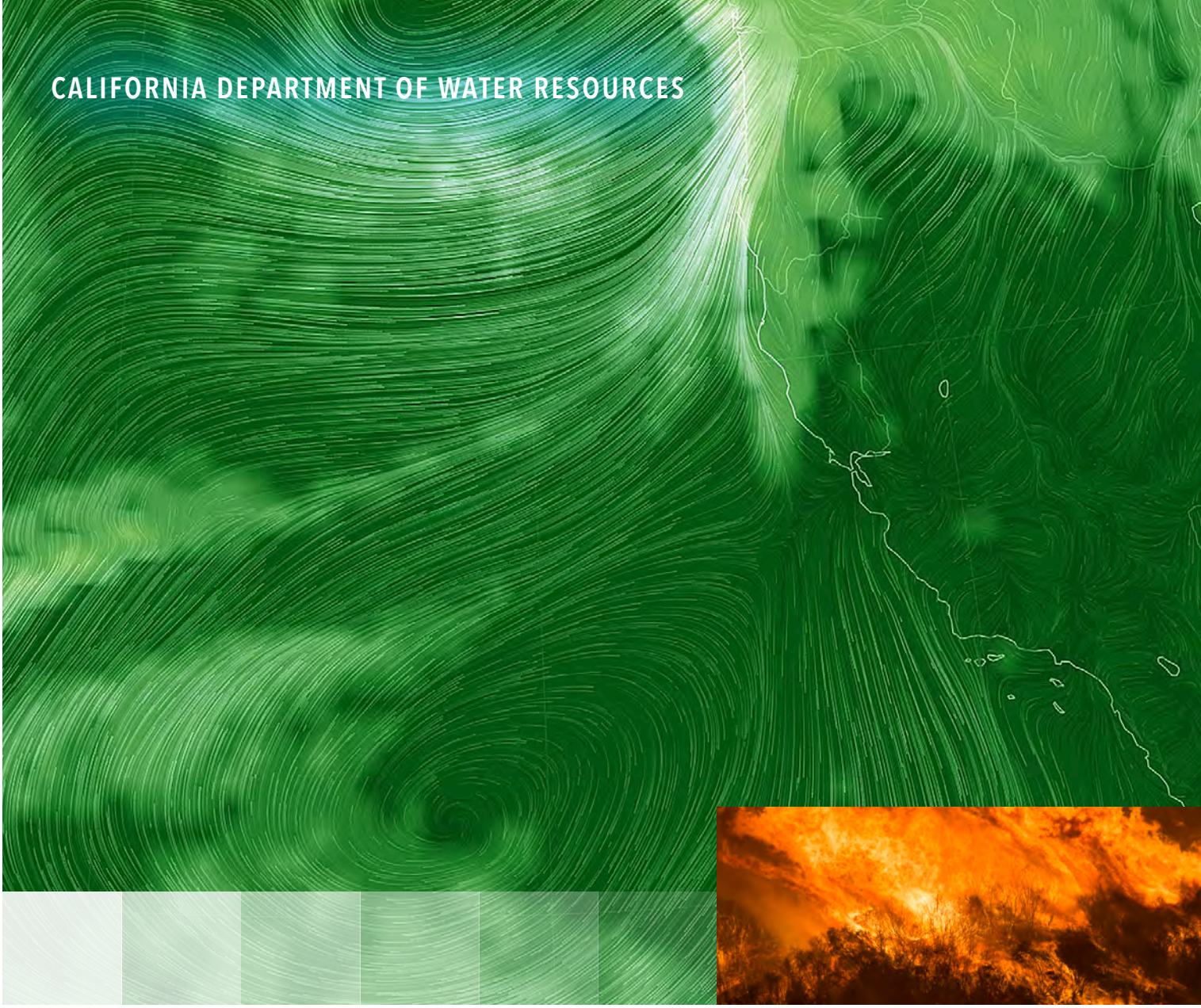
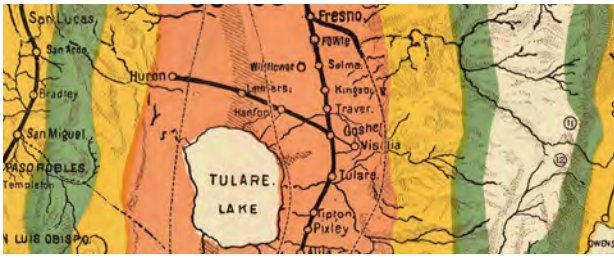
CALIFORNIA DEPARTMENT OF WATER RESOURCES



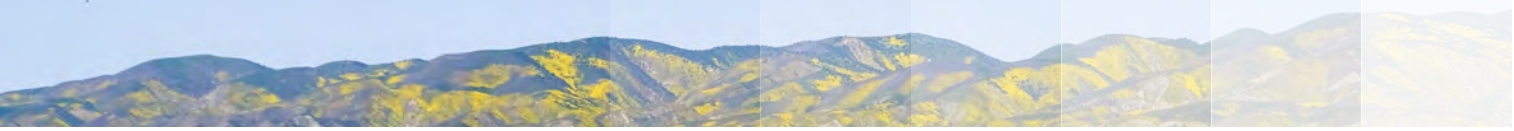


# HYDROCLIMATE REPORT

# Water Year 2017



Office of the State Climatologist



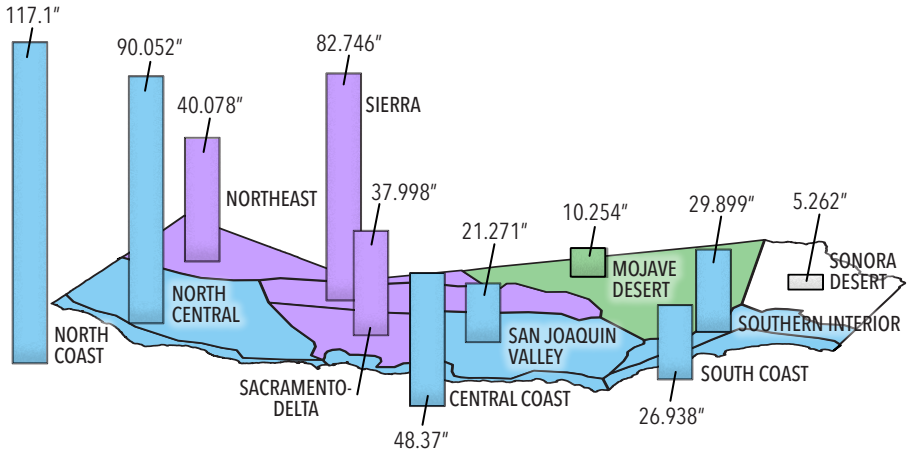
# Executive Summary

Water year (WY) 2017 began with lingering impacts from a severe and prolonged drought mitigated slightly by the previous WY. Expectations were uncertain for the WY with the potential for a weak La Nina event taking shape in the eastern tropical Pacific. Dry weather, cold storms or warm storms are all possible in this circulation pattern. No one foresaw the epic year that was about to unfold.

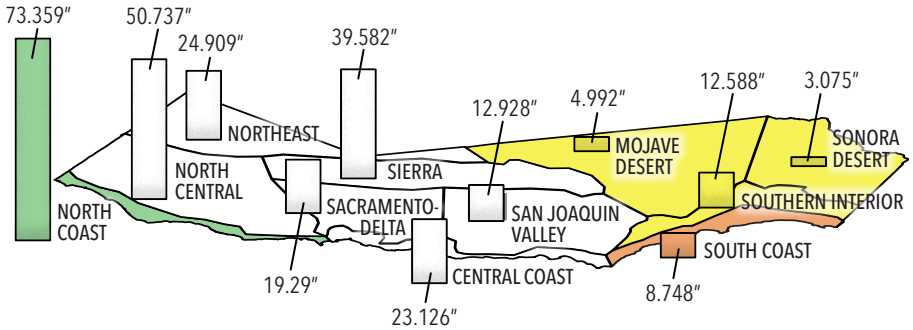
California's inter-annual precipitation variability was demonstrated in a dramatic fashion during this WY, with the state emerging from the preceding 5-year drought by virtue of one of the wettest WYs on record. California experienced record precipitation in some areas, including the Northern Sierra 8-Station index receiving 94.7 inches or 189 percent of average. The California Climate Tracker showed the wettest winter December through February statewide at 41.8 inches or 197 percent of average.

The graphic (right) shows a comparison of the 2017, 2016, and 2015 WYs and how dramatically statewide precipitation totals changed in the past three years. Along with precipitation extremes the state also experienced some of the warmest temperatures on record with the warmest summer minimum temperature statewide and the most days (72) over 100°F in Redding, CA.

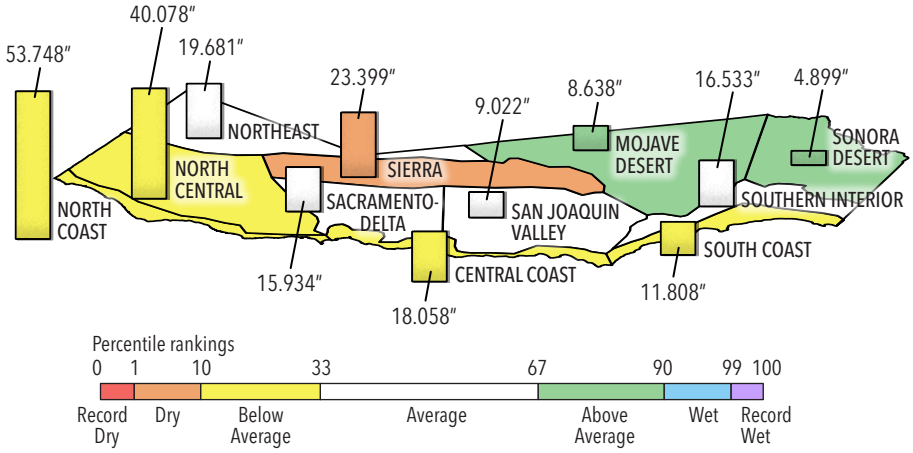
2017 Cumulative Precipitation in Inches for WRCC Climate Regions




2016 Cumulative Precipitation in Inches for WRCC Climate Regions




2015 Cumulative Precipitation in Inches for WRCC Climate Regions



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The State Climatologist Office would like to thank Peter Coombe, Elissa Lynn, and Kevin He for their contributions to the annual Hydroclimate Reports.

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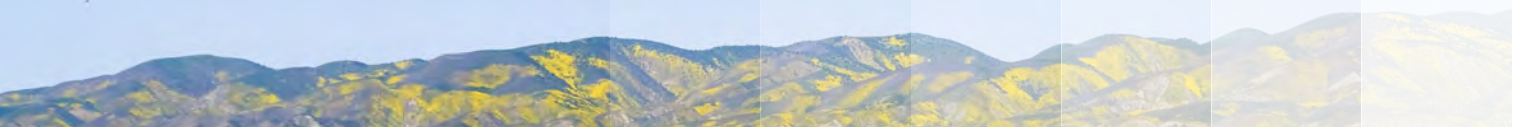
Front and back cover earth images courtesy of earth.nullschool.net



# Introduction

The Hydroclimate Report Water Year (WY) 2017 updates the 2016 report with data from WY 2017. This report includes key indicators for hydrology and climate in California and is updated annually with the newest available data to track important trends, provide a compilation of indicators, and provide graphical visualization of data that are of interest to water managers, the media, State government, and the research community.

As the Hydroclimate Report is a living document reflective of current needs, new data sources and analysis strategies are updated to provide the best scientific information available. Key indicators included in this Hydroclimate Report are listed in the table below. Hydroclimate is defined in this report as natural hydrologic processes such as streamflow, snowpack, sea level, and precipitation; which are directly and indirectly linked to climate features, such as temperature trends and the nature of annual storms that bring precipitation, providing a primary source of freshwater.

The hydrology and climate of California impact the California Department of Water Resources' (DWR) mission to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. DWR has a long history of tracking variables that may be of use in assessing climate change impacts on water resources. With the concern about climate change and hydrologic change indicated by modeling simulations and measured data, DWR recognizes the need to plan for the future and to track continuing data trends. Indications of an uncertain climate future means the State will have to plan, manage, and adapt differently than in the past. Going forward, additional new data or analysis methods may result in additional indicator metrics warranting inclusion in future reports. By tracking change through a collection of indicators on an annual basis, it is hoped that transitions of important thresholds can be better anticipated, enabling the continued refinement of adaptation strategies.

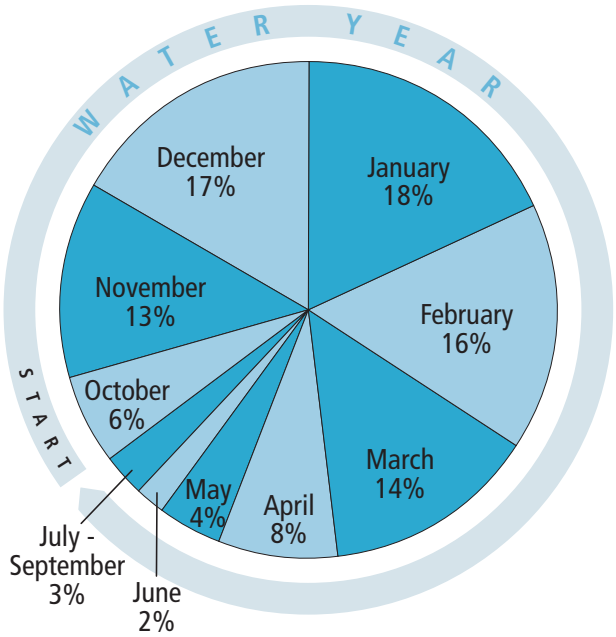
**Key Hydroclimate Indicators**

| Indicators | Spatial Resolution | Temporal Resolution | Period of Record | Data Source |
|---|---|---|---|---|
| Temperature (Air) | WRCC Climate Regions | Monthly Mean | 1895-present | WRCC |
| Temperature (Air) | NOAA Climate Divisions | Annual Calendar Year | 1895-present | NOAA |
| Precipitation | WRCC Climate Regions | Monthly | 1895-present | WRCC |
| Precipitation | Northern Sierra 8-Station | Annual Cumulative | 1921-present | DWR |
| Precipitation | San Joaquin 5-Station | Annual Cumulative | 1913-present | DWR |
| Atmospheric Rivers | Statewide | Annual Cumulative | 2016-present | Scripps |
| Water Year Type / Streamflow (Unimpaired) | Sacramento River Basin | April-July | 1906-present | DWR |
| Water Year Type / Streamflow (Unimpaired) | San Joaquin River Basin | April-July | 1901-present | DWR |
| Snowpack (Snow Water Equivalent) | Statewide | April 1st | 1950-present | Cooperative Snow Survey |
| Snowpack (Snow Water Equivalent) | Northern Sierra | April 1st | 1950-present | Cooperative Snow Survey |
| Snowpack (Snow Water Equivalent) | Southern Sierra | April 1st | 1950-present | Cooperative Snow Survey |
| Rain/Snow (Percent As Rain) | Selected Sierra Watersheds | Annual Cumulative | 1949-present | DWR/WRCC |
| Sea Level | Crescent City Tide Gauge | Monthly Mean | 1933-present | NOAA |
| Sea Level | San Francisco Tide Gauge | Monthly Mean | 1855-present | NOAA |
| Sea Level | La Jolla Tide Gauge | Monthly Mean | 1924-present | NOAA |

# What Is A Water Year?

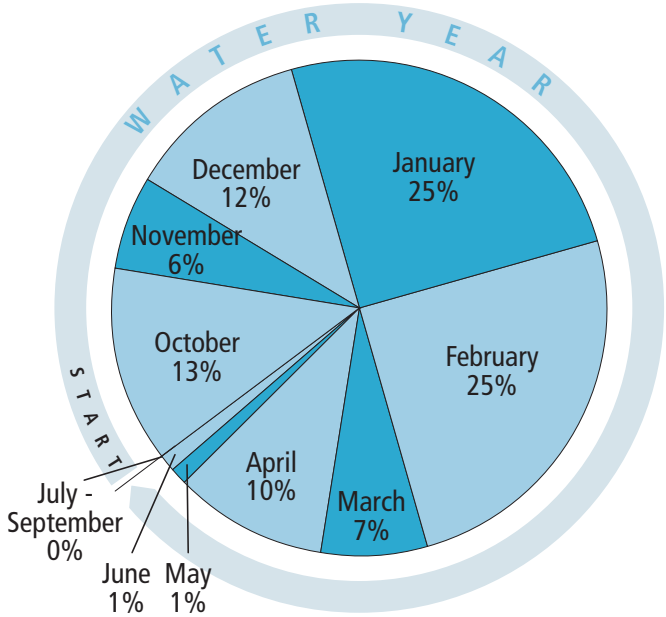
**Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)**

**Long Term Water Year Average by Month**




The chart above depicts typical precipitation by month and percent of total that California receives throughout each WY. Precipitation generally arrives at the start of the WY in October and continues to increase through the winter months. The months of December, January, and February provide half of our expected annual precipitation. This is also the main development period of California's snowpack.

**Water Year 2017 by Month**



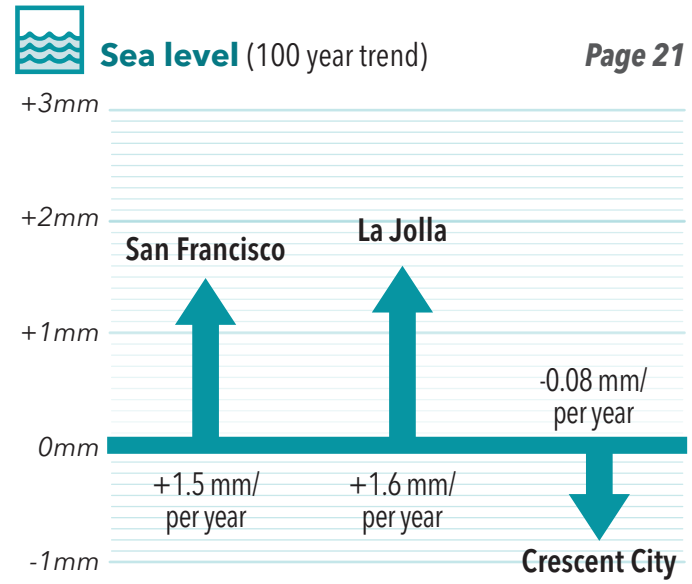

This chart represents monthly precipitation as percent of the total 2017 WY precipitation.

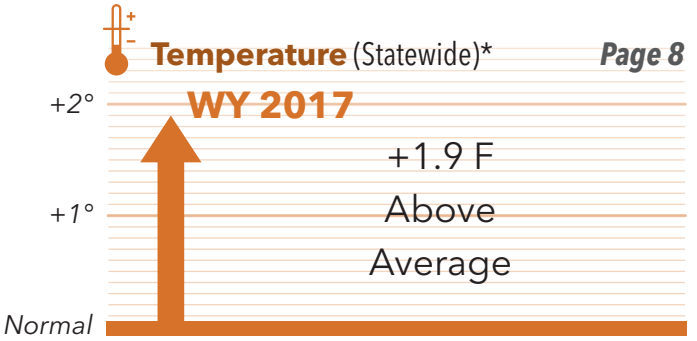
Hydrologic data such as precipitation and streamflow data are key indicators for the Hydroclimate Report. These data are typically represented as being within the WY. A WY (also discharge year or flow year) is a term commonly used in hydrology to describe a time period of 12 months during which precipitation totals are measured. Its beginning differs from the calendar year because precipitation in California starts to arrive at the start of the wet season in October and continues to the end of the dry season the following September. On a calendar year time scale, the October to December precipitation would not be accounted for, including snowpack that doesn't melt and run off until the following spring and summer. DWR defines a WY in California to include the period from Oct 1 to Sept 30. The 2017 WY covers the period from October 1, 2016 to September 30, 2017.

A comparison of the pie charts on the left between the long term average and WY 2017, shows that 50 percent of the total WY precipitation occurred in January and February.

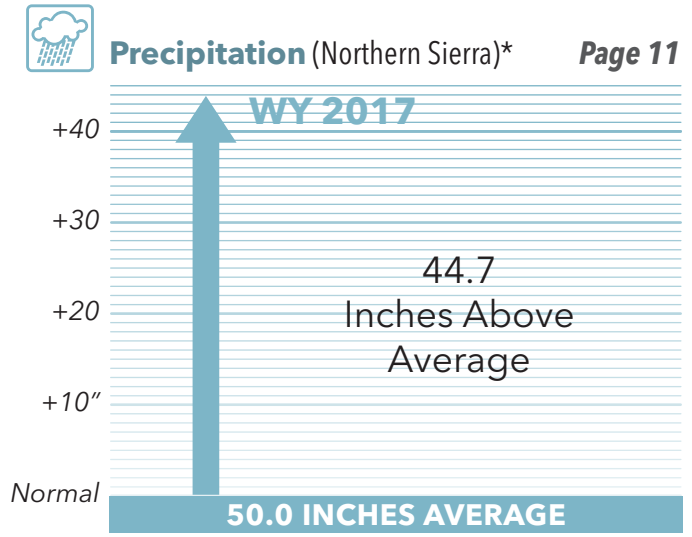
On average, the months of January and February typically accounts for 34 percent of total annual precipitation; however, in 2017 these two months accounted for half of the WY's total. Although 2017 was a record breaking year in total rainfall at 94.9 inches, the WY ended with an exceptionally dry period in the Northern Sierra 8-Station region (see map, page 11) with only 0.5 inches of precipitation being recorded for the months of July, August, and September. Precipitation for these three months usually accounts for 3 percent of the annual precipitation.

# California Hydroclimate Water Year 2017 "At A Glance"

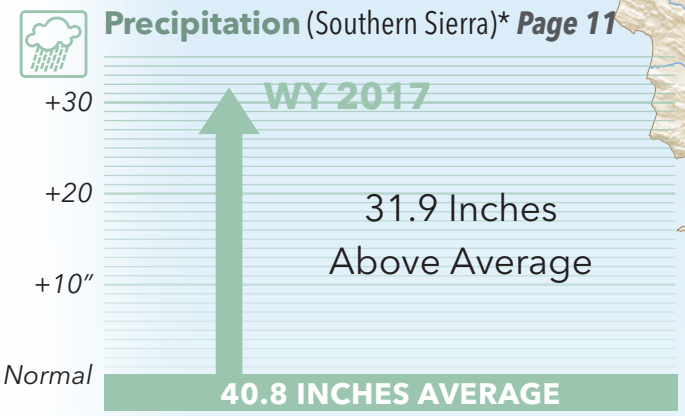



*Normal average air temperature represents 1949-2005 base period.

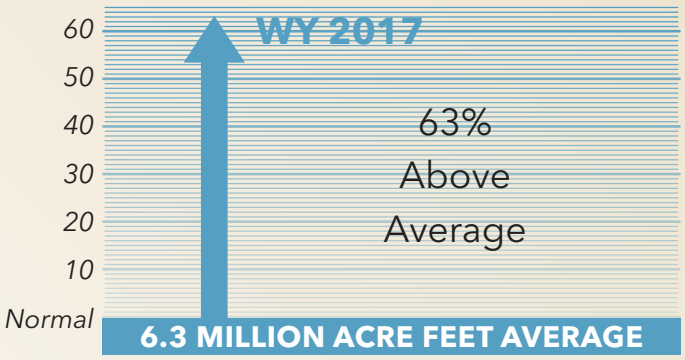



*Normal average precipitation represents 1961-2010 base period.



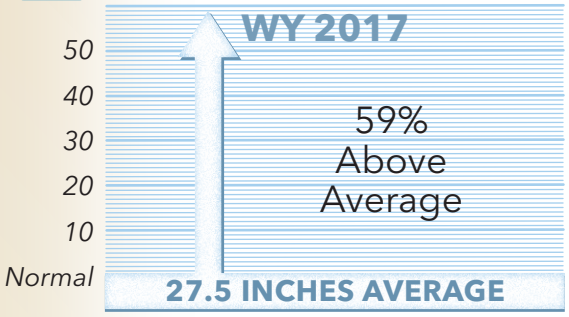

*Normal average precipitation represents 1961-2010 base period.

**Streamflow, April-July** (Sacramento River)* ***Page 20***



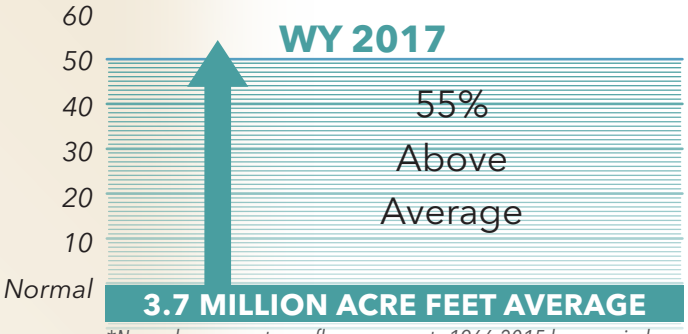

*Normal average streamflow represents 1966-2015 base period.

**Snowpack** (Statewide)* ***Page 14***

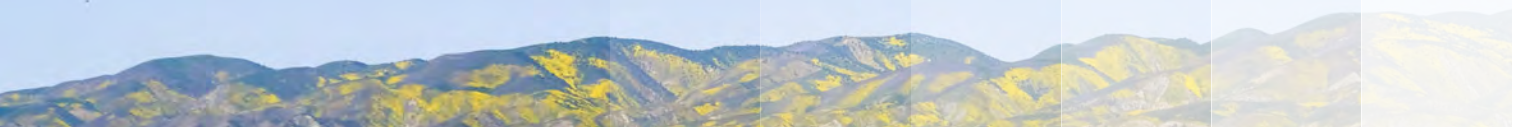



*Normal average snowpack represents 1961-2010 base period.

**Streamflow, April-July** (San Joaquin River)* ***Page 20***




*Normal average streamflow represents 1966-2015 base period.



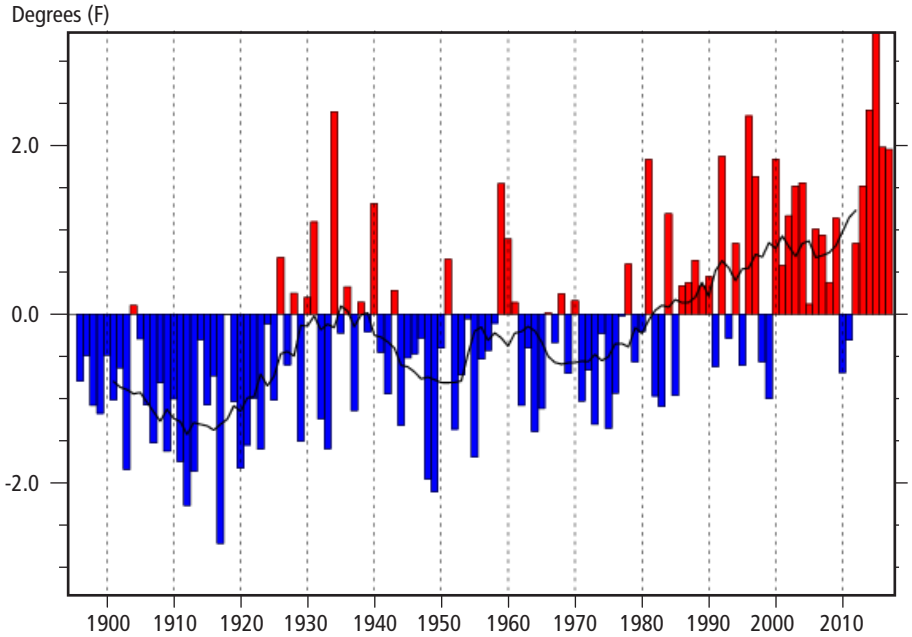
# Annual Air Temperatures

According to the Intergovernmental Panel on Climate Change (IPCC) the warming of the climate system is unequivocal. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The atmosphere and ocean have warmed, and each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (IPCC, 2014).

California's temperature record reflects global temperature trends. According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 1.4 °F since 1880, and two-thirds of the warming has occurred since 1975 (Hansen et al., 2010). According to the Western Region Climate Center (WRCC), California has experienced an increase of (1.3 to 2.3 °F) in mean temperature in the past century. Both minimum and maximum annual temperatures have increased, but the minimum temperatures (+1.9 to 2.8 °F) have increased more than maximums (+0.7 to 1.9 °F) (WRCC, 2018).

WY 2017 temperature measurements using WRCC and National Oceanic and Atmospheric Administration (NOAA) datasets demonstrate a continuing warming trend. Statewide average temperatures were ranked at 117 warmest out of 122 years of record dating back to 1895.

**California statewide mean temperature departure**, October through September




Black line denotes 11-year running mean

Departures from 1949-2005 base period:

| | | | |
|---|---|---|---|
| Linear trend 1895-present | +1.81 ± 0.47°F/100 yr | | |
| Linear trend 1949-present | +3.10 ± 1.13°F/100 yr | | |
| Linear trend 1975-present | +4.40 ± 2.48°F/100 yr | | |
| Warmest year | 59.4°F (+3.3°F in 2015 | Mean | 56.1°F |
| Coldest year | 53.4°F (-2.7°F) in 1917 | STDEV | 0.98°F |
| October-September 2017 | 58.0°F (+1.9°F) | Rank | 117 of 122 |

**Western Regional Climate Center (WRCC) California Climate Tracker**

- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly Mean

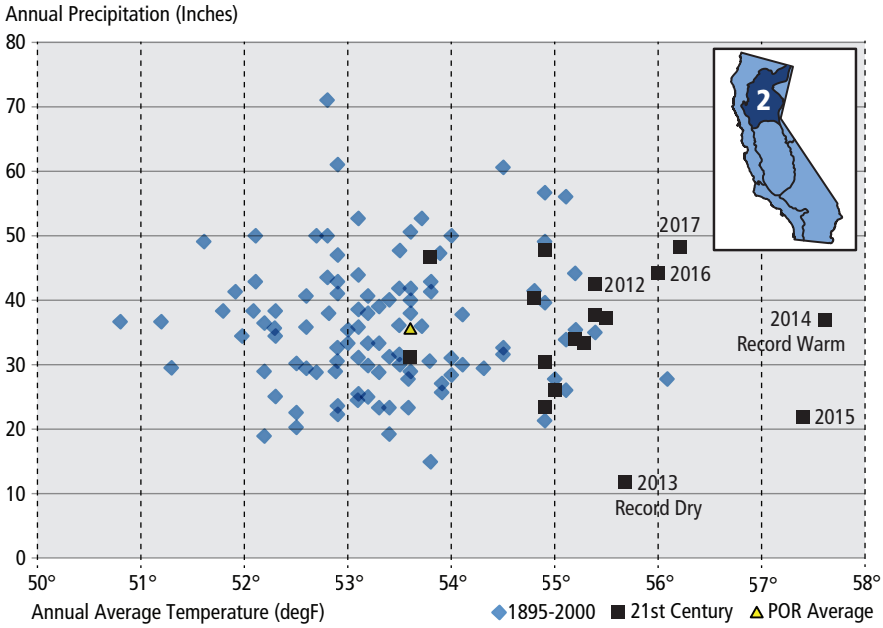
Graph shows "departures" for average (mean) and maximum temperatures each year from a long-term average (the years 1949 to 2005) i.e., the difference between each year's value and the long-term average.

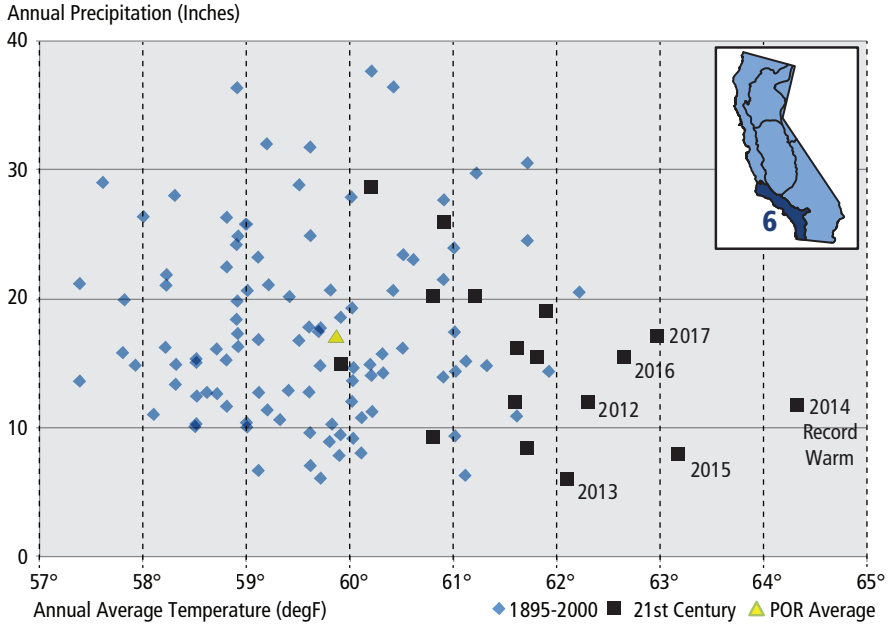
The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2017) for the contiguous United States. This data set is based on a calendar year instead of the hydrologic WY. There are 344 climate divisions in the US and this report's focus is on two climate divisions within California: Climate Division 2 (Sacramento Drainage) and Climate Division 6 (South Coast Drainage). For each climate division, monthly station temperature and precipitation values are computed from daily observations. Plots of annual precipitation versus annual average temperature are shown, using the annual average values from 1895-2017.

Within Climate Division 2 (Sacramento Drainage), the long-term record depicts a dramatic shift in annual average temperature. The data points from the 21st century are shown as boxes indicating an overall shift in climate compared to the historical record. The past four years are depicted as outliers, being some of the warmest and driest years on record.

Data from Climate Division 6 (South Coast Drainage) depicts even more annual precipitation variation from 5 to 40 inches per calendar year. The past 15 years since the turn of the century are also extremely warm and dry, indicating a change in climate.

**NOAA California Climate Divisions: #2 Sacramento Drainage; #6 South Coast Drainage**

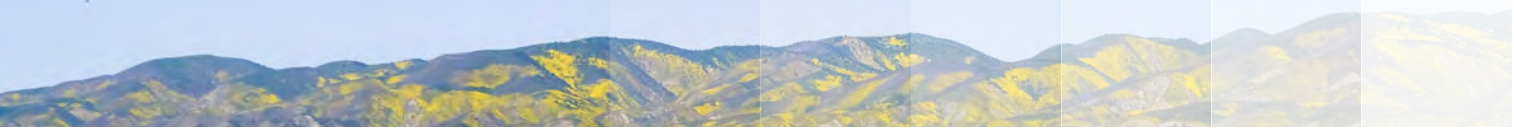



The Sacramento and South Coast Drainage Climate Division data plots show 2014 and 2015 as the warmest years on record. 2017 was the third warmest on record for the Sacramento Climate Division and third warmest for the South Coast. The combination of warmer temperatures and lower rainfall in the 21st Century are depicted as being outliers on the scatterplot graphs.

**NOAA Climate Division Calendar Year Data**

- Spatial resolution: NOAA California Climate Divisions
- Temporal resolution: Annual Mean



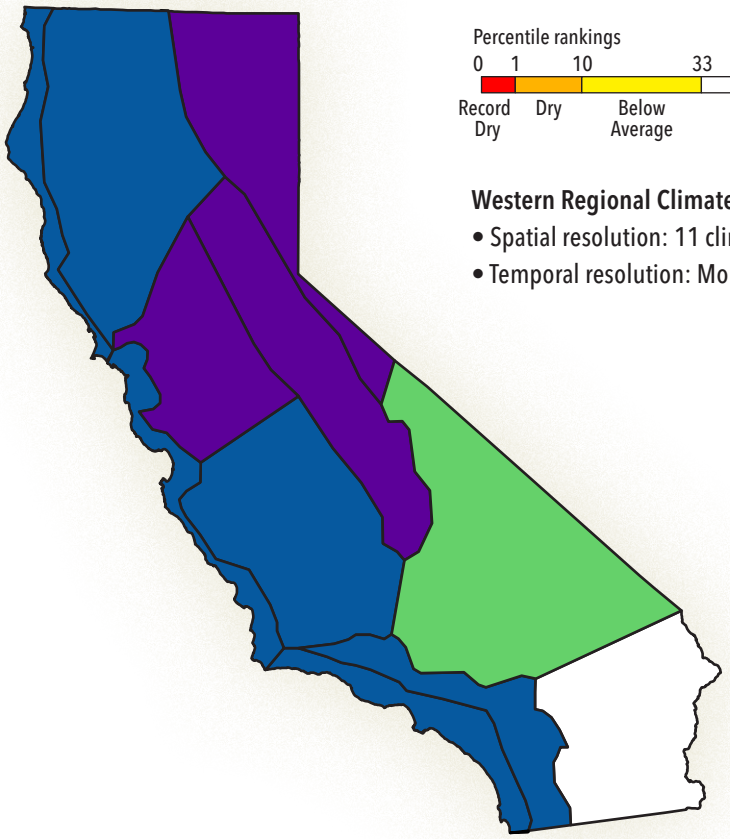
# Annual Precipitation

Annual precipitation data from California shows significant year-to-year variation. This inter-annual variability makes trend analysis difficult for this indicator. An analysis of precipitation records since the 1890's shows no statistically significant trend in precipitation throughout California. Although the overall precipitation trend is generally flat over the past 120 years, the precipitation record indicates significant decadal variability giving rise to dry and wet periods. A decadal fluctuation signal has become apparent in northern California where winter precipitation varies with a period of 14 to 15 years. This decadal signal has increased in intensity over the twentieth century resulting in more distinct dry and wet periods (Ault and St. George 2010). There is no known physical process driving this observed precipitation variability and remains an area for future research.

### Water Year 2017 Precipitation

Statewide precipitation trends were analyzed by the WRCC using a data set that includes precipitation values across California. A total of 195 stations across the state are included in this analysis. Cooperative Observer Network (COOP), station data along with the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database are considered in this analysis dating back to January of 1895. PRISM analyses depict wet, and record wet precipitation indices in WY 2017 for much of the Central Valley and northern and coastal areas of the State. The southeast experienced above average precipitation, while the Sonoran Desert was the only region with average precipitation.

**California Climate Regions Precipitation Rankings, Water Year 2017**

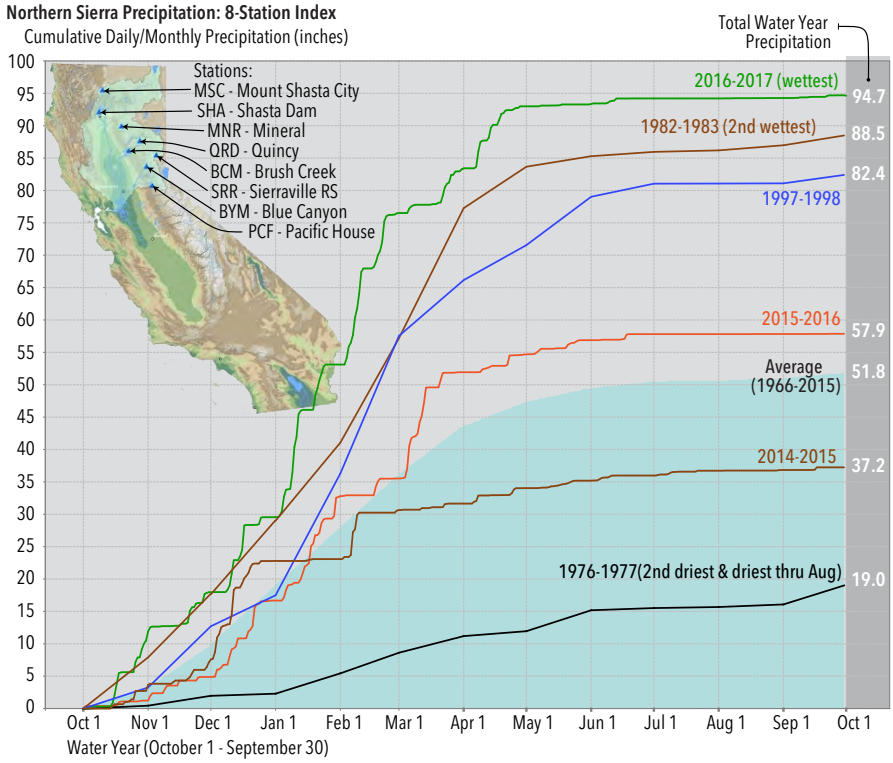


**Western Regional Climate Center (WRCC) California Climate Tracker**

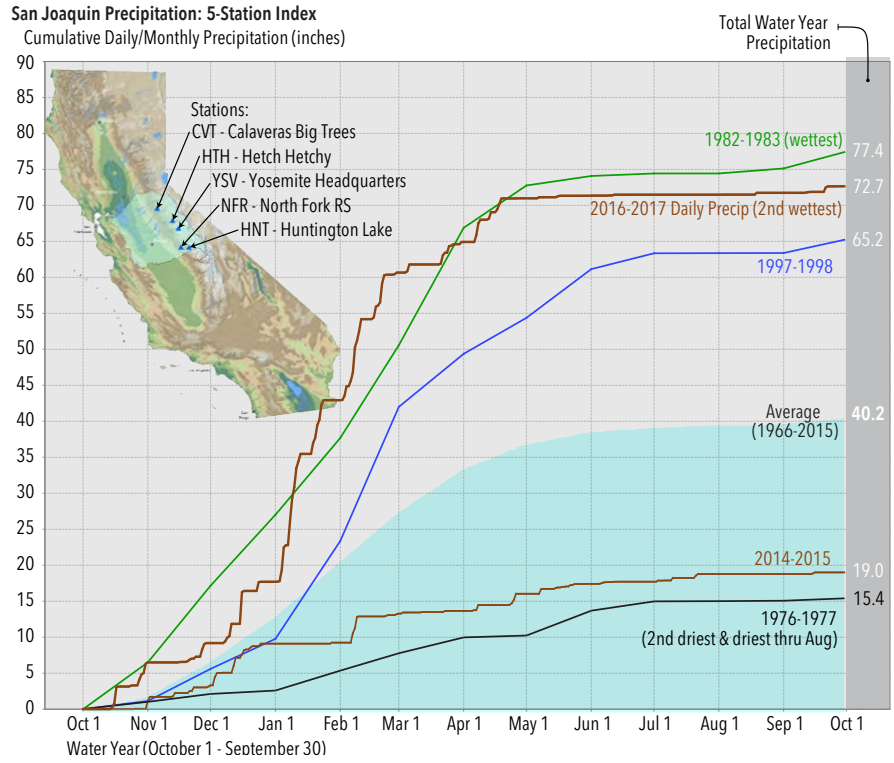
- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly, Water Year

## DWR Aggregate Precipitation Station Indices

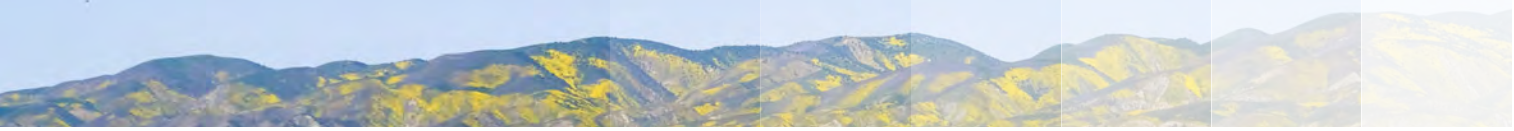
Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state. These precipitation station indices are located in the Northern and Southern Sierra and correspond well to the WY type on the Sacramento and San Joaquin River systems.




For WY 2017, the Northern Sierra Precipitation 8-Station Index shows total WY precipitation at 94.7 inches, wetter than previous all-time record in WY 1983. Accumulated precipitation in for the WY was 6.2 inches more than the record year, and 42.9 inches and 45 percent more precipitation than an average year. The significant amount of precipitation filled reservoirs alleviating drought conditions in much of California.




The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, received less precipitation than the Northern Sierra. WY 2017 had a total WY precipitation of 72.7 inches, which was just below the all-time record of 77.4 inches set in WY 1983. The cumulative precipitation of 72.4 inches for WY 2017 is almost 4 times as much as the 19.0 inches that was received only two years prior in WY 2015.



# Atmospheric Rivers

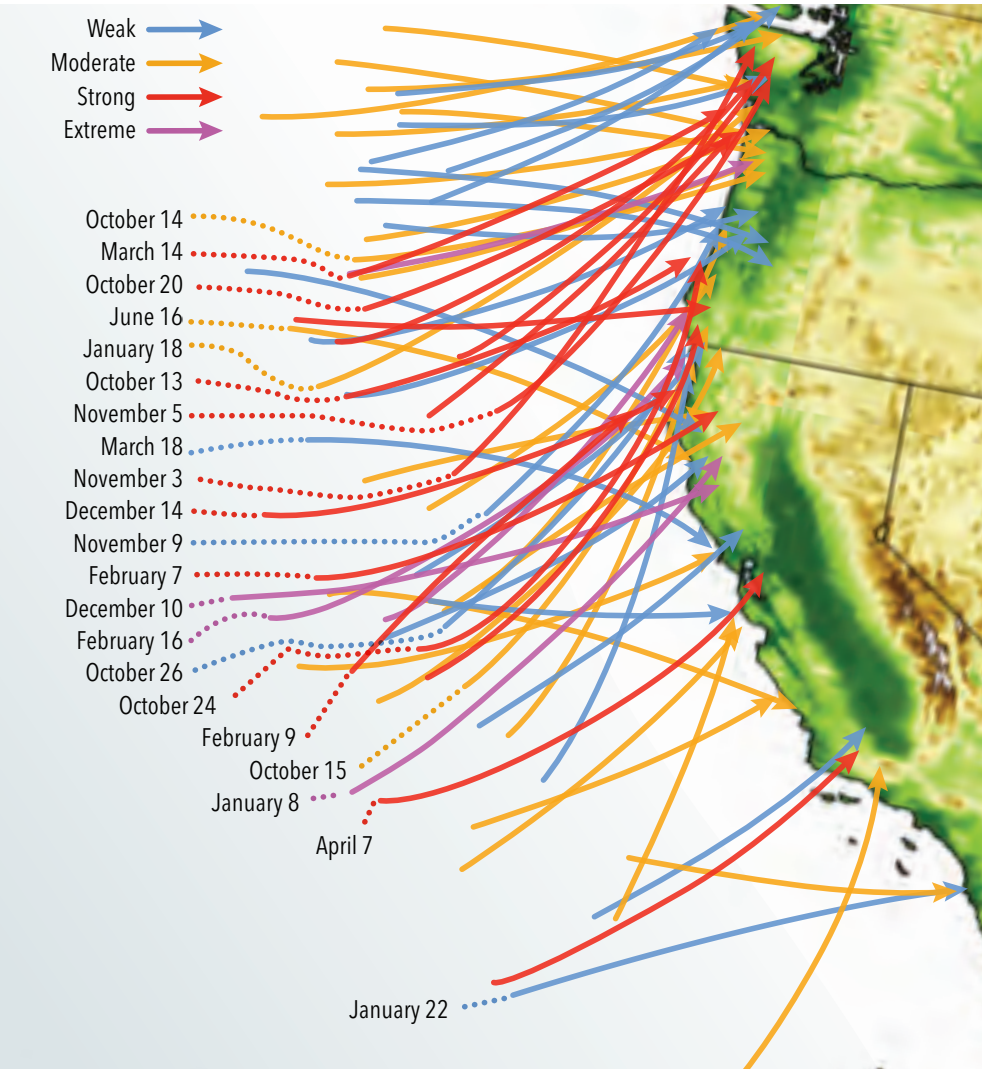
A limited number of precipitation-producing storms move over California every WY. Attention has recently turned to storms associated with atmospheric rivers (ARs) due to their impact on water supply and flooding. ARs are bands of intense water vapor concentrated in the lower atmosphere that can be entrained into the leading edge of winter storms that make landfall over California and the west coast of the United States. On average, ARs are 250 to 375 miles wide and can extend to over 1000 miles long. Typically, only a few strong AR storms impact California during the winter months, and on average, AR storms provide 30 to 50 percent of California's annual precipitation and 40 percent of Sierra snowpack. With warmer air, and changing ocean conditions, AR episodes have the potential to increase in duration and intensity yielding increases in precipitation from the largest storms (Dettinger, 2016).

Recent research into the characteristics of ARs at the Center for Western Weather and Water Extremes (CW3E) has yielded a categorization, the Ralph/CW3E AR Strength Scale, based on the amount of integrated vapor transport (IVT). IVT is a combination of the amount of water vapor in the atmosphere above a given point and the horizontal winds that move the water vapor. IVT has shown early promise for AR characterization as well as predictability in weather forecast models (Lavers et al., 2016). The AR Strength Scale includes four categories: weak, moderate, strong, and extreme. The categories are evenly divided in increments of 250 flux units of IVT with extreme being stronger than 1000 flux units.

The figure (top right, page 13) shows a characterization of the 68 ARs that made landfall along the US West Coast in WY 2017 as well as the location of maximum intensity of the AR when it hit the coast. Of the 68 landfalling ARs, 55 occurred in northern California and 43 occurred in Southern California. 3 out of 5 of the strongest ARs ranked as extreme on the Ralph/CW3E AR Strength Scale, and occurred in January and February over northern California. AR activity documented in the winter of 2017 was associated with strong precipitation. The January 8-10 AR produced 14% of normal statewide annual precipitation in just three days. The AR during Feb 7-9 produced

**An AR observation array at the Bodega Marine Laboratory in Bodega Bay, CA. Photo: DWR, June 27, 2017**

**Distribution of landfalling Atmospheric Rivers on the U.S. West Coast during water year 2017.**




Graphic: Center For Western Weather and Water Extremes (CW3E) Scripps Institution of Oceanography

9.5% of total annual California precipitation. Together, these AR events produced nearly a quarter of an entire normal year's precipitation in just 6 days, with each event including extreme intensity AR landfalls in the state.

The large number of landfalling ARs is one reason water year 2017 was record breaking wet. In addition, a large fraction of these events were strong, or even extreme in magnitude, contributing to the flooding and ancillary impacts. A high proportion of the ARs impacted the Northern Sierra 8-Station Index area, which exceeded its all-time precipitation record at 94.7 inches.

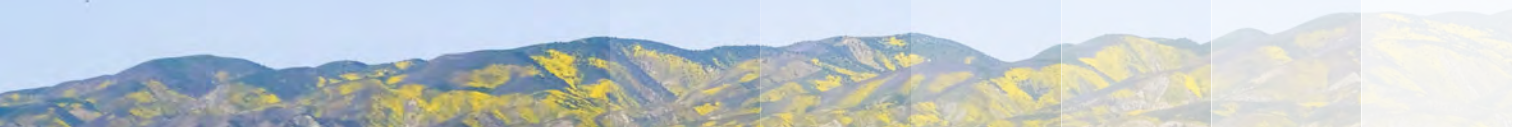
**Ralph/CW3E AR Strength Scale**

- 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 $m^{-1}$ $s^{-1}$

**Atmospheric River strength by month and 2017 water year totals.**

| AR Strength | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | WY Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weak | 1 | 3 | 4 | 1 | 2 | 2 | 6 | 1 | 1 | 0 | 0 | 0 | 21 |
| Moderate | 3 | 4 | 2 | 3 | 3 | 4 | 2 | 2 | 2 | 1 | 0 | 0 | 26 |
| Strong | 4 | 3 | 2 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 16 |
| Extreme | 2 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Total | 10 | 10 | 8 | 7 | 8 | 8 | 9 | 3 | 4 | 1 | 0 | 0 | 68 |

Table: Center For Western Weather and Water Extremes (CW3E) Scripps Institution of Oceanography



# Snowpack

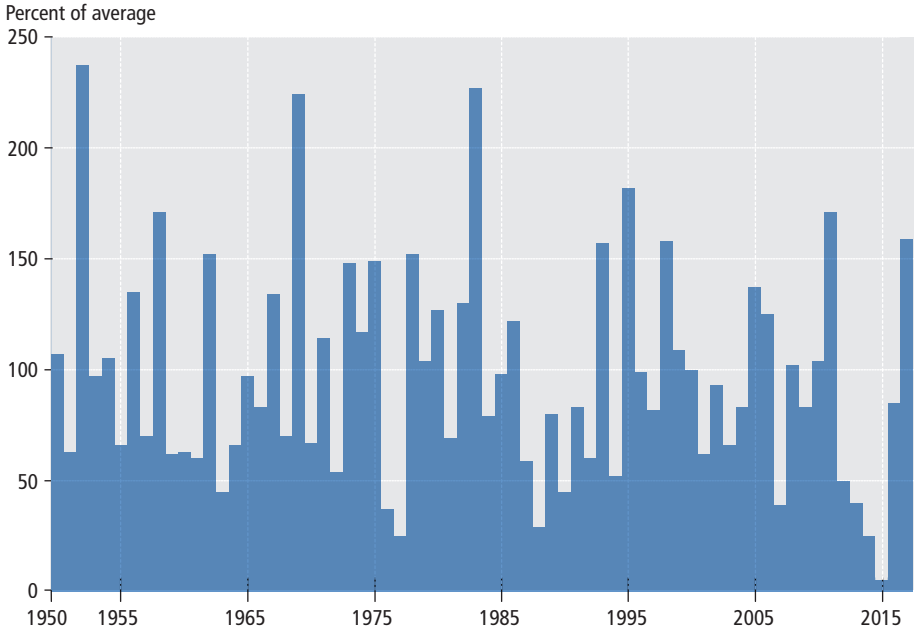
Snowpack is an essential water supply feature in California and historically provides approximately 15 million acre-feet of water accounting for one-third of the State's annual water supply. Numerous studies have reported declines in Western US snowpack in recent years and have been attributed to warming temperatures associated with climate change.

The California Cooperative Snow Surveys program has been actively collecting data since the 1930's from Northern and Southern Sierra locations. A consistent long-term historical record lends this data set to making a good indicator in of snowpack in California.

The California Environmental Protection Agency (EPA) Indicators of Climate Change in California (2013) report used a subset of the snowpack monitoring locations; 13 stations from Northern Sierra and 13 stations from Southern Sierra which were identified by Scripps Institution of Oceanography researchers for their completeness and to represent their respective regions.

The Hydroclimate Report will continue to track statewide snowpack trends and the Northern and Southern Sierra 13 station indicators with updated graphs each WY. Values presented are the April 1st Snow Water Equivalent (SWE), or snow-water content, as this is historically the date when the maximum snow accumulation has occurred at monitoring locations throughout the Sierra.

**Statewide snow water equivalent** (April 1)



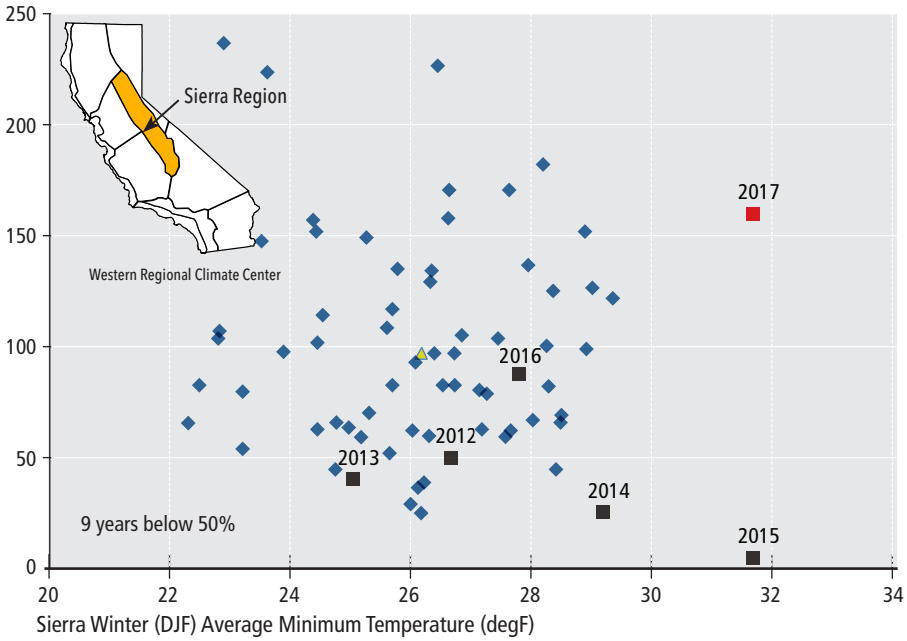

WY 2017 statewide snowpack water content was 159 percent of the long-term average. Comparing to historical snowpack records this year fell short of the wet WY of 1983 where April 1st SWE was 227 percent of average. Even though the total precipitation record was broken in WY 2017, snowpack fell short, possibly due to increased storm and mid-elevation temperatures.

**California Cooperative Snow Surveys - Snowpack**

- Spatial resolution: statewide, Northern Sierra, Southern Sierra
- Temporal resolution: Monthly Winter Season, April 1st SWE

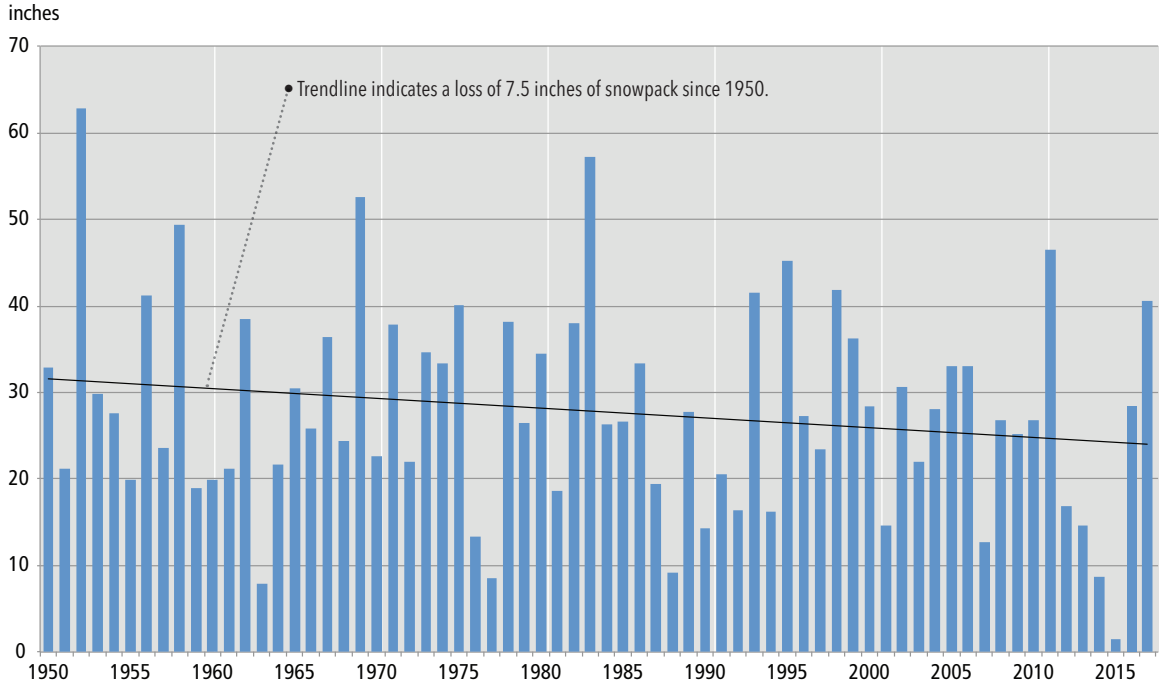
**Sierra snowpack vs Winter Temperature, 1950-2017**

April 1 Snowpack Percent Above Average - from California Cooperative Snow Surveys

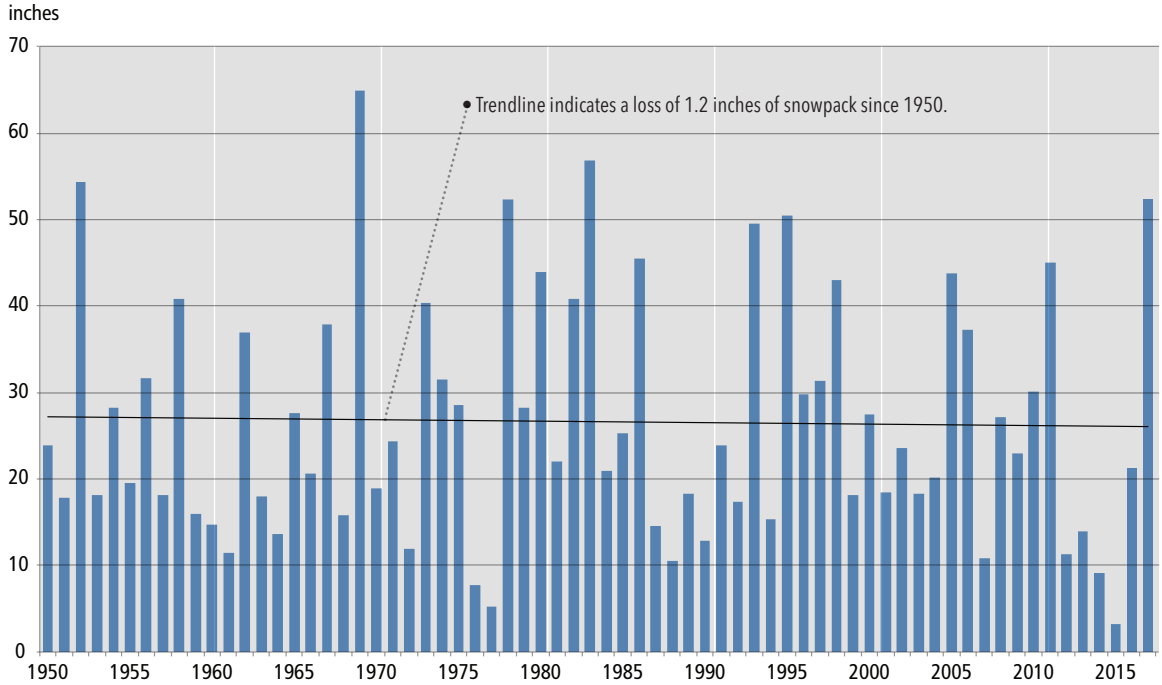



A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past six years labeled as boxes.

**April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses**




**April 1 Snow-Water Content, 13 Southern Sierra Nevada Snow Courses**

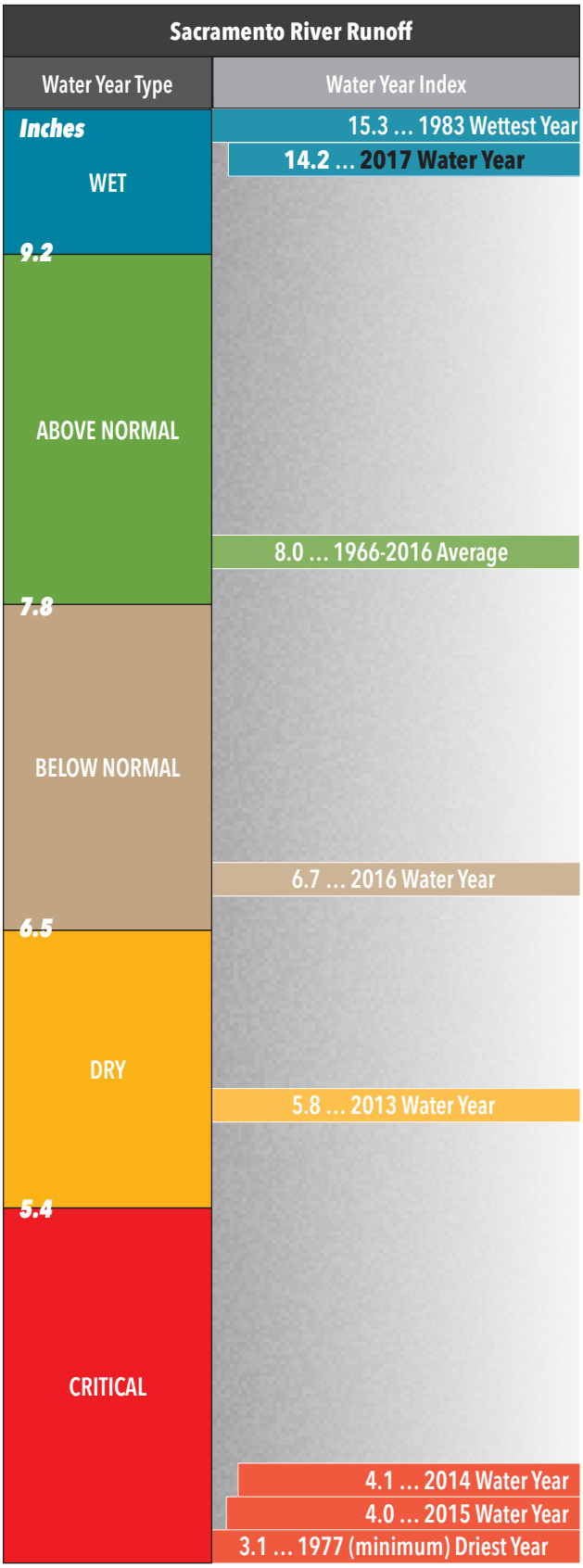



While precipitation totals for WY 2017 surpassed 1983 for the Northern Sierra 8-Station Index, snowpack at many of the snowcourses in the Sierras and Trinity Alps was lower when compared to 1983. While high elevation snowcourses are similar to 1983 April 1st SWE, lower altitude snowcourses had significantly less April 1st SWE compared to 1983 and is reflected in both graphics above. After a record breaking year of precipitation, lower elevation Northern Sierra 13 station group still shows a greater downward trend since 1950 as compared to the higher elevation Southern Sierra 13 station group. The overall trendline changed for both groups from 2016 to 2017, with the Southern courses changing from a loss of 3.6 inches to 1.2 inches of April 1st SWE since 1950, demonstrating how sensitive regression lines are to events near the end of the record. Up until 2011, Roos and Sahota (2012) had found that snowpack in the Southern Sierra 13 station group had increased, however that trend has reversed in the past 6 years.

# Water Year Type

California's water supply is defined by geographic and seasonal variability which are influenced by inter-annual climatic variability with year to year changes in precipitation and runoff. Runoff from the Sacramento and San Joaquin River basins provide much of the State's surface water supply and are classified into a WY type using an index system. Each WY, both river basins are classified in to one of five WY types; a "wet" year classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical). This WY classification system provides a means to assess the amount of water available from the basins and can be used as an indicator of long-term water supply trends. These WY type classifications or "indices" were developed by DWR for the State Water Resources Control Board (SWRCB) for the Sacramento and San Joaquin River hydrologic basins as part of SWRCB's Bay-Delta regulatory activities and are important for water planning and management through each WY.

Old Route 49 bridge crossing over the South Yuba River in Nevada City, California, saw local and regional visitors during the atmospheric river event across northern California on January 9, 2017. Photo: DWR, 2017



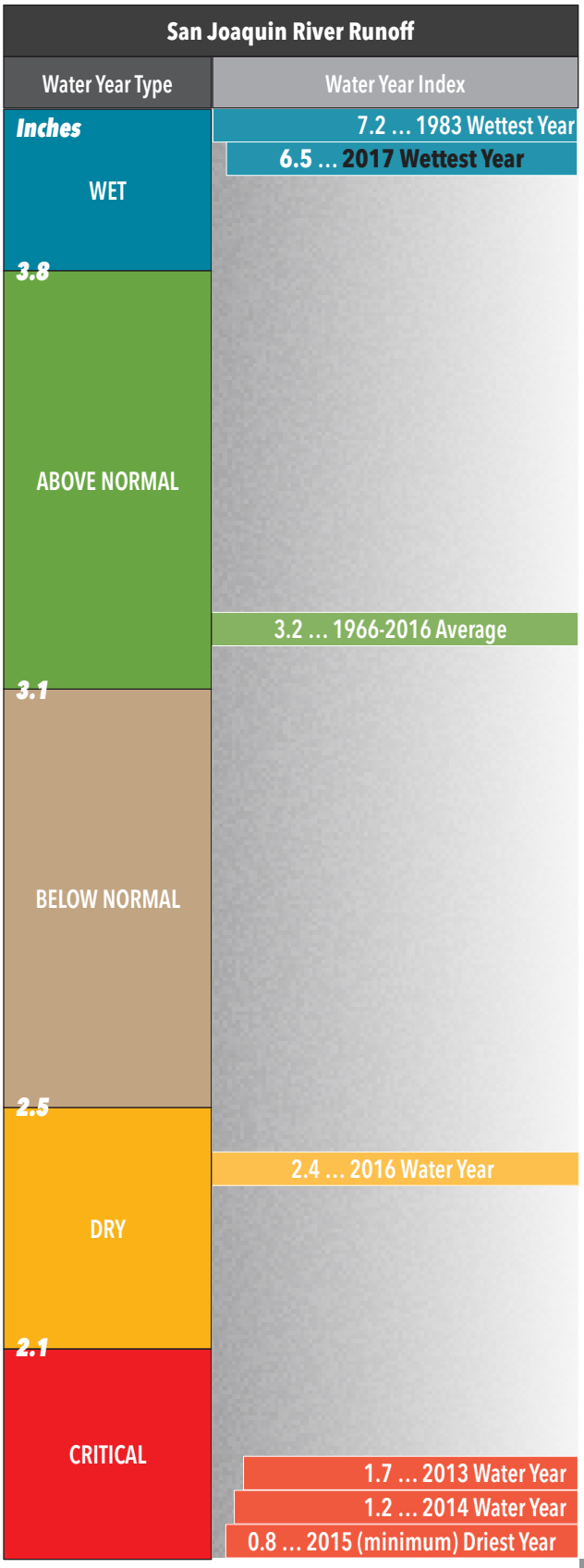

The Sacramento Valley 40-30-30 Index based on flow in million acre feet for WY 2017 was 212 percent of average with an index value of 14.2 classified as a "wet" WY type.

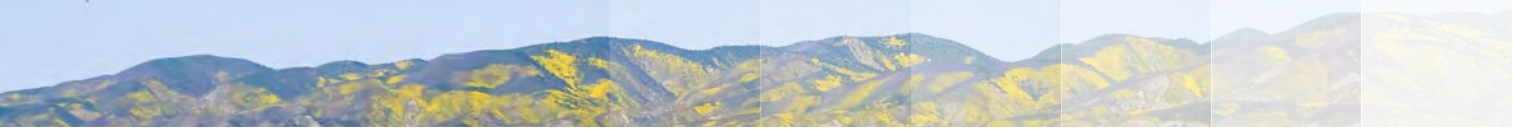
The WY classification system Sacramento and San Joaquin River basins was designed based on historical hydrology and the assumption of a stationary climate. With climate change and changing hydroclimatic conditions there is debate whether this stationary approach to the WY indices will be adequate to make water management decisions in the future. A recent modelling study by Null and Viers (2013) analyzed the context of climate change with the current WY classification system and found a significant shift in the indices due to warmer air temperatures, earlier snowmelt runoff resulting in changes to streamflow timing. With changing in climatic conditions, a more adaptive approach may be needed for water supply indices for the WY classification system to better represent current climate trends.

For more information on WY type classification, see Appendix (pg. 26-29).

High water levels in the Tuolumne River are evident from the La Grange Road Bridge (County Road J59) in Stanislaus County. For the first time in 20 years, the Don Pedro reservoir spillway released water through one of three 45-foot-gates, which further strained the river channels capacity. Photo taken February 23, 2017. Photo: DWR, 2017

The San Joaquin Valley 60-20-20 Index based on flow in million acre feet for WY 2017 was 251 percent of average with an index value of 6.5 classified as a "wet" WY type.





# Rain/Snow Trends

A change in the ratio of rain/snow to total precipitation in the winter and spring can have significant impacts on the ability to balance multiple water management objectives through reservoir operations. Using the methodology developed by DWR for estimating rainfall as a fraction of total precipitation, a trend towards a higher percentage of rain vs. snow in the total precipitation volume has been detected in California (DWR, 2016). Incorporating 2017 data shows that trend continuing across all major snowmelt water supply watersheds.

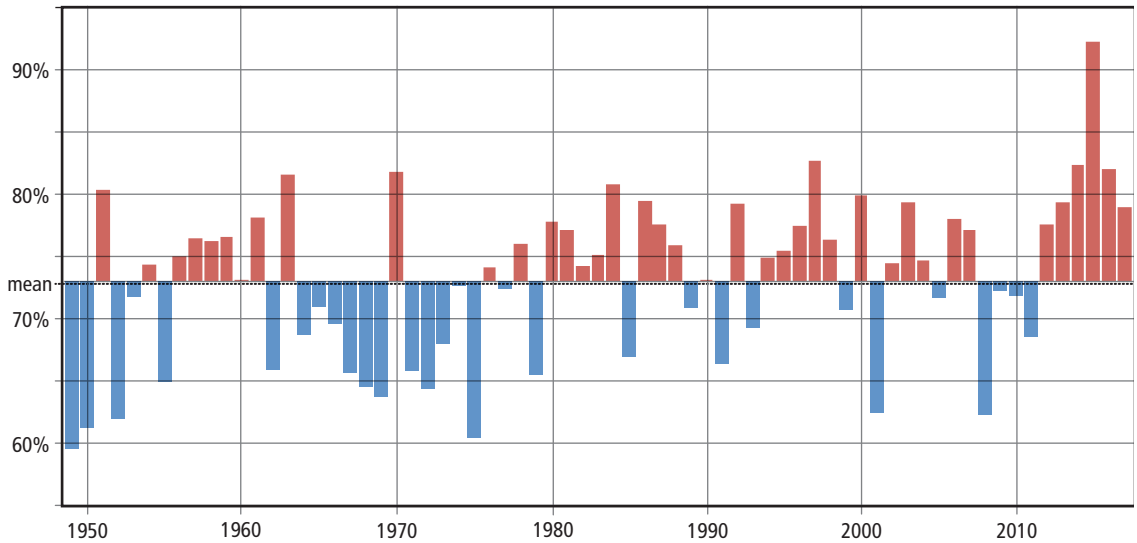
The figure on the right shows the analysis zones for rain/snow trends. Zone B includes Oroville reservoir, DWR's primary storage reservoir for the State Water Project. The graph below shows the historical trend of percentages of rain and snow for all Zones A-D, from 1949-2017. The mean shows the period average of rain making up 73% of total precipitation. Years that have a higher percentage of rain than the mean are more common and occur more successively in the recent last several years. The data show substantial interannual variability due to climate signals that occur on annual and decadal scales. Although not depicted, these trends are more evident in the northern parts of the state than central and southern portions, which are higher in elevation.

**Primary water supply watersheds:** The Analysis zones A-D indicate the study areas used by DWR to track rain/snow trends. They comprise the primary 33 watersheds that contribute to the State's water supply.

**Water Year percentage of rain for the analysis period WY 1949-2017 for All Zones A-D**

- Mean for 1st half of record: 71
- Mean for 2nd half of record: 75
- Mean for entire dataset: 73

Years with red bars have a higher percentage of rain than the mean, and years with blue bars have a lower percentage of rain than the mean.



The Table on the right shows a breakdown of the data into seasonal and WY time periods, comparing the first half and second half of the record for All Zones and Zone B.

For the entire WY in Zones A-D, the second half of the record shows an increase of 4%; from 71% in the first half to 75% in the second. There is an increase from the first to the second half in each seasonal period; 2% higher rain percentage in fall (Sep-Oct-Nov); 4% in winter (Dec-Jan-Feb); and, the highest increase, 10% in spring (Mar-Apr-May).

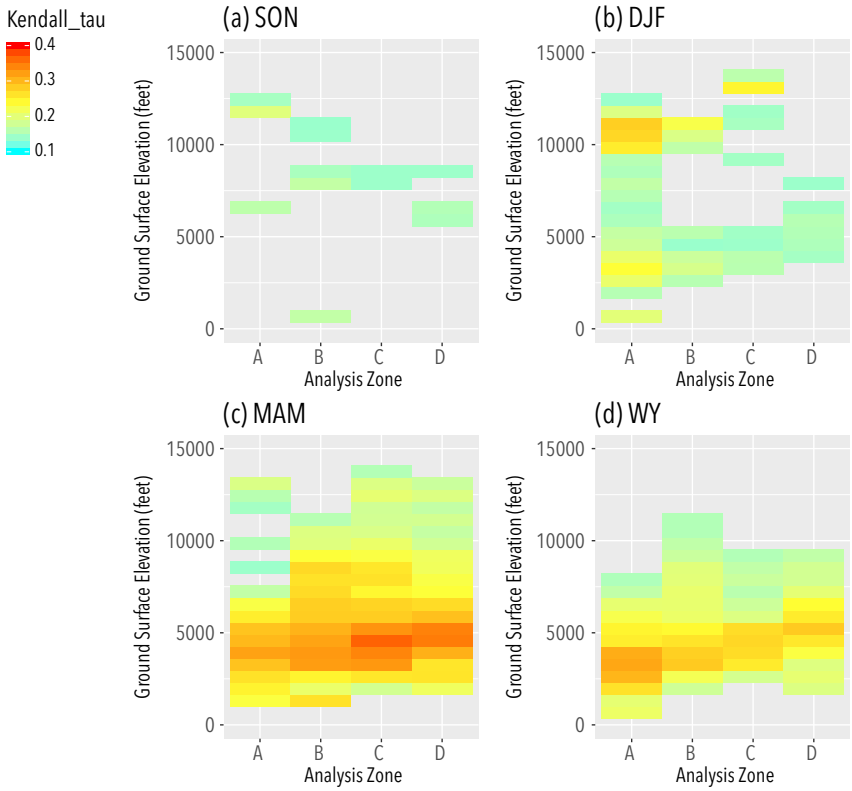
Zone B (Oroville reservoir) inflow shows the second half of the record with equal or higher percentage increases than the statewide trends. The entire period mean trends higher by 5%; fall is 3% higher; winter is 4% higher and spring is 10% higher. In WY 2017, the percentage of precipitation falling as rain in Zone B was 84%, well above the period of record average of 77%; the sixth year in a row that this Zone received above-the-mean percent rain.

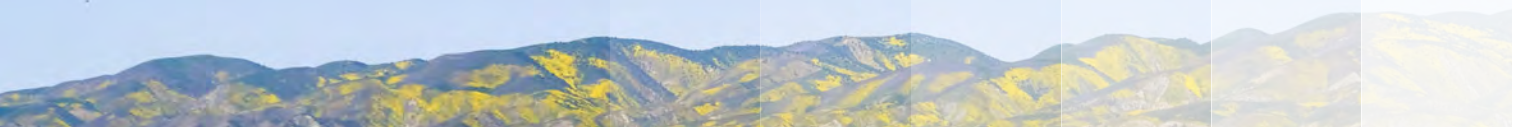
The data was separated into elevation bands to identify the levels where there are significant trends from snow to rain, shown in the figure to the right. Red and orange areas have moderate correlation between percentage rain; yellow and green areas have weak to no correlation; grey areas have no significant correlation. Mid-elevations, between 3,000' and 6,000' in California, are most vulnerable to a rain/snow transition, due to the climatology of the storms that occur. The most significant correlations of rain percentage increasing occur in the spring season, with little to no correlation occurring in fall, and moderate correlation in winter and for the entire WY.

**Percentage of Total Precipitation as Rain:** For WYs 1949-2017, a period of record of 69 years, the rain percentage of total precipitation is compared using the first half (34 years) and second half (35 years) of the record, to indicate trend for all Zones, and Zone B. (WY stands for WY, SON for September, October, November, DJF for December, January, February, and MAM for March, April, May).

| | First Half WY 1949-1982 (34 years) | Second Half WY 1983-2017 (35 years) | Increased percentage of rain (liquid) to total precipitation |
|---|---|---|---|
| **All Zones A-D** | | | |
| **WY** | 71 | 75 | 4 |
| **SON** | 85 | 87 | 2 |
| **DJF** | 66 | 70 | 4 |
| **MAM** | 64 | 74 | 10 |
| **Zone B (Oroville Reseroir Watershed)** | | | |
| **WY** | 74 | 79 | 5 |
| **SON** | 88 | 91 | 3 |
| **DJF** | 70 | 74 | 4 |
| **MAM** | 69 | 79 | 10 |

**Kendall-Tau Elevation Plot:** This figure shows the correlation value between percentage of rain and the season or entire WY, across different elevation bands (vertical axis) and Zones (horizontal axis). The strength of correlation is quantified by the Kendall tau metric; values greater than 0.3 usually indicate a strong positive correlation; a value between 0.1 and 0.3 indicates a moderate positive correlation; a value less than 0.1 indicates a weak to no correlation.





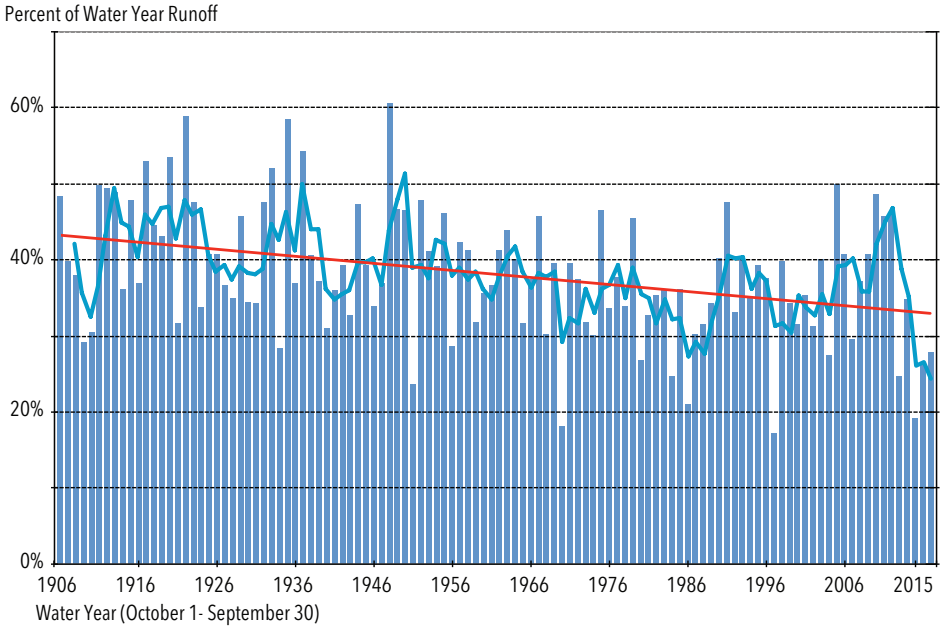
# Unimpaired Streamflow: Sacramento and San Joaquin River Systems

With increasing temperatures and corresponding loss of snowpack, how can a comparison be made representing spring snowmelt? Since the main watersheds in California have been altered by water development projects such as dams and diversions, historical natural hydrology flows would be difficult to compare. To overcome this, natural or "unimpaired" flows are calculated to indicate flow change in each WY from 1906 in the Sacramento River and 1901 in the San Joaquin River systems.

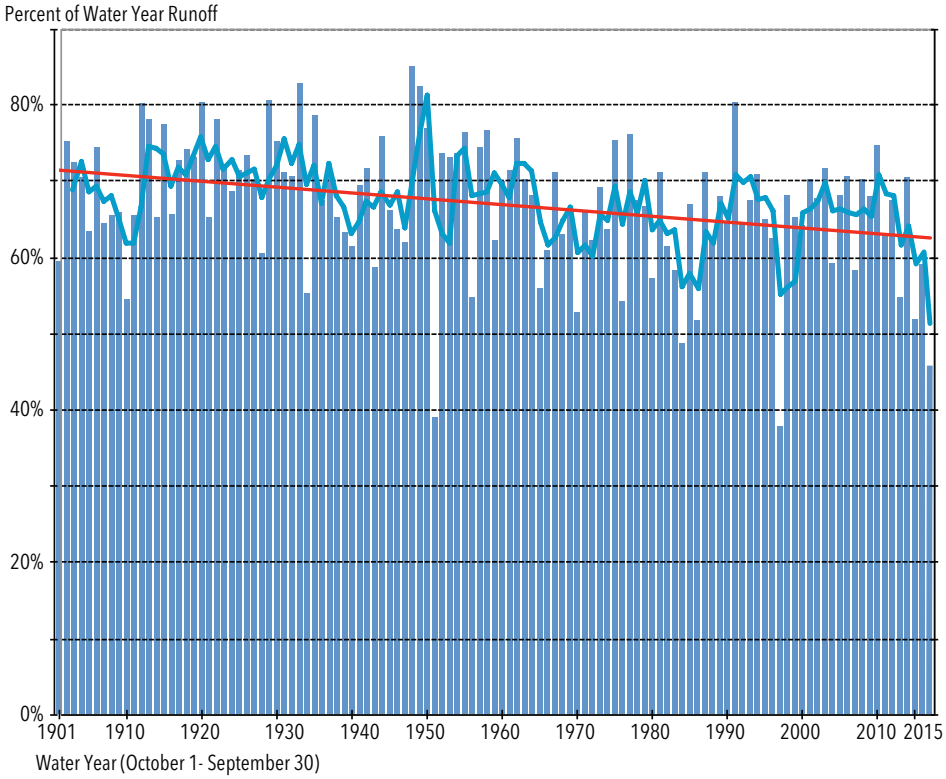
A method to quantify loss of snow pack and corresponding flow during the spring months was developed by DWR Chief Hydrologist Maury Roos in 1987. Instead of comparing seasonal snowmelt amounts, unimpaired flow occurring during the April through July snowmelt season is analyzed. Through this analysis, a distinct trend in flow loss is apparent. Currently, data indicate a 9 percentage point decline per century on the Sacramento and 6 percentage point decline on the San Joaquin River systems.

Even with an exceptionally wet winter in WY 2017, in the long term record, the percent of WY runoff during the April to July snowmelt period shows a declining trend for both the Sacramento and San Joaquin River systems.

**Sacramento River Runoff**, April - July Runoff in percent of Water Year Runoff




**San Joaquin River Runoff**, April - July Runoff in Percent of Water Year Runoff



# Sea Level

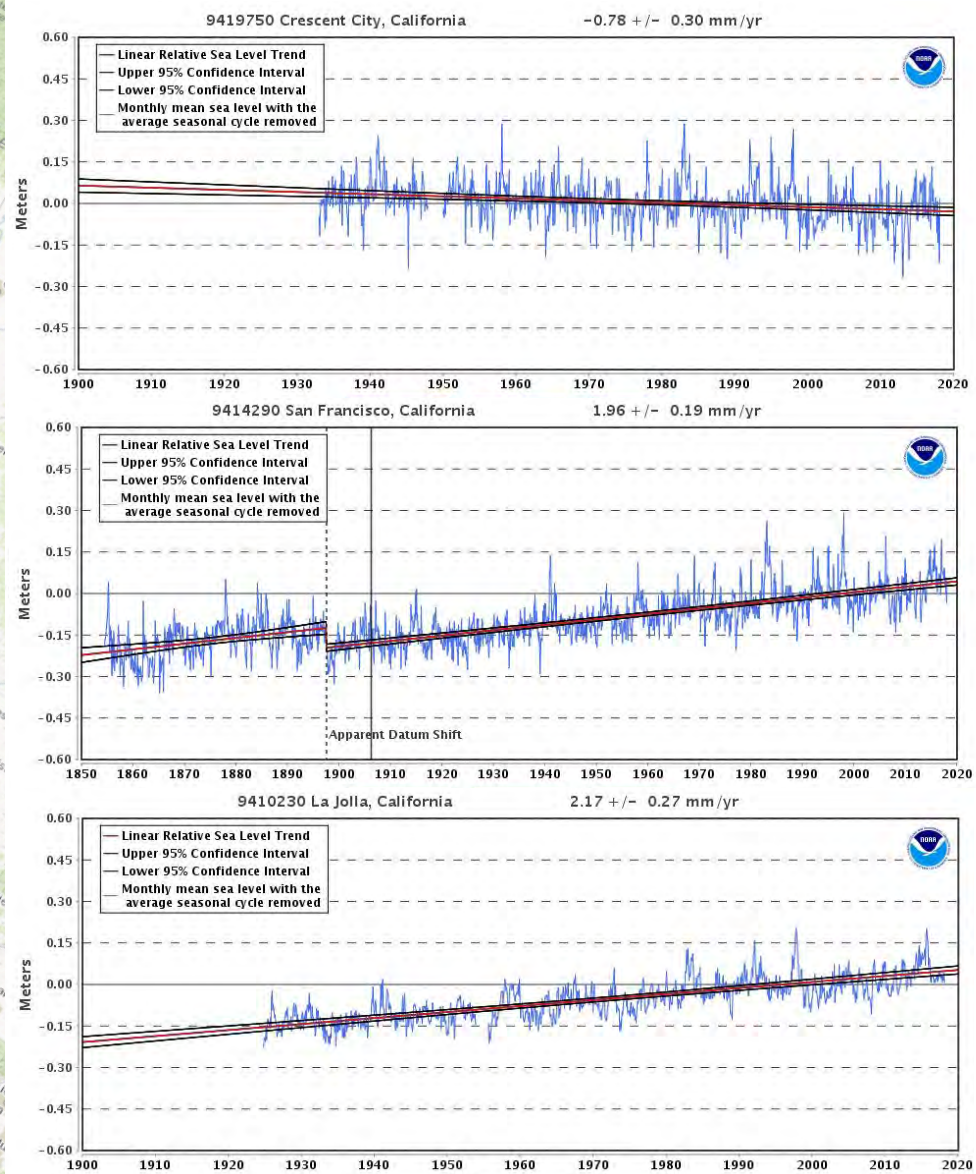
Sea level is tracked along the California coast by the National Oceanic and Atmospheric Administration (NOAA) at 12 active tide gauges, which range in their periods of record from 39 years (Point Arena) to 162 years (San Francisco). Mean sea level at three key coastal tide gauges Crescent City, San Francisco Golden Gate, and La Jolla are used as an indicator of change over time and to capture the broad scale geographic extent of the California coastline.

Local sea level for the shoreline of Southern and Central California (San Diego to Point Reyes) recorded at NOAA tide gauges range from less than 4 inches to just over 8 inches per century at the La Jolla tide gauge. Sea level at the Golden Gate tide gauge in San Francisco has shown a 7 inch per century increase, similar to average global measurements.

A general pattern of uplift shown at the Crescent City tide gauge, which has recorded relative sea level change averaging a decrease of 3 inches per century in sea level, or a drop in sea level relative to the coast, demonstrating that the coastline at this location is rising faster than sea level. At Cape Mendocino along the north central coast, a major tectonic boundary marked by the San Andreas Fault transition to the Cascadia Subduction Zone, which continues up the Pacific Coast to the state of Washington. From Cape Mendocino north for the next 120 miles to the Oregon border, the shoreline is being pushed upward due to subduction of the Gorda Plate beneath northern California.

Coastal uplift at the Crescent City tide gauge is subject to major periodic interruptions as geologic evidence indicates that the Cascadia Subduction Zone generates earthquakes of magnitude 8 or larger that can cause sudden subsidence along the coasts of northern California, Oregon and Washington. History shows a series of these events, which occur every 500 years on average, suggesting that sea-level rise along the California coast north of Cape Mendocino will change virtually instantaneously when the next large earthquake occurs.

**Mean sea level,** as measured at three key coastal guages



# Notable Climate Events and Weather Extremes

WY 2017 began with lingering impacts from a severe and prolonged drought mitigated slightly by the previous WY. Expectations were uncertain for the WY with a potential weak La Nina taking shape in the eastern tropical Pacific. Dry weather, cold storms or warm storms are all possible in this circulation pattern. No one foresaw the epic winter that was about to unfold.

October and November set the stage for winter with early storms re-wetting watersheds that have dried out over the long, hot summer. October started the year off strong with precipitation totals nearing record levels for the month in some locations. A strong storm in the second week of the month brought back memories of the Columbus Day storm of 1962. Some areas of the Sierra Nevada recorded more than 10 inches of precipitation in this event. November was closer to average maintaining watersheds in a state ready for runoff to respond quickly to winter storms.

December was a relatively quiet month to start the big-three months of precipitation. On average, half of California's precipitation arrives in the 90-day window from December through February. Two storms with AR conditions arrived in the second and third weeks of the month yielding above average precipitation for the month and locally high water in some locations in northern California. Snowpack remained below average though given the high freezing elevations during significant precipitation. As the year closed out, forecast models hinted at the possibility of a more active pattern in the New Year.

January opened with a period of storminess starting the 3rd, with snow levels rising from 4,000 feet to 8,000 feet as another AR crossed the State. Cold air behind the front yielded a noticeable increase in snowpack. This first storm was followed in close succession by two more AR events between January 6th through the 12th. The first event possessed strong to extreme water-vapor transport and freezing elevations exceeding 10,000 feet. Snowpack dipped slightly with this storm before growing significantly in the second, colder AR event with freezing elevations peaking briefly at 8,000 feet. One more notable AR event crossed the state on the 18th yielding more snowpack accumulation. In fact, snowpack was now above average and the regional Sierra precipitation indices (Northern Sierra 8-station index, San Joaquin 5-station index, and Tulare 6-station index) were all well above average. A wet to dry north to south gradient notable during the drought remained in place. However, the high moisture content extending above the height of the Sierra Nevada mountains provided ample moisture for heavy snow accumulation at high elevations in the Southern Sierra.

Agricultural field flooding in the Northern Sacramento Valley near the town of Maxwell that was flooded on February 19. Roads throughout the region were closed from flooding and mudslides. Reclamation districts patrolled levees, monitoring boils and sandbagging. Photo: courtesy of Michael Anderson, DWR

The heavy runoff from the cluster of AR events in the first half of the month led to high water in a number of locations. Oroville reservoir which started the month 750,000 acre-feet below its top of conservation storage was now encroached. The other major reservoirs along the Sierra Nevada were likewise at or above their conservation pool limits resulting in flood control releases. The Sacramento Weir was operated for the first time since 2006 to maintain channel flow limits by the city of Sacramento.

February brought a second and third cluster of AR events leading to more flood peaks. The first of these clusters contained three AR events in a 10-day period starting February 3rd. Freezing elevations started at 8000 feet for the first event but rose over 10,000 feet for the second and third events. Heavy precipitation associated with the large amounts of water vapor feeding the storms yielded a second

On May 20, 2017, more than 2 million cubic meters of rock and dirt collapsed down the steep slopes at Mud Creek on California's Big Sur coast. A pile of rubble almost a third of a mile wide buried California State Highway 1 more than 65 feet deep and added about 13 acres of new land to the coast. Photo: USGS, May 27, 2017

major flood wave for many areas of the Central Valley. The high water associated with this event was building on top of the above average base flows from January's flood waves.

The extreme weather was not limited to northern California. A strong AR storm hit southern California in February leading to some areas receiving close to a year's worth of precipitation in a few days. Storm-related damage from washed out roads, to flooding, and landslides across the State resulted in the activation of the State Emergency Operations Center to coordinate a multi-agency emergency response.

The multitude of AR events that occurred in winter (Dec/Jan/Feb) of 2017 resulted in record seasonal precipitation for the Northern Sierra 8-station index. The 58.6 inches of precipitation beat out WY 1956 by 1.3 inches. WY 1956 included the great flood of 1955 when more than 30 inches of precipitation was recorded on the 8-station index for December alone. WY 2017 is the first one in which more than 20 inches of precipitation was recorded in back to back months on the 8-station index.

As spring arrived in March, the heavy precipitation from AR activity continued, albeit at a slower pace. Temperatures warmed in the southeast deserts and surpassed 100°F at several observing stations. At the end of March, the statewide snowpack was 163% of average. This was more than the previous four years combined. The higher elevation central and southern Sierra had larger amounts of snow even though the northern region had more precipitation. The 163% of average for the April 1 snowpack ranked seventh largest with records going back to 1950.

As April began the snowmelt season, the first two weeks of the month brought 90% of the average precipitation seen in the four-month snowmelt season. Temperatures remained warmer than average throughout the spring, with an increasing number of observations above the 100°F threshold. The heavy snowpack provided ample runoff keeping river flows draining the Sierra Nevada high throughout the season. The peak in snowmelt runoff for the Southern Sierra did not occur until late June after summer started. The heavy snowmelt led to flooding issues in the Tulare Lakebed region and resulted in the DWR Flood Center being activated for more than 150 days for the 2017 WY. Lake Tahoe water elevations went from below the rim of the lake to its maximum level in a single year, which was a first since observations began.

Summer added its own flair to the epic year with record heat for the State. Numerous heat waves took place, with record high and low temperatures. Death Valley set a new record for highest average monthly temperature

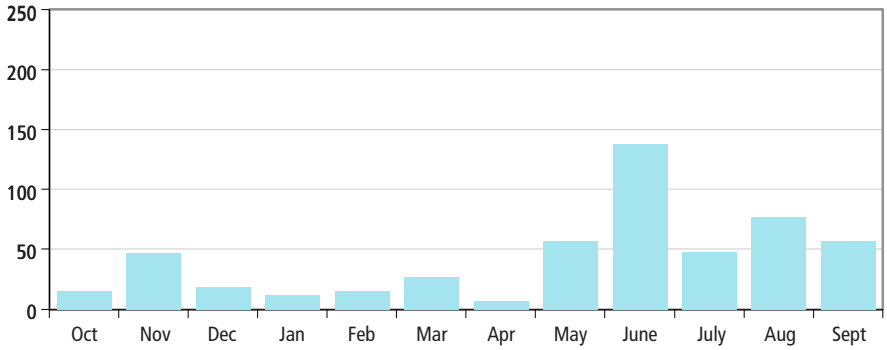
**Table 2.** Monthly temperature and precipitation anomalies for WY 2017 as computed by the California Climate Tracker of Western Region Climate Center.

| Month | Temperature Anomaly (°F) | Precipitation Anomaly (percent of average) |
|---|---|---|
| October | 0.5 | 283% |
| November | 2.6 | 70% |
| December | -0.2 | 119% |
| January | -0.6 | 237% |
| February | 1.9 | 219% |
| March | 3.8 | 73% |
| April | 1.8 | 170% |
| May | 2.3 | 30% |
| June | 3.7 | 84% |
| July | 3 | 8% |
| August | 3.3 | 56% |
| September | 1.4 | 12% |

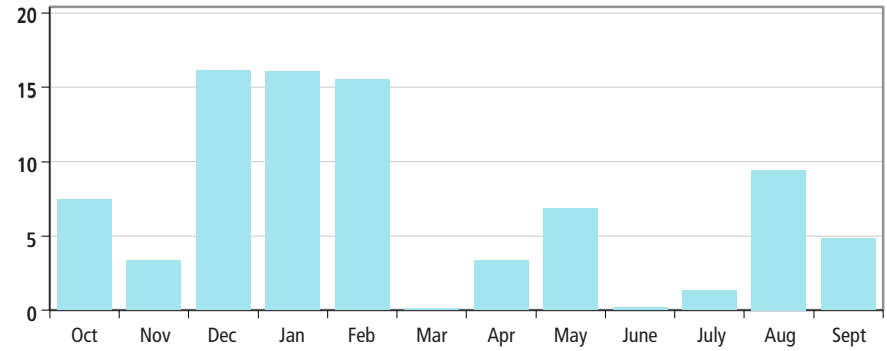
in July with a value of 107.4°F. The average high temperature for the month was 119.6°F and the average low was 95.6°F. Only two nights fell below 90°F. In Redding, CA, the temperature topped 100°F a record 72 times. The previous record of 69 times was set back in 1967. Statewide, the June/July/August average temperature was 73.8°F which also was a record high. The Southwest Monsoon also made an appearance in California in the latter part of the WY with the southeast part of the State receiving periods of heavy precipitation from thunderstorms. The WY closed out with cooler weather beginning to return and frost appearing in the higher elevations of the Sierra Nevada.

The California Department of Water Resources continues an outflow of 80,000 cubic feet per second from the damaged Lake Oroville flood control spillway on Friday morning. Photo: DWR, February 17, 2017

Number of Statewide Temperature Records by Month for Water Year 2017

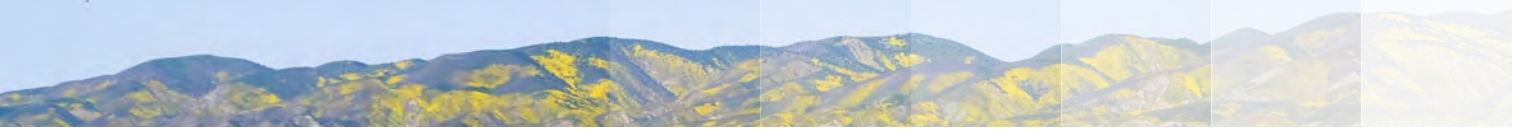



Number of Statewide Precipitation Records by Month for Water Year 2017



# Glossary

- **Anomaly:** The difference of a value over a specified period from the long-term average value (e.g. 1949-2005) over the same period.
- **Average Maximum Temperature:** The average of all daily maximum temperatures over a given time period.
- **Average Mean Temperature:** The mean value of the average maximum temperature and the average minimum temperature over a given time period.
- **Average Minimum Temperature:** The average of all daily minimum temperatures over a given time period.
- **Calendar Year (to date):** The interval between January and December (or to present month), inclusive.
- **Climate:** The average weather or the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years.
- **Climate change:** A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties (often by using statistical tests), and that persists for an extended period, typically decades or longer.
- **Climate model:** A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.
- **Climate variability:** Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.
- **COOP station:** Cooperative Observer Network (COOP), managed by the National Weather Service, consists of up to 12,000 weather stations across the United States that report daily measurements of precipitation and/or temperature.
- **Inhomogeneities:** Variations in data that are not attributed to climate variations. Non-climatic influences on the dataset can include abrupt changes due to changes in instrumentation or station location, as well as gradual changes due to growth of nearby vegetation or urban centers.
- **Linear Trend:** A simple method that fits a line (linear trend) to observations of a given variable over some time period. Beside each linear trend given on this set of pages is a 95% confidence interval that provides a measure as to how likely a trend is significant. For example, a trend of +2°F/100 years with an uncertainty interval of + or - 1°F/100 years says that with 95% confidence there is a positive linear trend, with a range between +1° and +3°F/100 years. On the other hand, a linear trend of + 2°F/100 years with an uncertainty interval of +/- 5°F/100 years does not provide conclusive evidence of a linear trend, as the range is between -3° to + 7°F/100 years. Confidence Intervals are calculated according to Santer et al 2000.
- **PRISM:** Parameter-elevation Relationships on Independent Slopes Model. A model that incorporates point measurements and topographic database to create a high resolution gridded climate database. More information on PRISM is available from Oregon Climate Service.
- **Percentile Ranking:** The ranking of a variable (e.g., temperature) over a given time period versus comparable time periods overall years of record, normalized to a 0 (coldest) to 100 (warmest) scale.
- **Precipitation:** The accumulation of water (in liquid form) that is deposited to the surface over a given time period.
- **Streamflow:** The amount of water flowing in a river.
- **Water Year (to date):** The interval between October and September (or to present month). For example the WY 2007 refers to the interval between October 2006 and September 2007.



# Appendix

## TEMPERATURE AND PRECIPITATION

### *WRCC California Climate Tracker*

http://www.wrcc.dri.edu/monitor/cal-mon/background_brief.html

Monthly station data, taken from cooperative observers (COOP), along with gridded data from the PRISM database, are used to assess climate across the state. The primary variables that are considered in this process are monthly average mean temperatures and monthly precipitation totals. COOP stations across the state that reported over 75% of observations over the time period 1949-2005, and continued to report in 2006. A total of 195 stations across the state are included in this analysis. We consider COOP station data along with the PRISM database dating back to January of 1895. Temperature data from the COOP stations have been adjusted for inhomogeneities, a procedure used to "correct" for non-climate shifts in temperature. No effort is made to adjust for urbanization or land-use changes. Inhomogeneity detection includes the entire period of record; however the dataset contains larger uncertainties prior to 1918 due to the limited number of stations reporting statewide.

### *NOAA U.S. Climate Divisional Dataset*

https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php

For many years the Climate Divisional Dataset was the only long-term temporally and spatially complete dataset from which to generate historical climate analyses (1895-2013) for the contiguous United States (CONUS). It was originally developed for climate-division, statewide, regional, national, and population-weighted monitoring of drought, temperature, precipitation, and heating/cooling degree day values. Since the dataset was at the divisional spatial scale, it naturally lent itself to agricultural and hydrological applications.

There are 344 climate divisions in the CONUS. For each climate division, monthly station temperature and precipitation values are computed from the daily observations. The divisional values are weighted by area to compute statewide values and the statewide values are weighted by area to compute regional values. (Karl and Koss, 1984).

### *Precipitation: DWR 8 Station and 5 Station Indices*

Department of Water Resources hydrologists use two mountain precipitation indexes to track daily accumulation of rain and snow during the winter rainy season for the major Central Valley basins. The first is the Northern Sierra 8 station average, a group of 8 precipitation stations extending from Mount Shasta in the north to near Lake Tahoe in the south, which corresponds quite well to the WY runoff of the Sacramento River system (the Sacramento four river index). A southern group of 5 Sierra stations comprise the 5 station index which correspond fairly well to WY runoff for the San Joaquin River (the San Joaquin four river index).

The 8 station precipitation index includes: Mt Shasta City, Shasta Dam, Mineral, Quincy, Brush Creek, Sierraville, Blue Canyon, Pacific House.

http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=8SI

The 5 station precipitation index includes: Calaveras Big Trees, Hetch Hetchy, Yosemite, North Fork RS, Huntington Lake

http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=5SI

## ATMOSPHERIC RIVERS

http://cw3e.ucsd.edu/

The Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, UCSD has developed a method in order to characterize atmospheric river (AR) events that make landfall along the US west coast. ARs are Identified using 6 hourly GFS Analysis derived integrated water vapor data. Arrows are drawn on the map where integrated vapor transport (IVT) within identified ARs was strongest over the US West Coast (Arrows do not identify all locations each AR impacted). Given the spatial scale of a landfalling AR, the landfall latitude is an approximation. Intensity is determined for each AR using the Ralph/CW3E AR strength scale using IVT.

## SNOWPACK

### *Bulletin 120 and Water Supply Index forecasts*

Water Supply Index (WSI) and Bulletin 120 (B120) forecasts are posted at:

WSI: http://cdec.water.ca.gov/cgi-progs/iodir/wsi

B120: http://cdec.water.ca.gov/cgi-progs/iodir?s=b120

### *Recent Changes in the Sierra Snowpack of California (Roos and Fabbiani-Leon, 2017)*

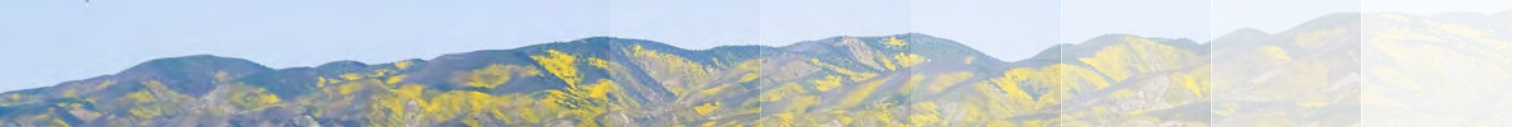
https://westernsnowconference.org/files/PDFs/2017Roos.pdf

During the 2012 Western Snow Conference, Roos and Sahota described contrasting trends for Sierrra snowpack. For a northern Sierra group of snow courses, a decline in April 1 measured water content was noted; however, for another group of southern Sierra courses, a small increasing trend in water content was noted. In both north and south, there was a decreasing trend in the volume of April through July runoff (mostly snowmelt) compared to total water year runoff. Now, after the drought, and a 2017 data update, the southern Sierra snowpack also shows a decreasing trend, although not as much as in the north.

### *Water Year Type: Unimpaired Flow (Runoff)*

http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, export of water to or import of water from other basins. Sacramento River Runoff is the sum (in maf) of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. The WY sum is also known as the Sacramento River Index, and was previously referred to as the "4 River Index" or "4 Basin Index". It



was previously used to determine year type classifications under State Water Resources Control Board (SWRCB) Decision 1485.

Sacramento Valley Water Year Index = 0.4 * Current Apr-Jul Runoff Forecast (in maf) + 0.3 * Current Oct-Mar Runoff in (maf) + 0.3 * Previous Water Year's Index(if the Previous Water Year's Index exceeds 10.0, then 10.0 is used). This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the Sacramento Valley WY type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination is based on the May 1 50% exceedence forecast.

### *Sacramento Valley Water Year Hydrologic Classification:*

| Year Type: | Water Year Index: |
|---|---|
| Wet | Equal to or greater than 9.2 |
| Above Normal | Greater than 7.8, and less than 9.2 |
| Below Normal | Greater than 6.5, and equal to or less than 7.8 |
| Dry | Greater than 5.4, and equal to or less than 6.5 |
| Critical | Equal to or less than 5.4 |

San Joaquin River Runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (in maf). San Joaquin Valley Water Year Index = 0.6 * Current Apr-Jul Runoff Forecast (in maf) + 0.2 * Current Oct-Mar Runoff in (maf) + 0.2 * Previous Water Year's Index(if the Previous Water Year's Index exceeds 4.5, then 4.5 is used). This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the San Joaquin Valley WY type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1 75% exceedence forecast.

### *San Joaquin Valley Water Year Hydrologic Classification:*

| Year Type: | Water Year Index: |
|---|---|
| Wet | Equal to or greater than 3.8 |
| Above Normal | Greater than 3.1, and less than 3.8 |
| Below Normal | Greater than 2.5, and equal to or less than 3.1 |
| Dry | Greater than 2.1, and equal to or less than 2.5 |
| Critical | Equal to or less than 2.1 |

Eight River Index = Sacramento River Runoff + San Joaquin River Runoff. This Index is used from December through May to set flow objectives as implemented in SWRCB Decision 1641.

The current WY indices based on forecast runoff are posted at:

http://cdec.water.ca.gov/water_supply.html

And published in DWR Bulletin 120:

http://cdec.water.ca.gov/snow/bulletin120

These indices have been used operationally since 1995, and are defined in SWRCB

Decision 1641: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/decision_1641/

This report is updated each fall once the data is available.

## SEA LEVEL TRENDS

http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

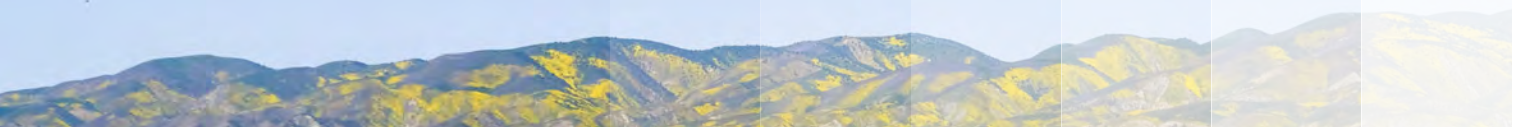
http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9419750

http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290

http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410230

The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 142 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to 240 global tide stations using data from the Permanent Service for Mean Sea Level (PSMSL). This work is funded in partnership with the NOAA OAR Climate Observation Division.

The mean sea level (MSL) trends measured by tide gauges that are presented on this web site are local relative MSL trends as opposed to the global sea level trend. Tide gauge measurements are made with respect to a local fixed reference level on land; therefore, if there is some long-term vertical land motion occurring at that location, the relative MSL trend measured there is a combination of the global sea level rate and the local vertical land motion. The global sea level trend has been recorded by satellite altimeters since 1992 and the latest calculation of the trend can be obtained from NOAA's Laboratory for Satellite Altimetry, along with maps of the regional variation in the trend. The University of Colorado's Sea Level Research Group compares global sea level rates calculated by different research organizations and provides detailed explanations about the issues involved.



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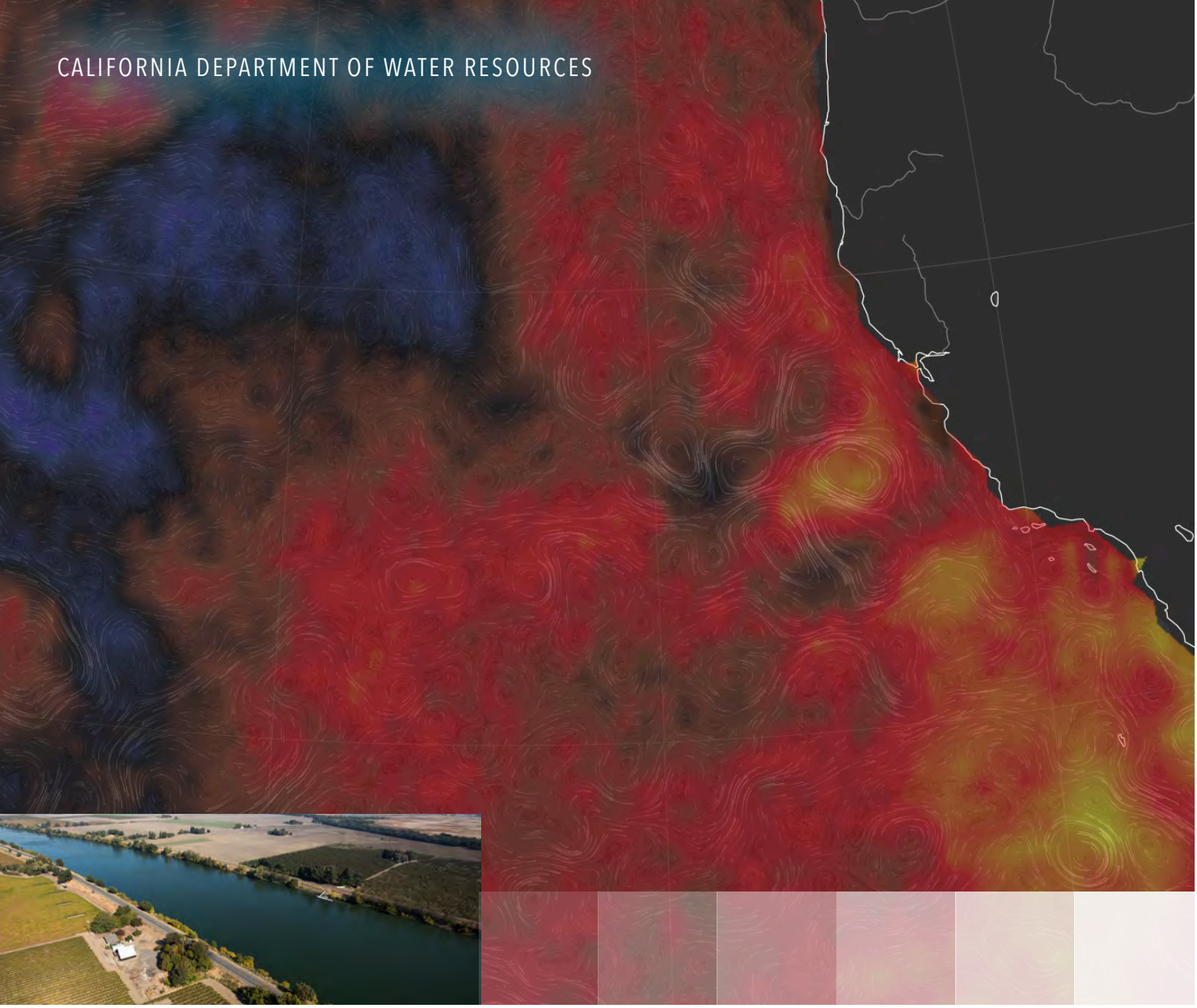
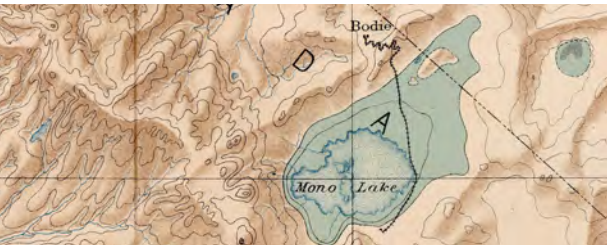
National Oceanic and Atmospheric Administration meteorologist Clark King sets up a meteorological tower, as part of an atmospheric river observatory being installed on Twitchell Island in Sacramento County, California on October 24, 2017. The weather station is equipped with instruments for measuring atmospheric conditions, to provide information for weather forecasts, and to study the weather and climate. Photo: DWR, 2017

CALIFORNIA DEPARTMENT OF WATER RESOURCES







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**Released August 2018**

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