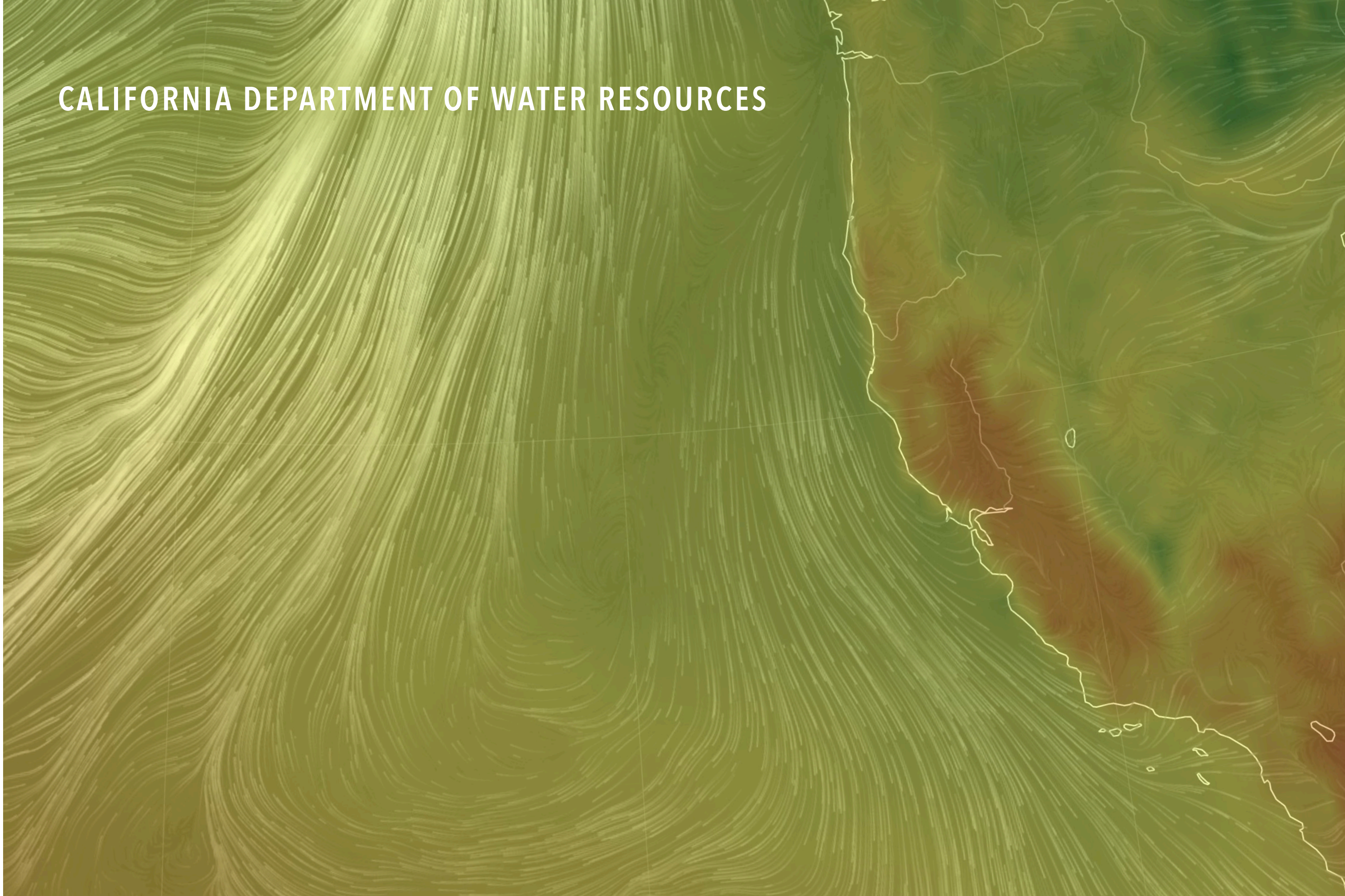
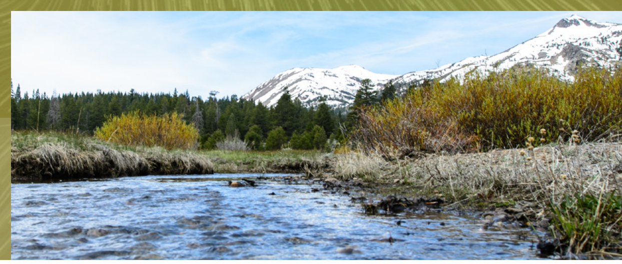
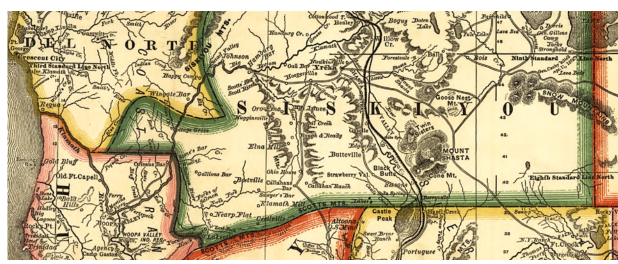
CALIFORNIA DEPARTMENT OF WATER RESOURCES







HYDROCLIMATE REPORT

Water Year 2018

Office of the State Climatologist

Executive Summary

Water year (WY) 2018 whipsawed from dry to wet and added high heat for the summer. The WY ended with 82 percent of average precipitation in the Northern Sierra and 20 percent below average April-July streamflow in the Sacramento River and 19 percent below average for the San Joaquin River. Peak statewide snowpack was only 60 percent of average. While precipitation and stream flow were below average, the big story of the 2018 WY were record temperatures that lead to several unprecedented and deadly wildfires in the state.

It was a record-breaking year for summer season air temperatures across California. The month of July was the warmest on record and the single warmest month in the history of the state. In early July, a 120°F maximum daily temperature was recorded at the Chino Airport in San Bernardino County on July 6, 2018. This was one of the highest maximum record temperatures in that region at an automated surface observing weather station. The Death Valley weather station at the National Park Service Visitor's Center saw an average daily temperature of 108.1°F for the month of July, breaking a world record for the hottest average monthly temperature. The high temperature at that location peaked at 127°F for four consecutive days at the end of July setting new records on each of the four days. In the central valley, Fresno reached a record number of consecutive days with highs 100°F or warmer for 30 days. According to the California Climate Tracker, July 2018 had the highest average temperature for the Sierra Climate Region at 70.1°F which was ranked the record warmest out of 124 years (right).

Record-breaking temperatures across the state amplified already dangerous fire conditions where vegetation fuels were exceptionally dry and prone to ignition. Several unprecedented and deadly California wildfires occurred in July including the Ferguson, Mendocino Complex, and Carr Fires. The Mendocino Complex became the largest wildfire to-date in California history (a combination of the Ranch and River fires). The Carr fire moved into the western side of Redding in Northern California, which resulted in a half-mile wide "fire whirl vortex" with winds reaching near 150 mph equivalent to a EF-3 tornado. The fire resulted in over 1,500 structures burned, total damages estimated at $1.7 billion, and six lives lost. The climate change narrative speaks to new extremes and more variability, WY 2018 exhibited both adding to a decade of new extremes and wild volatility with more indications of warming and its attendant impacts.

California Climate Regions Mean Temperature Percentile Rankings for July 2018

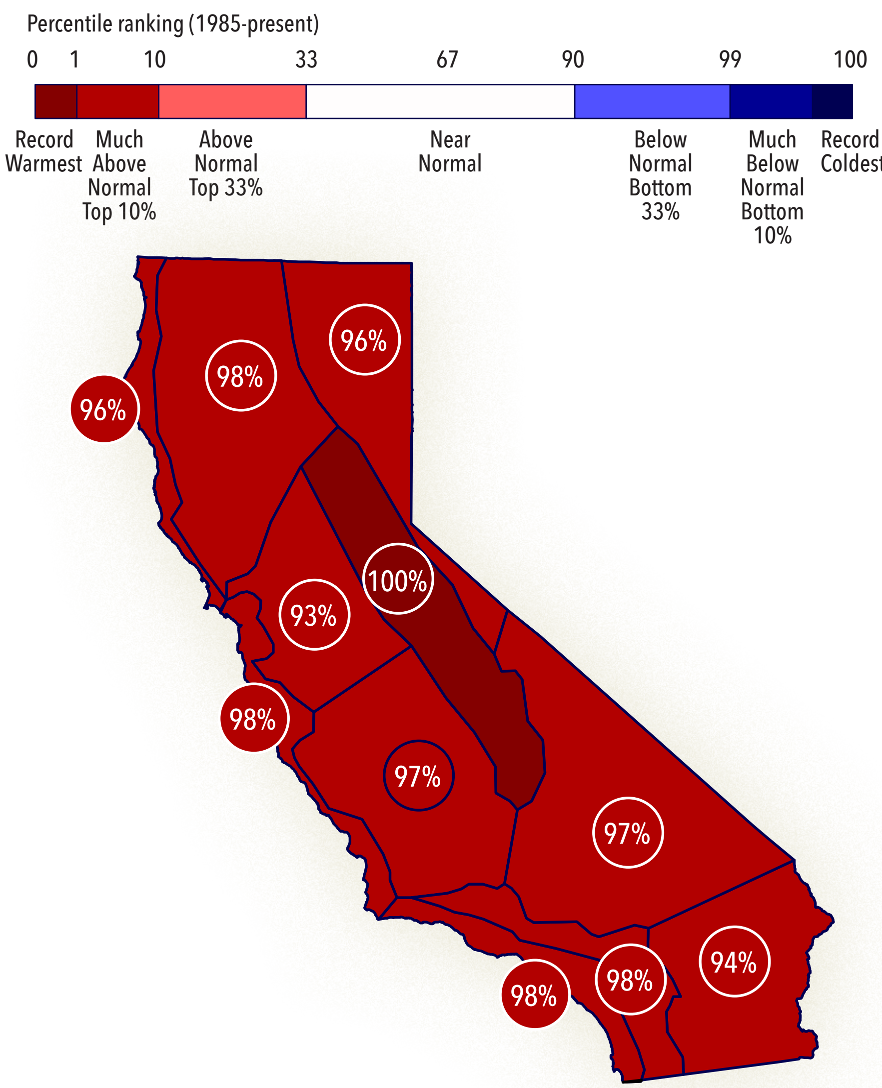


Table of Contents

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

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

Introduction

The Hydroclimate Report Water Year (WY) 2018 updates the 2017 report with data from WY 2018. 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.

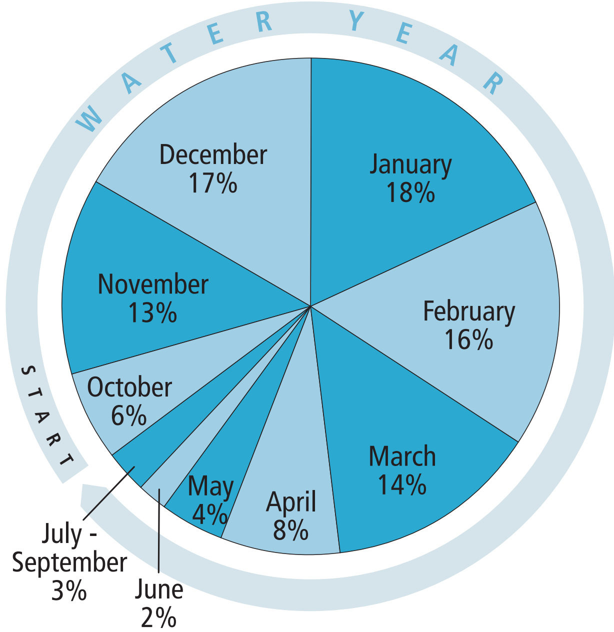
Key Hydroclimate Indicators

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?

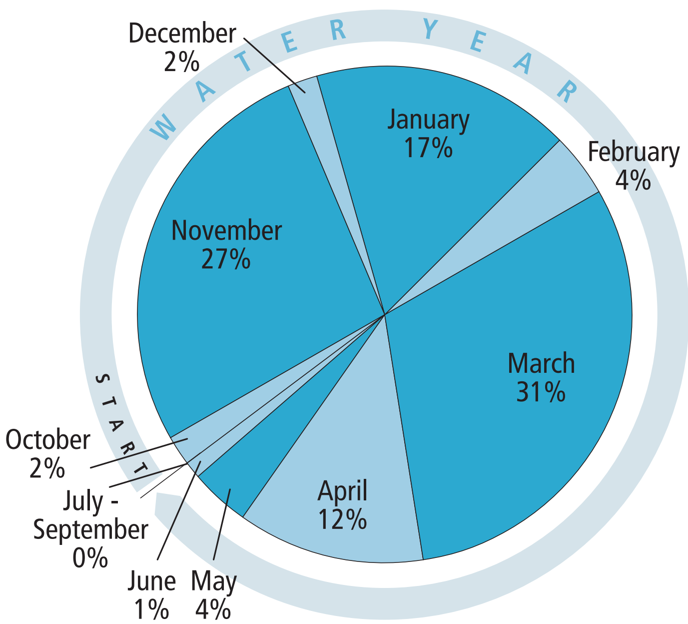
Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)

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 2018 by Month



This chart represents monthly precipitation as percent of the total 2018 WY precipitation.

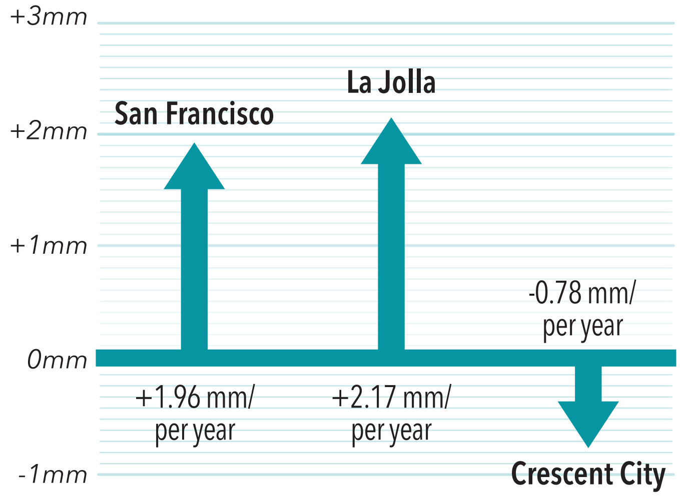
Hydrologic data such as precipitation and streamflow data are key indicators for the Hydroclimate Report. These data are typically represented as being within the WY. A WY (also discharge year or flow year) is a term commonly used in hydrology to describe a time period of 12 months during which precipitation 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 2018 WY covers the period from October 1, 2017 to September 30, 2018.

A comparison of the pie charts on the left between the long-term average and WY 2018, shows almost 60 percent of the total WY precipitation occurred in November and March.

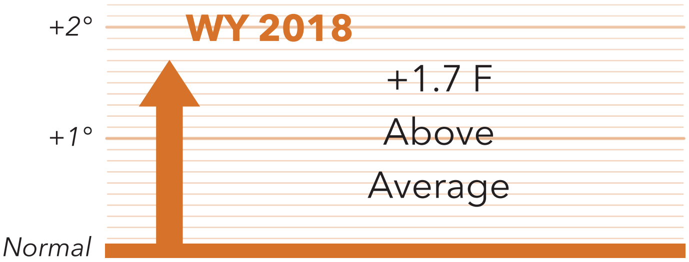
On average, the month of November accounts for 13 percent and March typically accounts for 14 percent of total annual precipitation; however, in 2018 these two months accounted for almost 60 percent of the WY's total. Precipitation during the winter months was less than normal where combined December, January, and February total precipitation was 45 percent below average. The total WY rainfall at 41 inches was less than the long-term average at 51.8 inches. The WY ended with a dry period in the Northern Sierra 8-Station region (see top figure, page 11) with only 0.5 inches of precipitation being recorded for the months of June, July, August, and September. This is less precipitation than expected even though a dry summer is typical for California's Mediterranean climate.

California Hydroclimate Water Year 2018 "At A Glance"

Sea level (100 year trend) Page 21

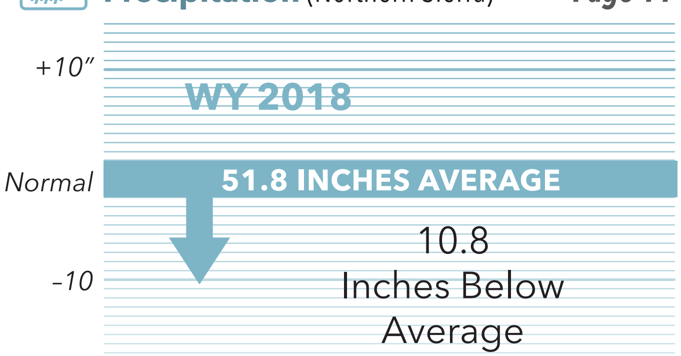


Temperature (Statewide)* Page 8



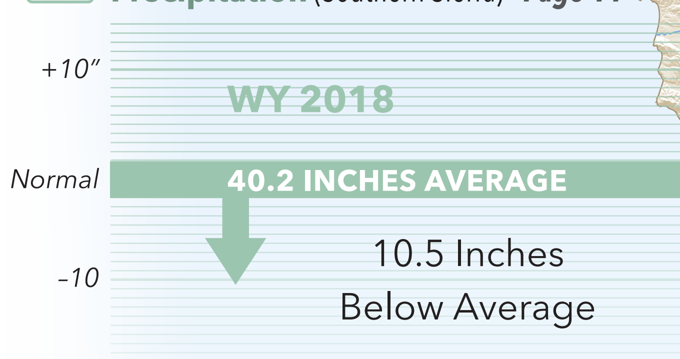
*Normal average air temperature represents 1981-2010 base period.

Precipitation (Northern Sierra)* Page 11

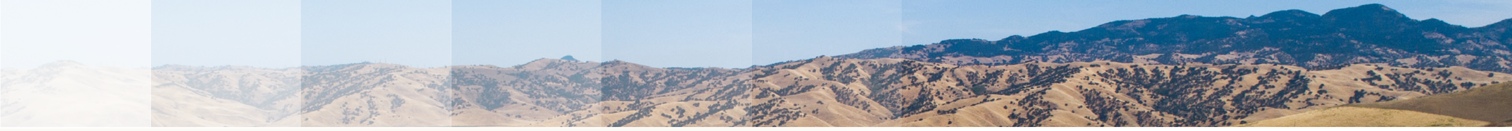


*Normal average precipitation represents 1961-2010 base period.

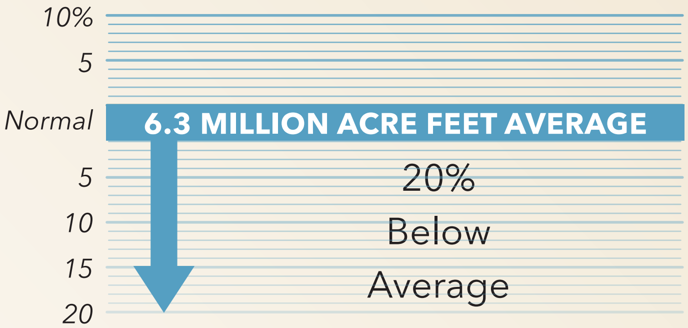
Precipitation (Southern Sierra)* Page 11



*Normal average precipitation represents 1961-2010 base period.

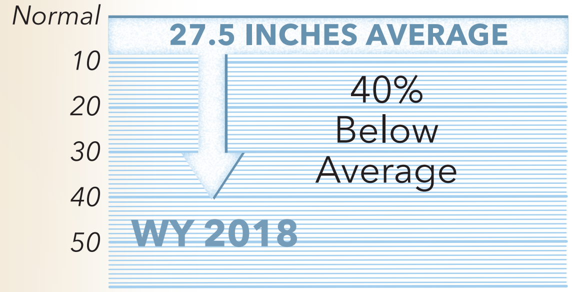


Streamflow, April-July (Sacramento River)* ***Page 20***



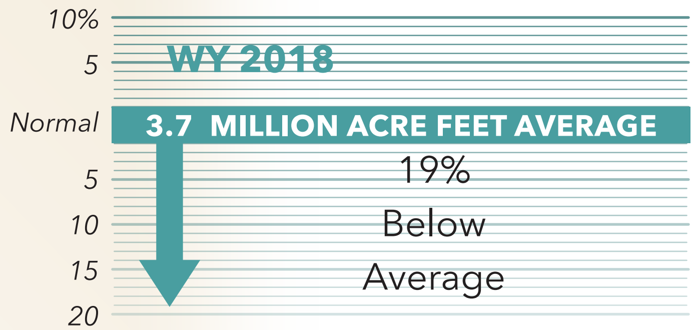
**Normal average streamflow represents 1966-2015 base period.*

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

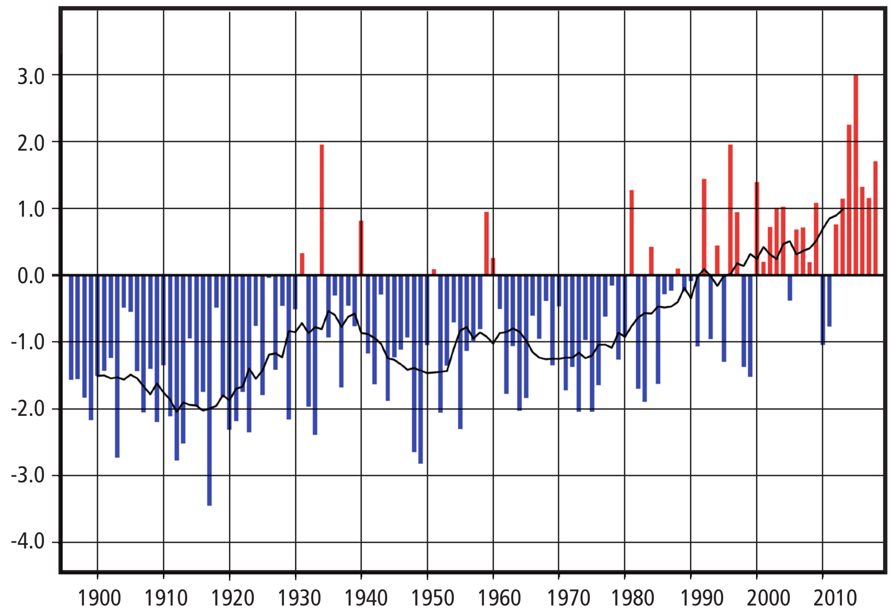
According to the Intergovernmental Panel on Climate Change (IPCC) the warming of the climate system is unequivocal. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The atmosphere and ocean have warmed since the pre-industrial period (1850–1900). The observed mean land surface air temperature has risen considerably more than the global mean surface (land and ocean) temperature. From 1850–1900 to 2006–2015 mean land surface air temperature has increased by 2.8°F while global mean surface temperature increased by 1.6°F. (IPCC, 2019).

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 2018 temperature measurements using WRCC and National Oceanic and Atmospheric Administration (NOAA) datasets demonstrate a continuing warming trend. Statewide average

California statewide mean temperature departure, October through September

Degrees (F)



Black line denotes 11-year running mean

Departures from 1981-2010 base period:*

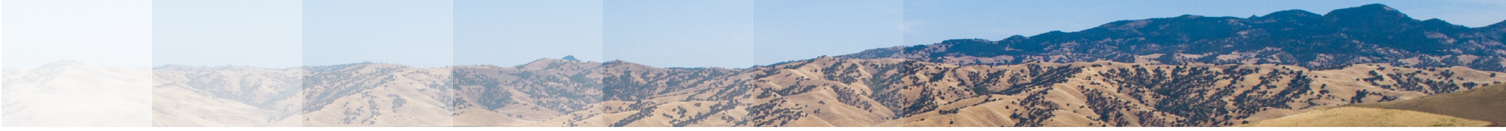
Mean: 58°F	Median: 58.1°F
Extremes:	Warmest: 61.0°F (+3.0°F from Average), 2015
	Coldest: 54.6°F (–3.4°F from Average), 1917
Most Recent WY:	October 2017-September 2018 (59.7°F (+1.7°F)
	Rank: 119 of 123 (1 = Record Coldest, 123 = Record Warmest)

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 1981 to 2010) i.e., the difference between each year's value and the long-term average.

*The PRISM model is used to generate this dataset and the California Climate Tracker product is updated as better data/info are available. Air temperature values may change slightly over time.



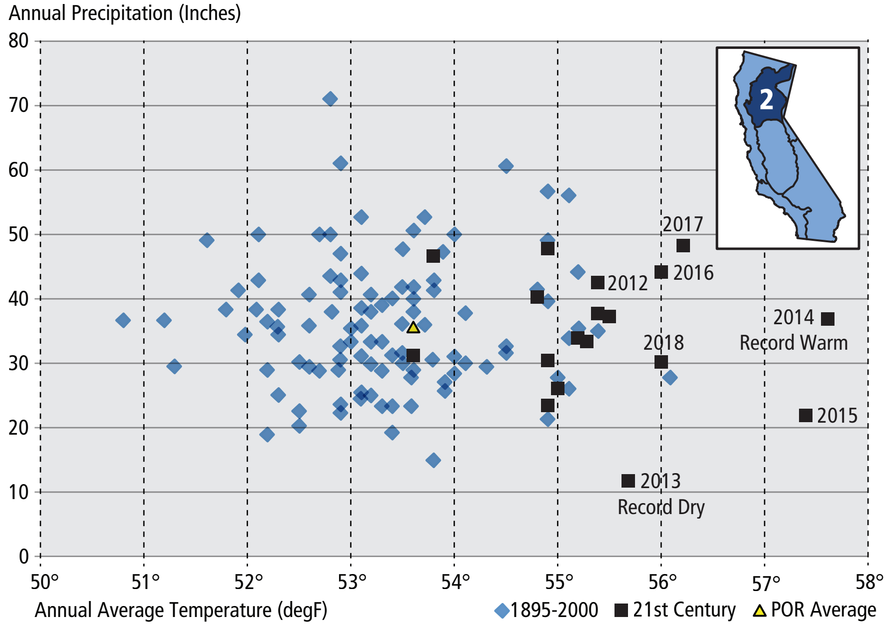
temperatures were ranked at 119 warmest out of 123 years of record dating back to 1895.

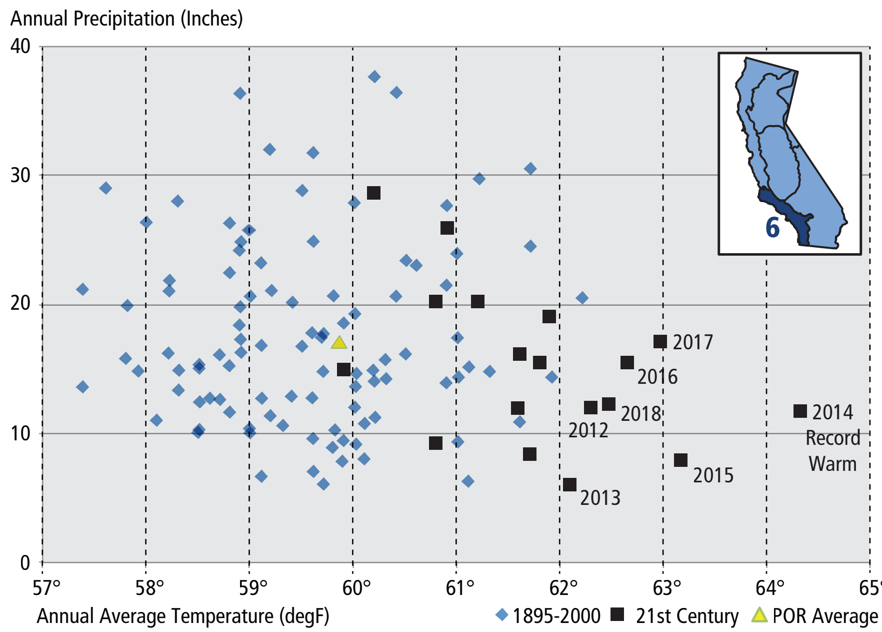
The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2018) for the contiguous United States. This data set is based on a calendar year instead of the hydrologic WY. There are 344 climate divisions in the US and 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 1895-2018.

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 several years are depicted as outliers, being some of the warmest 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 18 years since the turn of the century are also extremely warm and dry, indicating a shift in climate compared to the 20th century.

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. 2018 was the fifth warmest on record for the Sacramento Climate Division and also fifth 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

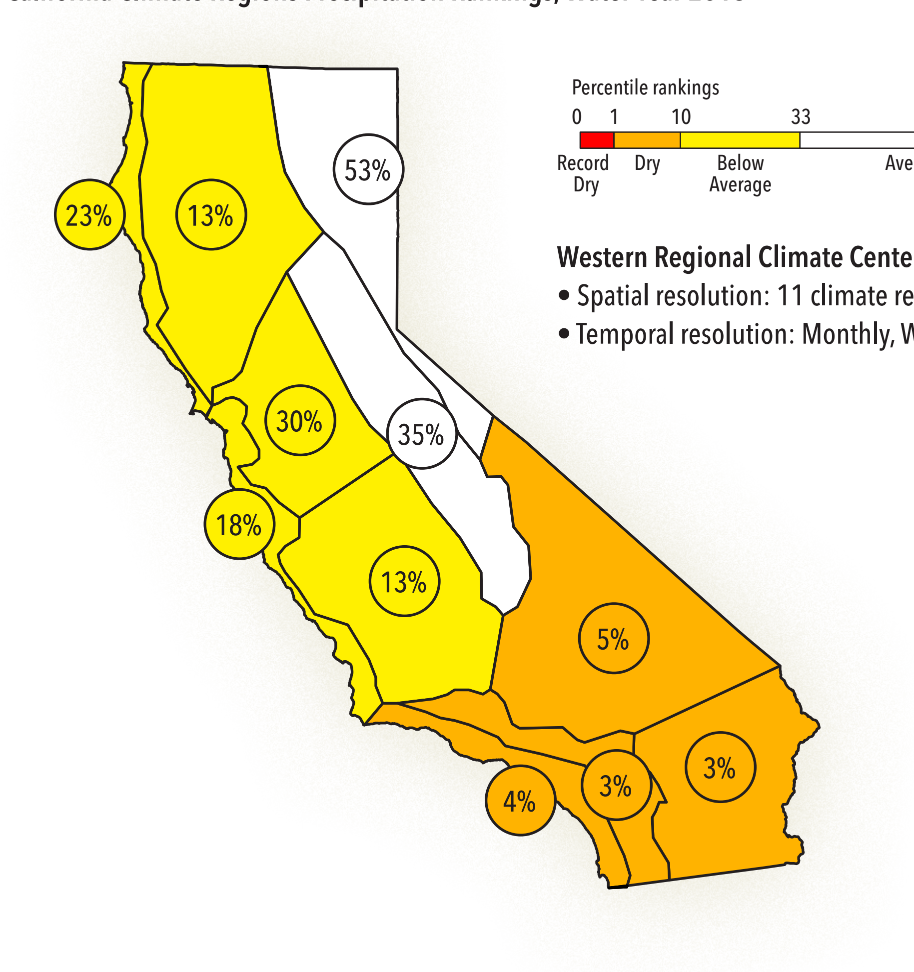
Annual Precipitation

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.

WY 2018 Precipitation

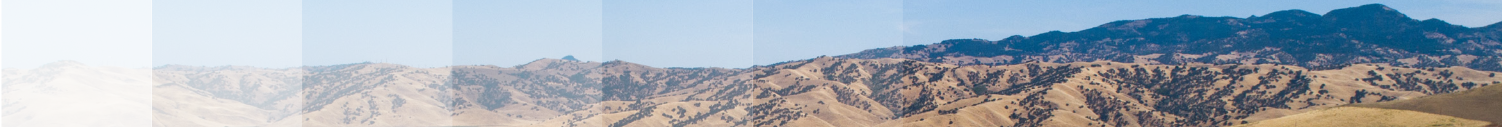
Statewide precipitation trends were analyzed by the WRCC using a data set that includes precipitation values across California. A total of 195 stations across the state are included in this analysis. Cooperative Observer Network (COOP), station data along with the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database are considered in this analysis dating back to January of 1895. PRISM analyses depict below normal precipitation for the Central Valley and northern and coastal areas of the State and record dry precipitation indices in WY 2018 for much of the south coast and southeast areas of the state.

California Climate Regions Precipitation Rankings, Water Year 2018



Western Regional Climate Center (WRCC) California Climate Tracker

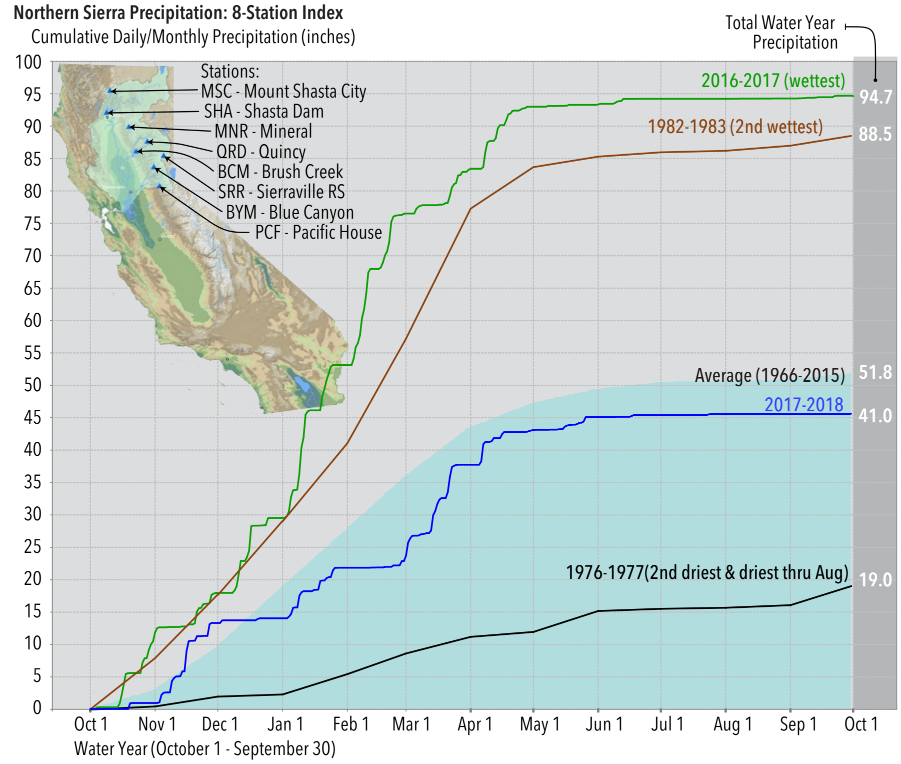
- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly, Water Year



DWR Aggregate Precipitation Station Indices

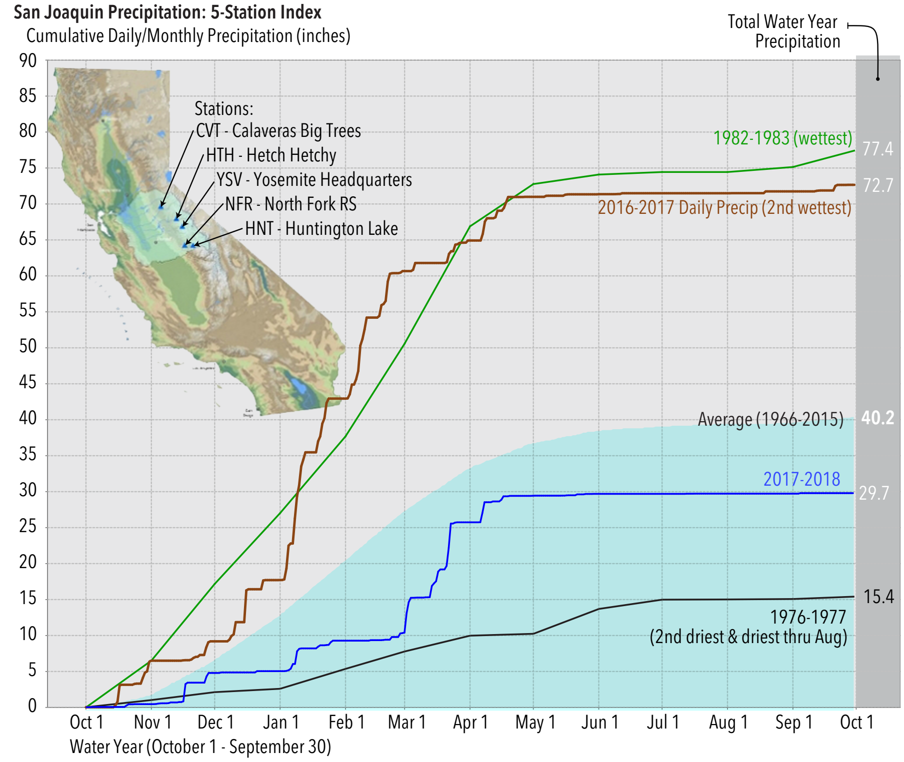
Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state. These precipitation station indices are located in the Northern and Southern Sierra and correspond well to the WY type on the Sacramento and San Joaquin River systems.

Northern Sierra Precipitation: 8-Station Index



For WY 2018, the Northern Sierra Precipitation 8-Station Index shows total WY precipitation at 41.0 inches, below the long term average of 51.8 inches. Accumulated precipitation in for the WY was 10.8 inches less than average, and 21 percent below normal. This below average precipitation is a possible contributor to a number of large wildfires across the state.

San Joaquin Precipitation: 5-Station Index



The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, received less precipitation than the Northern Sierra. WY 2018 had a total WY precipitation of 29.7 inches, which was below the average of 40.2 inches for the Southern Sierra. Cumulative precipitation for WY 2018 was 26 percent below normal.

Atmospheric Rivers

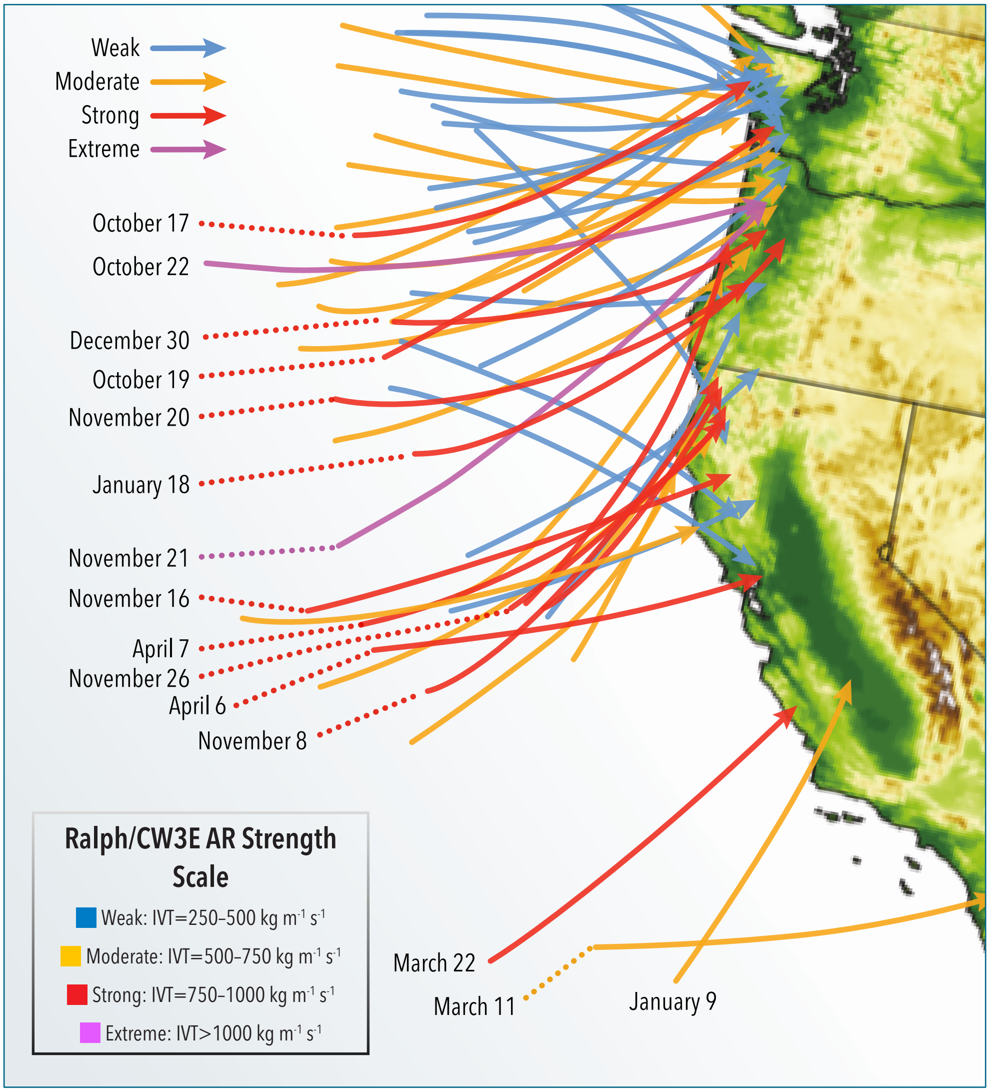
A limited number of precipitation producing storms move over California every WY. Attention has recently turned to storms associated with atmospheric rivers (ARs) due to their impact on water supply and flooding. ARs are long (approximately 1000 miles), narrow (less than 100 miles wide) bands of intense 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. 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 Ralph/CW3E 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 left, page 13) shows a characterization of the 55 ARs that made

An atmospheric river observatory has been installed on Twitchell Island, located in the Sacramento-San Joaquin Delta in Sacramento County, California. Photo taken January 10, 2018. Florence Low / California Department of Water Resources

Distribution of landfalling Atmospheric Rivers on the U.S. west coast during WY 2018.



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

landfall along the US west coast in WY 2018 as well as the location of maximum intensity of the AR when it hit the coast. Of the 55 landfalling ARs 36 occurred in Northern California and 18 occurred in Southern California. In the following years, more information on ARs will be included in the hydroclimate report including information on AR climatology as it is developed.

Atmospheric River strength by month and WY 2018 totals.

AR Strength	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
Weak	2	1	2	3	4	2	2	0	5	1	0	0	22
Moderate	0	2	3	6	2	3	0	0	0	0	1	3	20
Strong	2	4	1	1	0	1	2	0	0	0	0	0	11
Extreme	1	1	0	0	0	0	0	0	0	0	0	0	2
Total	5	8	6	10	6	6	4	0	5	1	1	3	55

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.

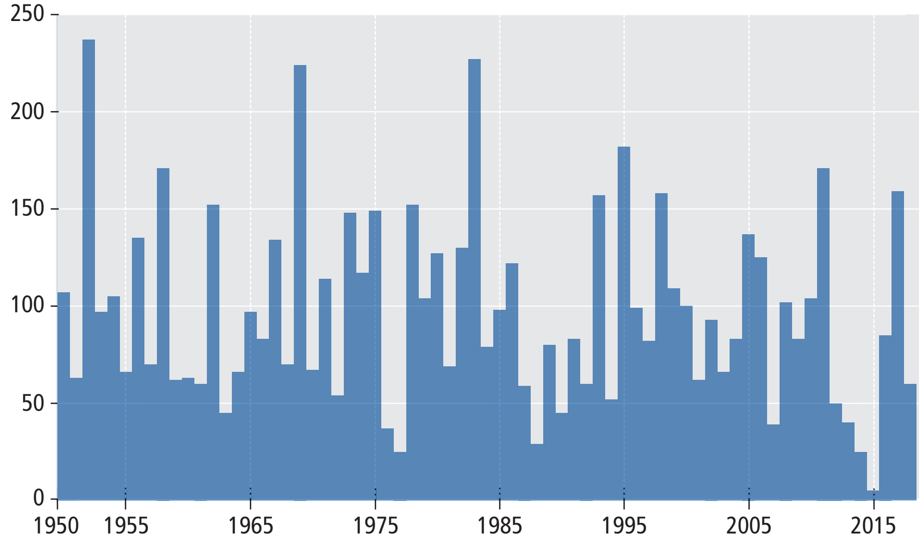
The California Cooperative Snow Surveys program has been actively collecting data since the 1930's from Northern and Southern Sierra locations. A consistent long-term historical record lends this data set to making a good indicator in of snowpack in California.

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)

Percent of average



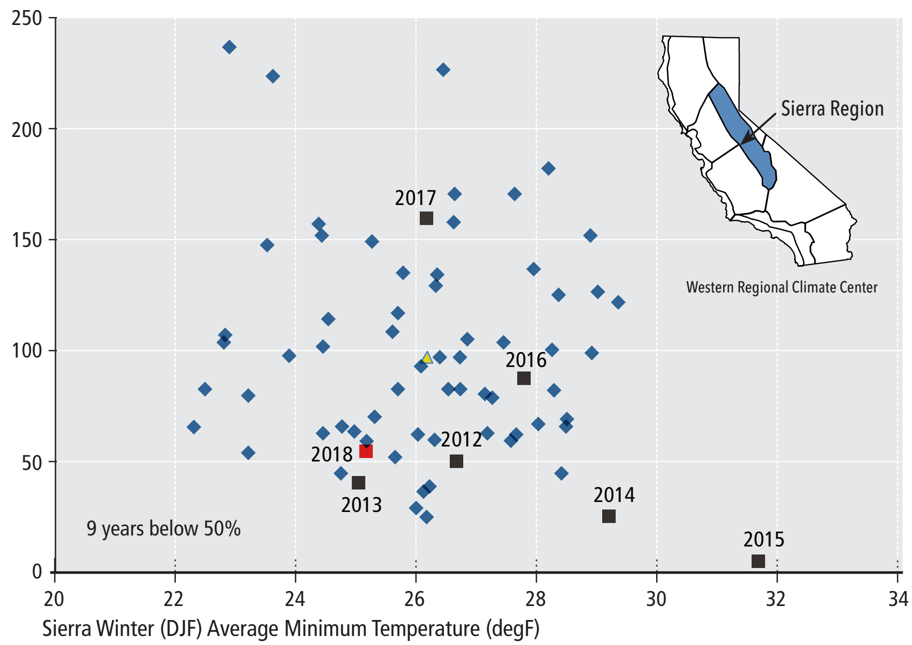
WY 2018 statewide snowpack water content was 60 percent of the long-term average. April 1st snowpack was significantly lower in comparison to the previous WY where state wide snowpack water content was 159 percent of the long-term average. A lack of strong atmospheric river storms likely played a role in snowpack content being lower than the long term and overall the trend since 1950 for this indicator is declining.

California Cooperative Snow Surveys - Snowpack

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

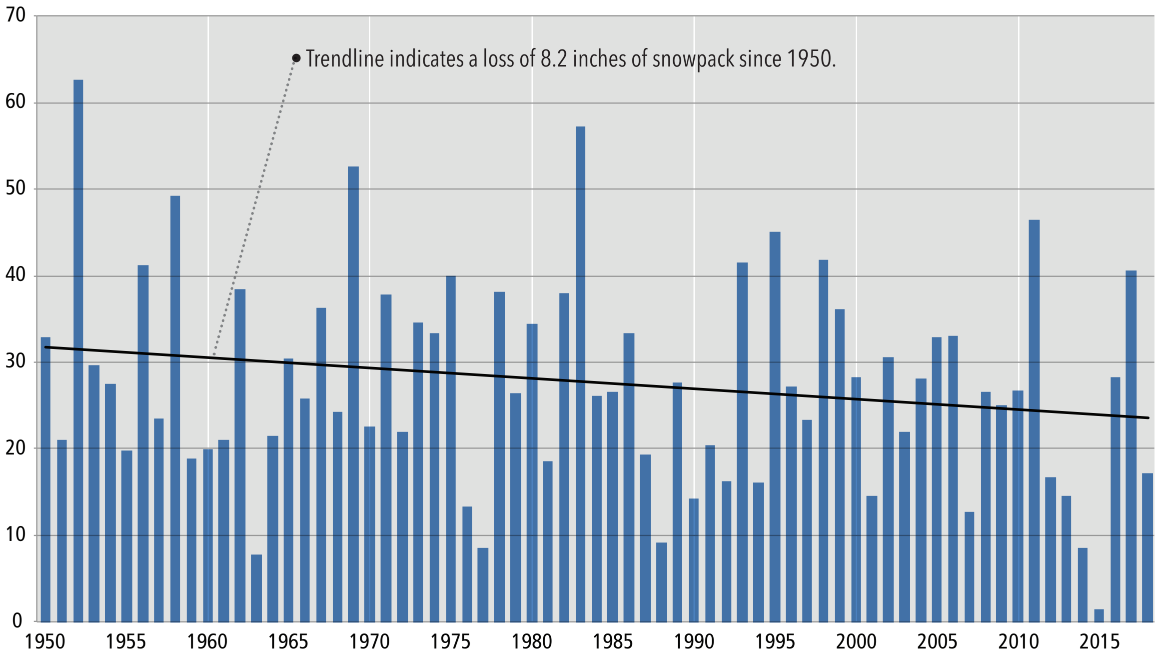
Sierra snowpack vs Winter Temperature, 1950-2018

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

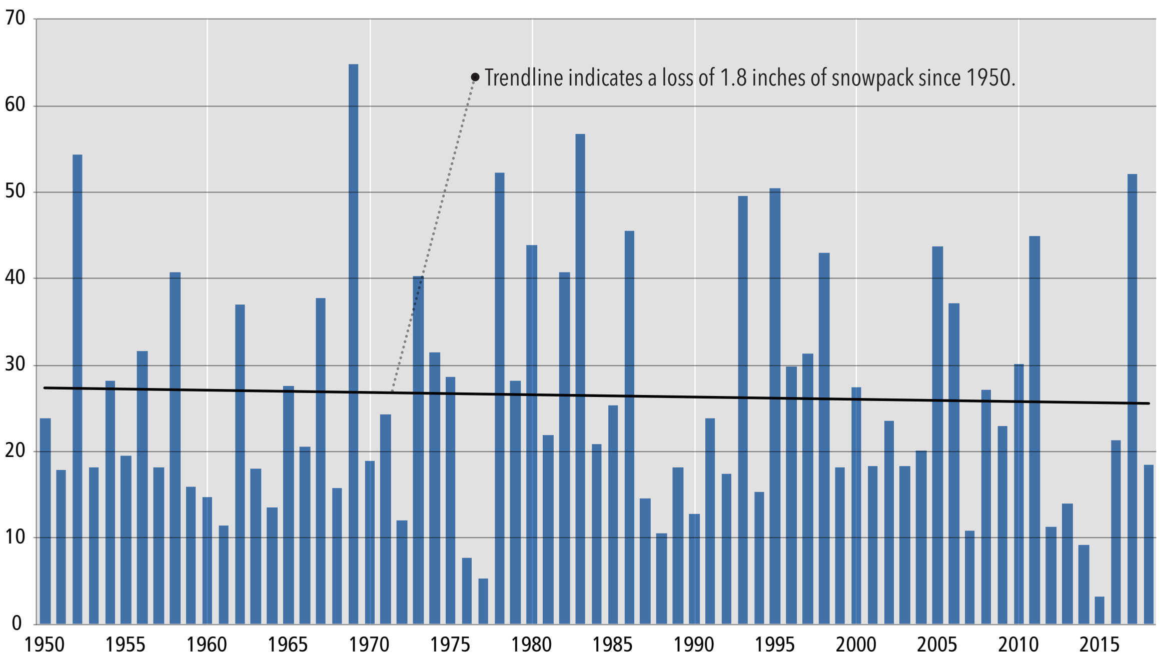


A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past seven years labeled as boxes.

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



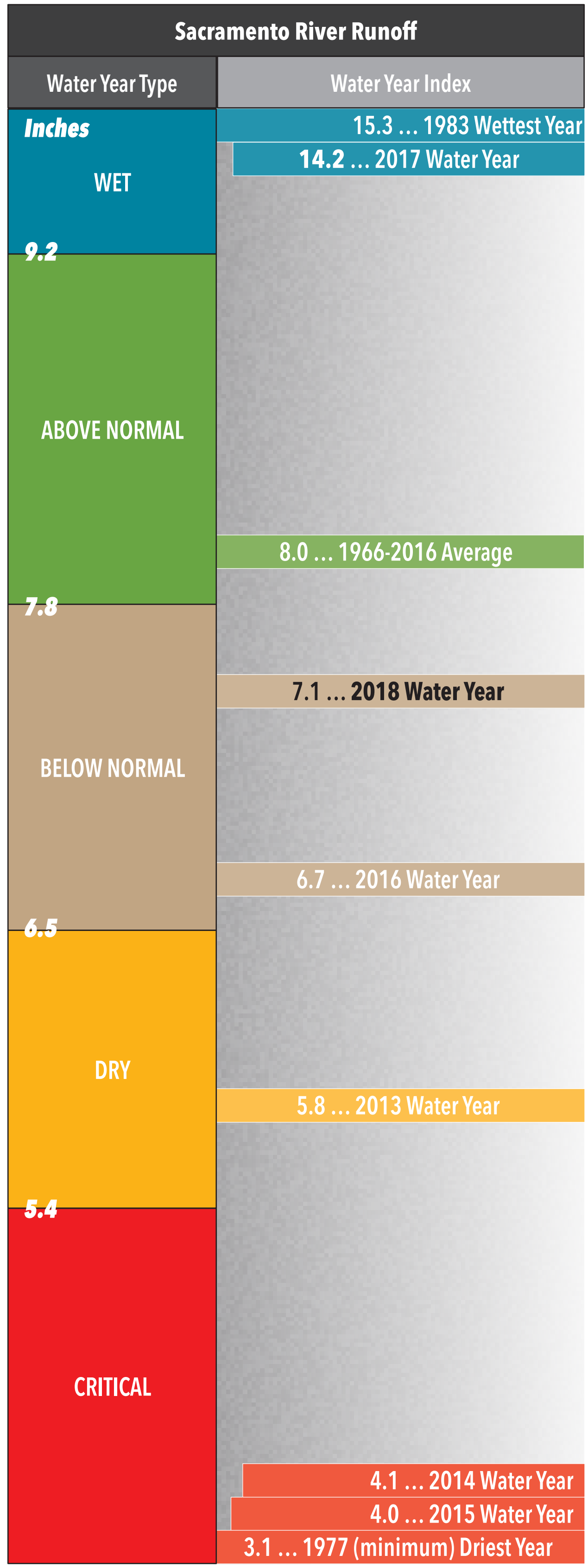
April 1 Snow-Water Content, 13 Southern Sierra Nevada Snow Courses



These figures demonstrate the trends in April 1st snowpack for 13 Northern and 13 Southern Sierra Nevada courses representative of their regions. In WY 2018 the Northern Sierra trend indicates a loss of 8.2 inches since 1950 where the Southern Sierra trend indicated a loss of 1.8 inches. Up until 2011, Roos and Sahota (2012) had found that snowpack in the Southern Sierra 13 station group had increased, however that trend has since reversed and will continued to be tracked in the annual DWR Hydroclimate Report.

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.



Waterfall upstream of CW3E stream gauge on Perry Creek, a tributary to Lake Mendocino. Photo by Carly Ellis, CW3E Field Researcher. Date: April 8, 2018

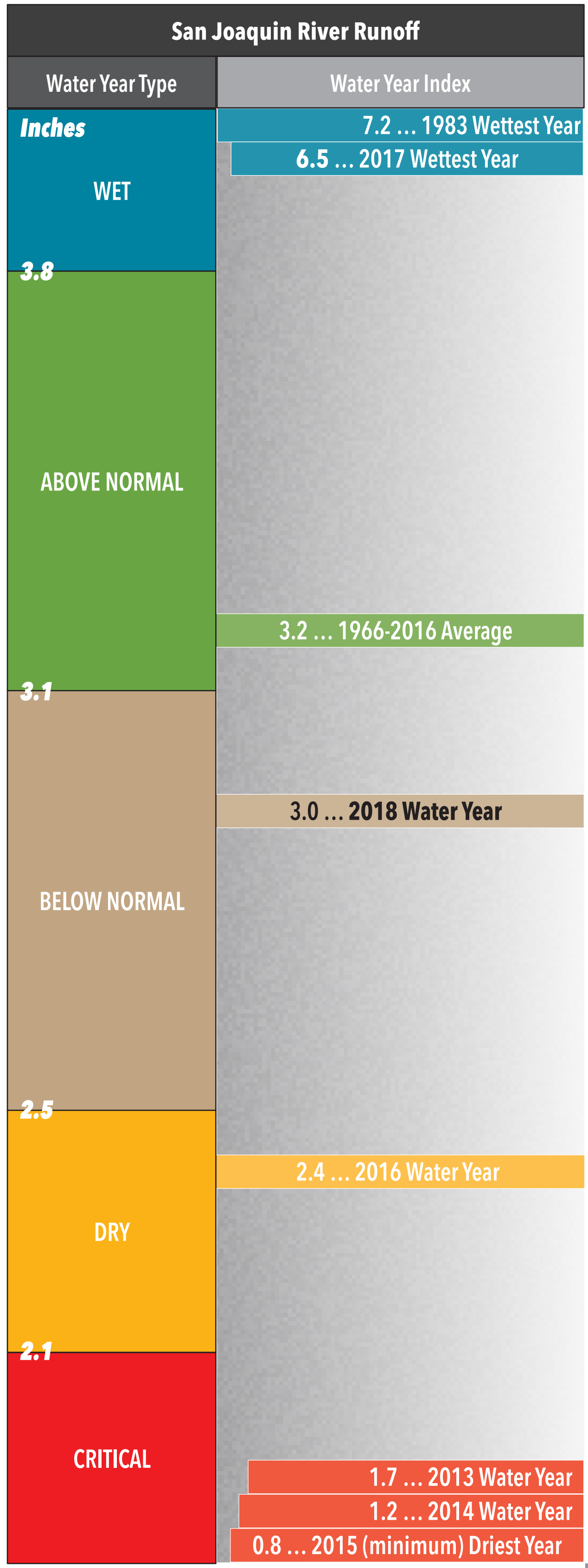
The Sacramento Valley 40-30-30 Index based on flow in million acre-feet for WY 2018 was 72 percent of average with an index value of 7.14 classified as a "below normal" WY type.

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).

Looking downstream during high flows at Cold Creek, a tributary to the East Fork of the Russian River and a CW3E stream gauging location. Photo by Carly Ellis. Date: April 7, 2018

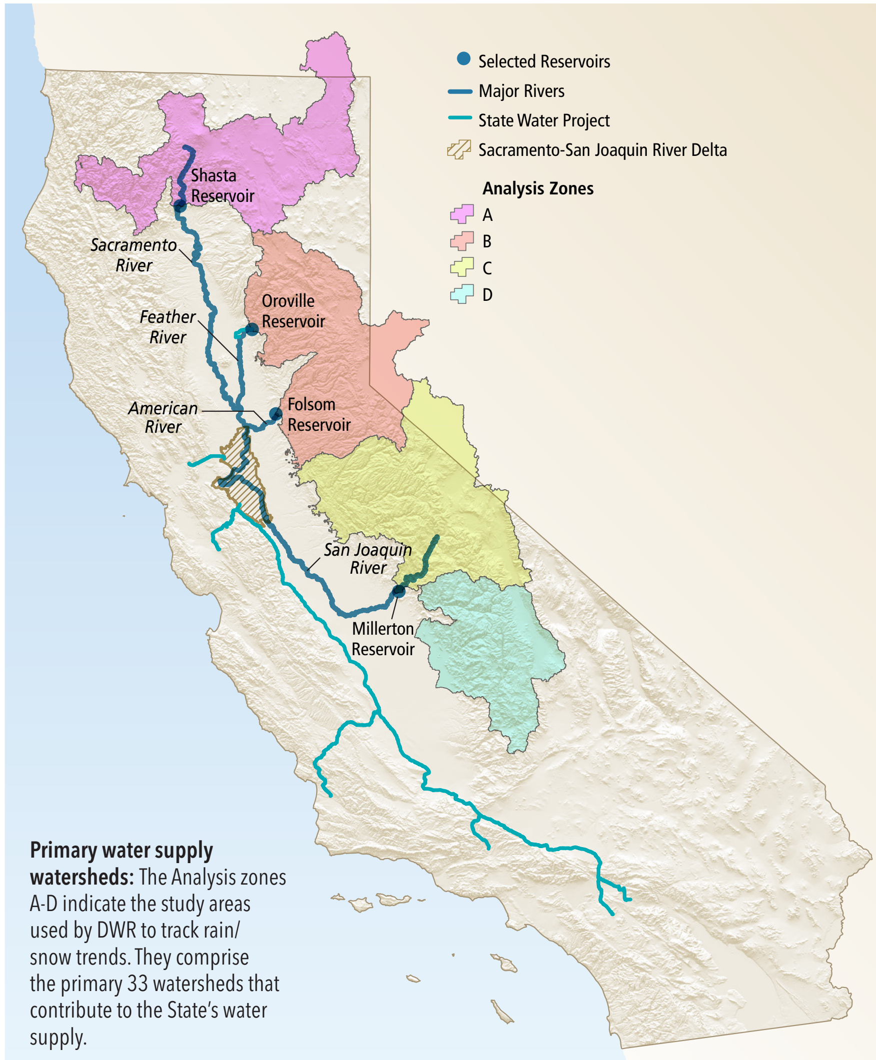
The San Joaquin Valley 60-20-20 Index based on flow in million acre-feet for WY 2018 was 81 percent of average with an index value of 3.03 classified as a "below normal" WY type.



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 2018 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 1949-2018. 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 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.

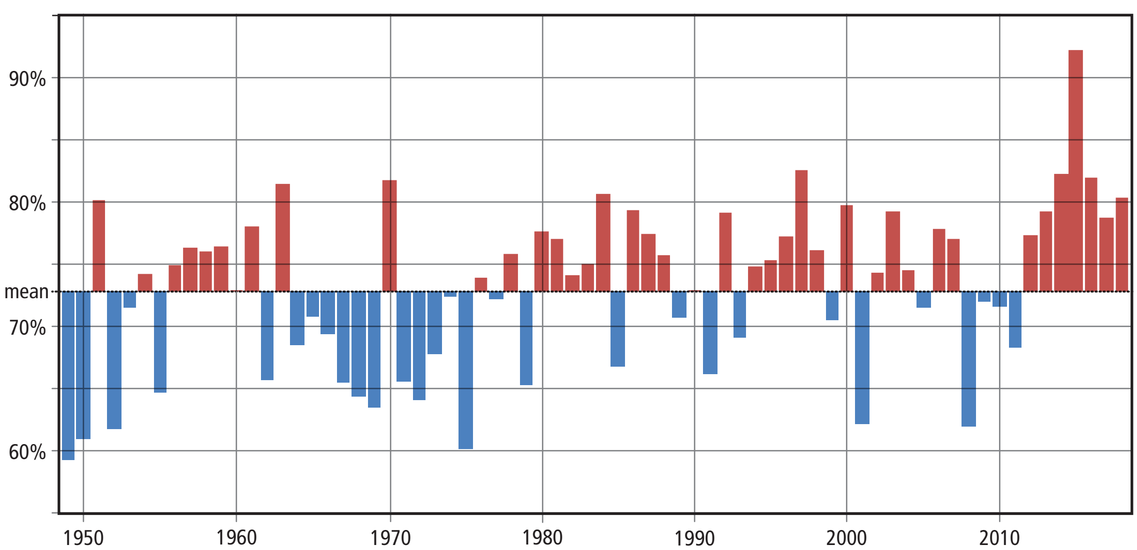


Primary water supply watersheds: The Analysis zones A-D indicate the study areas used by DWR to track rain/snow trends. They comprise the primary 33 watersheds that contribute to the State's water supply.

WY percentage of rain for the analysis period WY 1949-2018 for All Zones A-D

- Mean for 1st half of record: 71
- Mean for 2nd half of record: 75
- Mean for entire dataset: 73
- Mean for 2018: 81%
- Mean for the last decade:79

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.



For WY 2018, the percent of precipitation that fell as rain continued to be above the long-term and recent period means. This year's value was influenced by the timing of the precipitation over the course of the season and by the structure of the atmospheric rivers that contribute the majority of the seasonal precipitation accumulation. While both values were below normal for WY 2018, the amount of total precipitation was closer to average than the percent of average snowpack.

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).

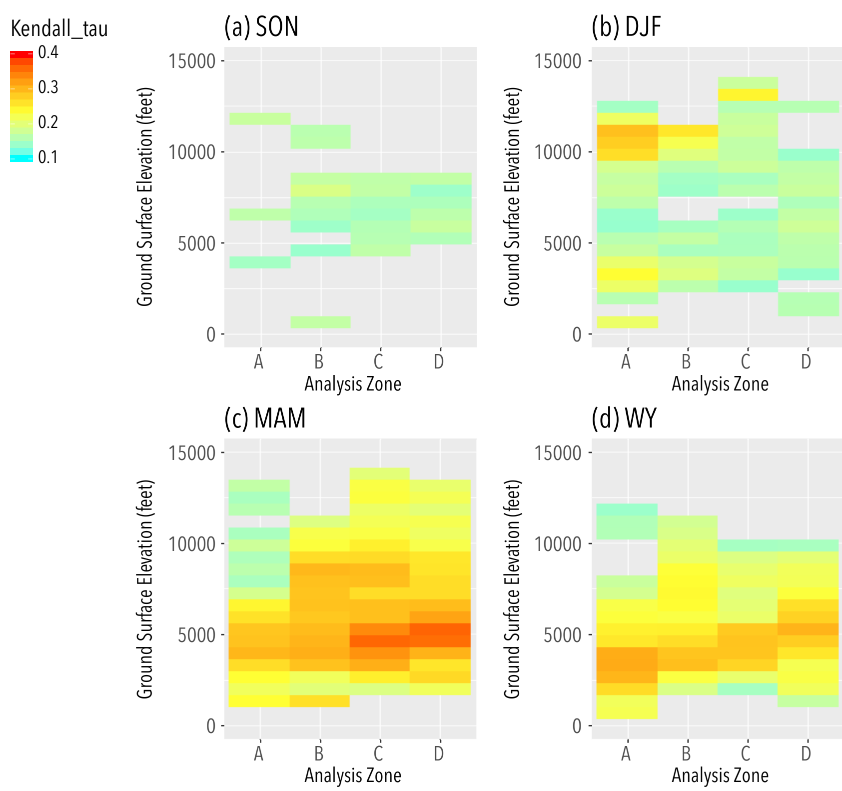
Zone B (Oroville reservoir) inflow shows the second half of the record with similar percentage increases to the statewide trends. In WY 2018, the percentage of precipitation falling as rain in Zone B was 83%, well above the period of record average of 73%; the seventh year in a row that this Zone received above average percent rain.

As elevation plays a significant role in the narrative of where the rain/snow changes are occurring, a statistical test was conducted to determine which elevations are showing detectable change. In the figure to the right, the Kendall's tau test was applied to the rain/snow metric data by elevation (y-axis) for each zone (x-axis) for each season and for the WY (four plots). In each graphic, areas colored orange or red show elevations where the relationship indicating more rain and less snow is strong. Areas colored yellow and green indicate a moderate to weak relationship. Including the 2018 WY, mid-elevations between 3,000 to 6,000 feet continue to indicate the zone where this transition is strongest, fueled largely by change being detected in the spring months, which shows a strong relationship across a broad range of elevations for all zones.

Percentage of Total Precipitation as Rain: For WYs 1949-2018, a period of record of 70 years, the rain percentage of total precipitation is compared using the first half (35 years) and second half (35 years) of the record, to indicate trend for all Zones, and Zone B. (WY stands for Water Year, SON for September, October, November, DJF for December, January, February, and MAM for March, April, May).

	First Half WY 1949-1983 (35 years)	Second Half WY 1984-2018 (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	75	79	4
SON	88	91	3
DJF	70	74	4
MAM	69	79	10

Kendall-Tau Elevation Plot: This figure shows the strength of the correlation by elevation (vertical axis) for each analysis zone (horizontal axis) and season or entire WY of the increasing rain to snow ratio. The strength of correlation is quantified by the Kendall's 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.



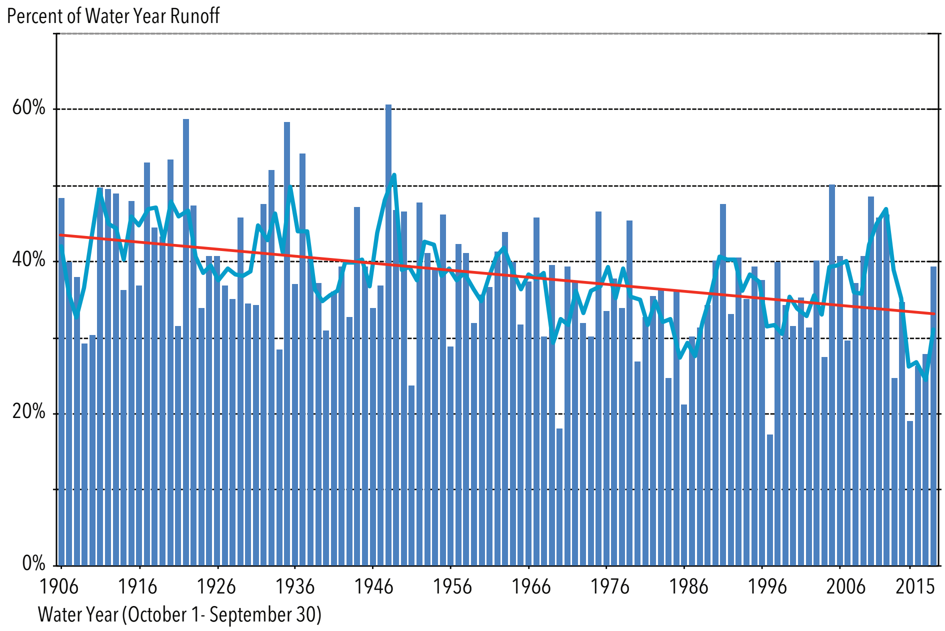
Unimpaired Streamflow: Sacramento and San Joaquin River Systems

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.

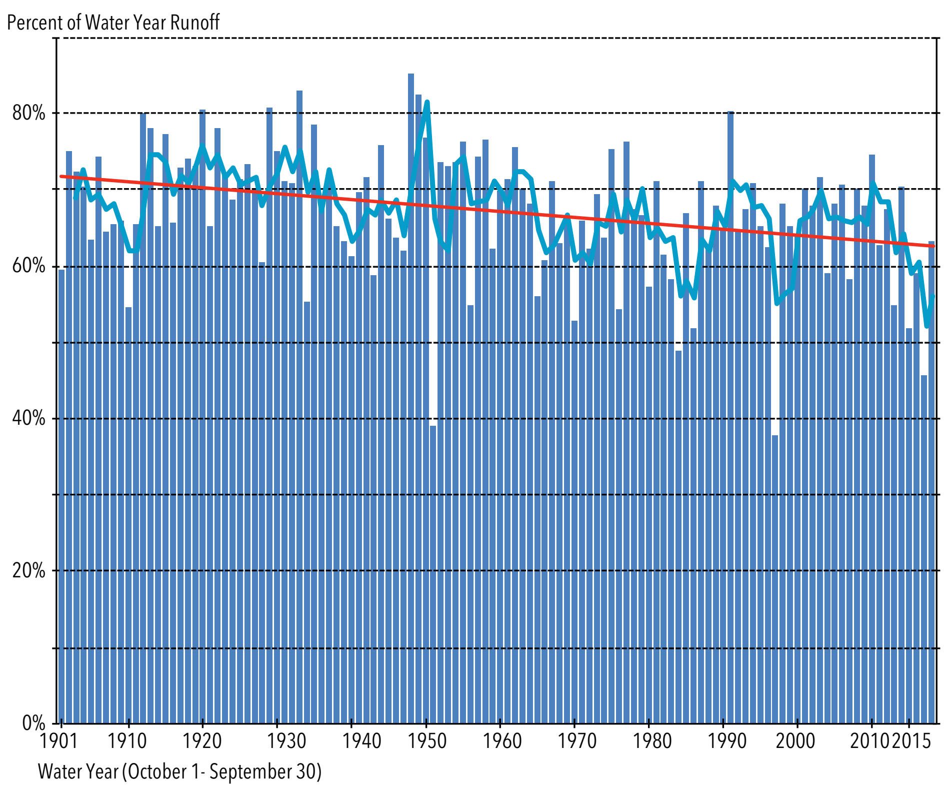
A method to quantify loss of snow pack and corresponding flow during the spring months was developed by DWR Chief Hydrologist Maury Roos in 1987. Instead of comparing seasonal snowmelt amounts, unimpaired flow occurring during the April through July snowmelt season is analyzed. Through this analysis, a distinct trend in flow loss is apparent. Currently, over the past 100 years data indicate a 9.6 percentage point decline per century on the Sacramento and 10.3 percentage point decline per century on the San Joaquin River systems.

With below average precipitation and snowpack, WY 2018 April through July streamflow was 20 percent below average at 5.1 million acre-feet in the Sacramento River and 19 percent below average at 3.0 million acre-feet in the San Joaquin River. 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
– Linear Regression (least squares) line showing historical trend – 3-year running average



San Joaquin River Runoff, April - July Runoff in Percent of Water Year Runoff
– Linear Regression (least squares) line showing historical trend – 3-year running average



Sea Level

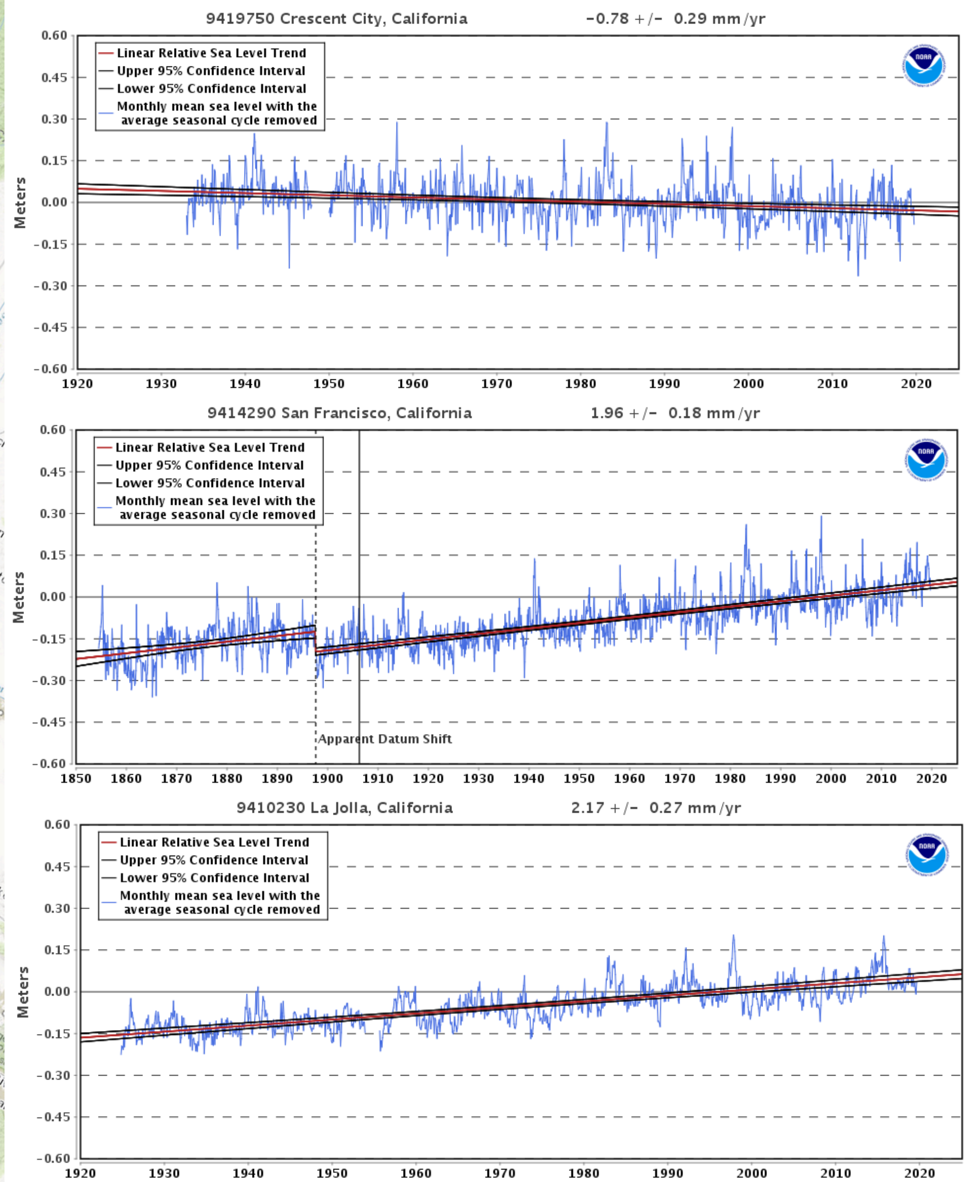
Sea level is tracked along the California coast by the National Oceanic and Atmospheric Administration (NOAA) at 12 active tide gauges, which range in their periods of record from 39 years (Point Arena) to 162 years (San Francisco). Mean sea level at three key coastal tide gauges Crescent City, San Francisco 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 2018 demonstrated variability within a WY can be as large as California's amazing year-to-year variability. October started dry and warm. Dry north winds created extreme fire weather which resulted in numerous fires across the State. In Napa and Sonoma counties, fires scorched the landscape and burned into the city of Santa Rosa.

November's precipitation was well above normal in the north, but dry conditions lingered in the south with Santa Ana wind events. Fire continued to be a problem including the Thomas fire in Santa Barbara and Ventura counties. This fire would become the State's largest fire in terms of acres burned. It burned into December leaving little time for post-fire recovery before winter rains set in.

December ended up being notably dry and above average for temperatures. The statewide average maximum temperature was the fourth warmest in 123 years of record while the statewide average precipitation for the month was the second driest. No atmospheric rivers (ARs) made landfall over California for the month.

Conditions shifted again in January with precipitation returning closer to average. An atmospheric river made landfall in Southern California in the first week of the New Year. Thunderstorms associated with the cold front of the system led to intense precipitation over the Thomas burn scar resulting in significant debris flows impacting coastal regions around the community of Montecito causing more than a billion dollars of damage and loss of life.

Crossing Boyes Creek, a tributary to the East Fork of the Russian River, during high flows to retrieve water chemistry samples from an automatic water sampler left out to collect during the event. This part of the creek is usually passable in a 4WD vehicle. Photo by Carly Ellis. Date: April 7, 2018

February whipsawed back to dry conditions with no AR landfalls over California. Statewide average precipitation was again the second driest on record, although temperatures were not as extreme as December. Statewide, for the three-month period of December, January and February, it was the third driest winter on record behind only 1977 and 1991. At the end of February, the statewide snowpack was only 23 percent of average for the date.

March turned wet with three moderate and one strong AR making landfall over California. Two moderate ARs back to back in a single week during the second week of March led to higher flows in rivers. Snowpack improved to 54 percent of average by the end of the month. Statewide, temperatures were close to average. At the end of March, a super-typhoon was observed in the tropical Pacific which is unusual for that time of year.

The remnants of the super-typhoon were entrained into a mid-latitude storm system that impacted California during the first week of April. When the system made landfall, record setting precipitable water and freezing elevation measurements were recorded with the atmospheric river observing network. While the period of record of this network is only ten years, the observations were notable from the standpoint that this was the first time a decaying tropical system impacted the Sierra Nevada in Spring.

Historically, such decaying tropical systems have impacted California in October. Even though the duration was relatively short, the intense rainfall and high freezing elevations led to the 10th largest flood peak on the Merced River.

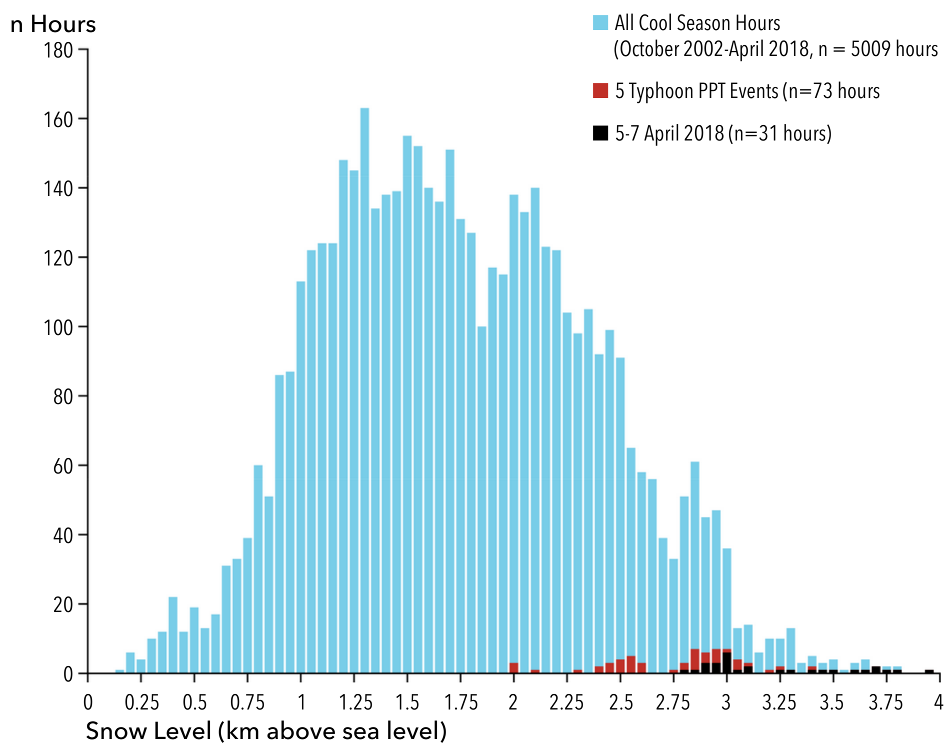
The high flows associated with the April storms helped offset the below average runoff from the below average snowpack. The automated snow sensor network showed no snowpack as of June 5th although snow may be present at higher elevations above the network. A warmer and drier than average May and June increased the risk of wildfire. The desert southeast recorded record temperatures in May and June with triple digit values. On the first day of summer, Death Valley set a new maximum daily temperature record of 126 degrees Fahrenheit. Summer heat would be a storyline for much of Southern California with the South Coastal region recording a record high value for seasonal average minimum temperature.

Fire returned to the landscape in July with the Carr fire burning significant portions of the landscape including parts of the community of Redding. The Mendocino complex re-set the record for acreage burned previously held by the Thomas fire. All told, WY 2018 recorded the largest, second largest and seventh largest fires in California's history.

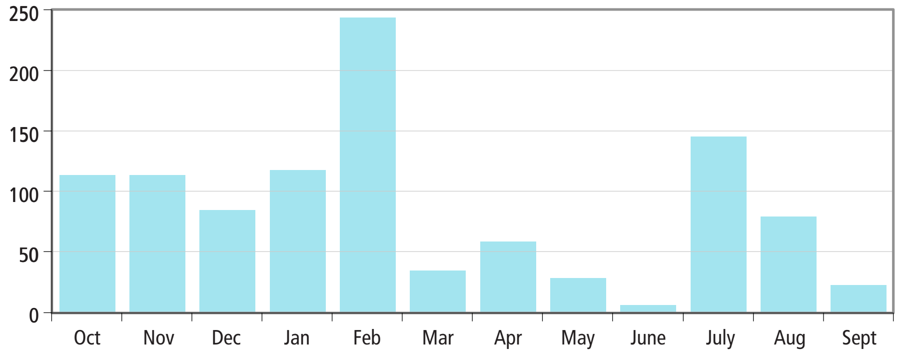
The April 2018 Extremely High Snow Level

In late March, an early season super typhoon developed in the western Pacific and became entrained into the jet stream and made its way across the Pacific. Approximately a week after the April 1 snowpack measurements were collected, and indicated a great improvement in snowpack during March, moisture from the typhoon supported a strong atmospheric river that impacted California and especially the Sierra Nevada. While this storm produced heavy precipitation, the most notable and damaging outcome was the extremely high snow levels (>12,000 ft) associated with this storm. The high snow levels and heavy precipitation resulted in substantial rainfall over the vast majority of the Sierra Nevada, leading to high elevation flooding (e.g., the Merced River in Yosemite Valley observed its highest April streamflow and the 10th highest streamflow of all time) and facilitated a rapid ripening of the snowpack, among other impacts. These snow levels were the highest observed at Chico, CA in the past 15 years. Such events with very high snow levels have historically happened in the fall, but may become more frequent in winter or spring in the coming decades.

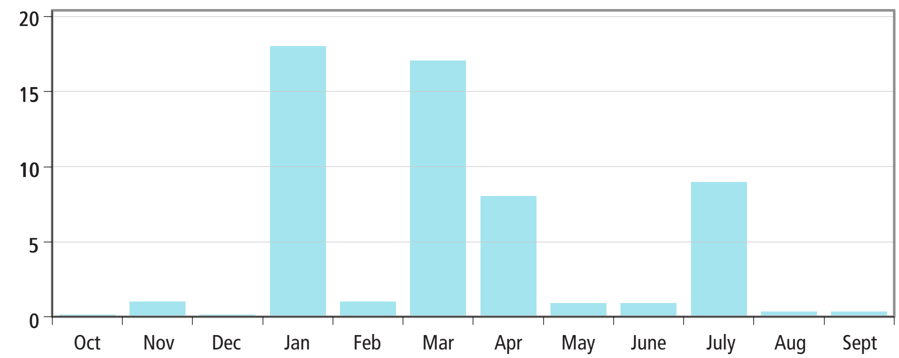
Histogram of hourly October-April snow levels at Chico, CA.



Number of Statewide Temperature Records by Month for Water Year 2018



Number of Statewide Precipitation Records by Month for Water Year 2018



Flooding at a CW3E water chemistry sampling site on the East Fork of the Russian River. A canoe was needed to retrieve sampling instrumentation typically reached on foot. Photo by Carly Ellis. Date: April 6, 2018.

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 Sierra 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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NOAA Tide Station, Crescent City. This station provides real-time water level for use by mariners, scientists and the community. These data are also tied to the tsunami warning network and are used to refine tide predictions and track long term trends. Photo: Peter Coombe

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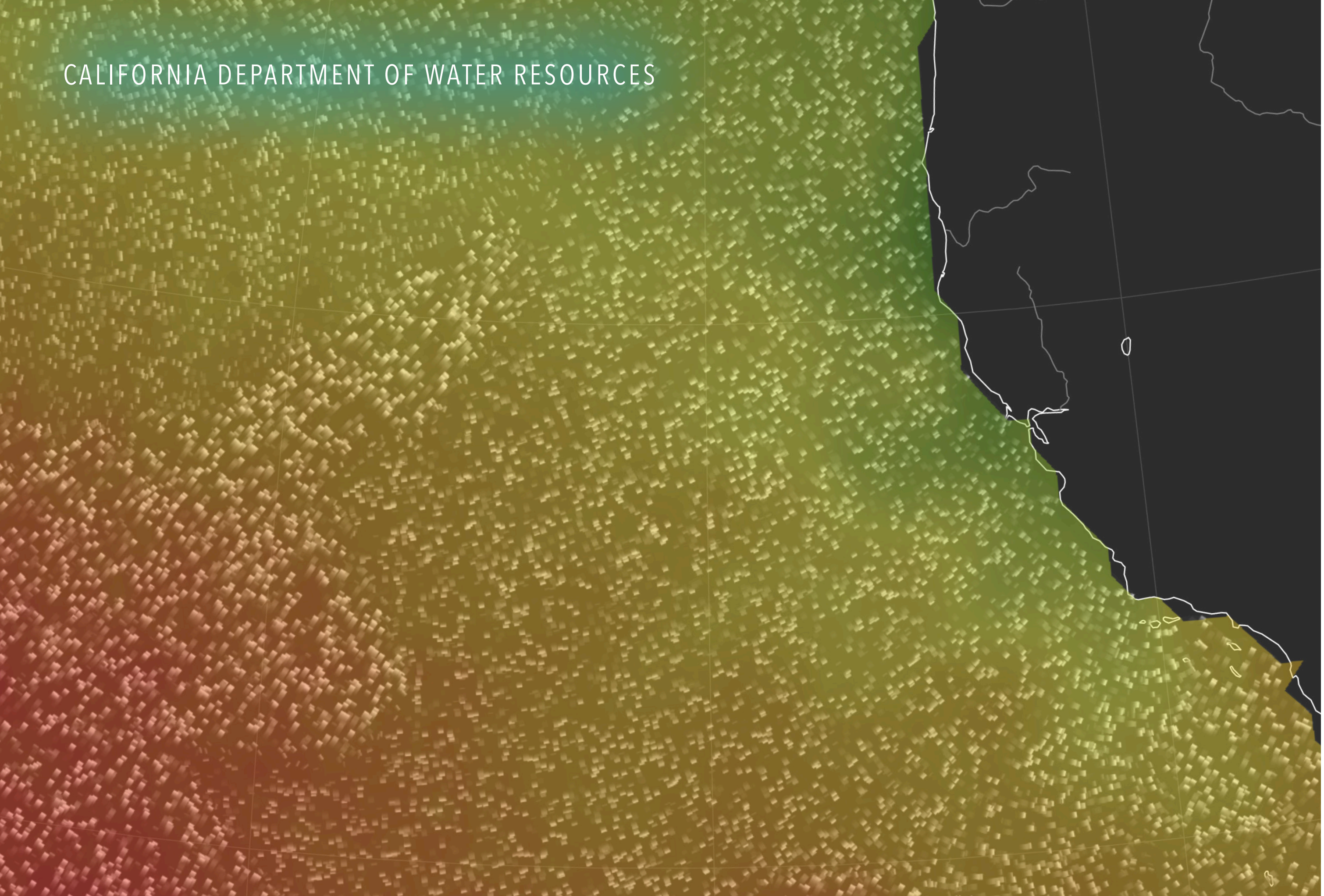

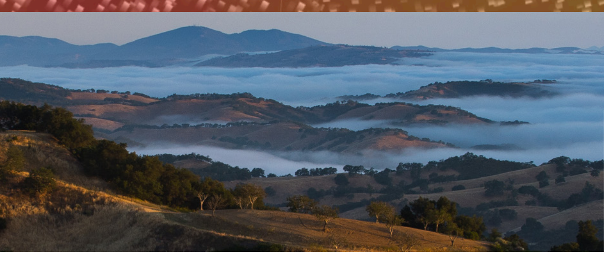

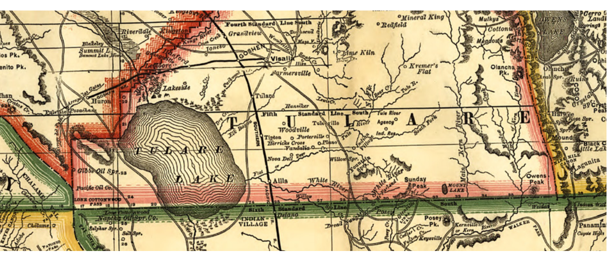

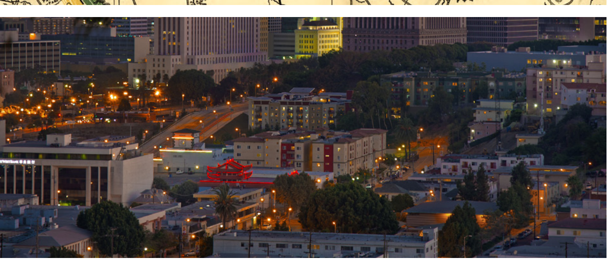

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