# Drought In California

January 2021

California Department of Water Resources | Natural Resources Agency | State of California

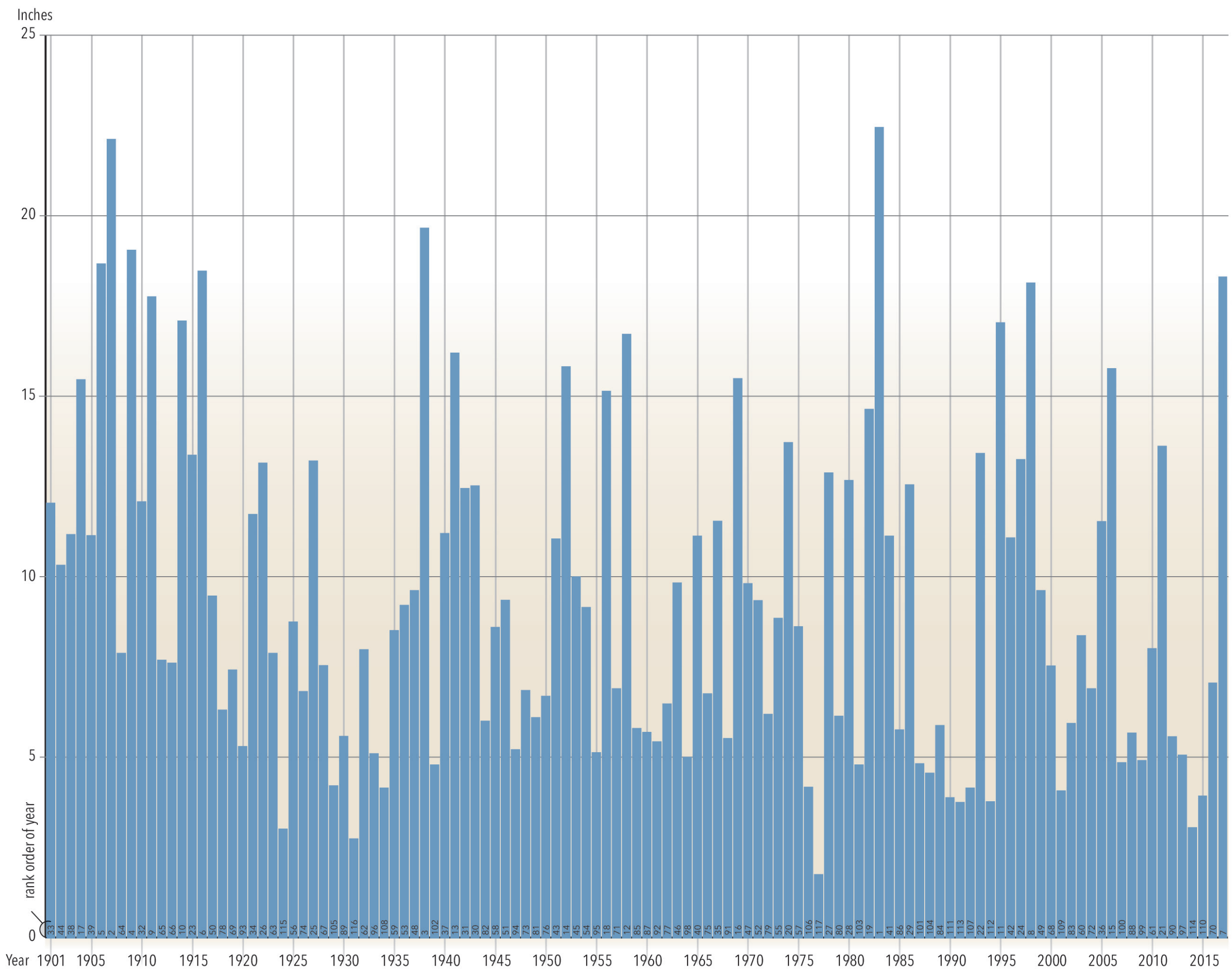
## Major Water Facilities

## DEFINING DROUGHT

California's annual water supply conditions are highly variable, and droughts are a recurring feature in the state's water budget. There are many ways that drought can be defined. Some ways can be quantified, such as meteorological drought (a period of below-normal precipitation) or hydrologic drought (a 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. A proclamation of emergency conditions pursuant to the California Emergency Services Act may be used to respond to drought impacts, but such a proclamation is not itself a definition of drought.

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 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.

Calculated Statewide Runoff




*Data: U.S. Geological Survey*

*An aerial view of Lake Powell, with Glen Canyon Dam in the foreground. The Colorado River Basin has been experiencing long-term drought conditions since 2000, resulting in lowered water levels at Lake Powell (shown here) and Lake Mead. The Colorado River has historically been a highly reliable water supply for Southern California, despite prolonged drought, thanks to the basin's 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. The existing guidelines expire at the end of 2025. Photo credit: Getty Images*

From a water use perspective, drought is best defined by its impacts on 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 interregional conveyance facilities—mitigates the effect of short-term (single-year) dry periods for most water users. Individual water suppliers may use criteria such as rainfall or 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 most water users, other types of impacts (such as increased wildfire risk or stress on vegetation and wildlife) remain.

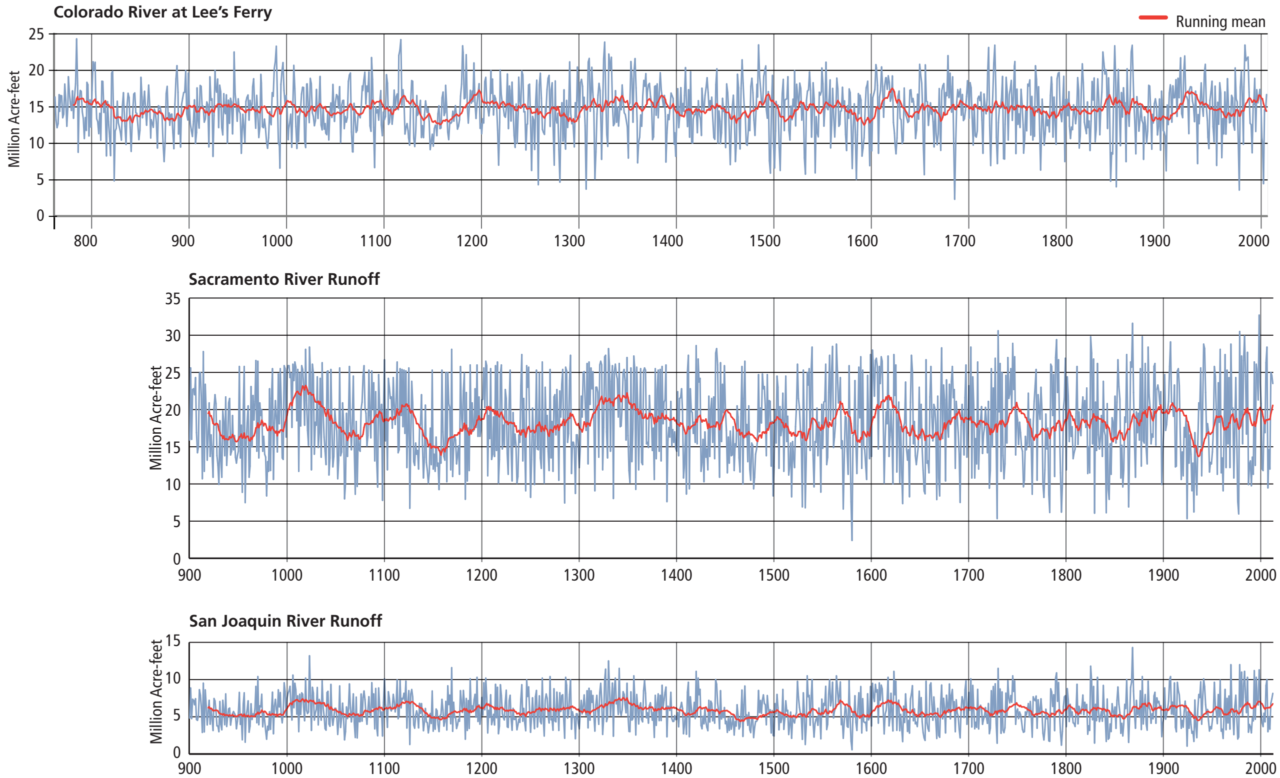
## DROUGHTS IN CALIFORNIA

Drought played a role in shaping California's early history, as the so-called Great Drought in 1863–1864 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 20th century droughts were of particular importance from a water supply standpoint—the droughts of 1929–1934, 1976–1977, and 1987–1992. More recent multiyear droughts occurred in 2007–2009 and 2012–2016.

The 1929–1934 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 evaluating and designing storage capacity and yield of large Northern California reservoirs. The 1976–1977 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 cutbacks 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 1976–1977 drought was construction of an emergency pipeline

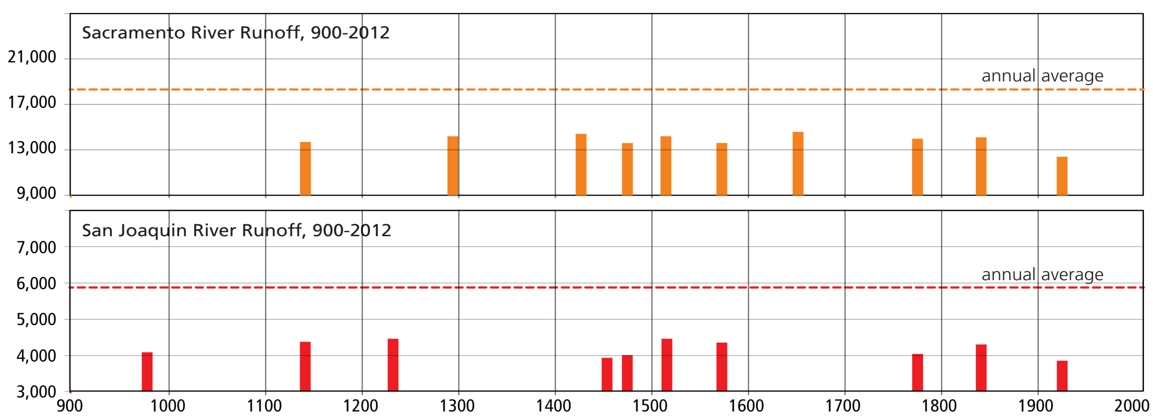
*Collecting a tree-ring sample near Ebbetts Pass. Data from multiple trees at one site are combined into a single record representative of the site.*

## 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* 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 1987–1992 drought stands out because of its six-year duration. Twenty-three counties declared local drought emergencies during that period. 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 State Water Project (SWP) supplies available to southern Santa Barbara County. The Department of Water Resources' state drought water bank and enactment of legislation clarifying water rights aspects of water transfers catalyzed development of the institutional framework for transfers that exists today.

Twenty-first century statewide droughts include the three-year 2007–2009 event and the five-year 2012–2016 event. These events were the first times statewide proclamations of emergency were used to respond to drought impacts and they also illustrated the effect of a warming climate on drought impacts. California tied its record for the lowest April 1st statewide snowpack set in Water Year 1977 (25 percent of average) in Water Year 2014 and then broke the record in Water Year 2015 (5 percent of average). Calendar years 2014 and 2015 were the warmest and second-warmest years of record, respectively, for statewide average temperature. New records for catastrophic wildfires were set during and after the 2012–2016 drought. That drought was the first time the State imposed mandatory urban water use reduction requirements on water suppliers, and all of California's 58 counties declared local emergencies. An iconic image of that drought was the temporary emergency pumping plant and pipeline used at the U.S. Bureau of Reclamation's Lake Cachuma to move water for the Santa Barbara area across the lake's dry bottom to the distribution system intake that had been stranded by falling lake levels. Although the statewide drought of 2012–2016 was ended by a wet Water Year 2017, localized drought conditions persisted in the Central Coast region and were not ended until a wet Water Year 2019.

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 and1930s—ranks among the driest events of the extended record.

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


*Agricultural impacts of the 2012-2016 drought were most widespread in the San Joaquin Valley, where Central Valley Project agricultural water contractors had zero allocations in 2014 and 2015. Reduced agricultural activity translated to economic impacts for small rural communities dependent on farm employment, creating increased demands on social services programs. Photo credit: Getty Images*

*A dry Lake Cachuma in February 2017. The temporary pipeline seen here entering the inlet tower to the Tecolote Tunnel connected a barge-mounted emergency pumping plant on the lake to the inlet. The dry lakebed illustrates lingering Central Coast drought impacts that were not mitigated by a wet Water Year 2017. It was not until early 2019 that lake levels recovered sufficiently to permit decommissioning of the temporary facilities.*

Land Idling Based on Satellite Imagery, September Comparison of a Wet 2011 with a Dry 2015

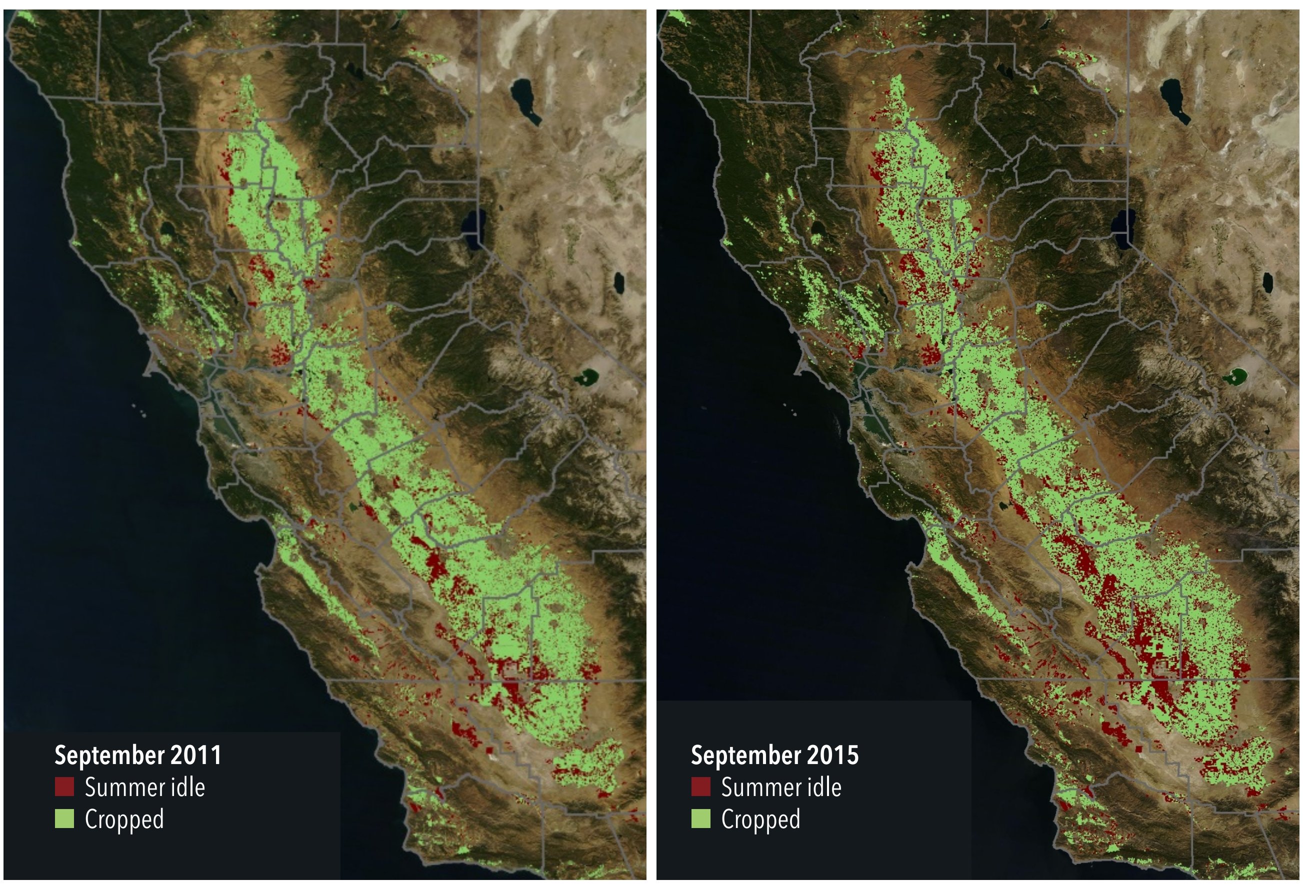
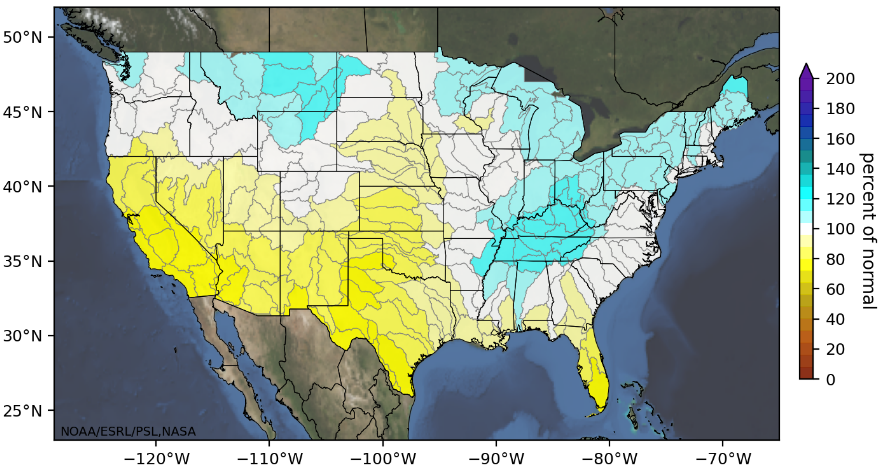


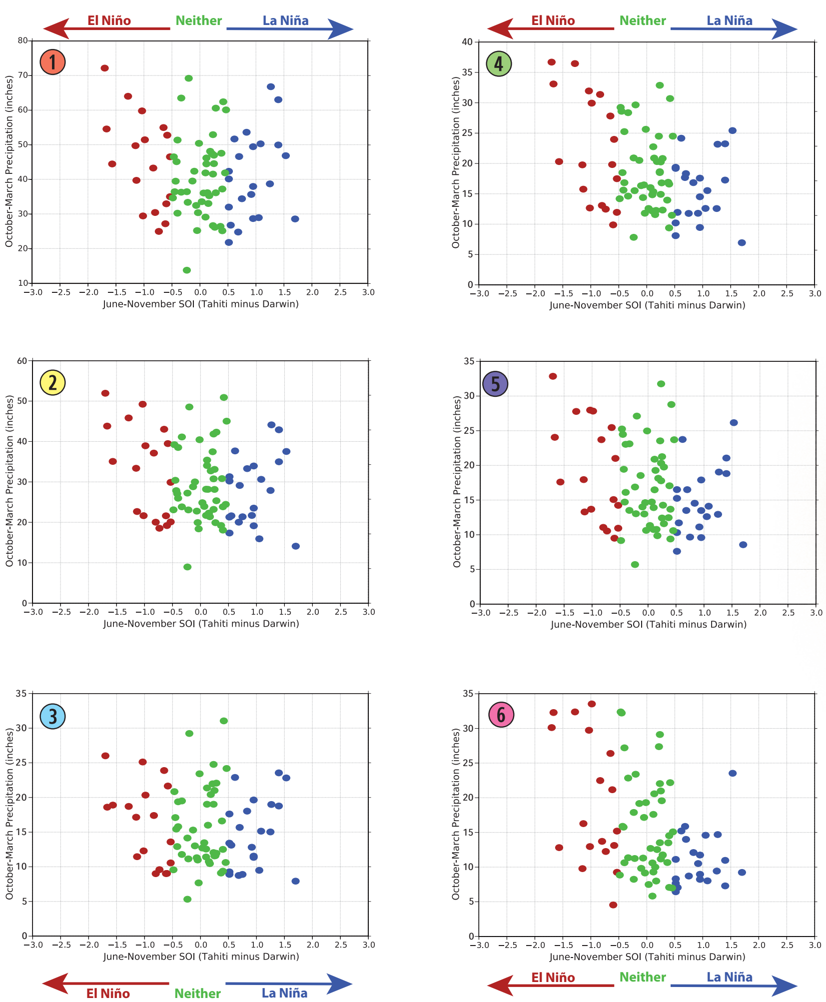

*Figure credit: NASA*

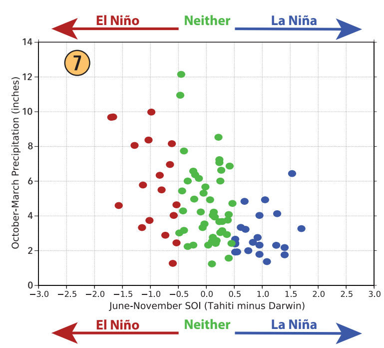
## PSL Forecast Anomalies 2020/2021




*An experimental research seasonal precipitation forecast prepared by the National Oceanic and Atmospheric Administration's (NOAA's) Earth Systems Research Laboratory for DWR. Although the need for skillful forecasts of seasonal precipitation to support water management decision-making has been expressed from the 1976-1977 drought onward through today, the skill of operationally issued forecasts remains low. A 2020 NOAA report to Congress prepared pursuant to Public Law 115-25 has outlined a research agenda for improving sub-seasonal to seasonal precipitation forecasting. Image courtesy of NOAA Earth Systems Research Laboratory.*

## El Niño–Southern Oscillation and California Precipitation



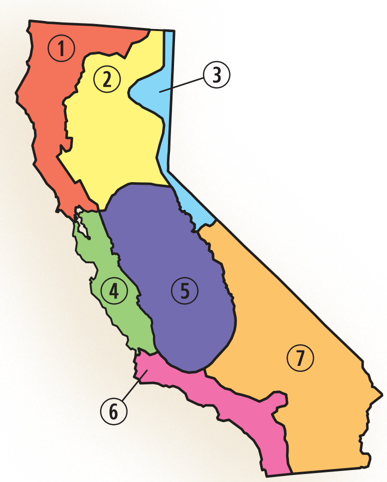




*Figure credit: Western Regional Climate Center*

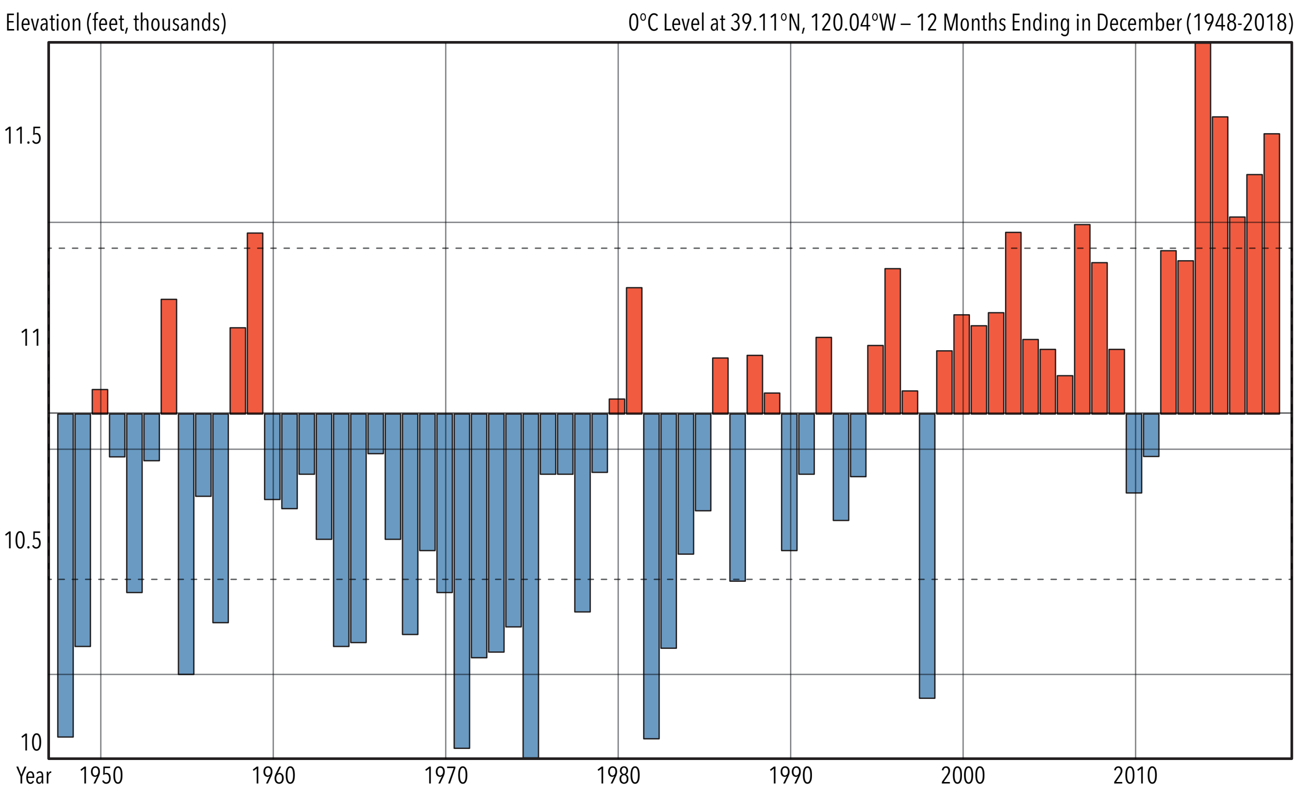
## DROUGHT CAUSATION AND PREDICTION

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 between November and March, with half of it occurring between December and February. 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 El Niño-Southern Oscillation (ENSO) offers only 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 show significant correlation with water year type for Northern and Central California. Seasonal precipitation forecasting is an important drought response tool and a research area requiring focused investment to develop the predictive ability needed to support water management.

*The December 2017 Thomas Fire in the hills above Santa Barbara. Five years of drought followed by a wet Water Year 2017 resulted in ample fuel for wildfires, combining dead trees and brush from the drought with heavy growth of annual grasses that became dry tinder in the summer. Photo credit: Getty Images*

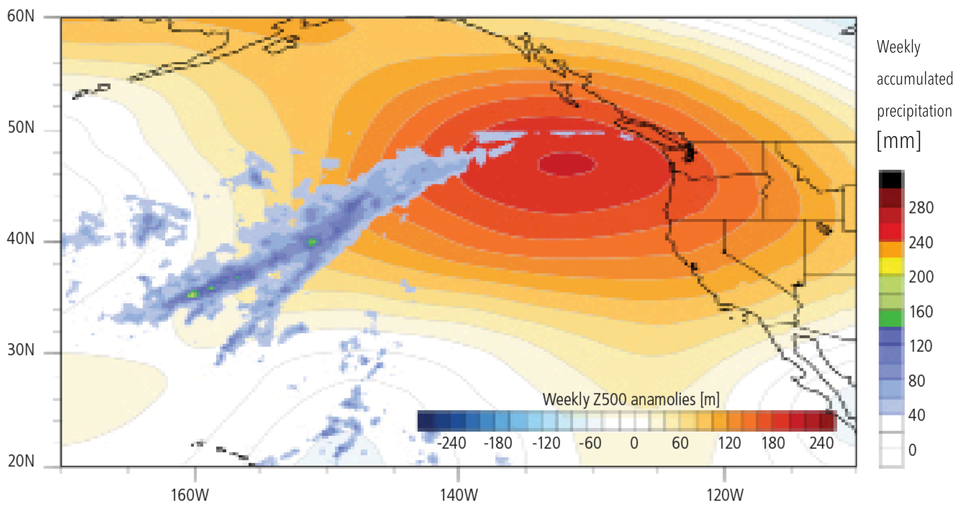
Annual Elevation of Freezing Level Over Lake Tahoe, Departure From Long-Term Mean




*Source: Western Regional Climate Center*

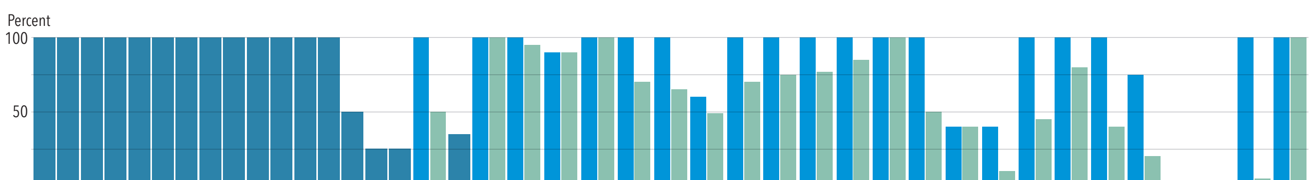
Climate change is expected to affect California's water supply conditions over the long term, with a significant impact being reduction in mountain snowpack. Climate change models show pronounced impacts–such as loss of half or more of Sierra Nevada snowpack–by the end of the century, with noticeable impacts occurring by mid-century. Even though some climate models predict that Northern California may be slightly wetter by century's end, the loss of winter storage capacity in mountain snowpack and warmer temperatures will exacerbate drought conditions. The record warm temperatures California experienced in the winters of Water Years 2014 and 2015 illustrate how future droughts may unfold, with greatly reduced spring runoff into major reservoirs and water temperatures too warm to support anadromous fish populations in many areas.

### Atmospheric Ridging Blocking Precipitation from Reaching West Coast




*Persistent atmospheric ridging that prevented winter precipitation from reaching California, popularly known as the "Ridiculously Resilient Ridge," was a defining feature during part of the 2012-2016 drought. Developing the ability to predict these conditions months in advance is an important aspect of improving drought preparedness. Figure credit: NASA Jet Propulsion Laboratory*

### Historical Central Valley Project Allocations to Agricultural Contractors

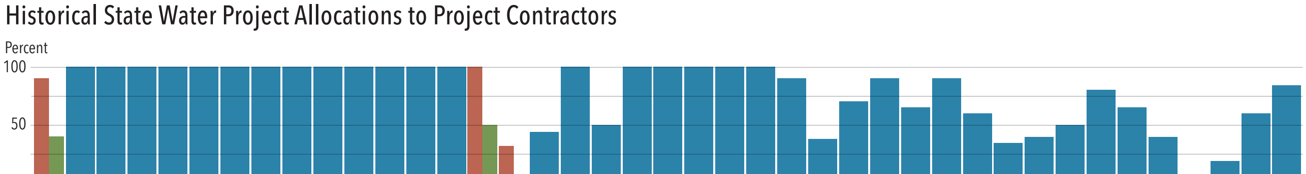



| Year | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 25 | 25 | 100/50 | 35 | 100/100 | 100/95 |

| Year | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 90/90 | 100/100 | 100/70 | 100/65 | 60/49 | 100/70 | 100/75 | 100/77 | 100/85 | 100/100 | 100/50 | 40/40 | 40/10 | 100/45 | 100/80 | 100/40 | 75/20 | 0/0 | 0/0 | 100/5 | 100/100 |

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




| Year | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 90/40 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100/50 | 30/0 | 45 | 100 | 50 | 100 |

| Year | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 100 | 100 | 100 | 90 | 39 | 70 | 90 | 65 | 90 | 60 | 35 | 40 | 50 | 80 | 65 | 40 | 5 | 20 | 60 | 85 |

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.

A dead citrus orchard in 2015 near Lindsay. The first-ever zero allocations of Class 1 water in the CVP's Friant service area in 2014 and 2015 were unexpected and came with substantial impacts for local residents.

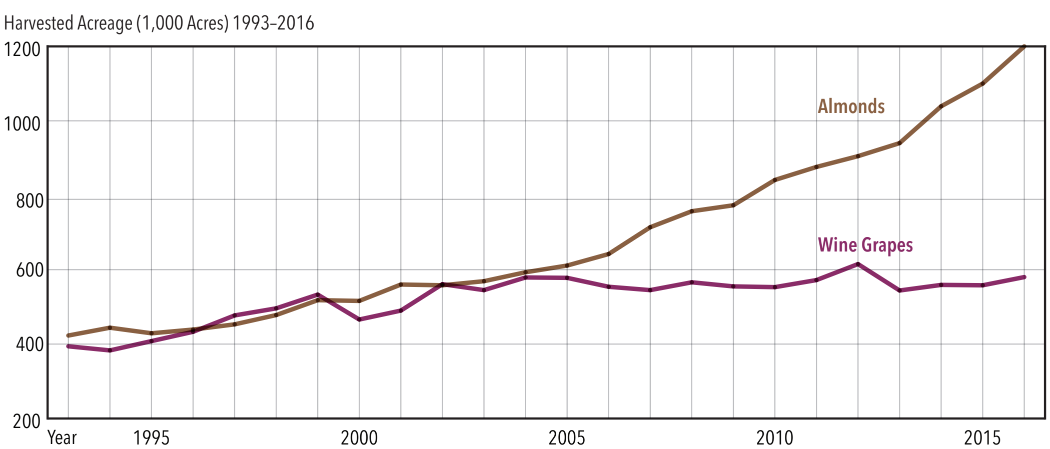
Orchard on the Westside of the San Joaquin Valley abandoned during the 2007-2009 drought.

## 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 are one of the largest economic impacts of drought, and California faces increasing wildfire risk from the combination of a warming climate and encroachment of urban development into the urban/wildland interface. As illustrated by the state's catastrophic 21st century wildfire seasons, devastating urban/wildland fire episodes occurred during or following a drought,

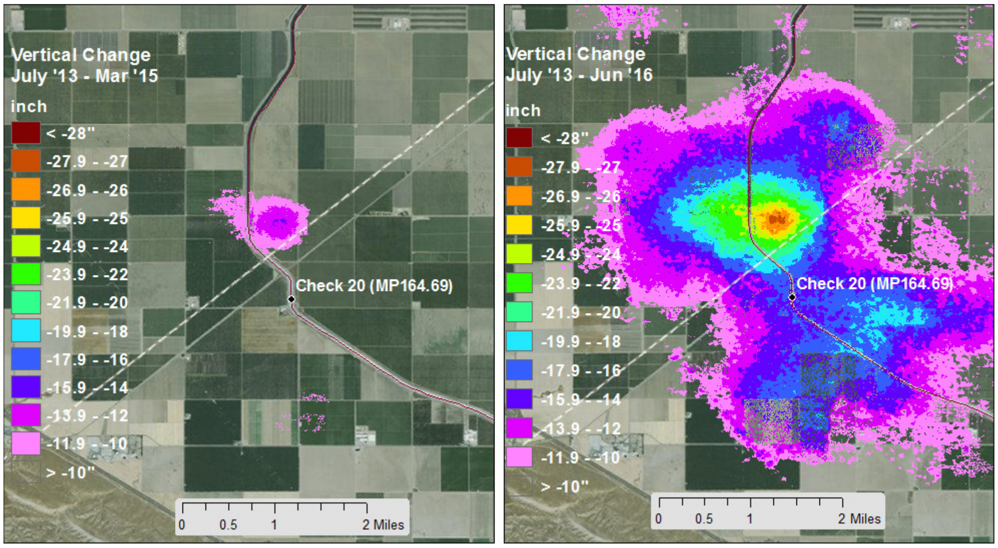
Cattle grazing near the California Aqueduct south of Bakersfield in February 2014. The livestock industry is affected early during droughts, when non-irrigated rangeland lacks sufficient forage to support producers' normal grazing operations. Livestock grazing conditions are typically a driver of U.S. Department of Agricultural drought disaster designations that enable federal financial assistance for producers. Photo credit: Getty Images

Example of Increased Acreage in Permanent Plantings




Data credit: California Department of Food and Agriculture and U.S. Department of Agriculture National Agricultural Statistics Service.
Note: The California Department of Food and Agriculture reclassified its definition of wine grapes in 2013.

Growth of Subsidence Hotspot Adjacent to California Aqueduct




*An interferometric synthetic aperture radar (InSAR) image of the growth of a subsidence hotspot adjacent to the California Aqueduct during the 2012-2016 drought, captured by an aircraft-based sensor. DWR contracted with the National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL) for InSAR subsidence monitoring during the drought. The monitoring revealed the widespread spatial extent of San Joaquin Valley land subsidence during the drought as well as subsidence rates matching earlier record highs of approximately one foot per year. Figure credit: NASA JPL*

*Subsidence north of Check 20 on the California Aqueduct near Avenal. DWR estimates that the aqueduct in this area has lost 20 percent of its original design capacity because of long-term subsidence.*

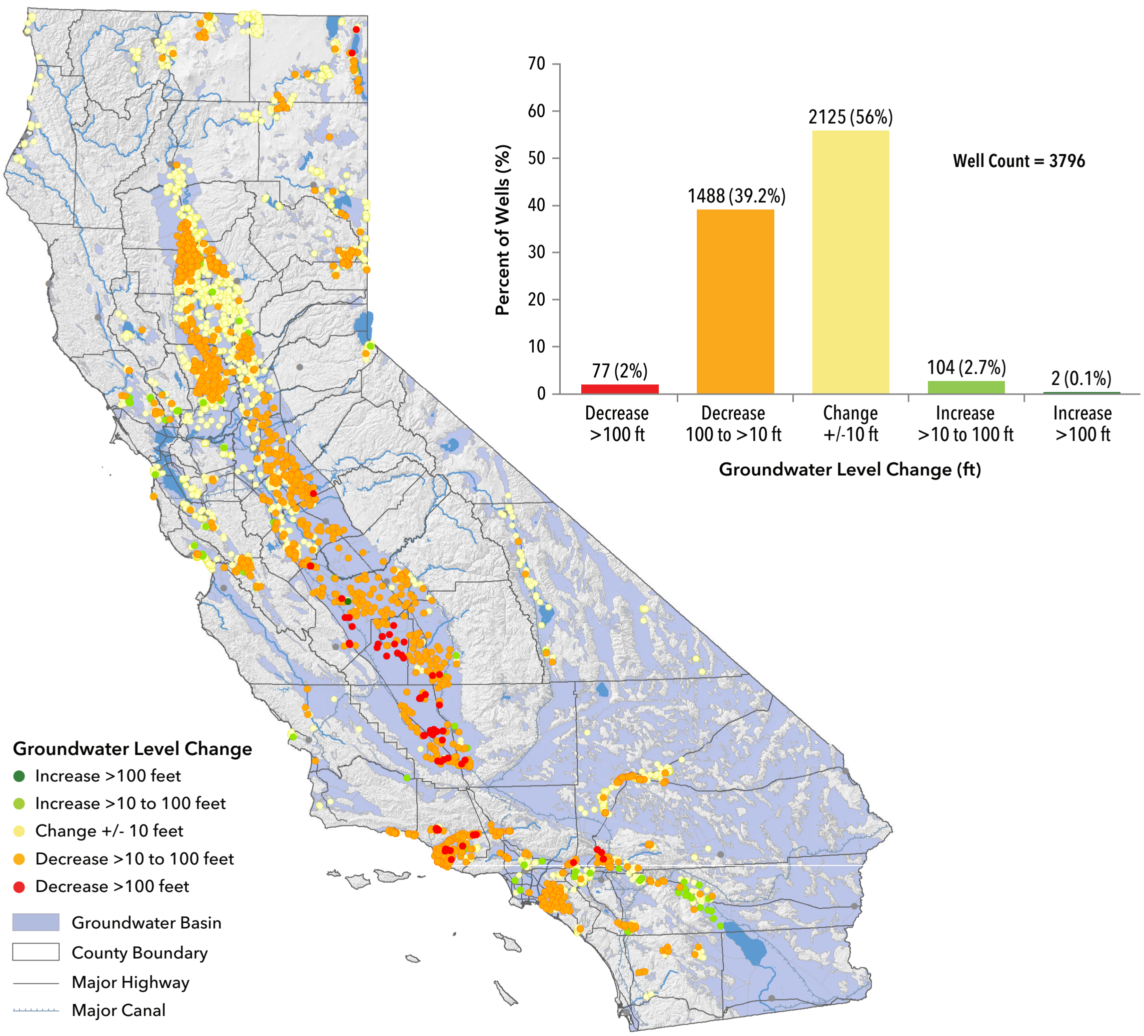
when dead timber and brush and dry vegetation created conditions favorable for massive fire outbreaks.

Multiple dry years predictably create problems for small water systems in at-risk areas. Urban water suppliers, particularly those serving larger metropolitan areas, typically provide reliable supplies for their customers, as they have the resources and the revenue base to prepare for and respond to drought impacts. Most serious water supply problems during droughts 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 (as well as self-supplied households on private wells) 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 have limited financial resources, constraining their ability to undertake major capital improvements. Most small system drought problems stem from dependence on an unreliable water source, often 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. CVP agricultural contractors in both the Sacramento and San Joaquin valleys received first-ever zero supplies in Water Years 2014 and 2015, leading to substantially increased groundwater pumping that in turn created other impacts, especially in the San Joaquin Valley. 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 socioeconomic impacts 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, climate change, or changes in institutional conditions. During the 1987–1992 drought, for example, the state's 1990 population was close to 80 percent of present numbers and irrigated acreage was

Cumulative Change in Statewide Groundwater Levels, 2012–2016 Drought

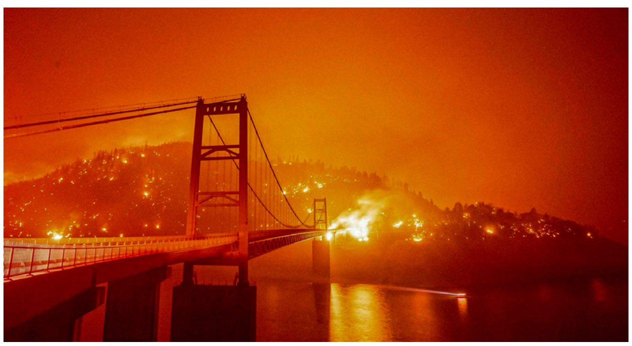



roughly the same as that of the present, but the institutional setting for water management differed significantly. Since that historical drought, California has had to reduce its use of Colorado River water to the State's basic interstate apportionment of 4.4 million acre-feet of consumptive use annually. The Central Valley Project Improvement Act of 1992 dedicated 800,000 acre-feet of project yield for environmental purposes. The regulatory framework for the SWP and CVP 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 Delta. The collective impacts of changed water supply and water use conditions can result in differences between historically observed drought vulnerability or 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 with diminished surface supplies increase their reliance on groundwater. The amount of water stored


*Following the 2017 Tubbs Fire, the City of Santa Rosa has been replacing destroyed or damaged water service lines and conducting extensive water quality testing in parts of its distribution system where contaminants from melted plastic pipes were detected. Photo credit: California Governor's Office of Emergency Services*



*Flames from the Bear Fire in September 2020 burn around Lake Oroville; the Bidwell Bar Bridge is in the foreground. DWR evacuated Hyatt Powerplant as a precautionary measure. The fire destroyed much of the small community of Berry Creek. Similarly, the 2018 Carr Fire burned the area surrounding the U.S. Bureau of Reclamation's Keswick Dam and powerplant, requiring evacuation of plant operators and resulting in boil water advisories for residents served by several small community services districts. Photo credit: Getty Images*

*The City of San Diego's San Vicente Dam, constructed in the 1940s, was raised 117 feet as part of San Diego County Water Authority's (SDCWA's) emergency storage project, more than doubling the reservoir's capacity and improving the drought resiliency of a region having relatively little local surface water or groundwater storage capacity. The enlargement was completed in 2014. Photo credit: SDCWA*

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 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 rural 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 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.

*In this September 2014 image, Tulare County residents with dry private wells are filling up their containers at a bulk tank for non-potable water at the Doyle Colony Fire Station in Porterville. Photo credit: Getty Images*

*Droughts leave long-lasting impacts on the landscape, such as the massive tree die-offs caused by bark beetle infestations experienced in the Tahoe Basin in 1987-1992 and in the central and southern Sierra Nevada in 2012-2016. These conditions exacerbate future wildfire risks. Photo credit: CAL FIRE*

## For More Information on Historical Droughts

Information about 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 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 1976-1977 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.* January 2020

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