SEPTEMBER 2017

Water Year 2017:
What a Difference a Year Makes

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

What a Difference a Year Makes

Water year 2017 (October 1, 2016 to September 30, 2017) dramatically illustrated the variability in California's annual precipitation, ending the state's 5-year drought and coming in at second place for statewide runoff, behind the wettest year of 1983. Virtually all of the state experienced at least average precipitation, and key Sierra Nevada watersheds were much above average. Governor Brown lifted the proclamation of statewide drought emergency he issued in 2014, although the state-declared emergency remained in selected central California counties experiencing lingering drought impacts. Prior to 2017, California had experienced a decade of largely dry conditions. Eight of the ten preceding water years were dry, and the water years of 2012-15 set a record for the driest consecutive four-year period of statewide precipitation.

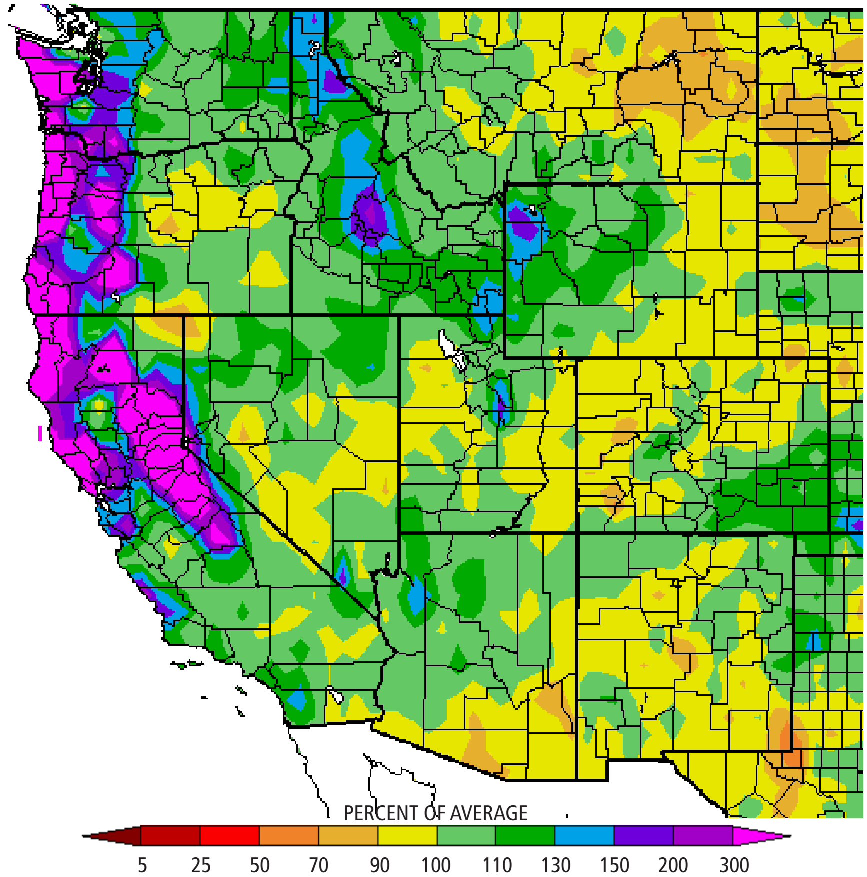
Gates on the Sacramento Weir were opened in 2017 to allow water to flow from the Sacramento River into the Yolo Bypass. The 1,920-foot long weir, constructed in 1916, is one of multiple structures making up the Sacramento River Flood Control Project. Its manually operated gates are opened based on forecasted river flows to reduce Sacramento River flood stages downstream of the American River confluence, to reduce flood risk to the metropolitan Sacramento area. Prior to water year 2017, the gates were last opened in December 2005.

(Above) This radar located at the Bodega Marine Laboratory is part of an atmospheric river observatory funded by the National Oceanic and Atmospheric Administration (NOAA) and DWR. Over the past decade California (DWR and the California Energy Commission) has invested more than $40 million on observing systems and related work to monitor and develop an understanding of the atmospheric river storms that cause major floods and are important contributors to water supply.

Precipitation

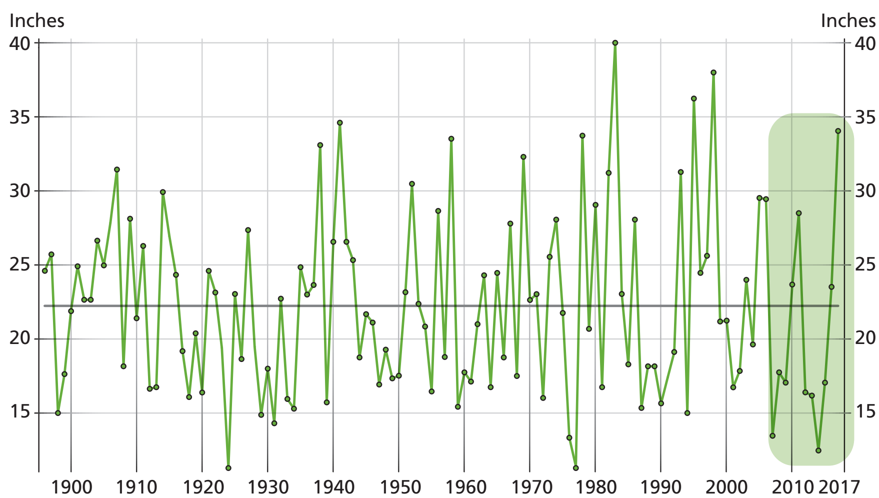
DWR's eight-station precipitation index for 2017 (which tracks conditions in the largest Central Valley watersheds important for water supplies) set a new record of nearly 95 inches, as compared to the long-term average of 50 inches. Despite near-record wet conditions for statewide total precipitation, 2017 did not approach the 1983 record for April 1 statewide snow water equivalent. Water year 2017 snowpack was still impressive, however, coming in at 163 percent of average on April 1. Water year 2017 did tie 1983 for a different benchmark record, the latest opening (June 29) of Tioga Pass Road at Yosemite National Park, thanks to a storm season that continued active into late spring. As recently as 2015, California had set a record for minimum April 1 statewide snowpack at only 5 percent of average, for a period that dates back to 1950.

Percent of Average Precipitation (%), 10/1/2016 - 9/17/17



Generated 9/16/2016 at Western Regional Climate Center (WRCC) using provisional data. NOAA Climate Centers

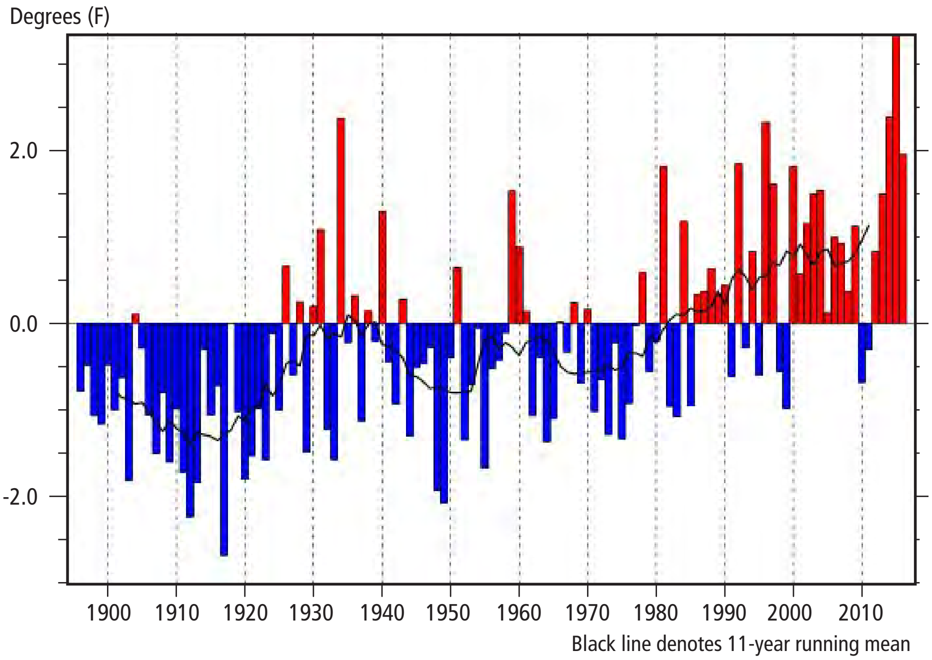
California Statewide Annual Precipitation (based on July 1 – June 30 year)



In the decade prior to water year 2017, only water year 2011 was significantly wetter than average. The statewide drought of 2007-09 was followed by the statewide drought of 2012-16.

NOAA National Centers for Environmental information, Climate at a Glance: U.S. Time Series, Precipitation, published September 2017, retrieved on September 7, 2017 from http://www.ncdc.noaa.gov/cag/

California Statewide Mean Temperature Departure, October through September



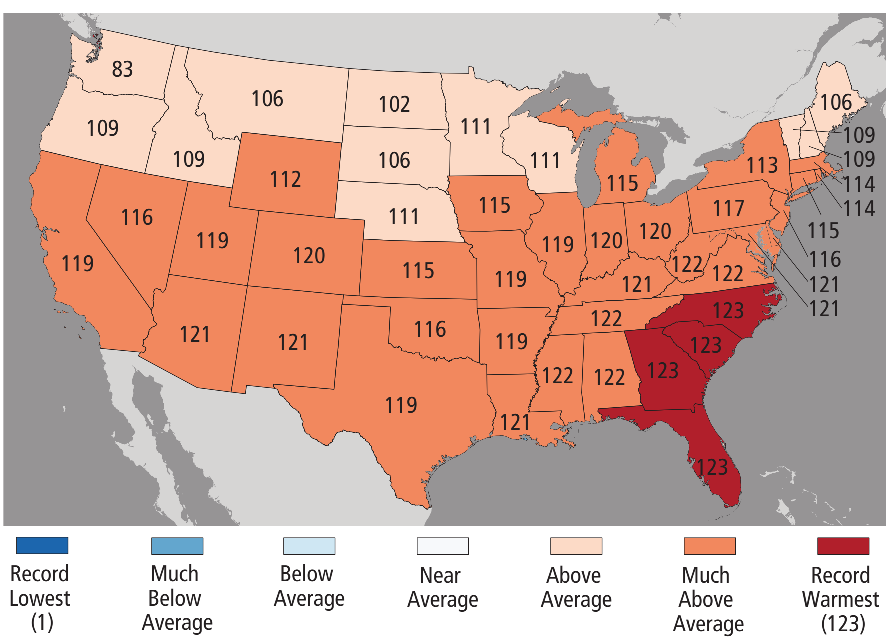
Departures from 1949-2005 base period:

Linear trend 1895-present	+1.76 ± 0.48°F/100 yr
Linear trend 1949-present	+3.00 ± 1.16°F/100 yr
Linear trend 1975-present	+4.25 ± 2.60°F/100 yr
Warmest year	59.4°F in 2015
Coldest year	53.4°F in 1917

Western Regional Climate Center

Statewide Average Temperature Ranks

January - August 2017; Period: 1895-2017



Data courtesy of NOAA/ National Centers for Environmental Information (NCEI)

Temperatures

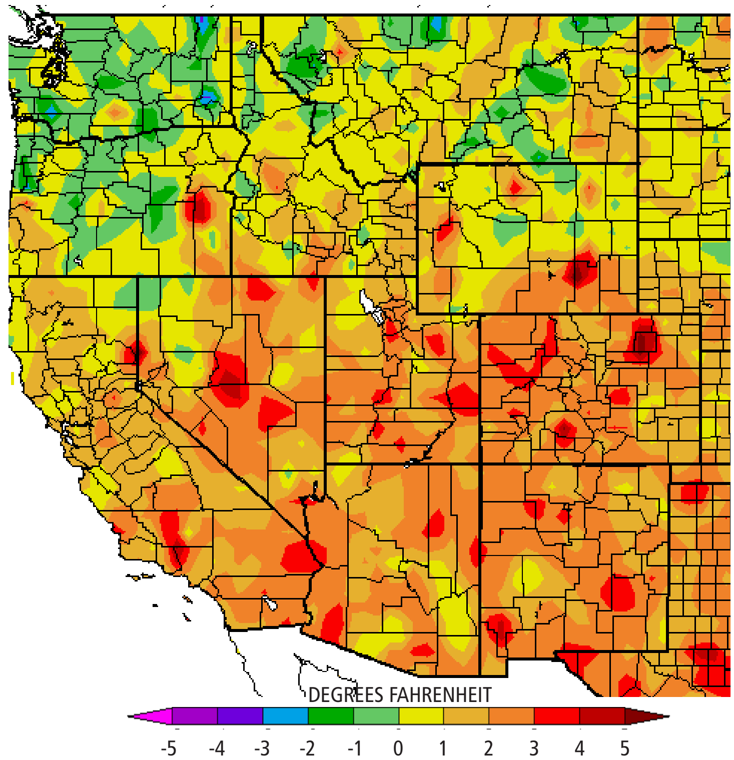
Water year 2017 continued a notable trend of warmer statewide temperatures that began in the 1980s. The summer of 2017 was the warmest on record for much of California with many site-specific temperature records being not just broken but shattered. Downtown San Francisco's new all-time record of 106 degrees was especially notable. Warming temperatures have many consequences, including influencing the percentage of precipitation that falls as rain as compared to snow, and affecting runoff through increased evaporation and through evapotranspiration from vegetation. In the last few years California has experienced record warm average temperatures, with 2015 holding the record for warmest water year. Record warm temperatures, especially during drought years, complicate operating the major Central Valley reservoirs to maintain river temperatures needed for salmonid species that require cold water at certain life stages.

Atmospheric Rivers and Flooding

Water year 2017 was noteworthy for the large number of atmospheric rivers making landfall in California, with the West Coast as a whole experiencing 53 of these events. Atmospheric rivers, concentrated bands of water vapor transported by strong winds, can cause extreme amounts of precipitation under the right weather conditions. California receives half of its average annual precipitation from December through February. Atmospheric river storms in January and February created high water conditions throughout much of the state. The February storms were especially memorable for the broad geographic extent of the localized flooding they caused in both Northern and Southern California. DWR's investment, in partnership with NOAA, in a monitoring system tailored to observing atmospheric river storms and improving related flood forecasting ability has yielded big dividends in understanding the role these storms play in California's climate.

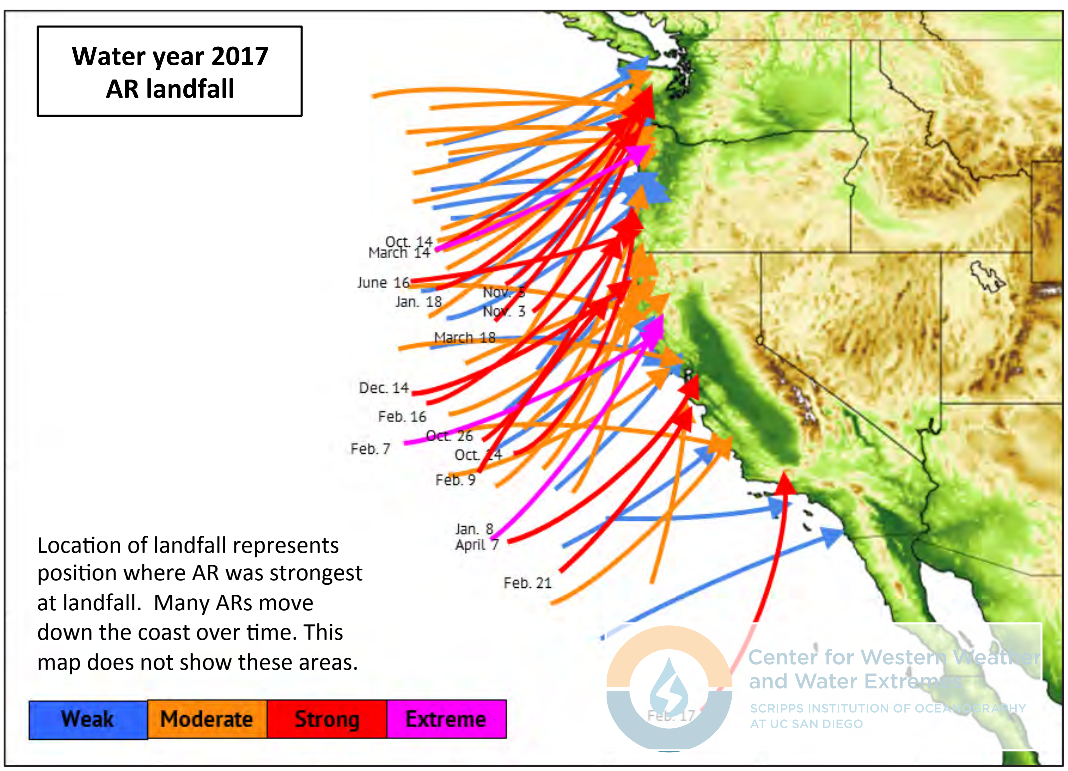
Atmospheric river storms have historically been the source of major California floods, as well as significant contributors to annual water supply. Although California's wettest years of 1983 and 2017 were fueled by atmospheric river storms, they were not years of major floods on the state's largest

Average Temperature Departure from Average (degF), 10/1/2016 - 9/17/17



Generated 9/16/2016 at WRCC using provisional data. NOAA Climate Centers

Distribution of Landfalling Atmospheric Rivers on the U.S. West Coast (From October 1, 2016, to April 12, 2017)



Atmospheric River Strength	Atmospheric River Count*
Weak	12
Moderate	21
Strong	13
Extreme	3

Weak: IVT=250–500 kg m^{-1} s^{-1}

Moderate: IVT=500–750 kg m^{-1} s^{-1}

Strong: IVT=750–1000 kg m^{-1} s^{-1}

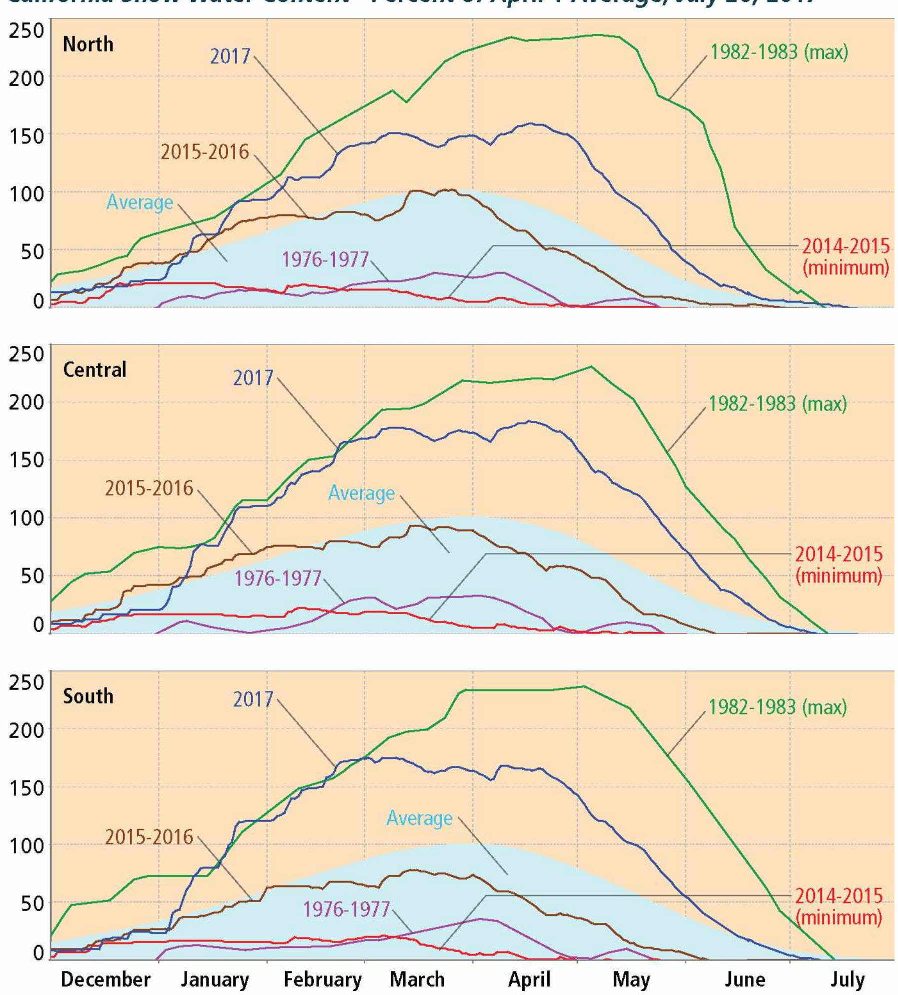
Extreme: IVT>1000 kg m^{-1} s^{-1}

IVT = integrated water vapor transport

Figure from Scripps Institution of Oceanography

February 2017 flooding in San Diego's low-lying Mission Valley, adjacent to the San Diego River. Photos courtesy of National Weather Service San Diego.

California Snow Water Content - Percent of April 1 Average, July 20, 2017



rivers thanks to the timing of individual storms. The most recent water year of major flooding was 1997 (known for the December 1996 – January 1997 New Year's Day floods).

Prospects for 2018 are Unknown

California's average annual precipitation depends on a small number of atmospheric river storms and is largely based on the number, timing, size, and characteristics of these storms. The absence of several larger storms can tip the balance between a dry year and a wet year. The sensitivity of the state's water budget to fluctuations in a small number of storms explains much of the annual variability in California's precipitation, which is the highest of that in the coterminous United States and contrasts notably with the relatively small fluctuation in annual precipitation experienced in the eastern United States.

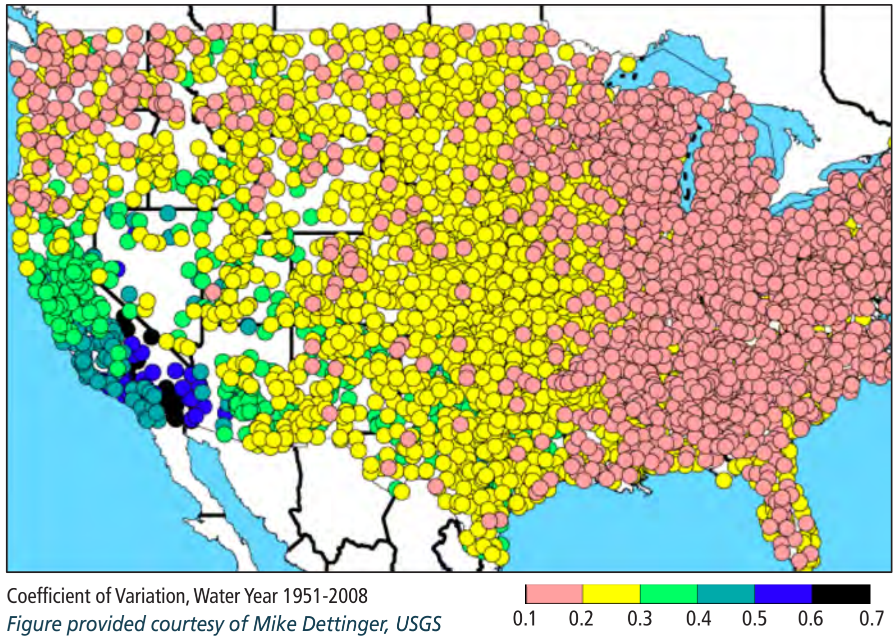
Developing the ability to predict conditions favorable for atmospheric river storms is key to improving the ability to predict precipitation with longer lead times than today's short-term, operational weather forecasts. DWR is working with researchers at the National Aeronautics and Space Administration and the Scripps Institution of Oceanography to develop first-ever experimental forecasts of land-falling atmospheric rivers, as a step toward encouraging longer-term forecasting capability for California.

Long-Term Forecasts

The National Weather Service (NWS) develops operational weather forecasts out to two weeks, although the forecasts are most accurate for individual storms in the first week. The NWS' Climate Prediction Center (CPC) prepares operational outlooks that cover the sub-seasonal to seasonal (S2S) time period. These longer-term forecasts that span from two weeks to a year in the future would be extremely useful for making many water management decisions, but the skill of present forecasts is not yet adequate to support decision-making.

Improving forecasts at S2S timescales is critically needed for improving efficiency of water operations. Much hope has been pinned on using the status of the El Niño – Southern Oscillation (ENSO) as an indicator of seasonal conditions, but the historical record for California shows that precipitation in most of the state has little relationship to ENSO conditions, except for a tendency in Southern California to link La Niña conditions with dryness. The inability to correctly predict seasonal precipitation in water year 2016 during one of the strongest El Niño events of record illustrates how much work remains to be done in this area.

Comparative Variability of Western Precipitation



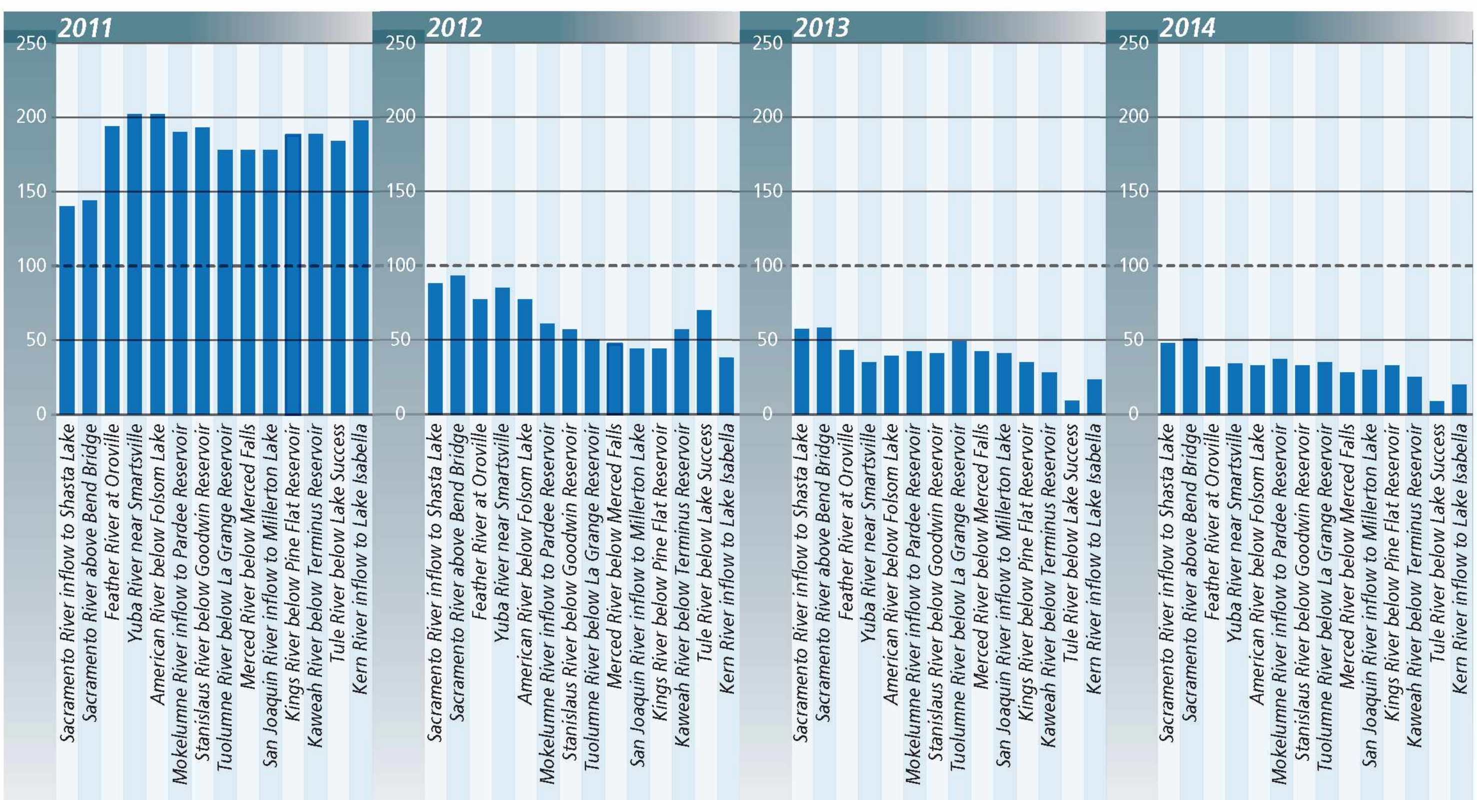
Coefficient of Variation, Water Year 1951-2008
Figure provided courtesy of Mike Dettinger, USGS

April 1st has traditionally been taken as the date of maximum snowpack accumulation in the Sierra Nevada. Snowpack was noticeably absent at the April 1, 2014, snow survey at Phillips Station adjacent to Highway 50 just west of the Lake Tahoe Basin. Two prior dry years plus a record dry start to the winter of 2013-14 had prompted Governor Brown to issue a statewide drought emergency proclamation in January 2014. In contrast, two vehicles are buried in the snow along Donner Pass Road in Soda Springs in April 2017.

Oroville Dam's spillways were damaged during the early February 2017 storm, ranked as an extreme landfalling atmospheric river. In addition to the damage at Oroville, multiple storms in a month that was wet statewide resulted in localized urban flooding in places as diverse as Maxwell, San Jose, and San Diego.

Forecasts for 2018

Present forecasting capability cannot provide a reliable prediction for water year 2018. The high annual variability in California's precipitation means that every year could hold the prospect for record wet conditions such as those experienced in 2017, or for a return to dry conditions. It is possible, for example, that 2017 could have been a wet outlier in long-term sequence of otherwise dry years, similar to the persistent dry conditions that have been experienced in the Colorado River Basin for all of the present century. In the absence of reliable predictive ability, Californians must be prepared for the worst in terms of hydrologic conditions even as we hope for the best.



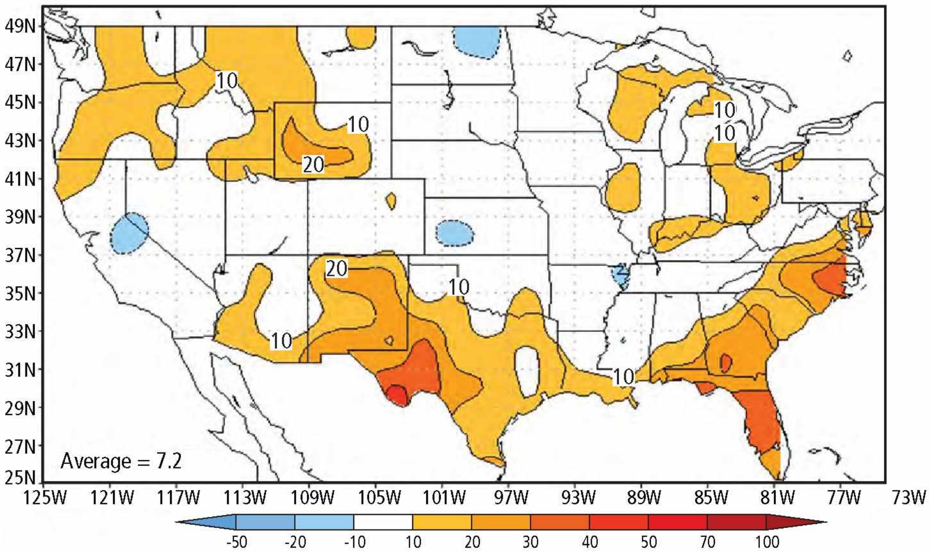
Hydrologic Impacts of a Wet 2017

Many of the hydrologic impacts of California's prior five-year drought were remedied by the wet conditions. For the first time since 2011, runoff in major river basins exceeded 150 percent of average, in some cases exceeding 200 percent of average. The abundant runoff replenished depleted soil moisture. Depleted surface water storage in most of the state's major reservoirs was refilled (excepting Lake Oroville, due to emergency repairs and reconstruction of its spillways).

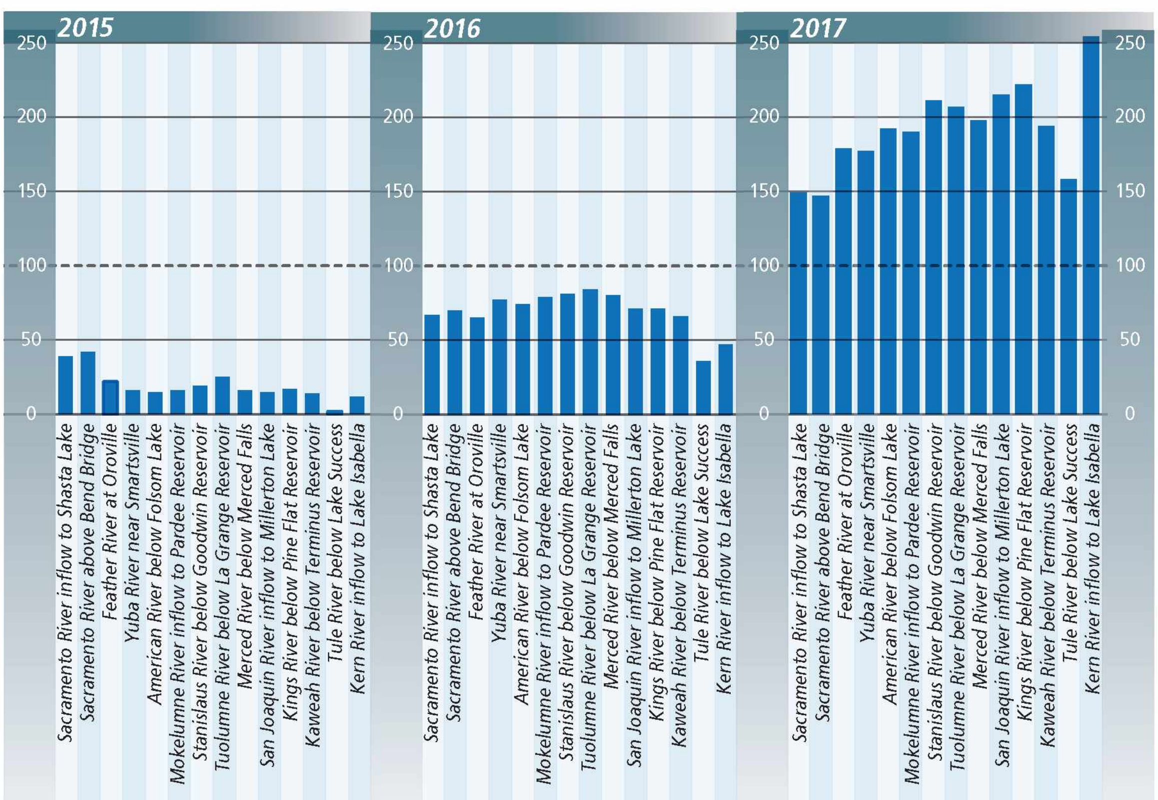
Total system storage increased only slightly in the interstate Colorado River Basin, however, remaining at a little over half full. The basin, an important water supply source for Southern California, did not experience

Seasonal (Lead 0.5 Months) Precipitation Heidke Score

DJF Manual Forecasts from 1995 to 2017



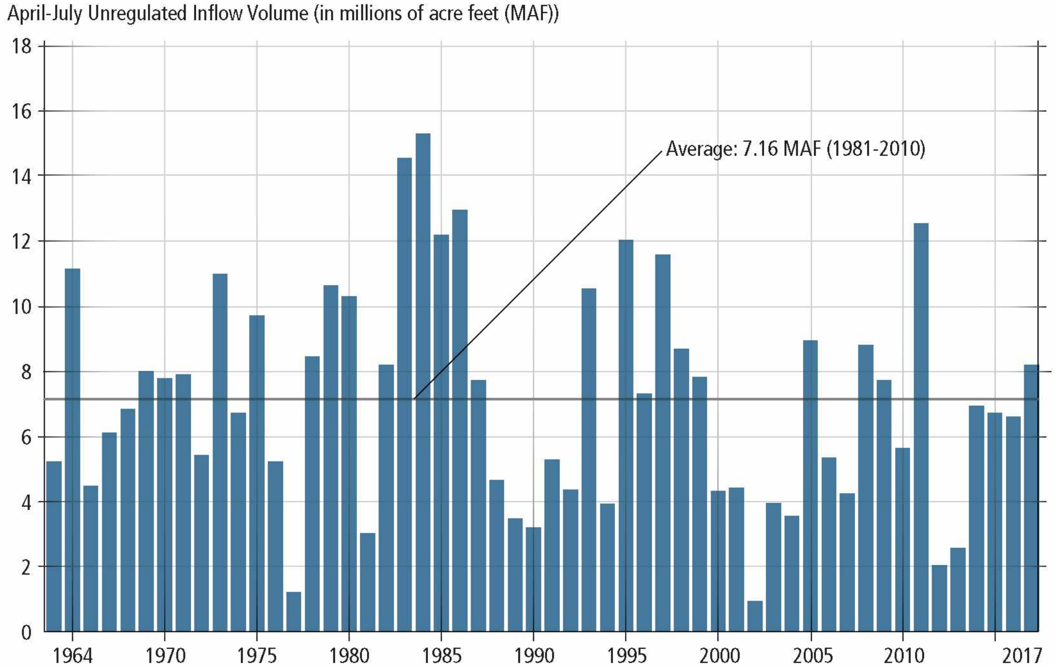
National Weather Service Climate Prediction Center verification of its historical three-month December/January/February outlook, as issued two weeks in advance of the forecast. Meteorologists use a metric called the Heidke skill score to evaluate the outlooks. The skill score ranges from -50 to 100, with 100 being a perfect score. A score of zero, represented by the white areas of the map, means that the outlook had no more skill than simply forecasting long-term average climate conditions. The average skill across the U.S. for the period of 1995 to 2017, was 7.2, or only slightly better than forecasting average conditions.



Water Year 2011-2017 April-July Runoff at Forecast Points on Major Central Valley Rivers, as Percentage of Average

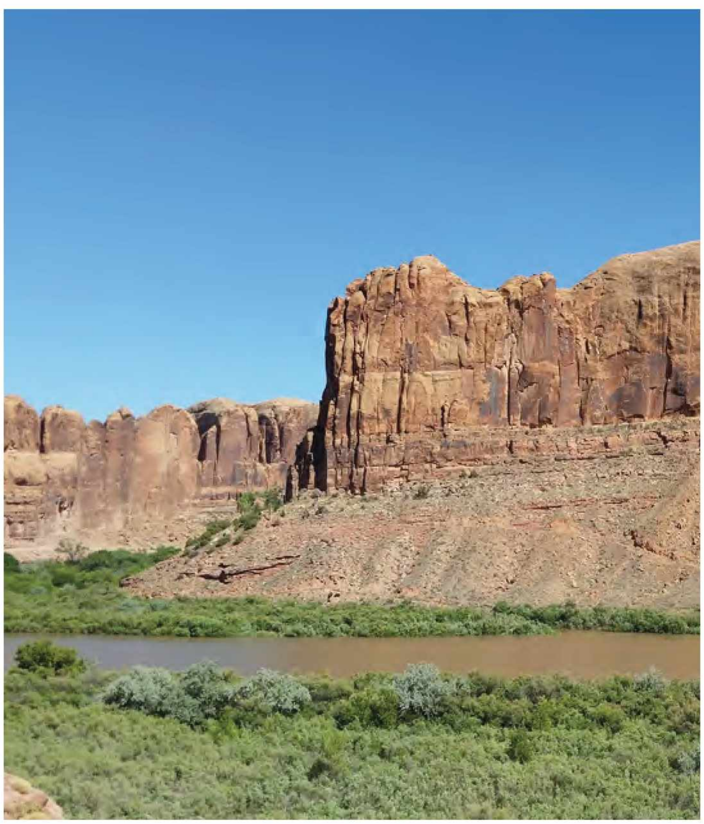
Lake Powell April-July Unregulated Inflow Volume

The Colorado River Basin has been experiencing a prolonged period of largely dry conditions, although water year 2017 inflow to Lake Powell ended up slightly above the long-term average.



U.S. Bureau of Reclamation

The Colorado River near Moab, Utah, upstream of the confluence with the Green River. Above average precipitation in the Green River Basin during water year 2017 helped Lake Powell inflows exceed the long-term average. About 85 percent of Colorado River system runoff comes from 15 percent of the watershed, from the high-elevation mountain areas of the Upper Basin above Lake Powell.



The impacts of land subsidence due to groundwater extraction can be seen at this well near Los Banos. When originally constructed the top of the well casing would have been at the ground surface. Groundwater depletion and land subsidence are examples of lingering drought impacts, and subsidence of the magnitude shown here is not recoverable regardless of how wet subsequent water years are. During the drought years of 2015 and 2016 very high rates of subsidence were observed in parts of the San Joaquin Valley, in the ballpark of a foot per year. A wet 2017 has for the moment put subsidence risks to water infrastructure on hold.

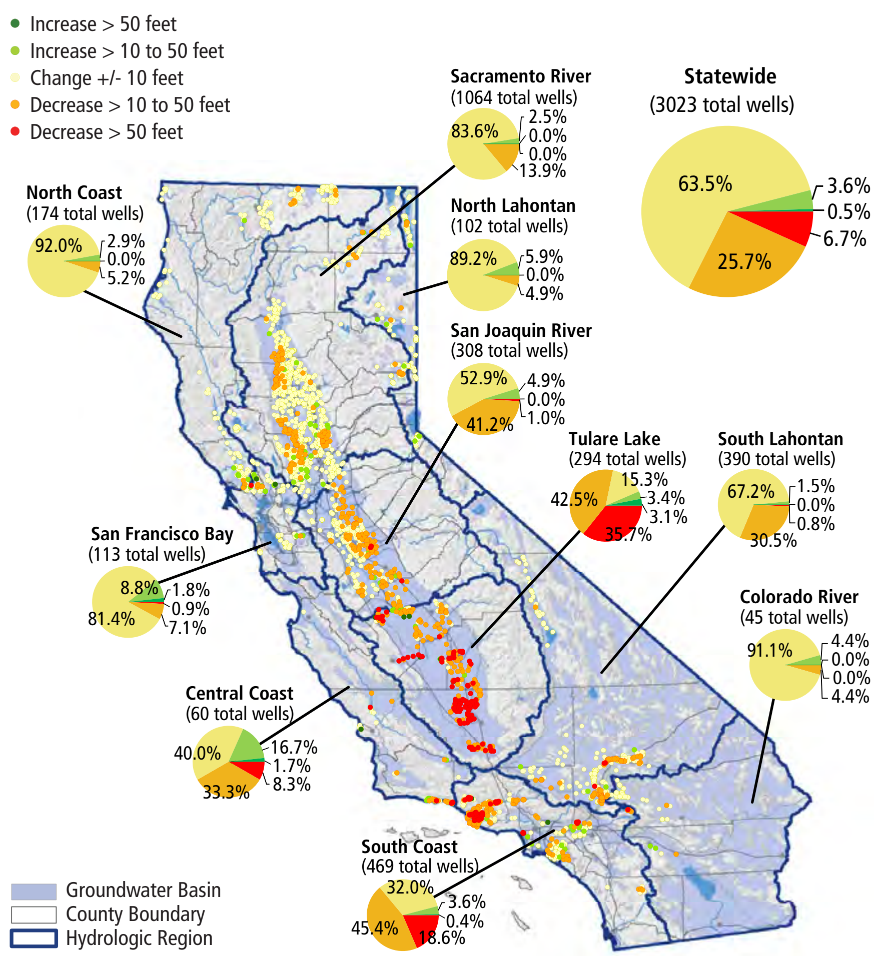
the record wetness seen in California, and its large volume of reservoir storage capacity (roughly four times the river's average annual flow) cannot easily be replenished in a single season. In contrast, a single wet year normally refills the comparatively smaller reservoirs within California, which hold only a fraction of a river's annual flow.

Groundwater Storage

Groundwater storage recovers more slowly than storage in reservoirs, with the specifics of recovery depending on the hydrogeologic characteristics of individual groundwater basins. Water levels may recover fairly quickly in shallow basins in direct contact with surface water, while other basins may take many years to recover. Deep confined aquifers in severely depleted groundwater basins may show no appreciable recovery because they require a very long time to recharge. Many of the wells for which DWR receives groundwater level monitoring data set records for new lows during the 2012-16 drought, especially in the San Joaquin Valley and to a lesser extent in the Ventura coastal plain. The very wet conditions of 2017 gave many parts of the state access to excess surface waters for both planned and impromptu groundwater recharge, and fall 2017 groundwater level data (not available until the end of the calendar year) should show the effects of the substantial recharge water available.

Dry private wells in the small unincorporated community of East Porterville were iconic of the 2012-2016 drought. DWR worked with partner agencies to build a new distribution system to connect homes with dry wells to a public water system. The first homes were connected in August 2016, and by end of 2017, more than 750 homes will be connected to a reliable water supply. Even though water year 2017 was very wet, there are still many dry and/or contaminated wells in the Central Valley. Throughout 2017, DWR continued to connect other small communities, such as Hardwick in Tulare County, to public water systems.

Groundwater Level Change - Spring 2011 to Spring 2017



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