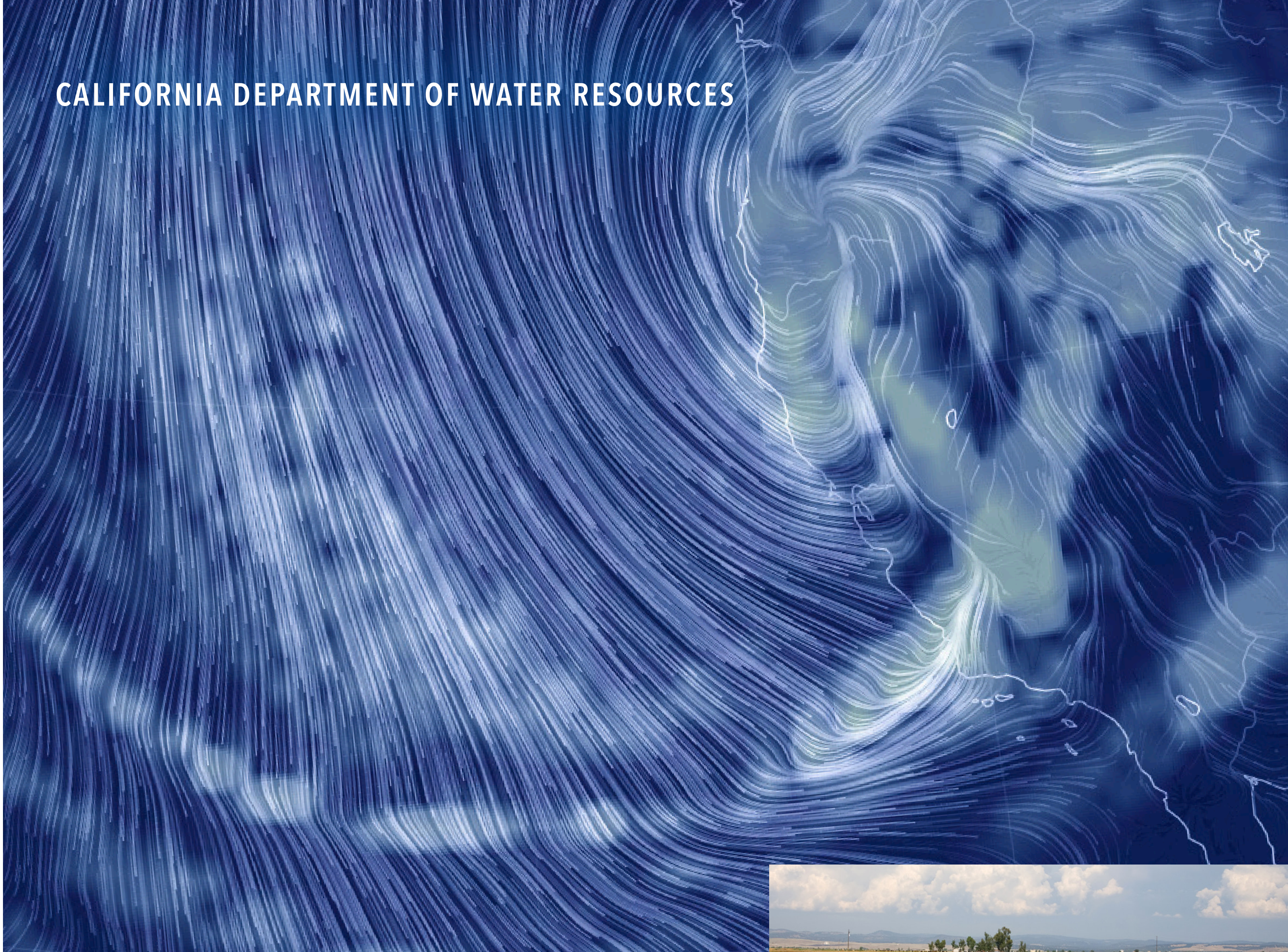
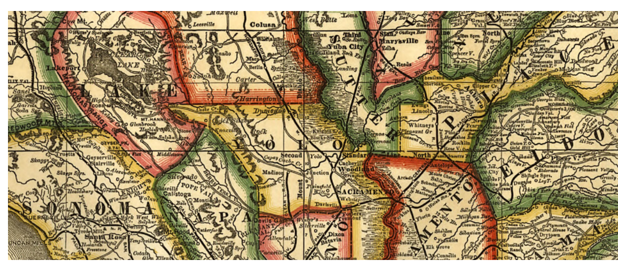
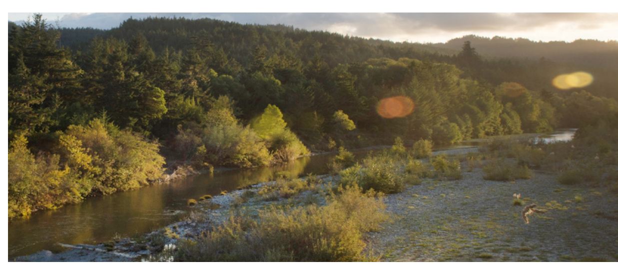
CALIFORNIA DEPARTMENT OF WATER RESOURCES



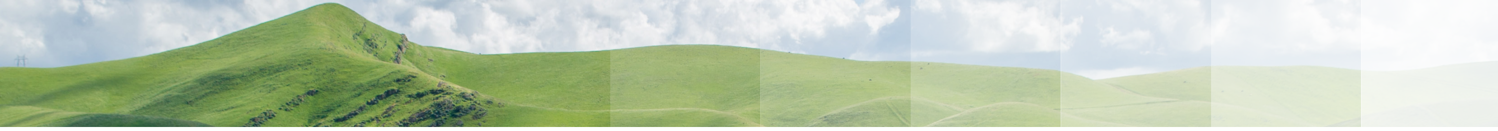
HYDROCLIMATE REPORT

Water Year 2019





Office of the State Climatologist



Executive Summary

Water year (WY) 2019 continued to demonstrate effects of climate change with greater variability and more extremes. Hydroclimate extremes presented themselves with atmospheric rivers causing both flooding and heavy snowpack. Before the wet winter and spring months, California experienced a very dry fall in where the devastating Camp Fire started on November 8, 2018 in Butte County. Fall transitioned to into a wet winter with 64 percent of the WY total for the DWR Northern 8-station index falling in the three months of January, February and March. Temperatures went from extreme cold in February to hot in August as the year progressed from winter to summer.

The WY ended with 139 percent of average precipitation in the Northern Sierra and 168 percent of average April-July streamflow in the Sacramento River and 171 percent of average for the San Joaquin River. Peak statewide snowpack was 175 percent of average marking the fifth largest snowpack with records dating back to 1950. February had the most significant storm events of WY 2019 when multiple atmospheric rivers (ARs) impacted the state leading to both significant flooding and massive snowpack building. It was the third largest monthly precipitation total for the DWR Northern 8-station index and the first time that more than 20 inches of precipitation in a single month did not cause flooding on west slope watersheds of the northern Sierra. Precipitation percents of average for February are depicted for the California Hydrologic Regions (right). The gain in statewide snowpack in February 2020 (20 inches) was twice the combined April 1 snowpack values of 2014 (9 inches) and 2015 (1 inch). WY 2019 also recorded the coldest average maximum temperature for February for California in 125 years of record.

The extremes did not stop with February as May recorded 309 percent of average precipitation for the month on the 8-station index and August recorded the fourth warmest average minimum temperature statewide in 125 years of record. The breakdown of the polar vortex in winter of WY 2019 led to cross-polar flow in the Arctic and may have been the source of cold air for the Sierra to build the exceptional snowpack while the lower elevation watersheds of the coastal range flooded. More research is needed to fully diagnose this facet of a warming world and the complex dynamics that produce California's weather and hydroclimate.

Precipitation Percents of 1981-2010 Averages for February 2019, by Hydrological Region

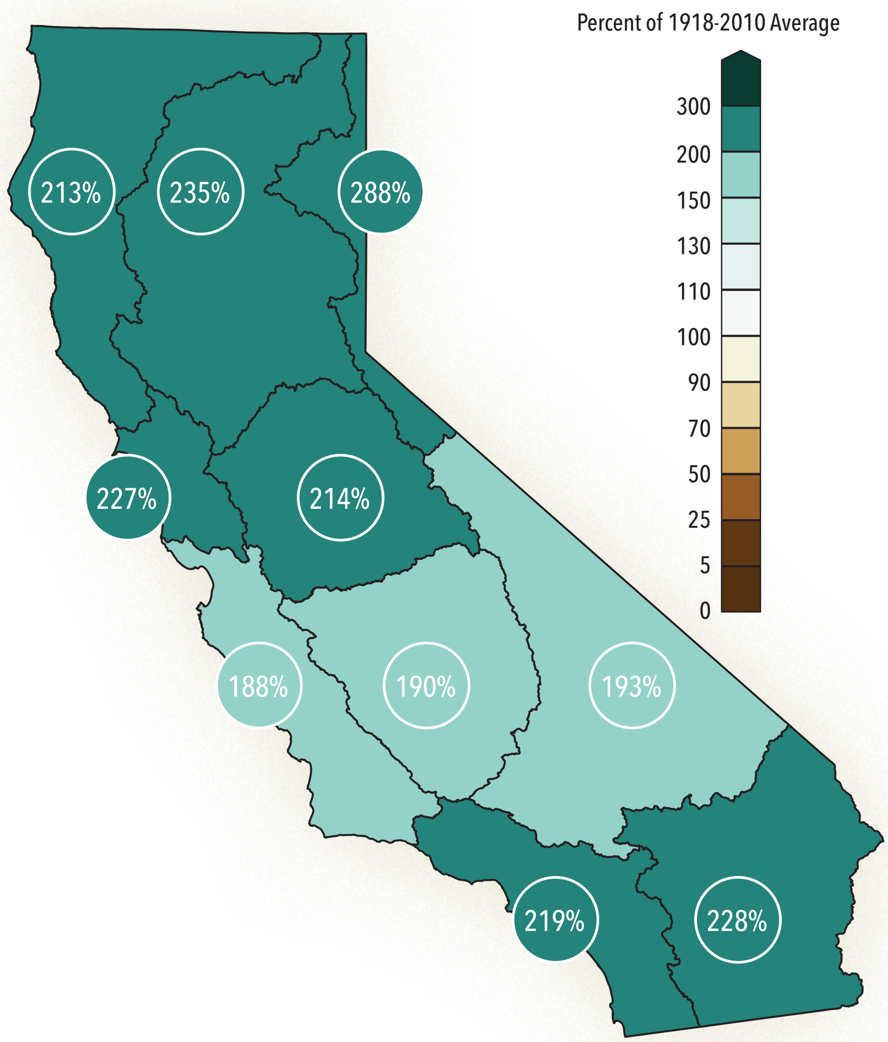
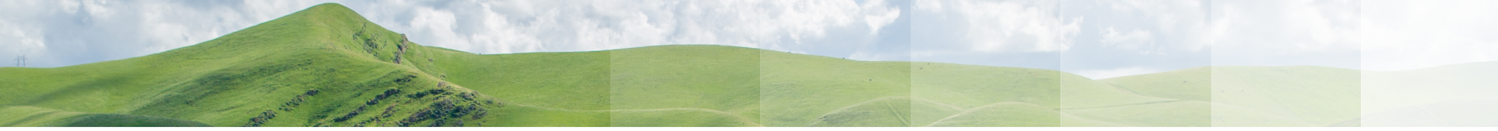


Table of Contents

The State Climatologist Office would like to thank Peter Coombe, Elissa Lynn, Benjamin Hatchett, and the California Nevada Applications Program 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) 2019 updates the 2018 report with data from WY 2019. 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.

For WY 2019, the report builds upon an indicator that incorporates the measurements of freezing elevation during precipitating events, called Snow Level Radar. This metric is key to determining how much runoff results from a given storm. It is anticipated that in the years ahead, the freezing elevation during precipitating events will include higher values for longer periods of time as a manifestation of more rain and less snow. The report also describes the methodology and advances the assessment of rain/snow trends in the major water supply watersheds.

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. By tracking the change through a collection of indicators on an annual basis, it is hoped that transitions past important thresholds can be better anticipated enabling the continued refinement of adaptation strategies for water resources management.

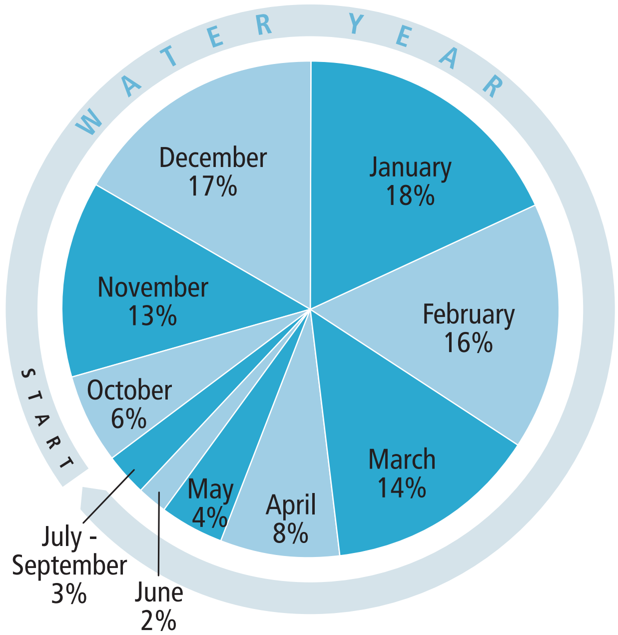
Key Hydroclimate Indicators

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	1949-2018	WRCC/PRISM
Snow-Level Radar	Colfax / Blue Canyon	November-April	2010-present	NOAA
Sea Level	Crescent City Tide Gauge	Monthly Mean	1933-present	NOAA
Sea Level	San Francisco Tide Gauge	Monthly Mean	1855-present	NOAA
Sea Level	San Diego Tide Gauge	Monthly Mean	1906-present	NOAA

What Is A Water Year?

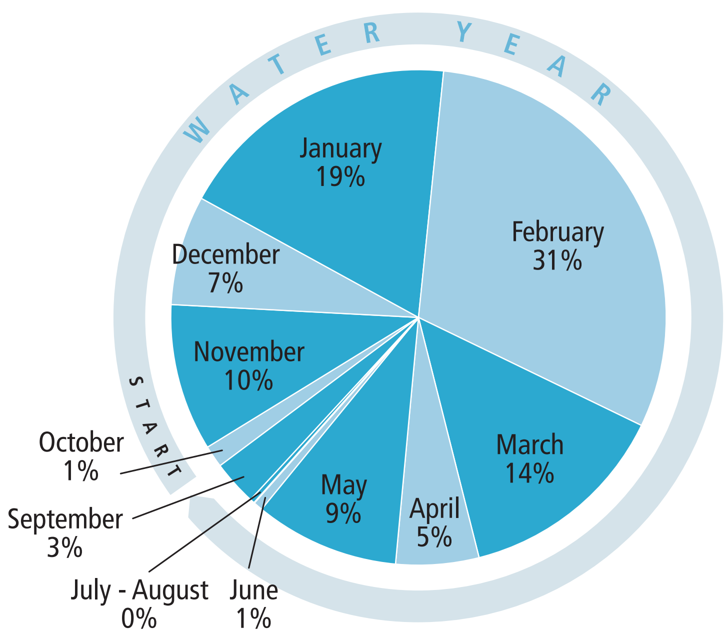
Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)

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.

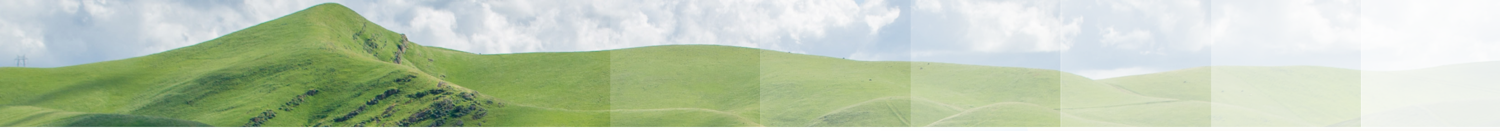
Water Year 2019 by Month



This chart represents monthly precipitation as percent of the total 2019 WY precipitation.

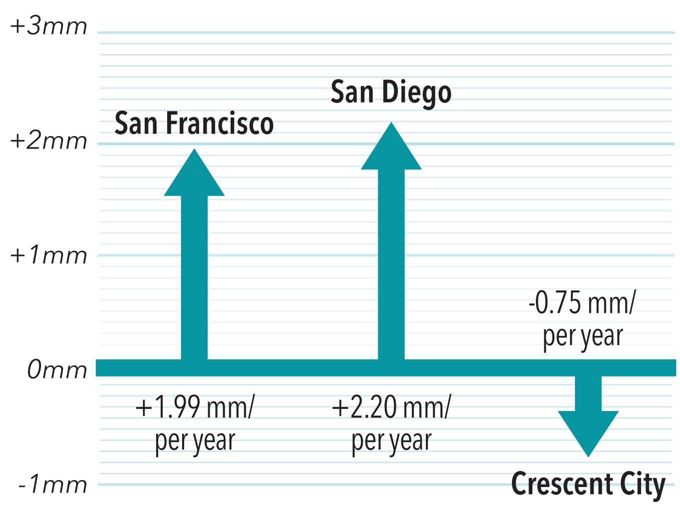
Hydrologic data such as precipitation and streamflow are key indicators for the Hydroclimate Report. These data are typically represented as being within the WY. A WY (also discharge year or flow year) is a term commonly used in hydrology to describe a time period of 12 months during which precipitation 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 October 1 to September 30. The 2019 WY covers the period from October 1, 2018 to September 30, 2019.

A comparison of the pie charts on the left between the long-term average and WY 2019, shows almost 64% of the total WY precipitation occurred from January through March. On average, the months of January, February, and March account for 48% of the average total annual precipitation. In May, 309% of average precipitation fell marking this as the sixth wettest May in the period of record that dates back to WY 1921. The total WY rainfall at 70.7 inches was considerably more than the long-term average at 51.8 inches, but only the sixteenth wettest year. The WY ended with a wet September with 2.07 inches of precipitation being recorded in the Northern 8-Station area.

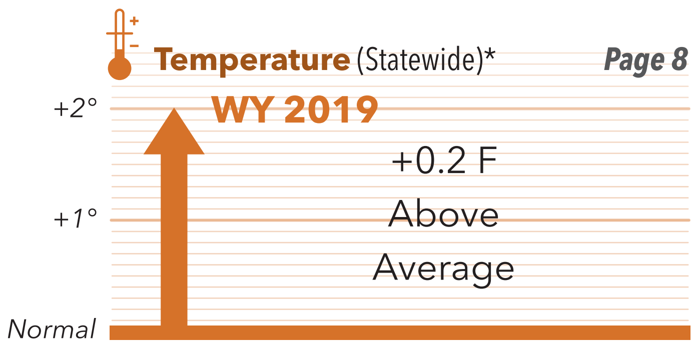


California Hydroclimate Water Year 2019 "At A Glance"

Sea level (100 year trend) *Page 22*

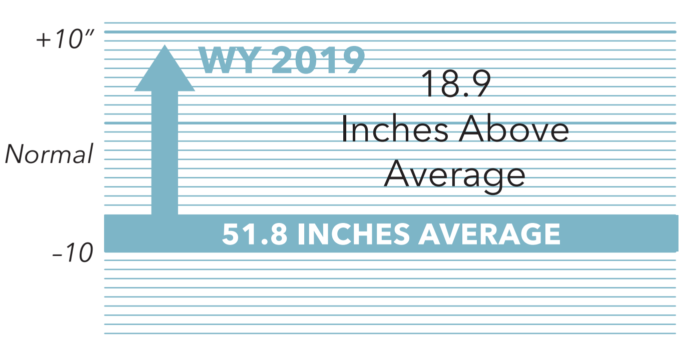


Temperature (Statewide)* *Page 8*



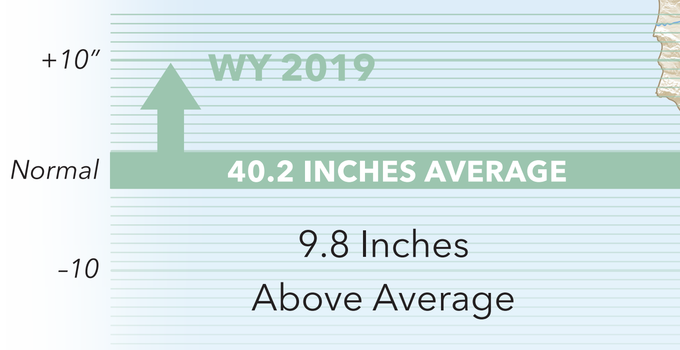
*Normal average air temperature represents 1981-2010 base period.

Precipitation (Northern Sierra)* *Page 11*



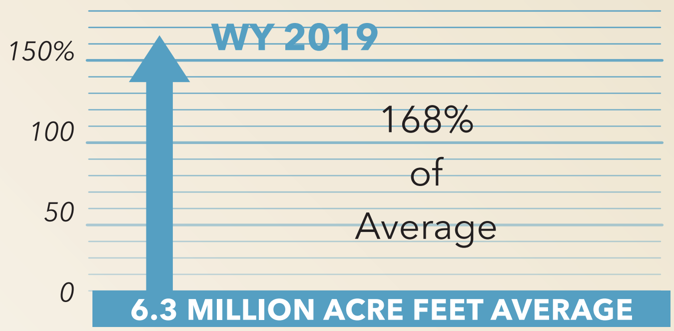
*Normal average precipitation represents 1966-2015 base period.

Precipitation (Southern Sierra)* *Page 11*



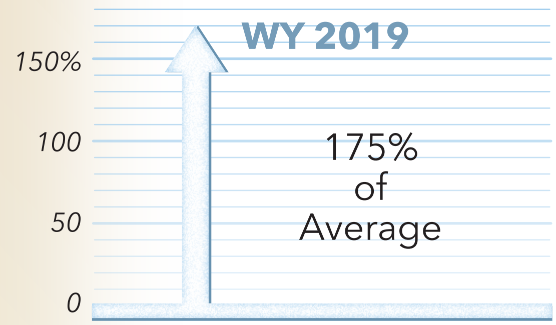
*Normal average precipitation represents 1966-2015 base period.

Streamflow, April-July (Sacramento River)* ***Page 21***



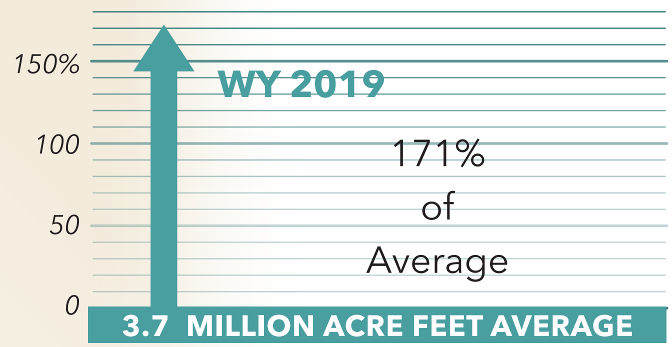
**Normal average streamflow represents 1966-2015 base period.*

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



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

Streamflow, April-July (San Joaquin River)* ***Page 21***



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

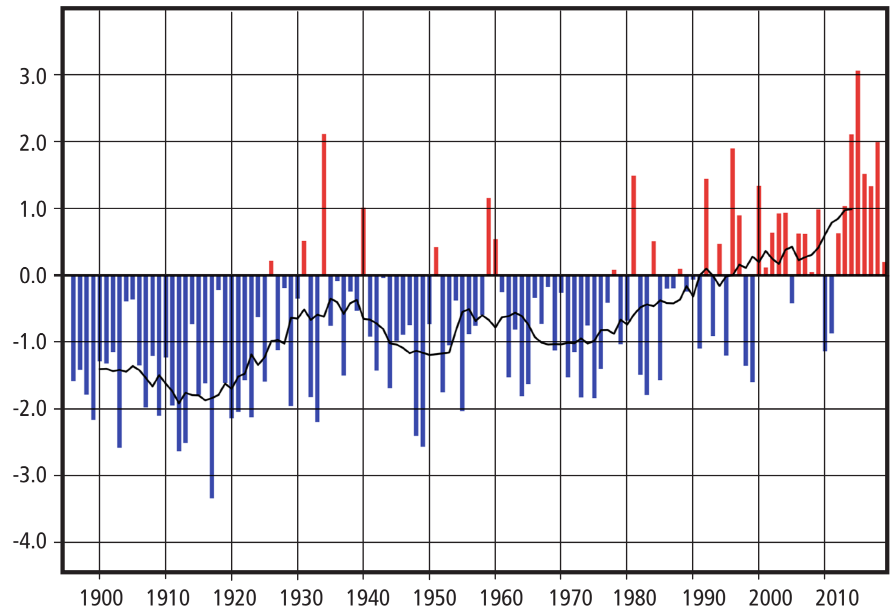
Annual Air Temperatures

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 by1.6°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 in mean temperature in the past century. The warmest year on record has been 2015 where temperatures were above 3.1°F from average. WY 2019 was 0.2°F above average from a 57.8°F 1981-2010 base period average temperature. Statewide average temperatures were ranked at 27th warmest out of 124 years of record dating back to 1896. (WRCC, 2020).

California statewide mean temperature departure, October through September

Degrees (F)



Black line denotes 11-year running mean

Departures from 1981-2010 base period:*

Mean: 57.8°F	Median: 57.9°F
Extremes:	Warmest: 60.9°F (+3.1°F from Average), 2015
	Coldest: 54.5°F (–3.3°F from Average), 1917
Most Recent WY:	October 2018-September 2019 (58.0°F (+0.2°F)
	Rank: 97 of 124 (1 = Record Coldest, 124 = Record Warmest)

Western Regional Climate Center (WRCC) California Climate Tracker

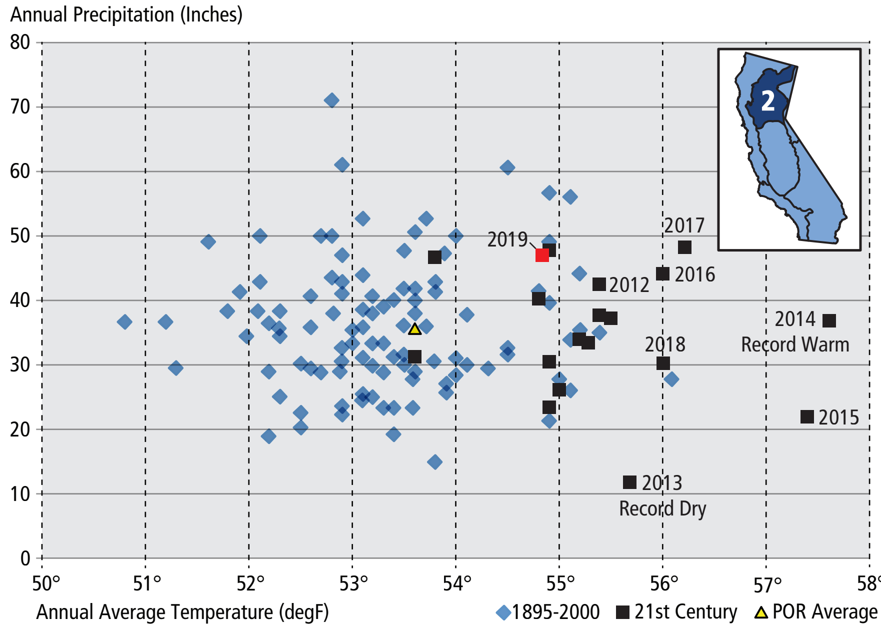
- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly Mean

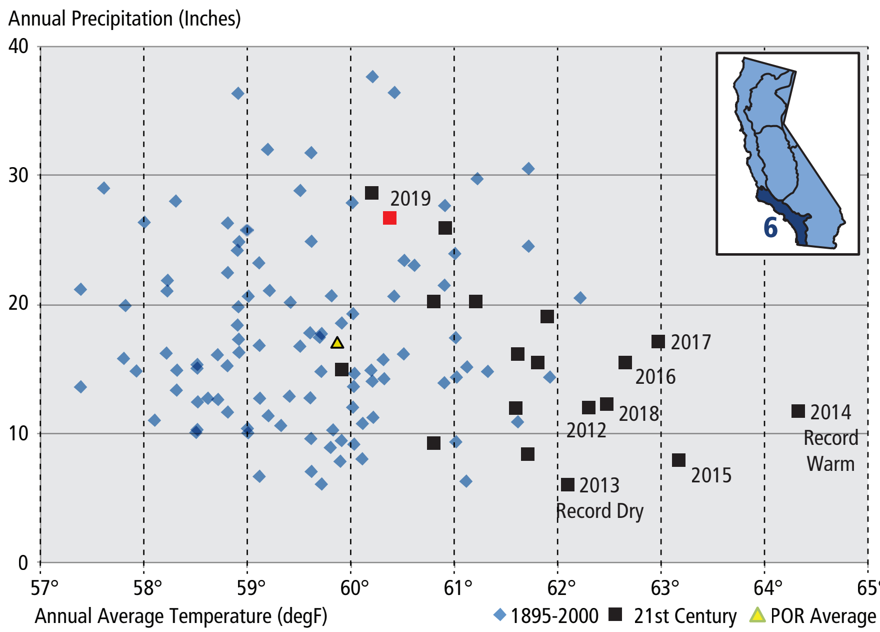
Graph shows "departures" for average (mean) and maximum temperatures each year from a long-term average (the years 1981 to 2010) i.e., the difference between each year's value and the long-term average.

*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.

The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2019) 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 1895-2019. 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 19 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. 2019 annual average temperature plots are depicted for the Sacramento Climate Division (54.8°F) and for the South Coast (60.4°F). 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

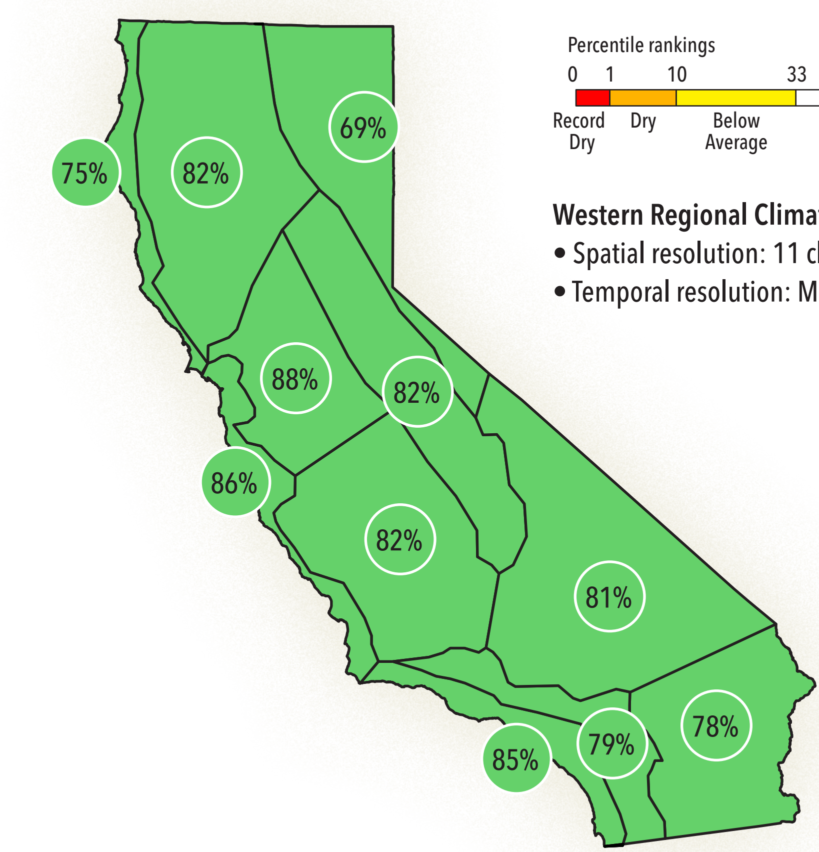
Annual Precipitation

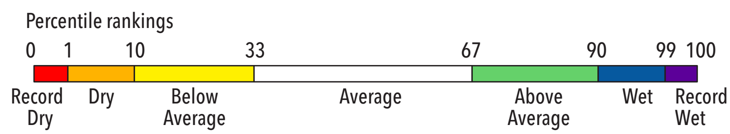
Annual precipitation data from California shows significant year-to-year variation. This inter-annual variability makes trend analysis difficult for this indicator. An analysis of precipitation records since the 1890's shows no statistically significant trend in precipitation throughout California. Although 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 ongoing research.

WY 2019 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 above normal precipitation for the all the climate regions in the state.

California Climate Regions Precipitation Rankings, Water Year 2019



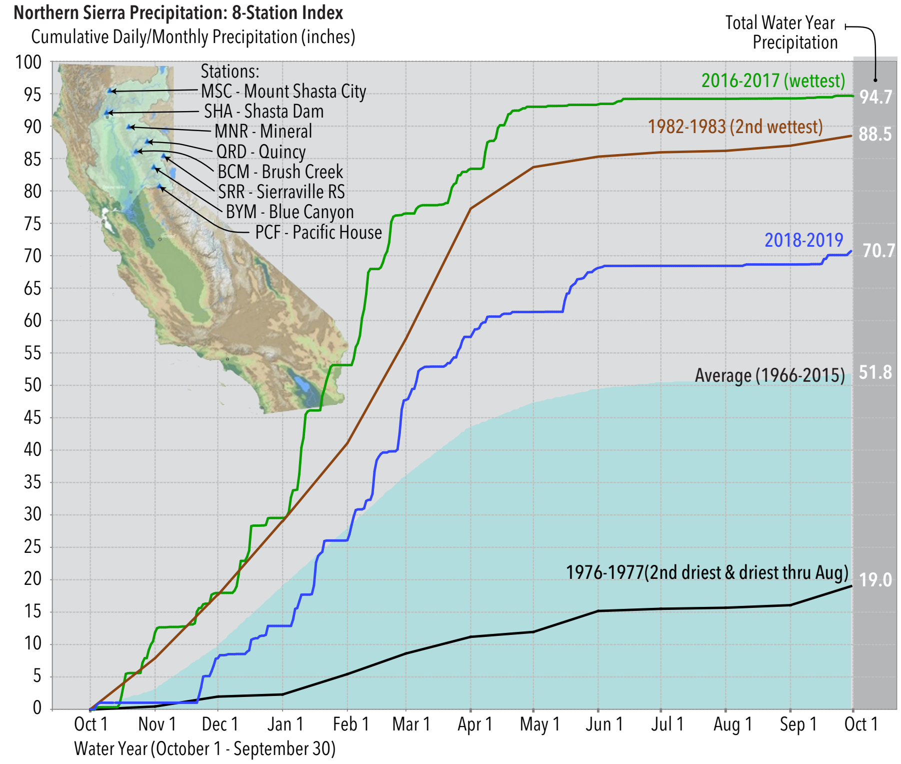


Western Regional Climate Center (WRCC) California Climate Tracker
- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly, Water Year

DWR Aggregate Precipitation Station Indices

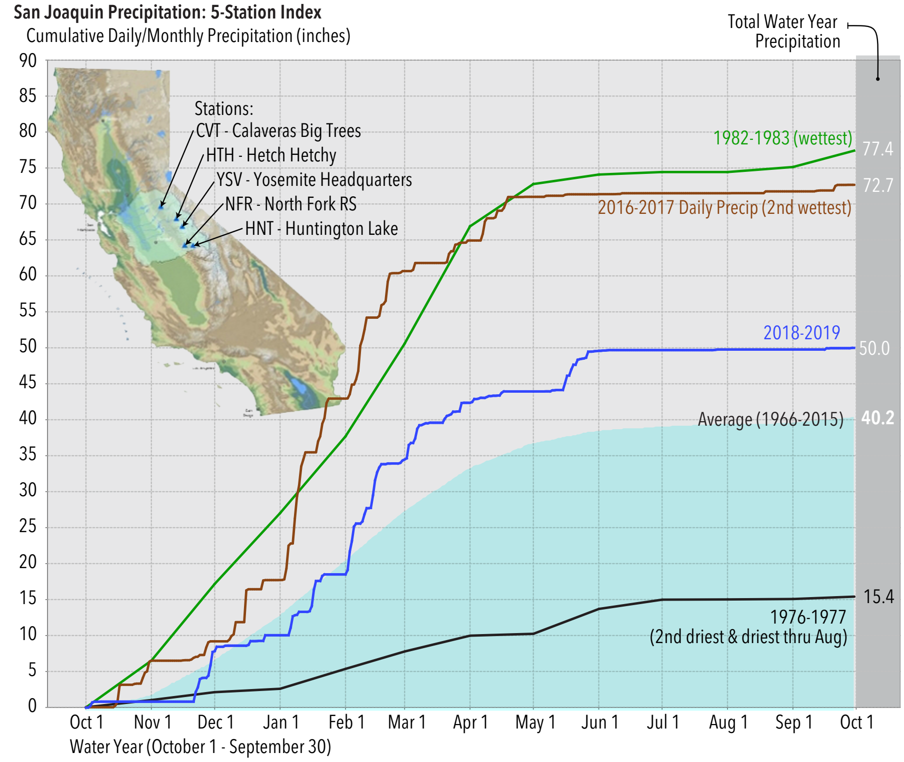
Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state. These precipitation station indices are located in the Northern and Southern Sierra and correspond well to the WY type on the Sacramento and San Joaquin River systems.

Northern Sierra Precipitation: 8-Station Index



For WY 2019, the Northern Sierra Precipitation 8-Station Index shows total WY precipitation at 70.7 inches, above the long-term average of 51.8 inches. Accumulated precipitation in for the WY was 18.9 inches above average, and 36 percent above normal. No measured precipitation accumulation until late November was likely a factor for late season wildfires, including the Camp Fire in Northern California.

San Joaquin Precipitation: 5-Station Index



The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, typically receives less precipitation than the Northern Sierra. WY 2019 had a total WY precipitation of 50.0 inches, which was above the average of 40.2 inches for the Southern Sierra. Cumulative precipitation for WY 2019 was 24 percent above 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).

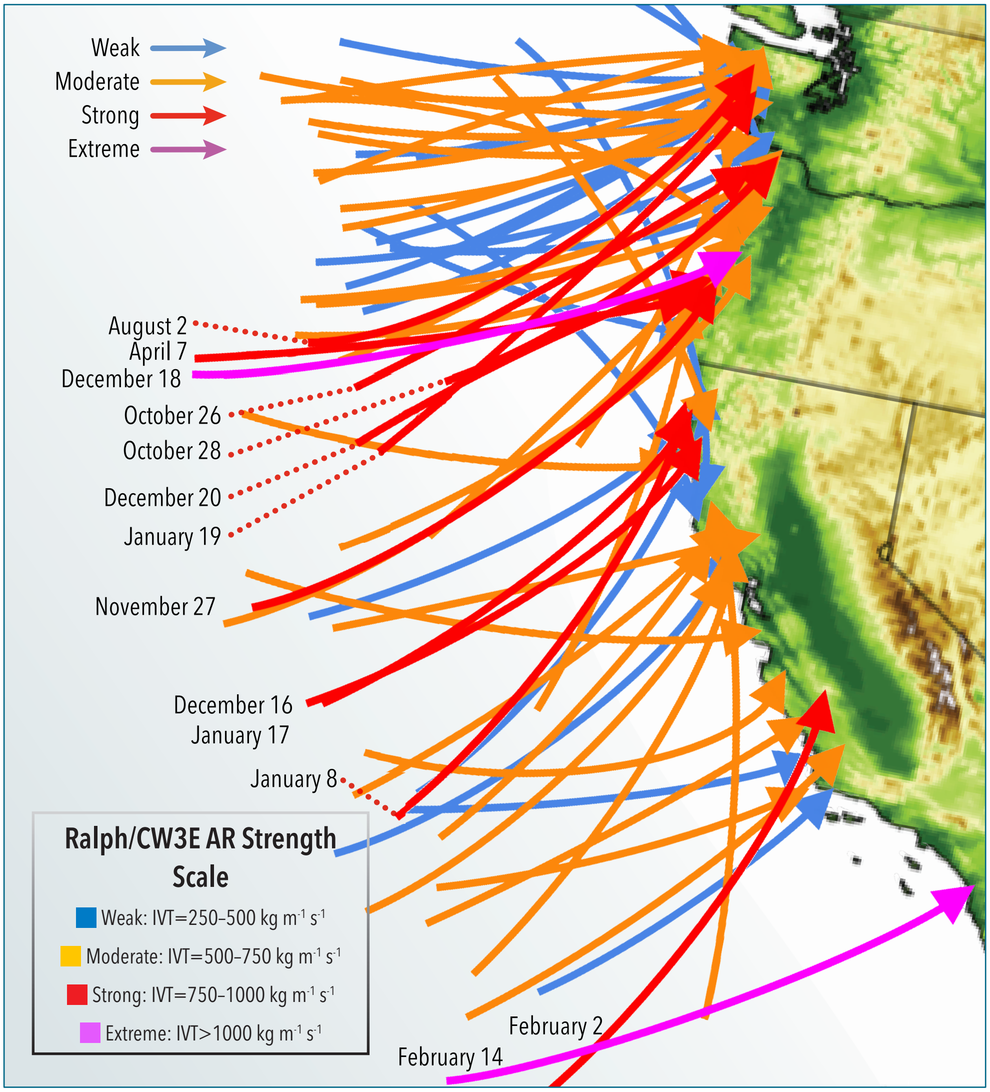
Recent research into the characteristics of ARs at the Center for Western Weather and Water Extremes (CW3E) has yielded a categorization, the Ralph/CW3E AR Strength Scale, based on the amount of integrated vapor transport (IVT). IVT is a combination of the amount of water vapor in the atmosphere above 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 64 ARs that made landfall along the US West Coast in WY 2019

An atmospheric river observatory located in in McKinleyville, located in Humboldt County, California. Photo taken December 2015. Clark King / NOAA.

as well as the location of maximum intensity of the AR when it hit the coast. Of the 64 landfalling ARs, 49 occurred in Northern California and 21 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.

Distribution of landfalling Atmospheric Rivers on the U.S. west coast during WY 2019.

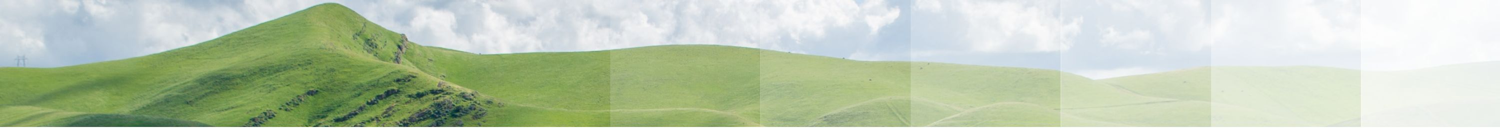


Graphic: Center For Western Weather and Water Extremes (CW3E) Scripps Institution of Oceanography

Atmospheric River strength by month and WY 2019 totals.

AR Strength	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
Weak	1	2	3	0	0	2	3	2	1	1	2	2	19
Moderate	3	4	3	5	4	3	2	2	0	2	1	3	32
Strong	2	1	2	3	1	0	1	0	0	0	1	0	11
Extreme	0	0	1	0	1	0	0	0	0	0	0	0	2
Total	6	7	9	8	6	5	6	4	1	3	4	5	64

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



Snowpack

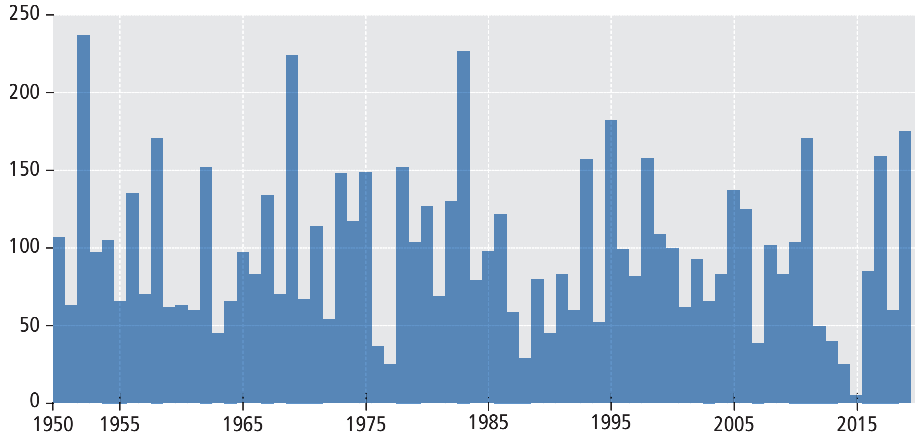
Snowpack is an essential water supply feature in California and historically provides approximately 15 million acre-feet of water accounting for one-third of the State's annual water supply. Numerous studies have reported declines in Western US snowpack in recent years and have been attributed to warming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



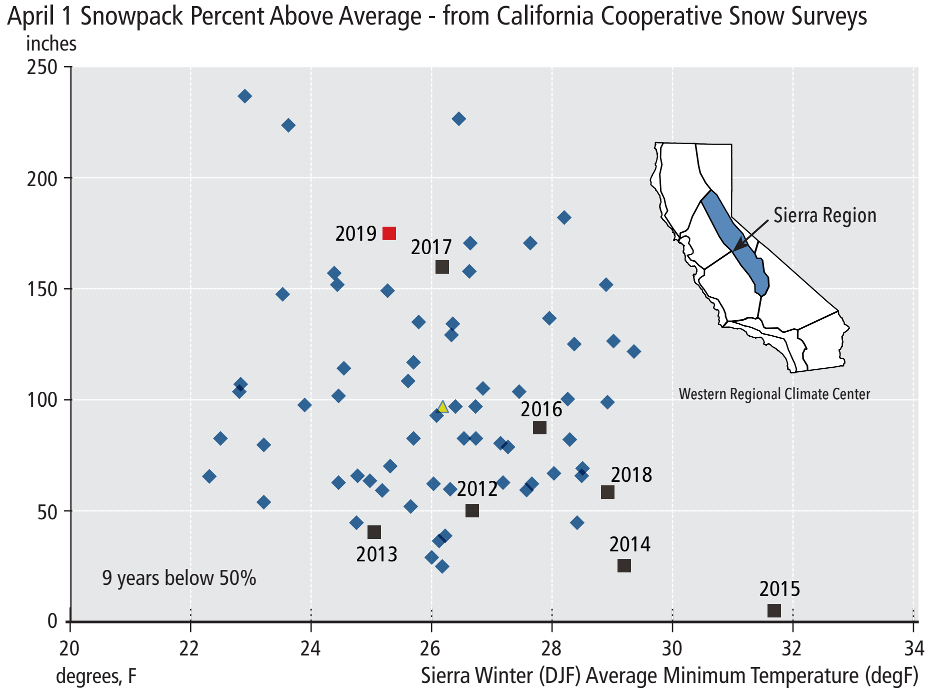
WY 2019 statewide snowpack water content was 175 percent of the long-term average. April 1st snowpack was significantly higher in comparison to WY 2018 where state wide snowpack water content was just 58 percent of the long-term average. Multiple strong atmospheric river storms in February played a role in bringing snowpack content significantly higher than the long term, marking the fifth largest snowpack with records dating back to 1950. The exceptional snowpack in 2019 bolstered the water supply outlook in California, however, the long-term trend for this indicator is still on the decline since 1950.

California Cooperative Snow Surveys - Snowpack

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

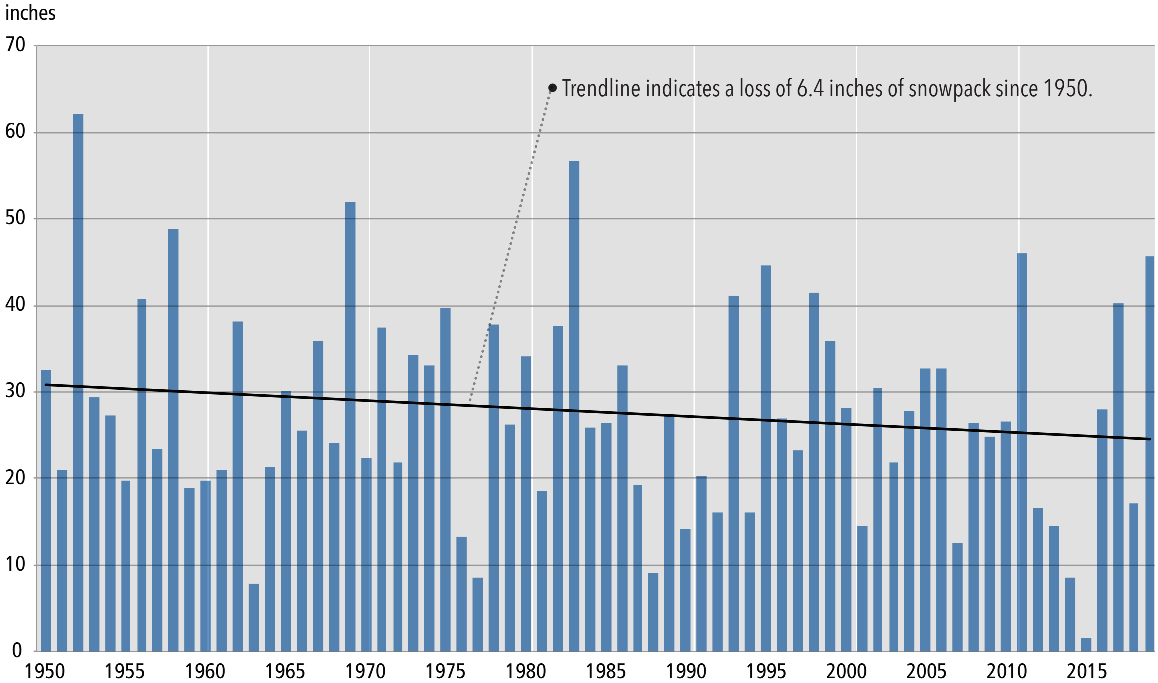
Sierra snowpack vs Winter Temperature, 1950-2019

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

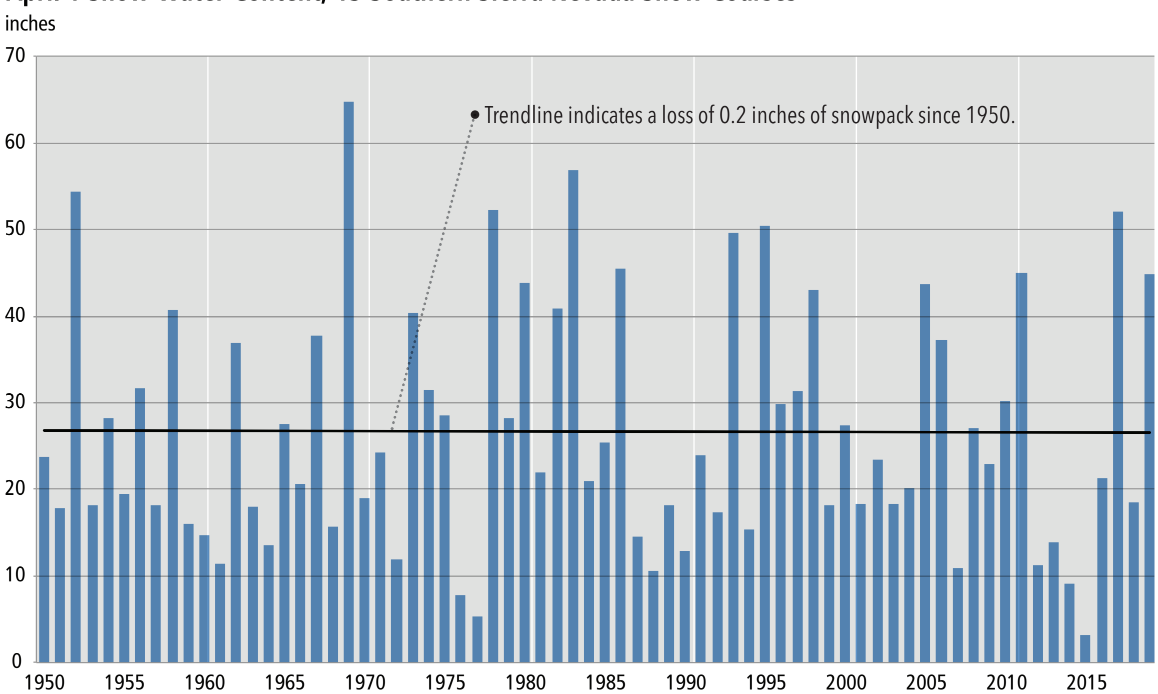


A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past seven years labeled as boxes.

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



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



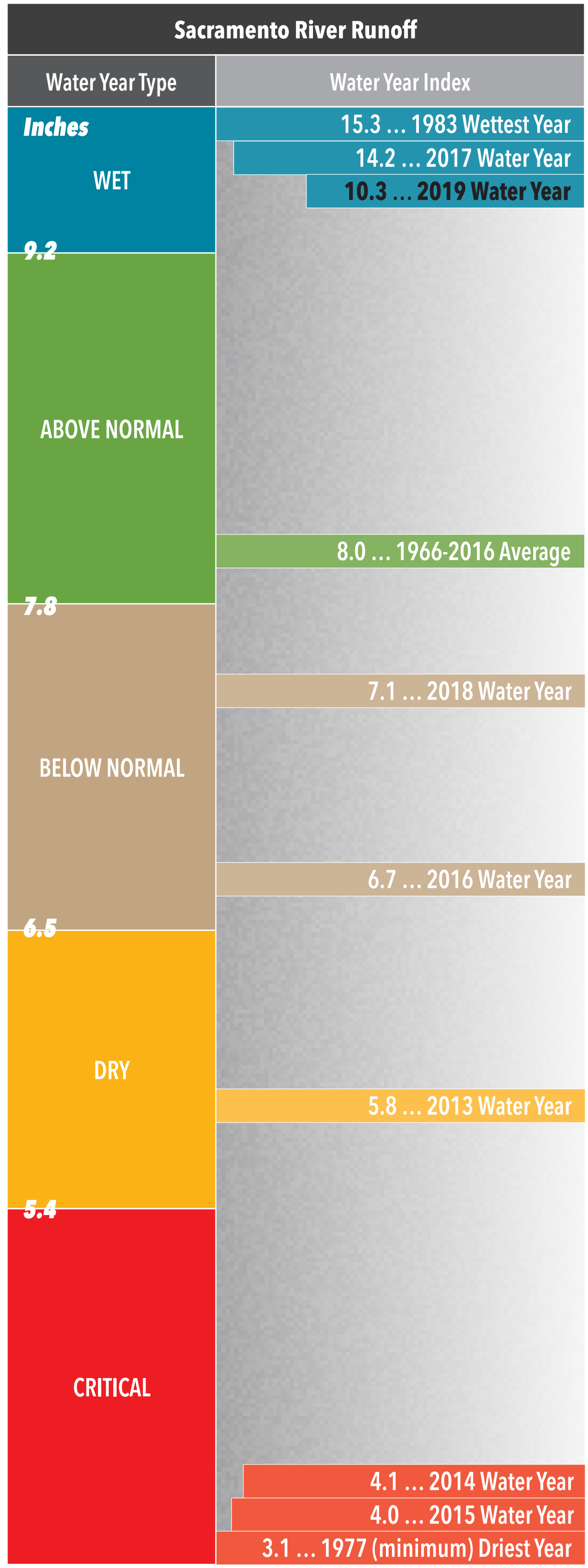
These figures demonstrate the trends in April 1st snowpack for 13 Northern and 13 Southern Sierra Nevada courses representative of their regions. In WY 2019 the Northern Sierra trend indicates a loss of 6.4 inches since 1950 where the Southern Sierra trend indicated a loss of 0.2 inches.

The overall trendline changed for both Northern and Southern regions from 2018 to 2019. With the addition of 2019 snow survey data, the Southern region SWE trend changed from a loss of 1.8 inches to a loss of 0.2 inches since 1950. This demonstrates how sensitive regression trend lines are to events near the end of the record. In the coming years, this trend comparison will need to be watched closely as higher elevations of the Southern Sierra 13 station group are considered to be less affected by rising snow lines. Up until 2011, Roos and Sahota (2012) had found that snowpack in the Southern Sierra 13 station group had increased, however that trend since reversed and will continued to be tracked in the 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.

Water is released from Lake Natoma at Nimbus Dam in Sacramento County, California as a precaution against flooding after an atmospheric river storm dumped heavy rain and snow across Northern California. Photo by Kelly M. Grow, California Department of Water Resources. Date: February 28, 2019.



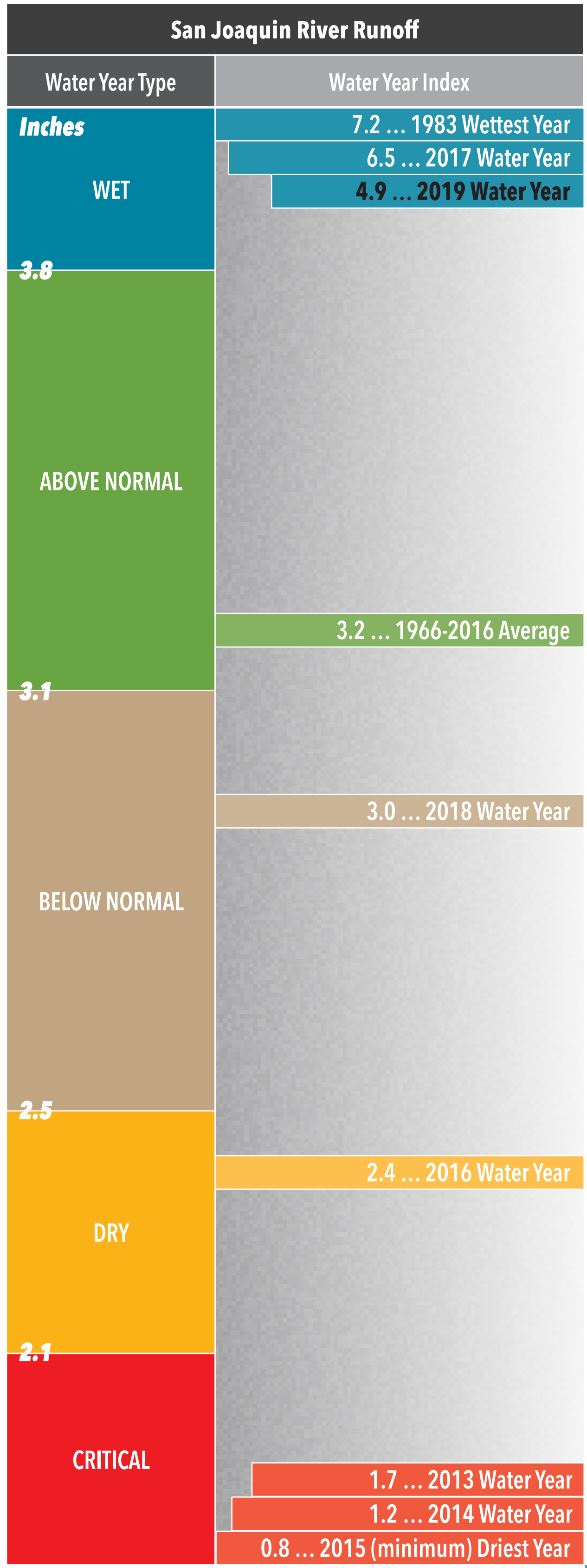
The Sacramento Valley 40-30-30 Index based on flow in million-acre feet for WY 2019 was 138 percent of average with an index value of 10.3 classified as a "wet" WY type.

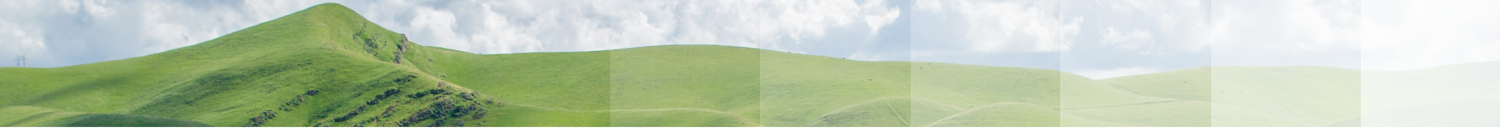
The WY classification system Sacramento and San Joaquin River basins was designed based on historical hydrology and the assumption of a stationary climate. With climate change and changing hydroclimatic conditions there is debate whether this stationary approach to the WY indices will be adequate to 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).

Fast-moving waters of the South Yuba River flow toward the Old Route 49 bridge in Nevada City, California during an atmospheric river storm in Northern California. Photo by Kelly M. Grow, California Department of Water Resources. Date: February 27, 2019.

The San Joaquin Valley 60-20-20 Index based on flow in million-acre feet for WY 2019 was 159 percent of average with an index value of 4.9 classified as a "wet" WY type.





Rain/Snow Trends

Mountains are natural reservoirs of water in California. Water is stored in the snowpack that accumulates during the cool season and is released during the warm season as snow melts. Historically, the middle and upper elevations of California's mountains receive the majority of cool season precipitation as snow. Because of California's dependence on snow-derived water supplies and susceptibility to flooding from snow melt events, it is an ideal location to examine changes in historical precipitation phase partitioning (meaning the fraction of precipitation that falls as rain vs. snow). Sparse observational networks and complex topography, combined with dataset inadequacies, have previously limited the use of precipitation partitioning for operational purposes. To overcome these limitations, DWR (2014) developed a methodology to study historical rain/snow trends at spatial scales relevant to broader management goals and with finer scale details across elevational and climatic gradients which was updated in 2019. See figures 1-3 for a description of the methodology used and findings. Beginning with the 2020 Hydroclimate Report, updates to these figures will be provided incorporating WY 2019 and 2020 data. This 2019 Report presents the methodology and data through WY 2018.

By combining a digital elevation model and fine scale gridded precipitation data (each grid cell is 4 km on a side) with coarse scale freezing-level and precipitation data from an atmospheric reanalysis, we can estimate precipitation partitioning across landscapes from 1948-2018. Freezing level elevations can be found using the Western Regional Climate Center's North American Freezing Level Tracker (NAFLT, https://wrcc.dri.edu/cwd/products/). The method produces watershed-aggregated monthly time series of total precipitation and percentage total precipitation estimated as snow (%SNOW) at 200 m increments from 0-4000 m. Temporal trends in historical rain/snow partitioning were evaluated spanning water years 1949-2018 using the non-parametric Mann-Kendall test modified to account for temporal autocorrelation at each grid point. These time series are analyzed for the entire WY (October-September), fall (September-November), winter (December-February), and spring (March-May). This allows for a

Figure 1: Estimated changes in %SNOW (in % decade-1) for (a) winter (Dec-Feb), (b) spring (Mar-Apr), and (c) for the full cool season (Oct-Apr). Thick contours denote California Department of Water Resources regional analysis zones, which comprise the primary 33 watersheds that contribute to the State's water supply. Thin black contours denote United States Geological Survey HUC-8 watersheds. Only grid points with statistically significant ($p<0.05$) trends are shown.

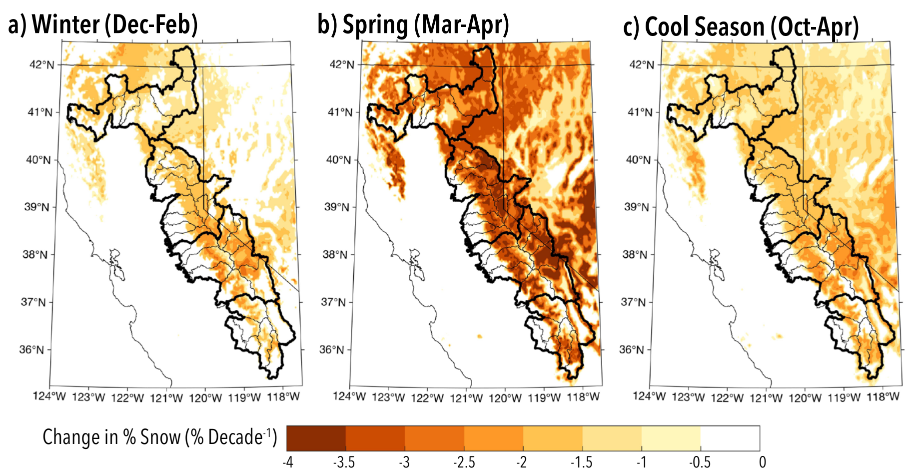
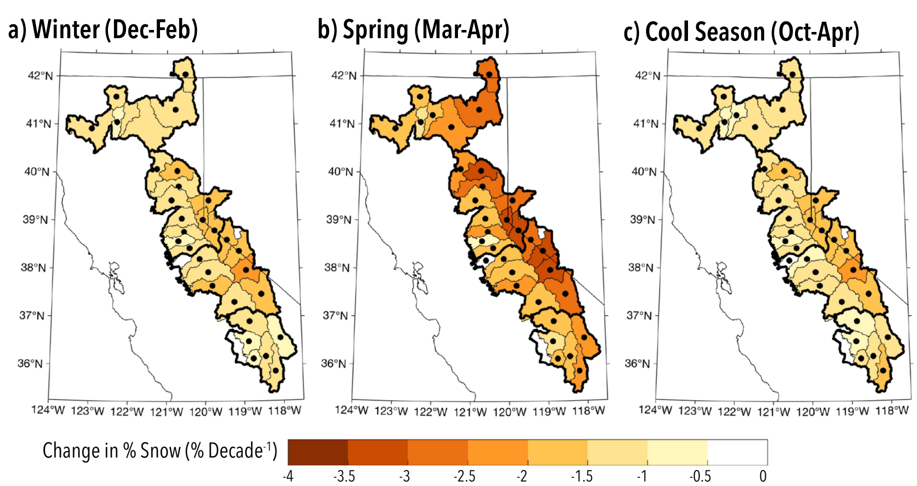


Figure 2: Aggregating trends to the USGS HUC-8 watershed scale demonstrates how the DWR approach can be used to interpret changes at the watershed scale. Note stronger trends in spring (b) as well as slightly stronger trends on eastward-draining watersheds. Filled black circles indicate statistically significant ($p<0.05$) trends of decadal changes in % snow.



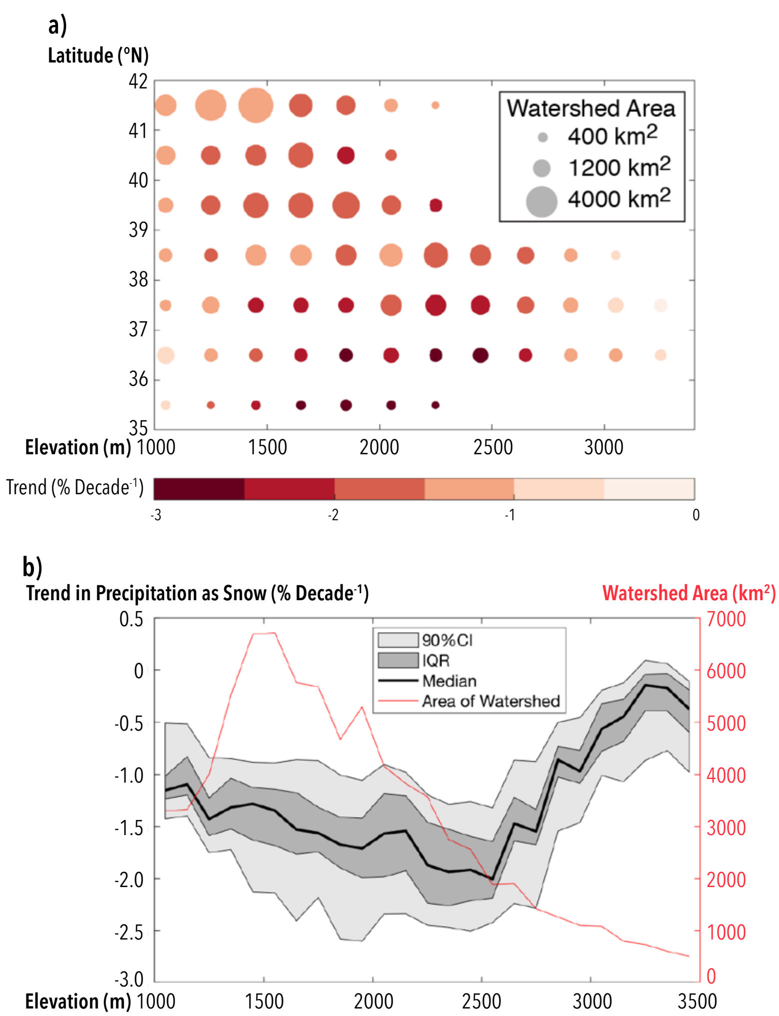
new approach to estimating spatial patterns and trends in precipitation partitioning over elevational and latitudinal gradients in major water supply basins.

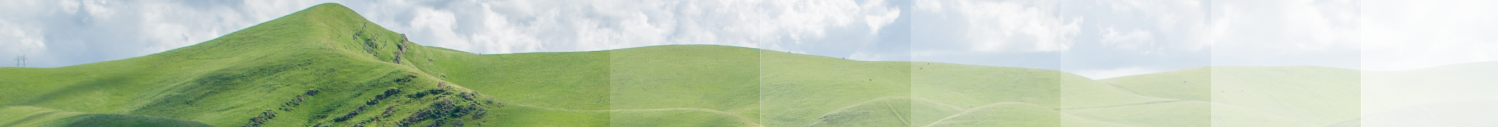
This approach confirms widespread declines over California in percent of precipitation falling as snow. The largest magnitude and most widespread changes are occurring in spring at elevations near and below the freezing elevation. The spring season signal of increasing precipitation as rain, especially in middle elevation zones and southern upper elevation zones, is consistent with declines in peak snowpack and earlier timing of runoff. The highest elevation regions in the Sierra Nevada have not experienced significant declines in precipitation falling as snow to date, although with continued warming and higher freezing levels, this region will likely undergo a transition to more rain, less snow, as well.

Many current reservoir management paradigms require the maintenance of a flood pool during the cool season, meaning this water cannot be stored for later beneficial use and must be managed as a hazard rather than a resource. Changes in the fraction of precipitation falling as snow during the cool season can have significant impacts on the ability of water managers to balance management objectives (e.g., water supply, ecosystem demands, recreation) through reservoir operations. Expectations from climate change projections suggest that dynamic adaptation strategies will have to be employed to maintain the functionality of existing water management infrastructure.

The largest negative trends across the four analysis zones were seen at mid-elevations of 1800-2500 m (-1.5 to -2% decade-1) becoming weaker at higher elevations that are climatologically well above the freezing elevation during winter months. Lower elevations (<1800m) occupy a larger portion of the collective watershed area and had significant declines in %SNOW (-1 to -1.5% decade-1). The largest declines in %SNOW at mid-elevations are found in the southern extent of the region, consistent with Figure 1. Note the strongest negative trends south of 38°N compose a much smaller geographic extent of overall water supply watersheds than those located further north in California.

Figure 3: Trends in %SNOW exhibit strong spatial patterns than can further be explored and understood by binning trends by elevation; (a) aggregated trends in %SNOW (% decade-1) by latitude and elevation (dot size is scaled by area of watershed occupying each elevation and latitude bin); (b) elevation-based trends (aggregated over all latitudes) of %SNOW (% decade-1) showing median (black line), the interquartile range (IQR, dark grey shading), and 90% confidence intervals (CI, light gray shading) on the left y-axis. Right y-axis shows the total watershed area occupied by each elevation bin (red line; km2). Aggregations were performed on grid points within the subset of DWR analysis zones (thick black contours in Figure 1).



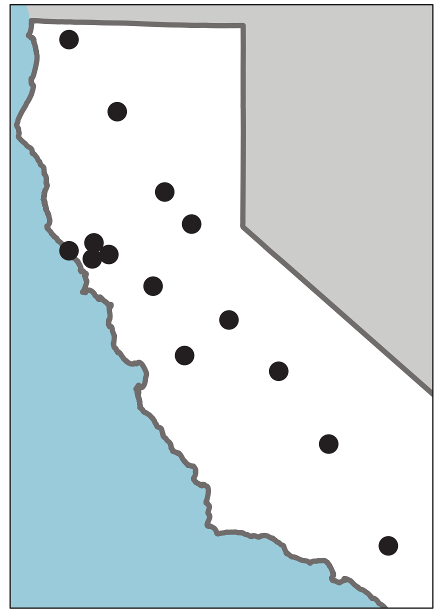


Snow-Level Radar

The WY 2019 Hydroclimate Report introduces a new indicator that provides information about snow level, or the elevation at which snow turns to rain, in the atmosphere. Snow-Level Radar is a result of research from the NOAA Hydrometeorology Testbed (HMT) Legacy project between the Earth Systems Research Laboratory and CA DWR. These ground-based snow level observing radars are positioned in a north-south transect of California providing high resolution observations during storms and are part of the statewide HMT observing network that provide information on extreme precipitation events and long-term climate observations.

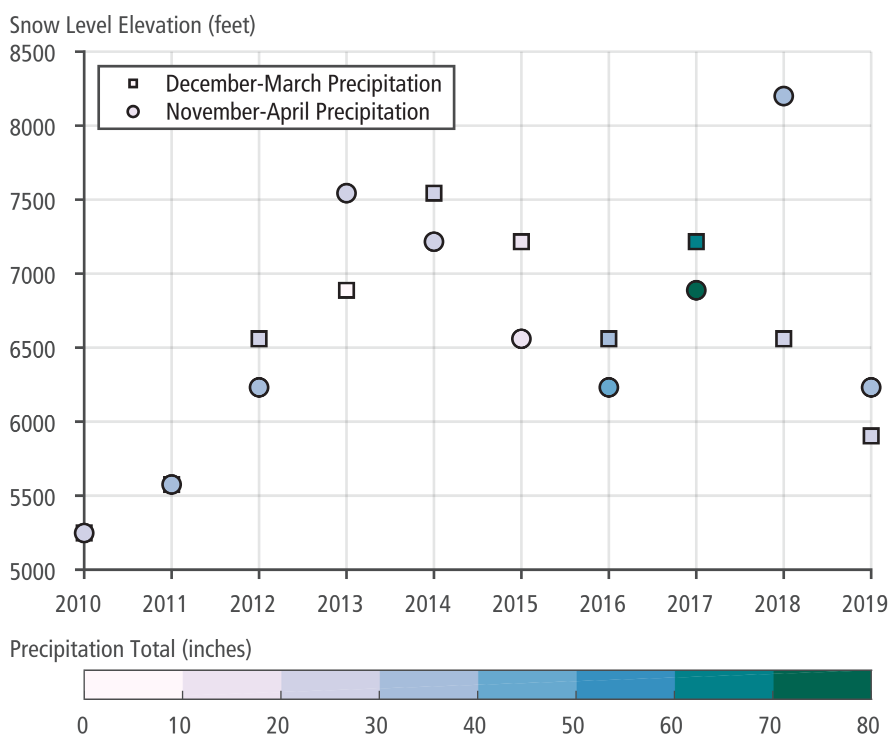
This indicator provides new data to address research questions about how a warming climate affects the snow level during storms. Variations in snow level control the amount snow accumulating in the water supply watersheds of the Sierra Nevada and southern Cascades. Changes in the fraction of precipitation falling as snow can have significant impacts to water management objectives such as protection from higher flood flows, seasonal water supply forecasting, and long-term supply trends.

A recent study that employed snow-level sensing radar measurements identified a statistically significant trend in higher winter snow levels in the northern Sierra Nevada between 2008-2017 (Hatchett et al., 2017). However, due to the short duration of the snow level dataset, continued collection of observations are needed to determine if the higher snow level trend continues. As more data is collected and research becomes available, this indicator will continue to be tracked in upcoming Hydroclimate Reports.



Snow-Level Radar observing station locations in California

Snow level elevations at which 50% of total precipitation fell at or below during two time periods for the Highway 80 corridor using hourly Colfax snow levels and Blue Canyon precipitation. December-March (squares), is when the majority of snowpack accumulation occurs. The full cool season (November-April; circles), during which winter storms occur, is also shown. Dot/square colors correspond to total precipitation for the respective time periods, shown in the colorbar at the bottom. The figure demonstrates that snow level at the Colfax radar station have been trending upward since 2010 with winter and cool season annual variability. Note the difference in WY 2018; this is due to the warm atmospheric river in early April that brought heavy precipitation with extremely high snow levels. January is not included in the 2019 data as a result of the federal government shutdown.

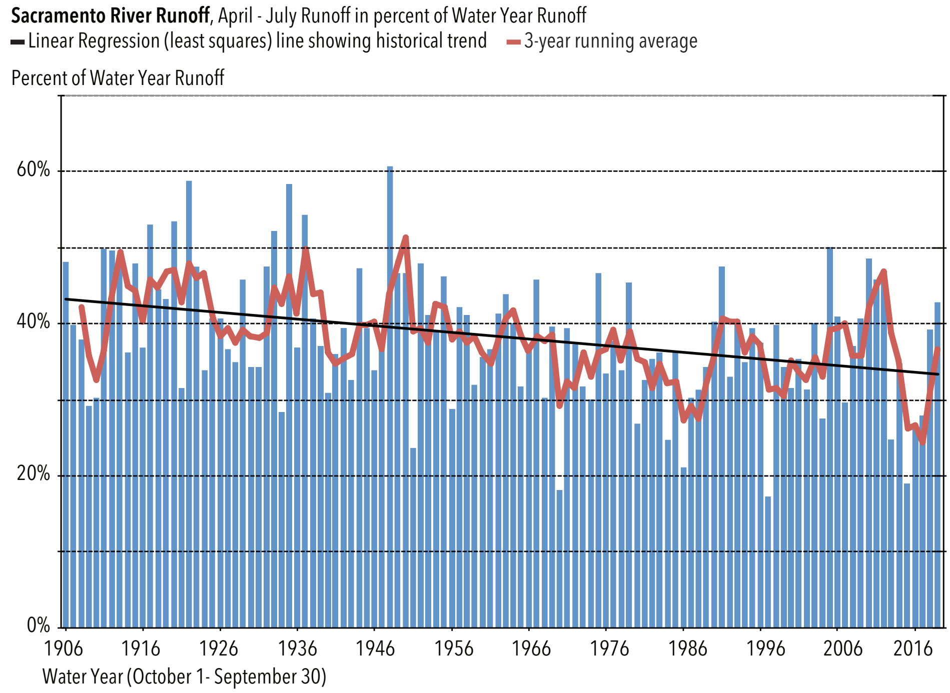


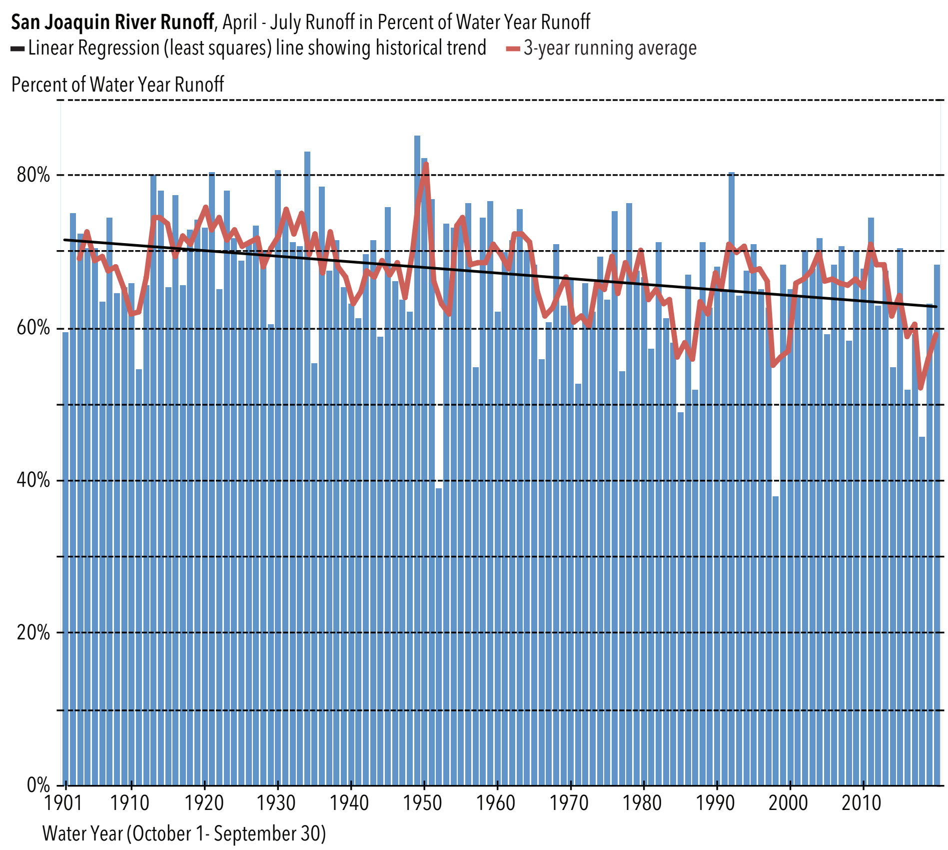
Unimpaired Streamflow: Sacramento and San Joaquin River Systems

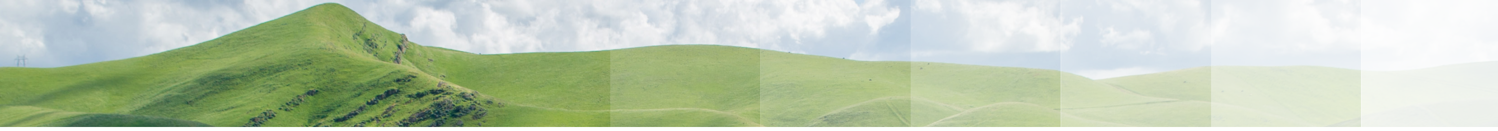
With increasing temperatures and corresponding loss of snowpack, how can a comparison be made representing spring snowmelt? Since the main watersheds in California have been altered by water development projects such as dams and diversions, historical natural hydrology flows would be difficult to compare. 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 snowpack 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 9.0 percentage point decline per century on the Sacramento and 9.8 percentage point decline per century on the San Joaquin River systems.

With above average precipitation and snowpack, WY 2019 April through July streamflow was 168 percent above average at 10.6 million-acre feet in the Sacramento River and 171 percent of average at 6.4 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 system.







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 San Diego are used as an indicator of change over time and to capture the broad scale geographic extent of the California coastline. For WY 2019, the La Jolla tide gauge in previous Hydroclimate Reports was substituted for the San Diego tide gauge as NOAA trend analysis for La Jolla was discontinued.

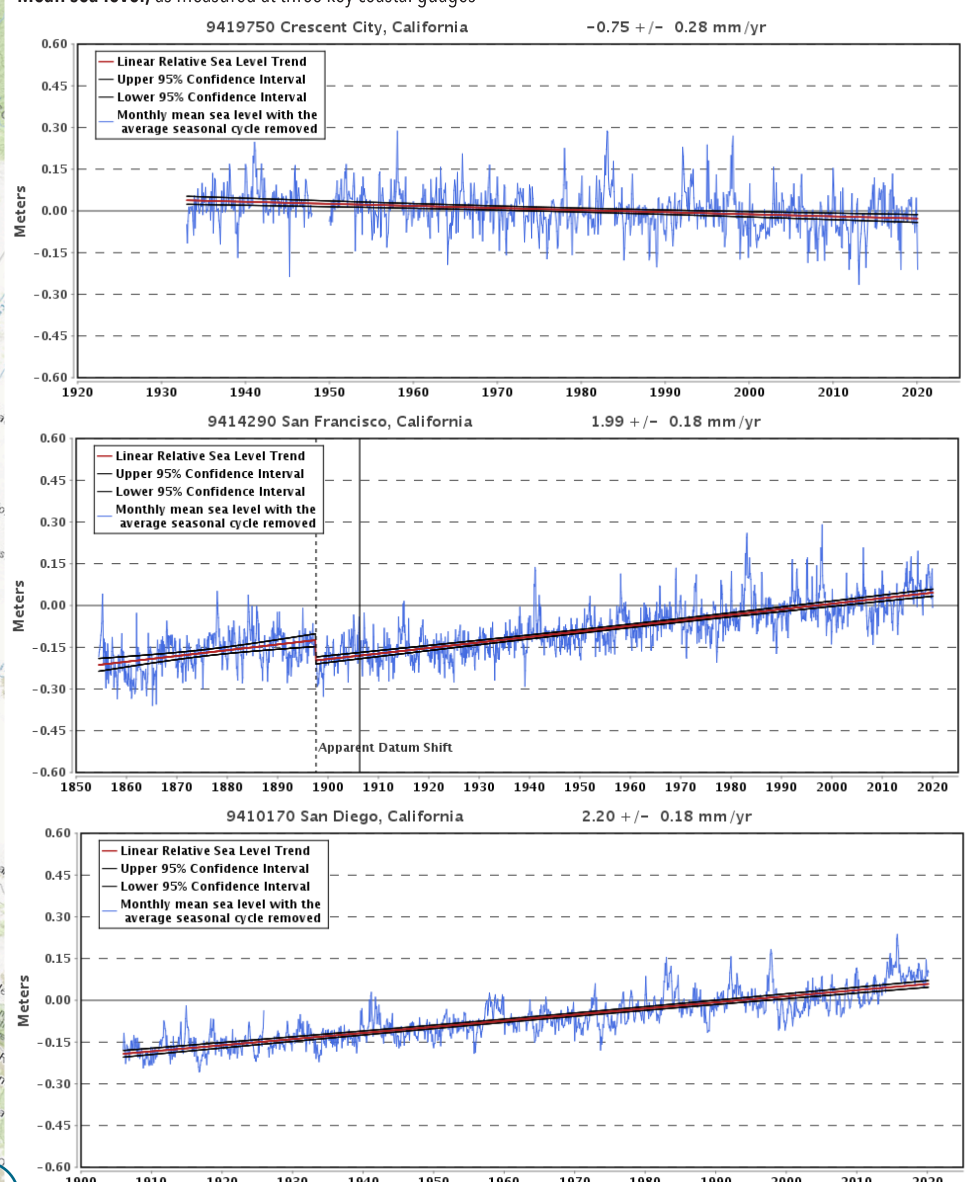
Local sea level for the shoreline of Southern and Central California (San Diego to Point Reyes) recorded at NOAA tide gauges range from less than 4 inches to just over 8 inches per century at the San Diego tide gauge.

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

Heavy rain in the Russian River watershed in Sonoma County, brought by several atmospheric rivers, caused waterways to overflow their banks, including a turbid Lake Mendocino. Photo by Carly Ellis, Center For Western Weather and Water Extremes. Date: February 27, 2019.

WY 2019 demonstrated variability within a WY and manifested a number of extremes along the way. October started with an early pulse of precipitation, but then went dry until the third week of November. Temperatures were warmer than average across the State. Dry, north winds in November created extreme fire conditions that manifested in the Camp Fire which destroyed the community of Paradise in the Sierra foothills east of Chico. The Camp Fire would become the sixth largest fire in State history, burning 153,336 acres, the most destructive fire, destroying 18,804 structures, and the deadliest fire, claiming 85 lives.

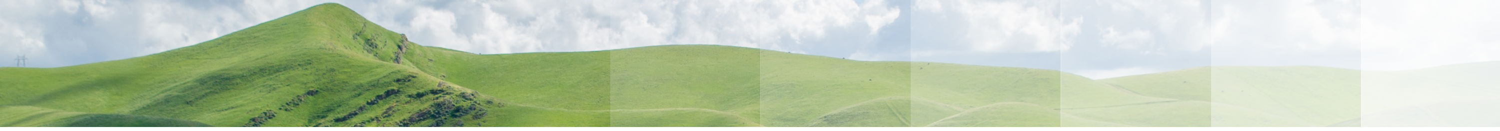
December ended up being dry with above average temperatures. Precipitation was below 50% of average for the Sierra Nevada and Central Coast regions. Snowpack was below average at the end of the month with the statewide value at 69% of average for the date.

Conditions shifted in January with precipitation returning to above average across the State. Temperatures were above average in Northern California and near normal in the south. Two significant storm systems impacted the State during the month with widespread precipitation and elevated river flows. This would provide wet antecedent conditions for the coming months.

In sharp contrast to the previous year's February, multiple ARs impacted California in 2019. Flooding occurred in coastal watersheds and on Central Valley watersheds draining from the Coastal mountains. The Russian River at Guerneville came close to posting a new record high flood when the second category 4 AR impacted the watershed in a two-week period. Cache Creek came close to exceeding its channel capacity near interstate 5. The Northern Sierra 8-Station Index recorded the third largest value for February accumulation with 21.7 inches. The years with two higher recorded values in 1986 and 2017 both had significant flooding on west slope Sierra watersheds. In 2019 however, cold air in place over the Sierra from cross-polar flow from an unstable polar jet stream led to a historic gain in snow water equivalent (SWE). Snow water equivalent is the depth of water over a given area if all the snow over that area were melted. At the end of February, the statewide snowpack was at 152% of average for the date. Further study is needed, but it is hypothesized that the cross polar flow that led to cold conditions over the Sierra was the result of low seasonal ice cover in the Arctic Ocean.

March continued the above average precipitation with elevated river flows persisting through the month. Snowpack continued to accumulate leading to the fifth largest April 1st snowpack since 1950 with almost four feet of SWE.

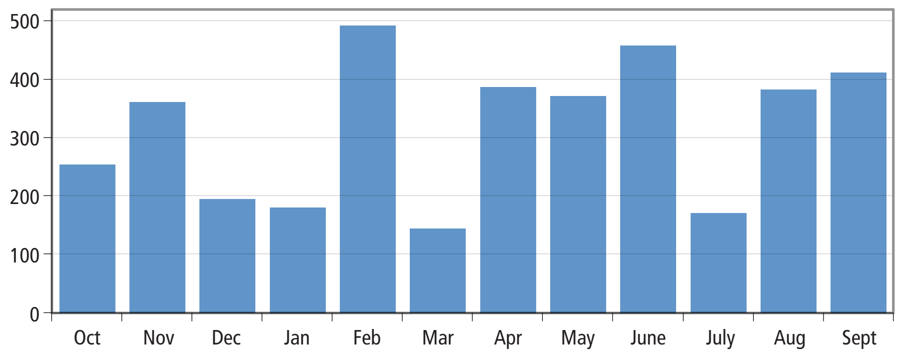
April returned to below average precipitation and above average temperatures. One third of the snowpack melted out during the month. Conditions changed again in May when statewide precipitation was the sixth highest for a given May, in 125 years of data. Another third of the snowpack melted out in May based on the reports of automated stations. However, it is important to note that these automated stations preferentially sample lower and mid-elevation snowpack and under-represent



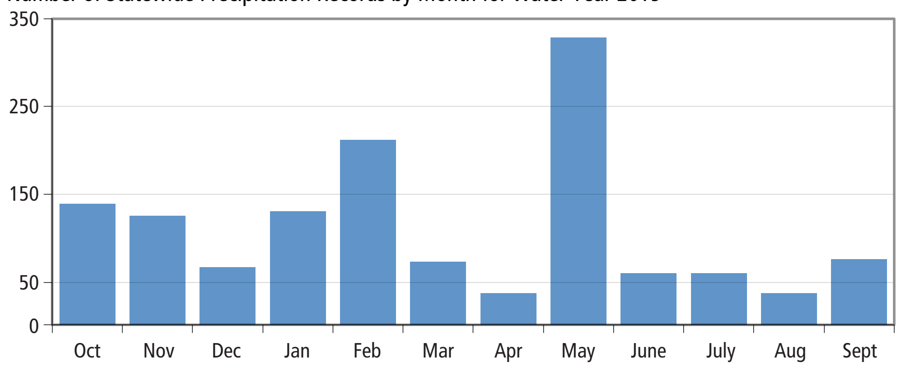
high-elevation snowpack. For maximum temperatures it was the tenth coldest May on record.

Temperatures oscillated between above and below average throughout the summer, with August being the 4th warmest August as the notable extreme. The WY closed out with some September rain, leading to above average precipitation for the month and below average temperatures.

Number of Statewide Temperature Records by Month for Water Year 2019



Number of Statewide Precipitation Records by Month for Water Year 2019



In late February 2019, up to 15 inches of rain fell over three days across the Russian River watershed in Sonoma County causing significant flooding, closing roadways, cutting off neighborhoods and damaging infrastructure including the Barlow Marketplace in Sebastopol, where many businesses were inundated by floodwaters of the Laguna de Santa Rosa a tributary to the Russian River. Photo by Nina Oakley, Desert Research Institute. Date: February 27, 2019.

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

https://wrcc.dri.edu/Climate/Tracker/CA/

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

https://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/snow/current/snow/index.html

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 WY 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=9410170

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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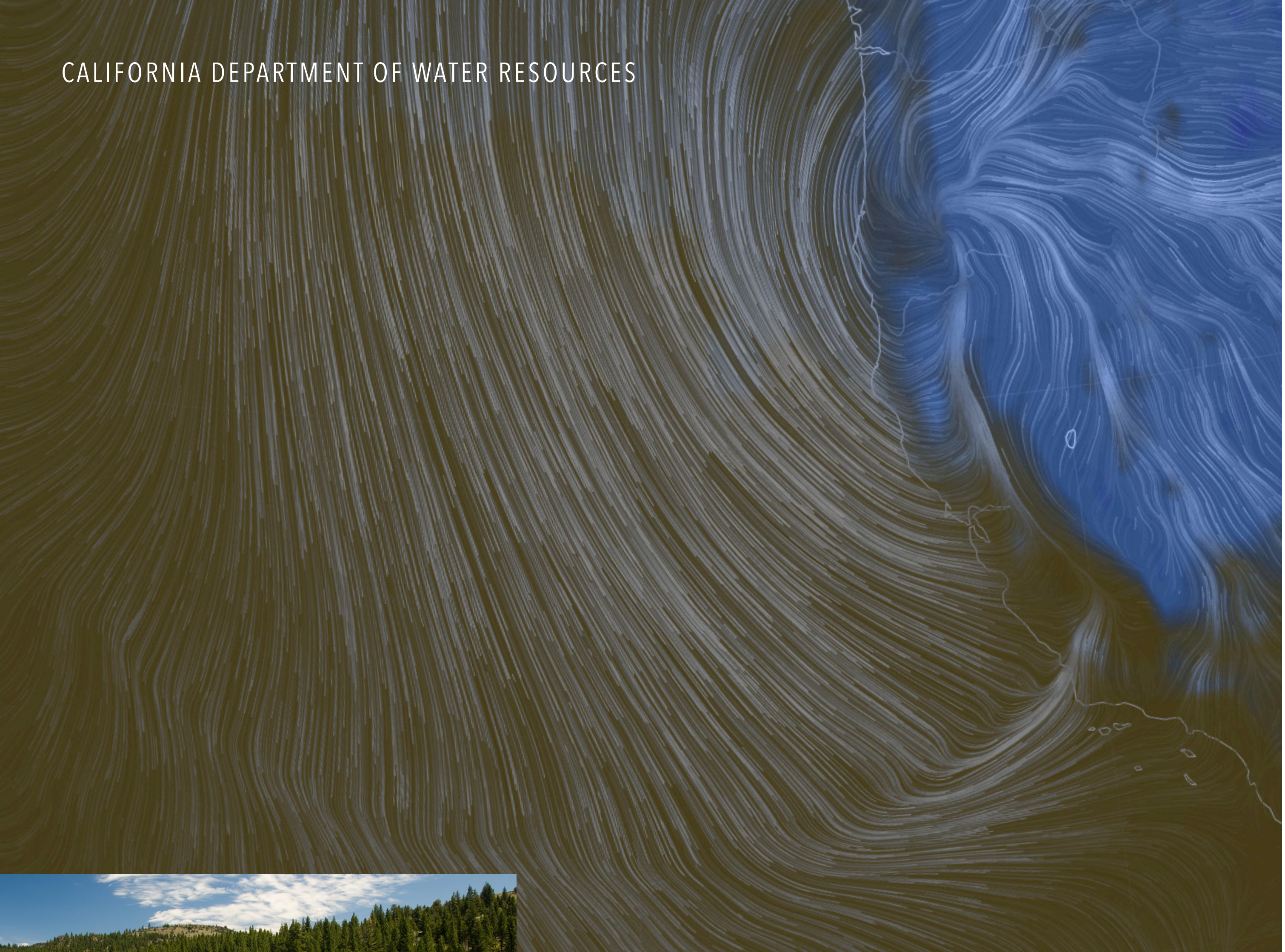
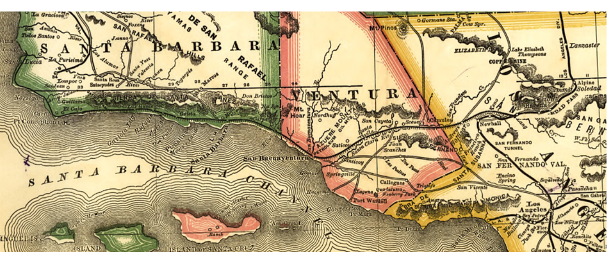
John King, Water Resource Engineer, for the California Department of Water Resources, Snow Survey Section plunges the long aluminum snow depth survey pole into the snow during the fifth California Department of Water Resources snow survey of the 2019 season at Phillips Station in the Sierra Nevada Mountains. The site is approximately 90 miles east of Sacramento off Highway 50 in El Dorado County.

CALIFORNIA DEPARTMENT OF WATER RESOURCES





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