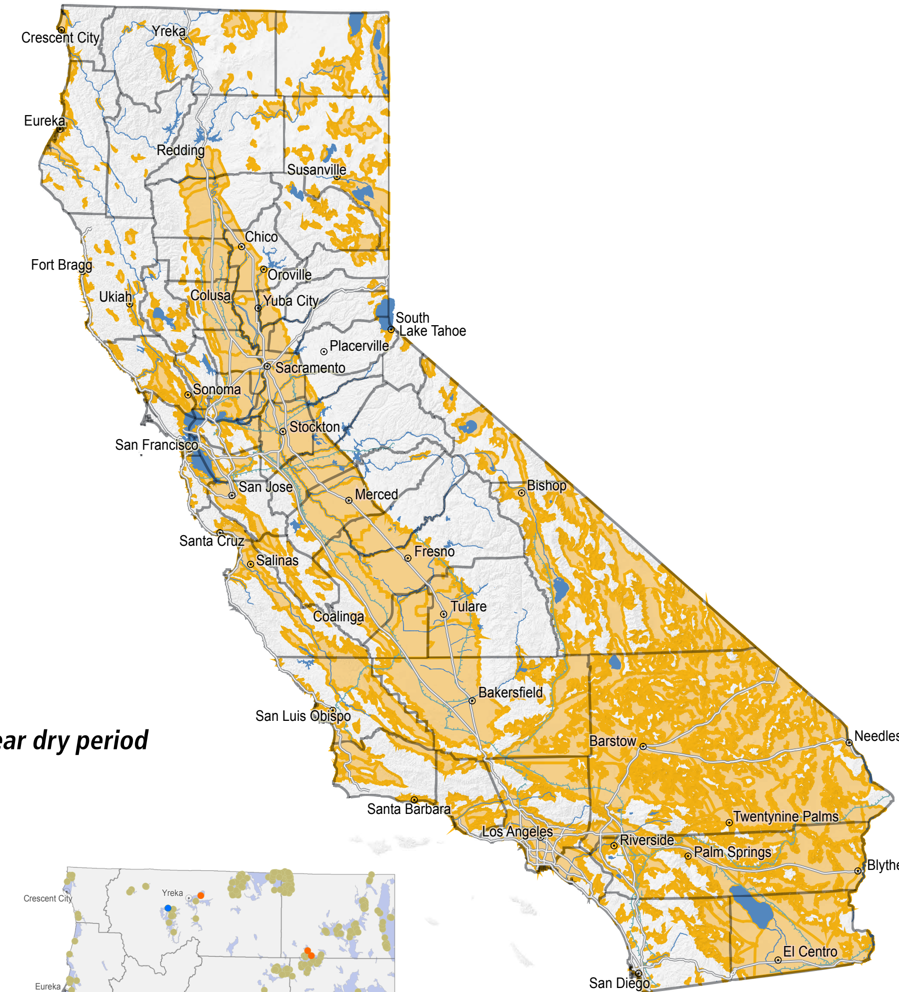
CDFA Harvested Acreage (1,000 Acres) 1993-2012



Statewide acreage data from California Department of Food and Agriculture

California groundwater basins

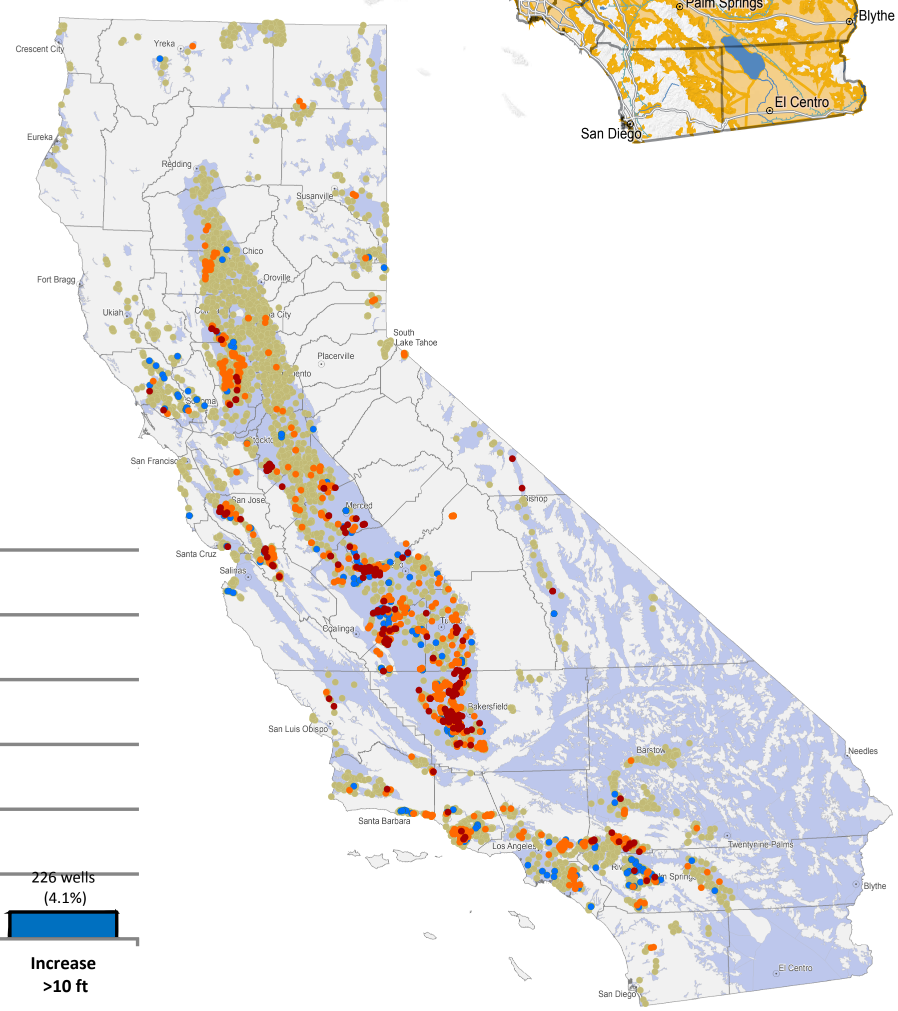
- Groundwater Basin/Subbasin
- Hydrologic Region Boundary
- County Boundary
- Major Highway
- Major Canal



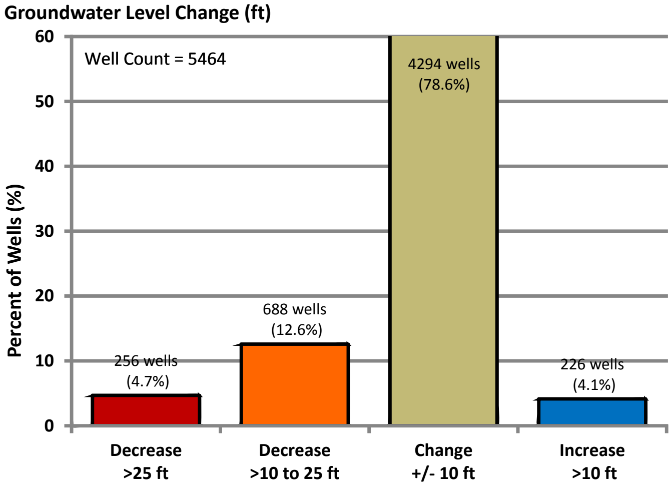
Changes in groundwater levels over a multi-year dry period

Difference

- > 10 ft increase
- +/- 10 ft change
- > 10 to 25 ft decrease
- > 25 ft decrease
- Groundwater Basin
- County Boundary



Groundwater Level Change (ft)



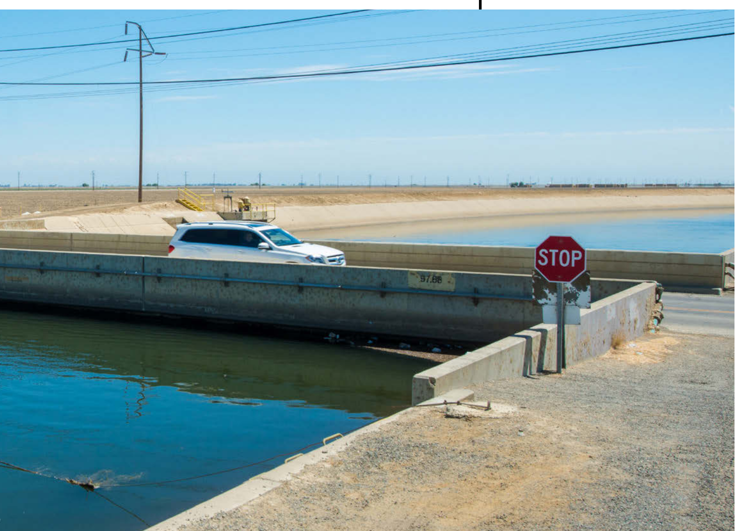
conditions. During the 1987-92 drought, for example, the state's 1990 population was close to 80 percent of present amounts and irrigated acreage was roughly the same as that of the present, but the institutional setting for water management differed significantly. Since that historical drought, California has had to reduce its use of Colorado River water to the state's basic interstate apportionment of 4.4 million acre-feet of consumptive use annually. The Central Valley Project Improvement Act of 1992 dedicated 800,000 acre-feet of project yield for environmental purposes. The regulatory framework for the State Water Project (SWP) and CVP has changed significantly in terms of new Endangered Species Act requirements to protect certain fish species, and State Water Resources Control Board water rights decisions governing the water projects' operations in the Sacramento-San Joaquin River Delta. The collective impacts of changed water supply and water use conditions can result in differences between historically observed drought vulnerability and resilience and circumstances that may occur in the future.

DROUGHTS AND GROUNDWATER

Under average hydrologic conditions, close to 40 percent of California's urban and agricultural water needs are supplied by groundwater, an amount that increases in dry years when water users whose surface supplies are reduced increase their reliance on groundwater. The amount of water stored in California's aquifers is far greater than that stored in the state's surface water reservoirs, although only a fraction of that groundwater can be economically and sustainably extracted for use. Although large alluvial groundwater basins (see figure) support most of California's groundwater use on a volumetric basis, groundwater extracted from fractured bedrock (fractured rock groundwater) is the sole source of supply for many small water systems and private well owners in foothill and mountain areas. Generally speaking, fractured rock groundwater systems store far less water than do alluvial basins and are markedly dependent on annual precipitation for recharge. Yields of wells drilled in fractured rock can vary greatly over short distances due to highly site-specific geologic conditions.

Increased groundwater use during droughts is typically reflected in declining groundwater levels in alluvial groundwater basins. In basins not experiencing long-term overdraft, a pattern of water level drawdown during dry conditions and recovery during wet conditions normally occurs. Drought exacerbates water level decline in overdrafted basins, potentially increasing the risk of adverse impacts such as land subsidence or migration of poor-quality groundwater to production wells. The San Joaquin Valley, for example, has been an area of long-standing overdraft and land subsidence, and significantly increased rates of subsidence have been observed in parts of the valley during drought years. Over time, implementation of the 2014 Sustainable Groundwater Management Act is expected is to alleviate these impacts.

Other common drought-related groundwater impacts include an increase in the number of new wells being drilled or of existing wells being deepened; private residential wells historically represent the single largest category of new or deepened wells. Drought tends to exacerbate well interference problems, where deep high-production irrigation wells may cause water level drawdowns that result in nearby shallow residential wells going dry. Drought-related private residential well problems are common in fractured rock groundwater production areas.



Russell Avenue bridge over the Delta-Mendota Canal. Differential subsidence has reduced the clearance between the bottom of the bridge and the canal water surface.

PREPARING FOR DROUGHTS & MITIGATING DROUGHT IMPACTS

California's extensive system of statewide and regional-scale water infrastructure greatly enhances the state's drought resilience by providing the capacity for facilitating water transfers and exchanges. Lessons learned from past droughts and from disasters such as earthquakes and wildfires have fostered system interconnections among the state's major water utilities, helping enable mitigative measure such as transfers.

Over more than three decades, California's voters have authorized substantial amounts of state financial assistance to local urban and agricultural water agencies, funding projects — such as water conservation, water recycling, or groundwater storage – that are tools for drought preparedness. In recent years, the 2002 Integrated Regional Water Management Act established state policy of encouraging local agencies to work cooperatively to manage local and imported water supplies to improve their quantity, quality, and reliability. In 2002 and 2006 the voters approved two bond measures which specifically authorized a combined $1.5 billion for water supply-related integrated regional water management planning and projects; Proposition 1 in 2014 added another $510 million for this purpose.

Drinking water supplies are additionally covered by statutory and administrative provisions. California Water Code Sections 10610 et seq. require that public water systems providing water for municipal purposes to more than 3,000 customers or serving more than 3,000 acre-feet annually prepare an urban water management plan and update it every five years. The plans must include a water shortage contingency analysis that addresses how systems would respond to supply reductions of up to 50 percent, and must estimate supplies available in a single dry year and in multiple dry years. The plans must also address systems' responses to catastrophic supply interruptions. Although smaller water systems are not covered by these requirements, state drinking water regulations require that the systems demonstrate technical, financial, and managerial capacity (including having an emergency response plan) as part of being eligible for financial assistance.

In the agricultural sector, individual water users (i.e., growers) are eligible for a variety of programs authorized by the Farm Bill and administered through the U.S. Department of Agriculture. Programs range from risk management programs (crop insurance) to disaster financial assistance for drought impacts or prevented planting.

Many managed water supplies have associated environmental regulatory requirements that provide dry year protections such as mandated instream flows for fishery purposes. Operations of the State Water Project and federal Central Valley Project in the Sacramento-San Joaquin River Delta, for example, are intensively managed to meet water quantity and quality requirements for fish species of special concern. Major wildlife refuges in the Central Valley have been guaranteed specific quantities of water since the 1992 passage of the Central Valley Project Improvement Act.

New Exchequer Dam on the Merced River, with the old Exchequer Dam exposed by low water levels in February 2015. Declining reservoir levels in water year 2015 exposed foundations of old townsites and other structures, and forced some small water systems to relocate pump intakes or find other water sources.

For More Information on Historical Droughts

Detailed information on California's historical droughts is available in DWR reports documenting the hydrology, impacts, and response actions associated with these events. The reports listed below are available on DWR's website or at the California State Library, Government Publications Section.

- *The California Drought – 1976.* May 1976
- *The California Drought 1977, An Update.* February 1977
- *The Continuing California Drought.* August 1977
- *The 1976-77 California Drought – A Review.* May 1978
- *California's 1987-92 Drought, A Summary of Six years of Drought.* July 1993
- *Preparing for California' s Next Drought, Changes Since 1987-92.* July 2000
- *California's Drought of 2007-09, An Overview.* November 2010
- *California's Most Significant Droughts: Comparing Historical and Recent Conditions,* February 2015

FALL 2015
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www.water.ca.gov/drought