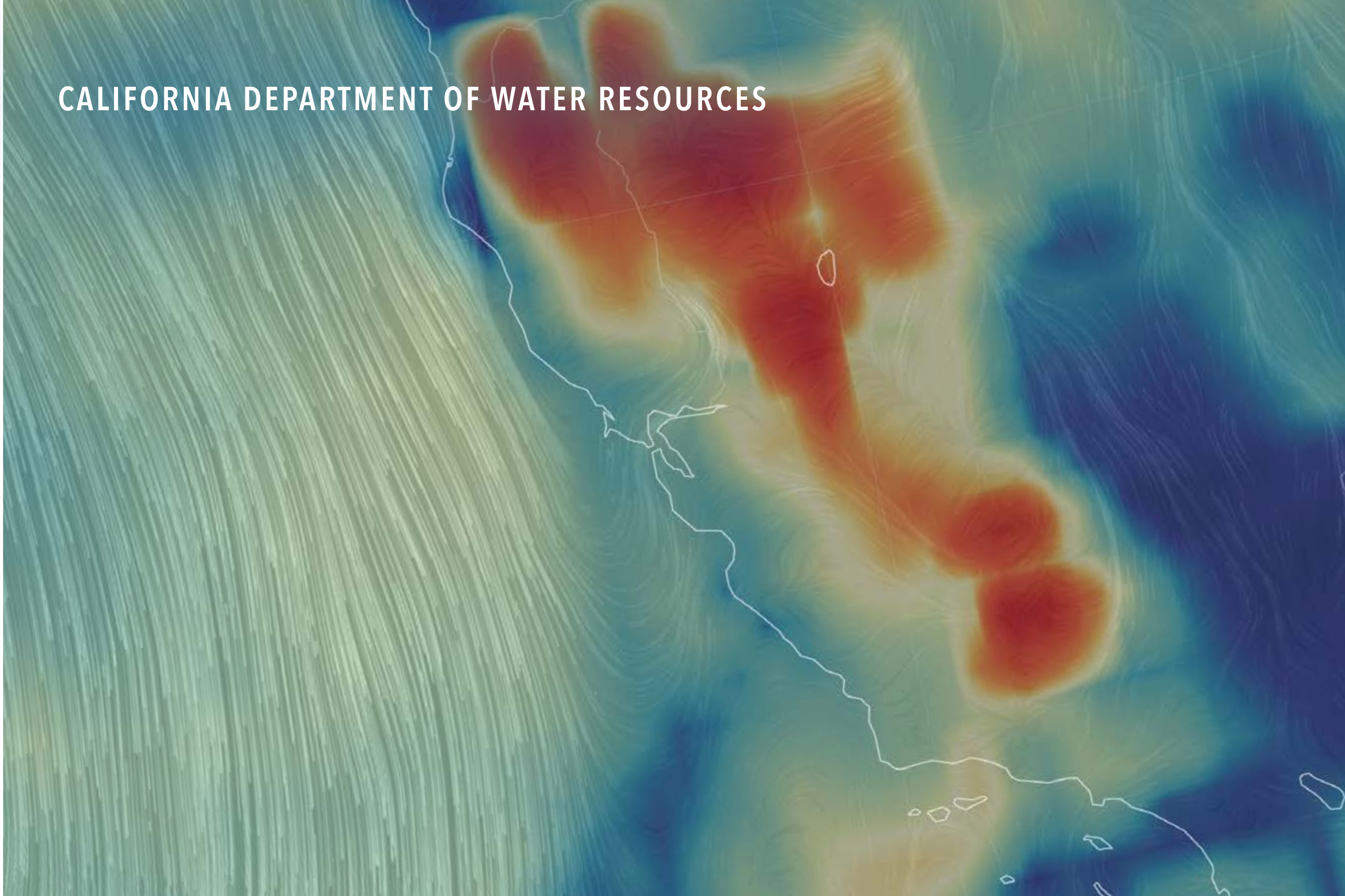
CALIFORNIA DEPARTMENT OF WATER RESOURCES



HYDROCLIMATE REPORT
Water Year 2021

Office of the State Climatologist

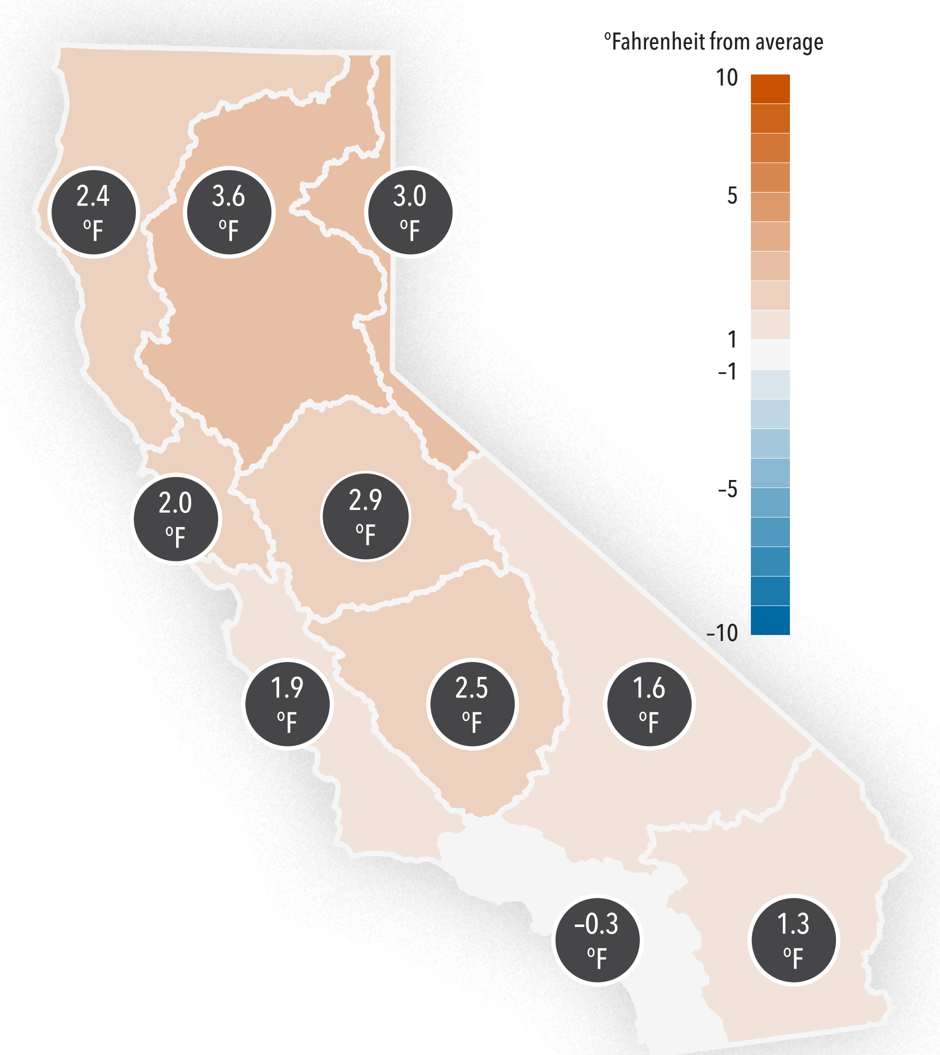
Executive Summary

Water year (WY) 2021 added to the climate change narrative with extreme dryness leading to record setting drought conditions. In both precipitation and temperature, there were new extremes with a record dry and warm spring being most notable. Late fall onset occurred again this year arriving in late November starting the seasonal snowpack on very dry soils. The WY ended with 48 percent of average precipitation statewide making it the second driest year in 126 years of record. It was also second warmest for statewide average temperature. For two-year totals, WY 2021 set a record, recording less precipitation than WY 1977. There was only one significant storm in the WY in late January which included low elevation snow and very strong damaging winds. The April 1 statewide snowpack registered 62% of average. Peak snowpack at 64% of average occurred the week before April 1. Runoff from the snowpack was far below expectations due to the dry antecedent conditions and record dry and warm spring. The lack of runoff resulted in the need for emergency drought response measures.

The summer of WY 2021 included a much stronger monsoon season for the southwestern United States than the previous year. Some of that precipitation made it as far west as San Diego. The Central Valley saw record heat in July and substantial fires including the Dixie, Caldor, and El Dorado fires. A thunderstorm on July 30 created a post fire debris flow in the El Dorado fire region. Heading into fall the eastern tropical Pacific sea-surface-temperatures were indicating a second year of La Nina conditions. Reservoir storage neared or recorded new record lows setting the stage for extreme antecedent conditions for WY 2022.

Due to the growing number of new extremes appearing during the WY, we are introducing a new section to the Hydroclimate Report – Signposts of Change. This is a way to view both local and global extreme events that are markers of a changing climate. Tracking climate change is key to efforts to build resiliency through the employment of adaptation strategies. Understanding when to employ an adaptation strategy and when to modify the strategy based on the pace of change or amount of change is critical to successful resilience development.

Temperature departures from 1981-2010 computed averages for 2020-2021 water year (October-September), by hydrological region



Front and back cover earth images courtesy of earth.nullschool.net. Cover: Wind and Particulate Matter, August 21, 2021 02:00 local time; back cover: Sea Surface Temperature Anamolies, same date, time.

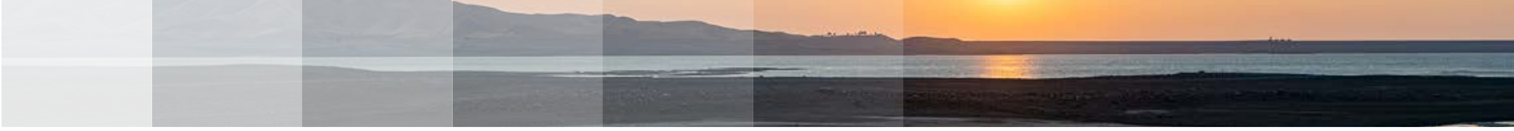


Table of Contents

The State Climatologist Office would like to thank Peter Coombe, Elissa Lynn, Benjamin Hatchett, Jamie Anderson, Alex Perez, and the California Nevada Applications Program for their contributions to the annual Hydroclimate Reports.

The 2021 Water Year Hydroclimate Report is dedicated to Maury Roos.

For 43 years, Maury oversaw work at DWR on flood forecasting, hydrology, water supply and snowmelt forecasting, meteorology, and related subjects. As Chief Hydrologist, he also provided advice on floods, drought, climate change, and weather modification studies. He retired in 2000, and then worked part-time as a retired annuitant until 2019.

Maury was a pioneer of hydroclimate studies and brought climate change to the forefront with a paper and presentation at the Pacific Climate Workshop at Asilomar in March 1987. His paper Possible Changes in California Snowmelt Patterns *was one of the first to recognize a reduction in the percentage of water coming during the snowmelt period at over 10 percent per century. Some people refer to this as the "The Roos Effect" which continues to show declining snowmelt runoff. The Hydroclimate Report continues his legacy by using his original developed methods for the Unimpaired Streamflow indicator on page 20.*

From growing up on a farm in Ripon, California, earning his engineering degree in 1957, and over a half century of public service, Maury has made tremendous contributions to hydroclimate knowledge which make many of the indicators in this report possible today.

Introduction

Welcome to the Hydroclimate Report for WY 2021 - an annual report highlighting weather and climate events in California. The report updates a collection of hydroclimate indicators important to the Department of Water Resources for tracking a changing climate. The indicators include metrics for precipitation, temperature, snowpack, runoff, and sea level rise.

In the years ahead, continuing work on atmospheric rivers will yield additional metrics to help characterize these how these events that are central to California's water supply and flood events are impacted by a warming world. Characterizing the strength of the atmospheric river by the amount of wind and water vapor being transported, known as integrated vapor transport, plus associated freezing elevations during the events are two characteristics currently being investigated.

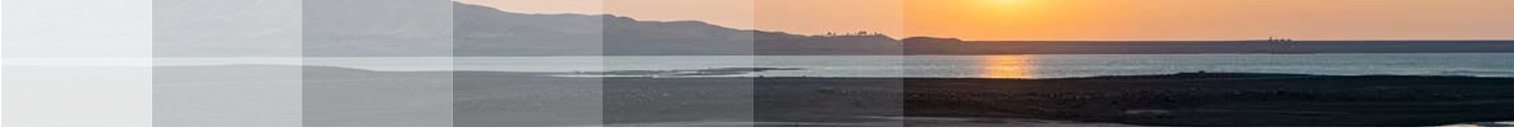
By tracking the change through a collection of indicators on an annual basis, it is hoped that transitions past important thresholds can be better anticipated enabling the continued refinement of adaptation strategies for water resources management.

For WY 2021, the report builds upon an indicator that incorporates the measurements of freezing elevation during precipitating events. 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 data comes from a collection of snow level radars installed in 2007 that are positioned in the foothills of the Sierra Nevada. Other signposts of change are also being investigated including a metric to characterize dry periods or the lack of sufficient atmospheric rivers to make an average or above WY.

WY 2021 illustrated variability at a sub-seasonal time scale with additional examples of extremes including record dryness and record heat. The annual Hydroclimate Report will be organized in the following fashion. After the introduction, the collection of indicators is presented. After the indicators, an overview of weather and climate events of the past year is presented highlighting unusual or new extreme events that have occurred. The report showcases potential additions to the collection of indicators in future years.

Key Hydroclimate Indicators

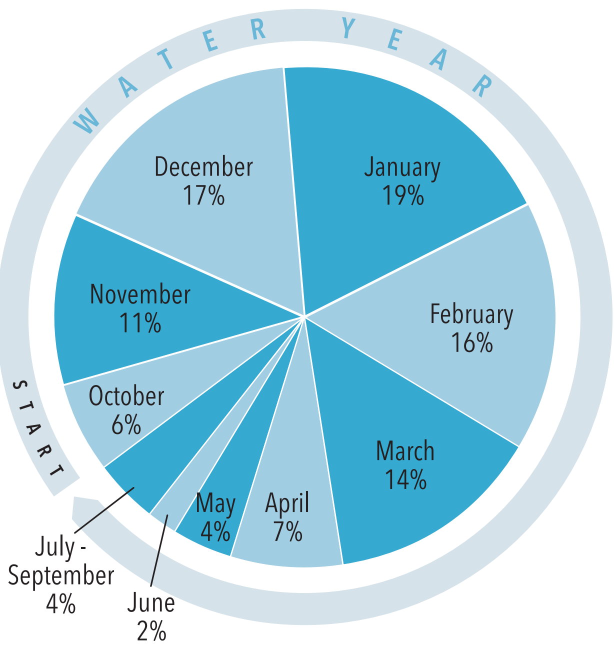
Indicators	Spatial Resolution	Temporal Resolution	Period of Record	Data Source
Temperature (Air)	WRCC Climate Regions	Monthly Mean	1895-present	WRCC
Temperature (Air)	NOAA Climate Divisions	Annual Calendar Year	1895-present	NOAA
Precipitation	WRCC Climate Regions	Monthly	1895-present	WRCC
Precipitation	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?

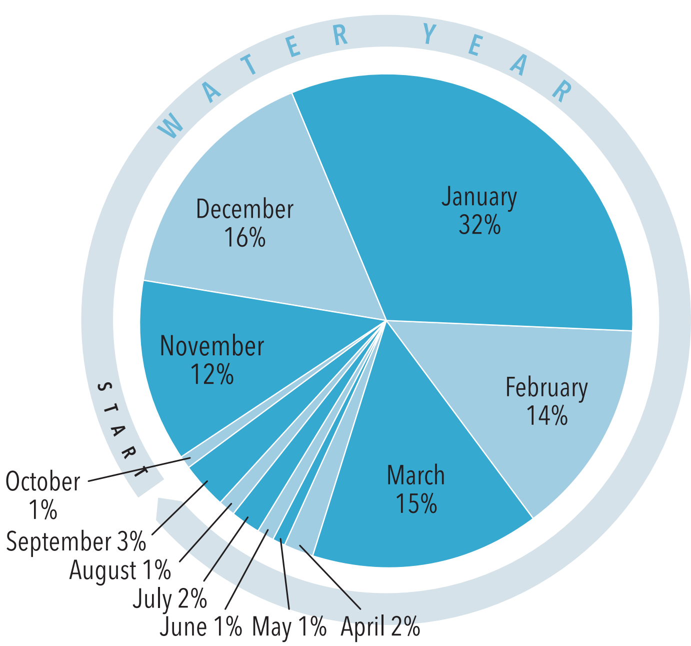
Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)

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 2021 by Month



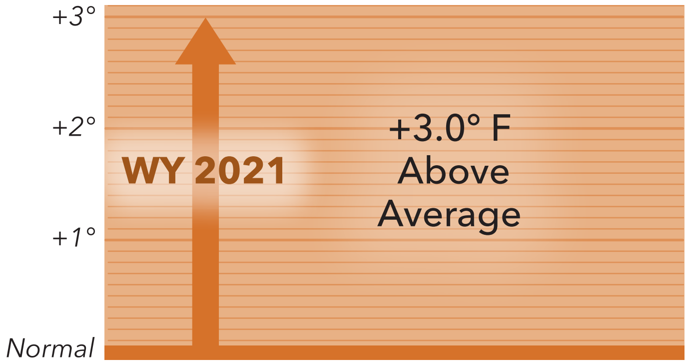
This chart represents monthly precipitation as percent of the total 2021 WY precipitation.

Hydrologic data such as precipitation and streamflow data are key indicators for the Hydroclimate Report. These data are typically represented as being within the water year (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 2021 WY covers the period from October 1, 2020 to September 30, 2021.

A comparison of the pie charts on the left between the long-term average and WY 2021, shows almost 54 percent of the total WY precipitation occurred in January and March. On average, the months of January, February, and March account for 48% of the average total annual precipitation. February was very dry, only receiving 0.02 inches of precipitation, the lowest since the start of the Northern Sierra 8-station index in 1921. The total WY rainfall at 31.7 inches was considerably less than the long-term average at 51.8 inches. The WY ended with a dry September with no precipitation being recorded in the Northern 8-Station area.

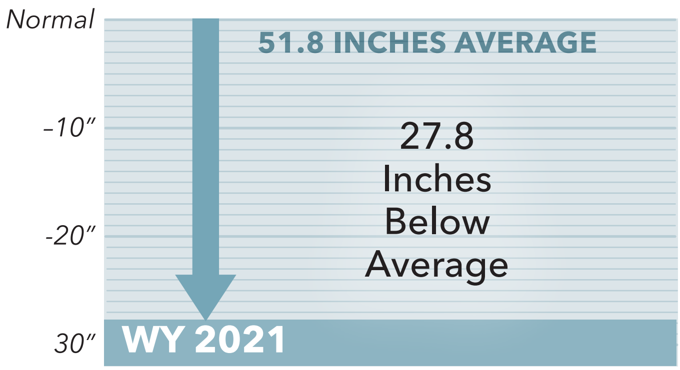
California Hydroclimate Water Year 2021 "At A Glance"

Temperature (Statewide)* *Page 8*



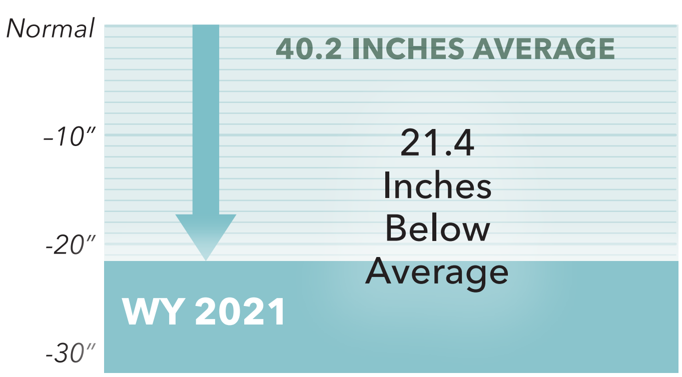
*Normal average air temperature represents 1981-2010 base period.

Precipitation (Northern Sierra)* *Page 11*



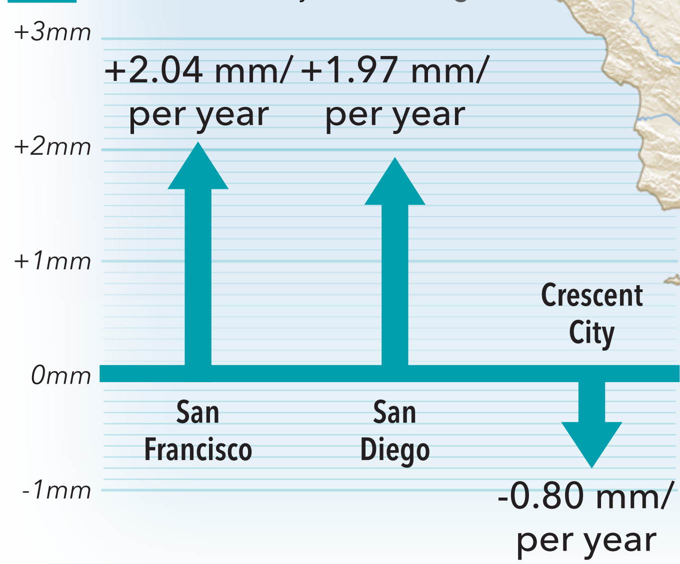
*Normal average precipitation represents 1966-2015 base period.

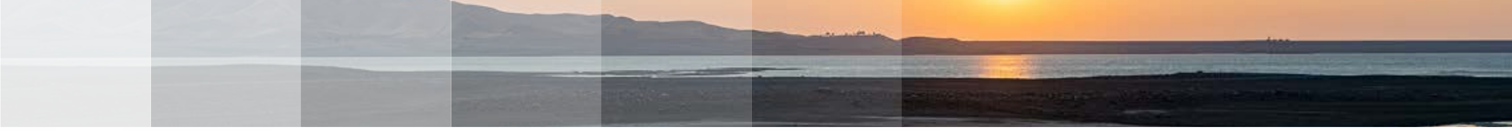
Precipitation (Southern Sierra)* *Page 11*

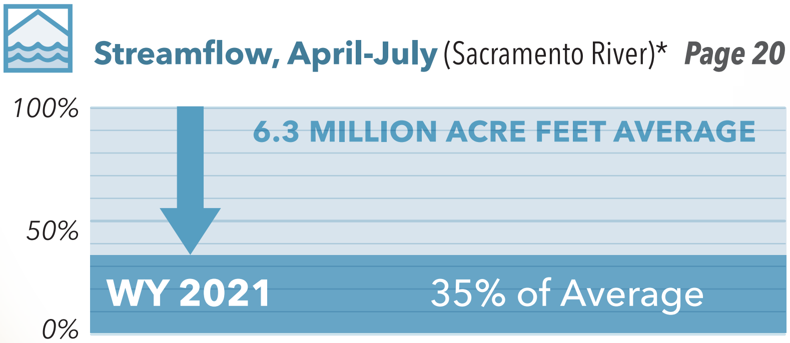


*Normal average precipitation represents 1966-2015 base period.

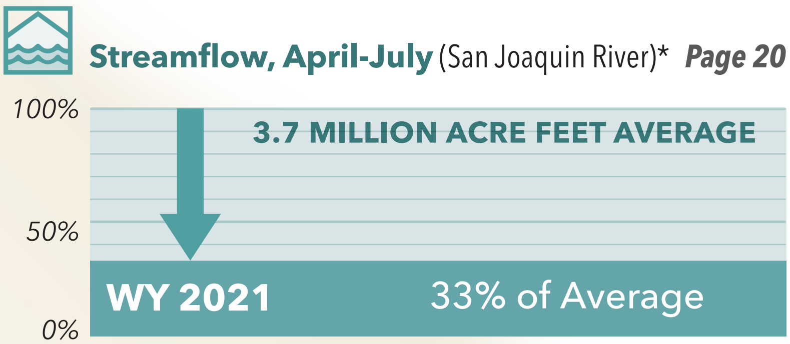
Sea level (100 year trend) ***Page 21***







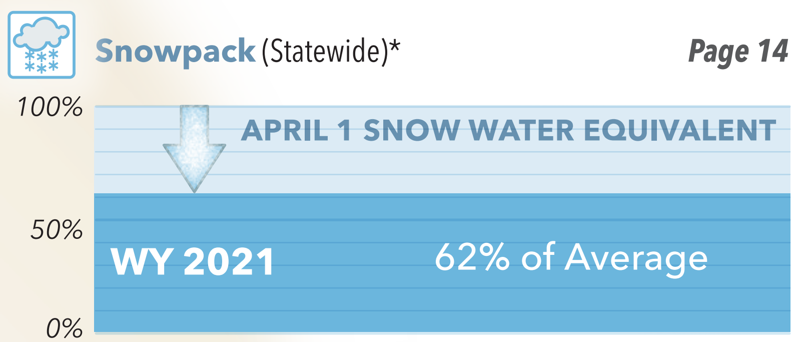
*Normal average streamflow represents 1966-2015 base period.



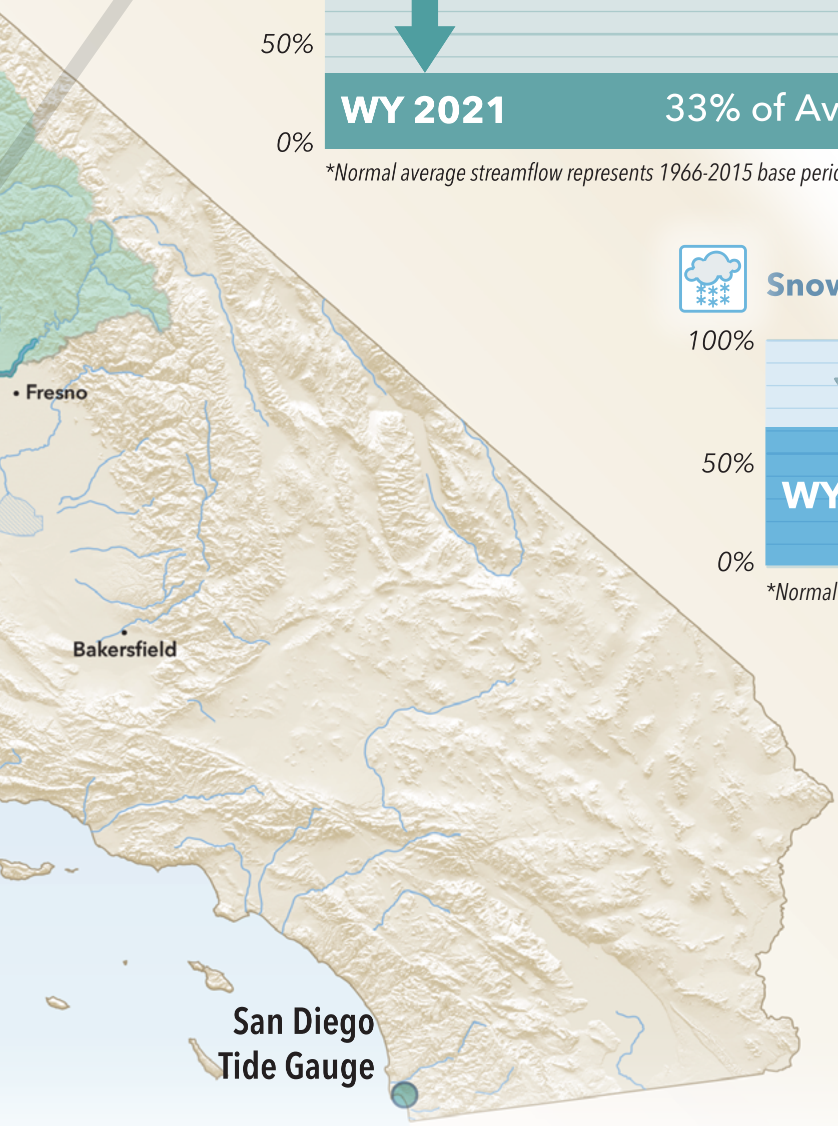
*Normal average streamflow represents 1966-2015 base period.

Indicators in Context

The DWR Hydroclimate Report is updated each WY to reflect key indicators that can be used to assess long-term trends and is focused on reporting characteristics of a changing climate that impact California's water resources. Also, of importance in generating data trends are annual values that represent each WY, which spans from October 1st through September 30th. At a Glance focuses on the measured values for the reporting WY using several key indicators that are discussed in further detail throughout the report. A select group of key indicators are visually represented to depict the 2021 WY values or departure from a long-term average or reference period. Precipitation and snowpack are depicted in the graphic and are related the below average streamflow for the April-July period for both Sacramento and San Joaquin watersheds. Also, the statewide temperature was above average for the 2021 WY compared to the 1981-2010 base period. Sea level trends are depicted with their locations shown geographically on the California coast.



*Normal average snowpack represents 1966-2015 base period.



Annual Air Temperatures

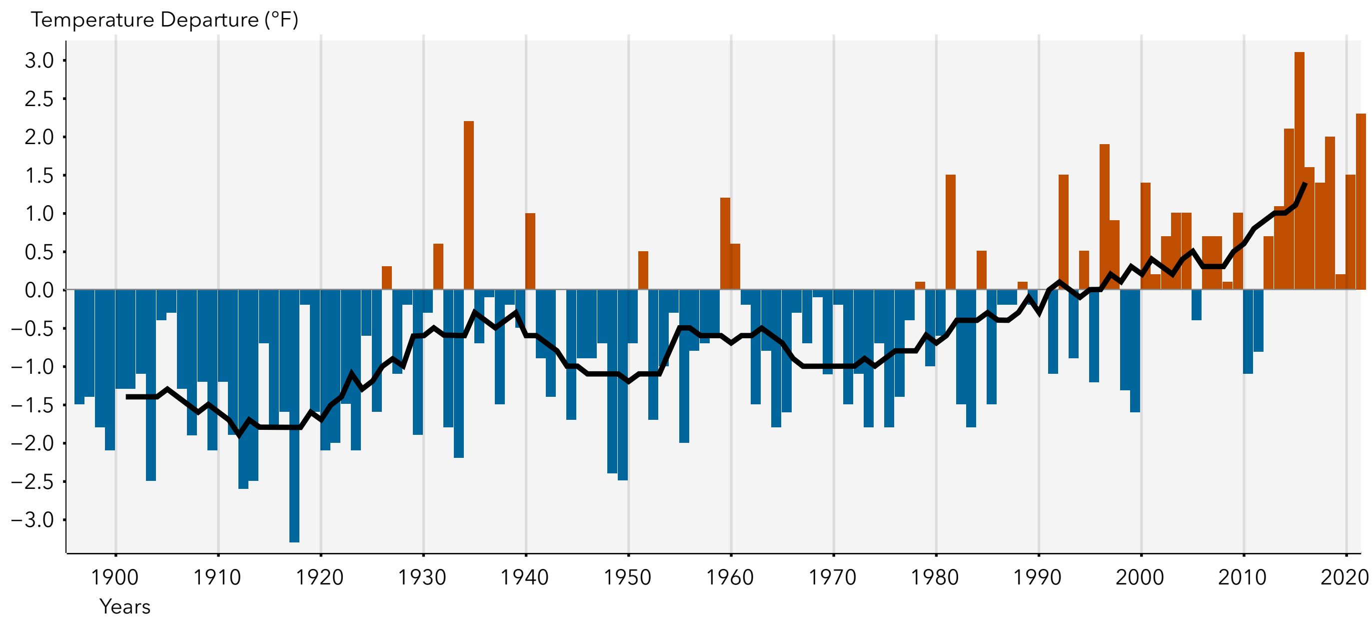
According to the Intergovernmental Panel on Climate Change (IPCC), the warming of the climate system is unequivocal. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The atmosphere and ocean have warmed since the pre-industrial period (1850–1900). The observed 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. The upward trend in the globally averaged temperature shows that more areas are warming than cooling. According to NOAA's 2020 Annual Climate Report, the combined land and ocean temperature has increased at an average rate of 0.13°F per decade since 1880; however, the average rate of increase since 1981, 0.32°F, has been more than twice that rate.

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 2020 was 1.4°F above average, at 59.2°F, when compared to a 1981-2010 base period average temperature. Statewide average temperatures were ranked at 117 making WY 2020 the 8th warmest out of 125 years of record dating back to 1895. (WRCC, 2021).

The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2020) 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

California statewide air temperature departures from 1981-2010 averages October through September

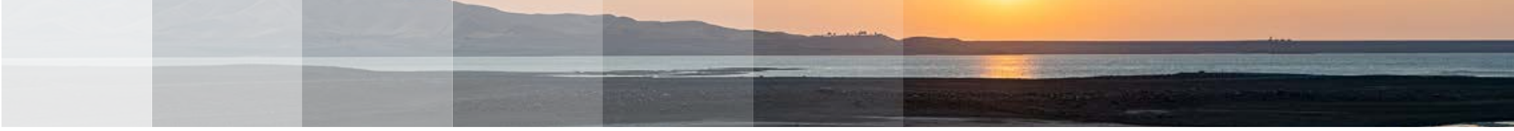


11-Year Running Mean

Western Regional Climate Center

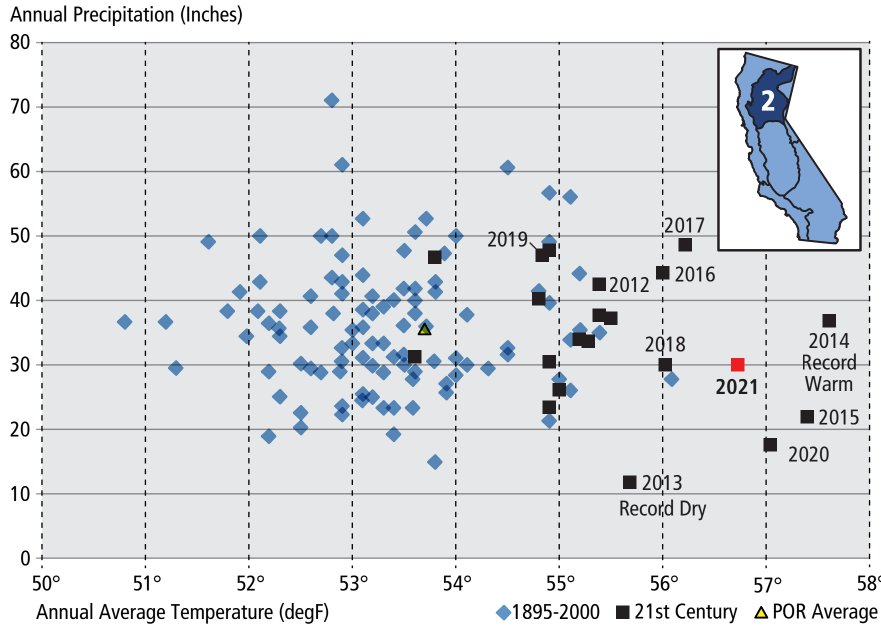
Summary Statistics

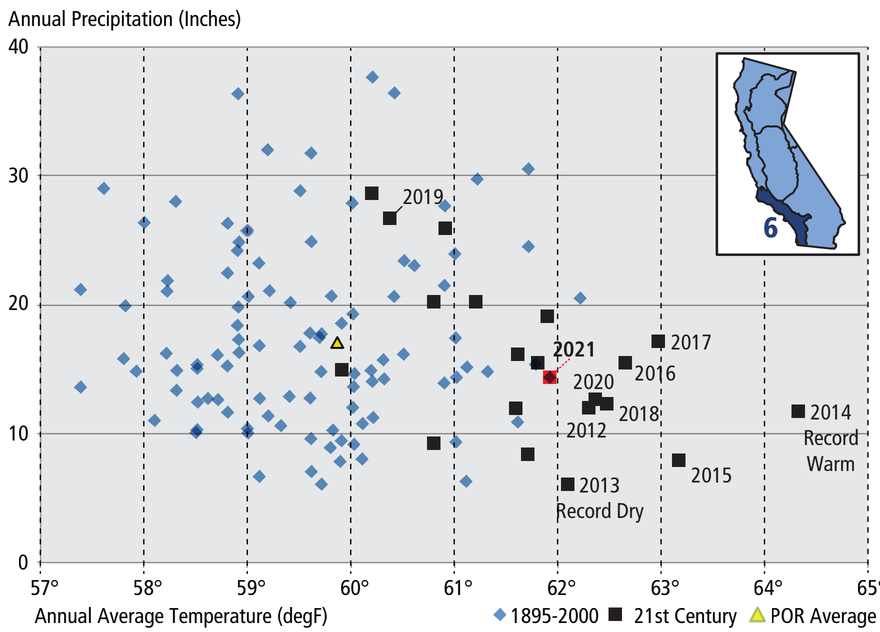
1981-2010 Averages	Extremes	Most Recent Year
Mean: 57.8°F	Warmest: 60.9°F (+ 3.1 °F from Average), 2015	October 2019-September 2020 | 59.2°F (+ 1.4 °F) | Rank: 117 of 125
Median: 57.9°F	Coldest: 54.5°F (- 3.3 °F from Average), 1917	(1 = Record Coldest, 125 = Record Warmest)



of annual precipitation versus annual average temperature are shown, using the annual average values from 1895-2021. Within Climate Division 2 (Sacramento Drainage), the long-term record depicts a dramatic increase 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 21 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. 2021 annual average temperature plots are depicted for the Sacramento Climate Division (57.0°F) and for the South Coast (62.4°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

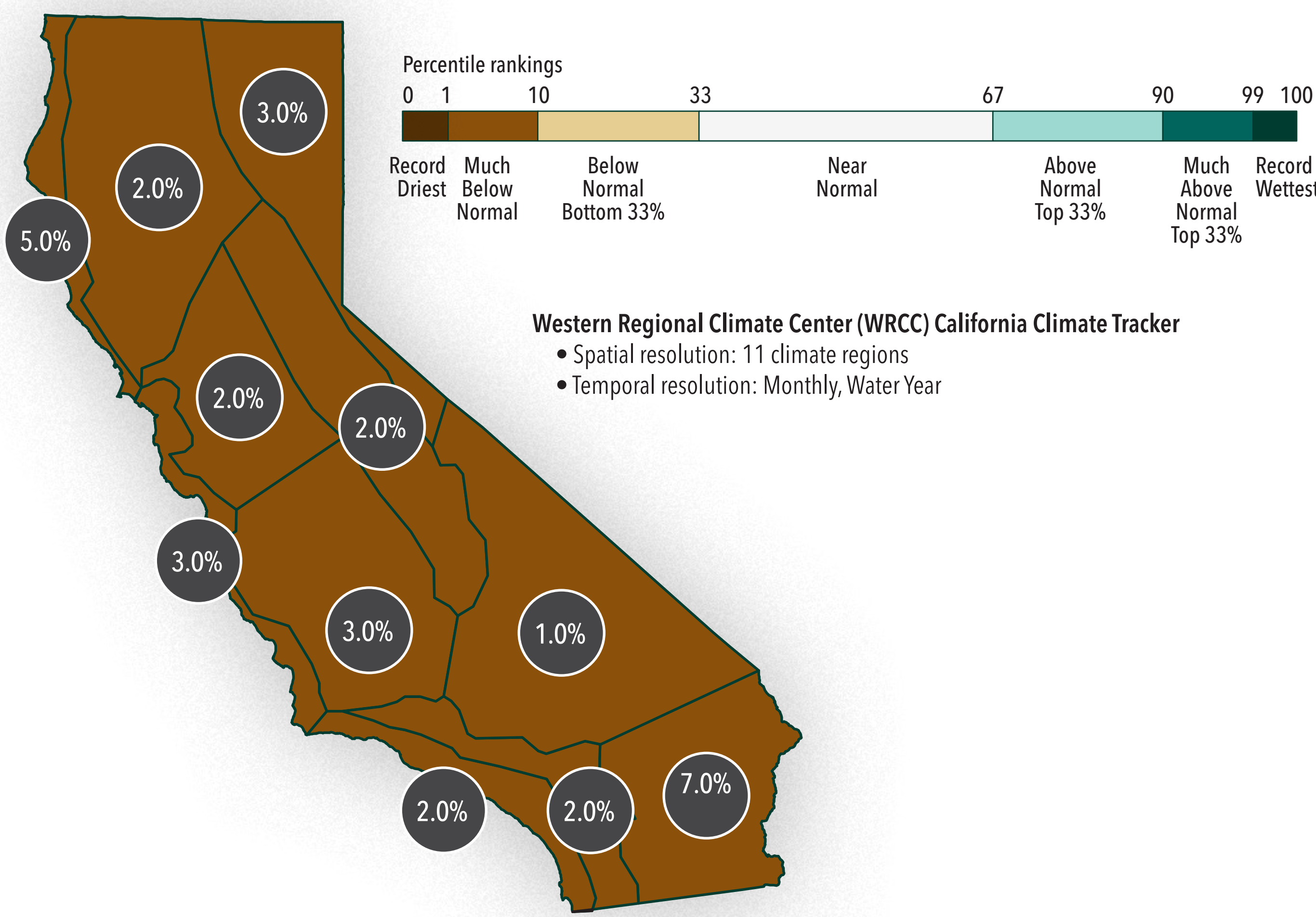
Annual precipitation data from California shows significant year-to-year variation. This inter-annual variability makes trend analysis difficult for this indicator. An analysis of precipitation records since the 1890's shows no statistically significant trend in precipitation throughout California. Although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

WY 2021 Precipitation

Statewide precipitation trends were analyzed by the Western Regional Climate Center (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 near record dry conditions across the state.

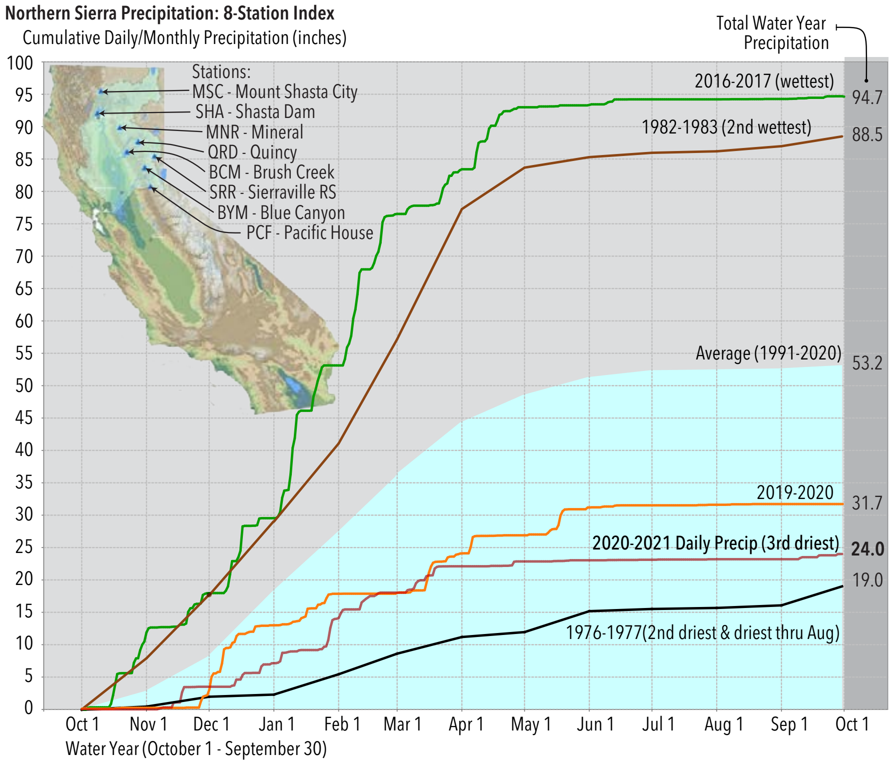
In the graphic below, the water year 2021 observed annual average temperature is depicted in its percentile ranking in climate divisions developed at Western Region Climate Center. All of the regions but the far southeast desert region ranking in the bottom 5% of the historical record.

California Climate Regions Precipitation Rankings, WY 2021

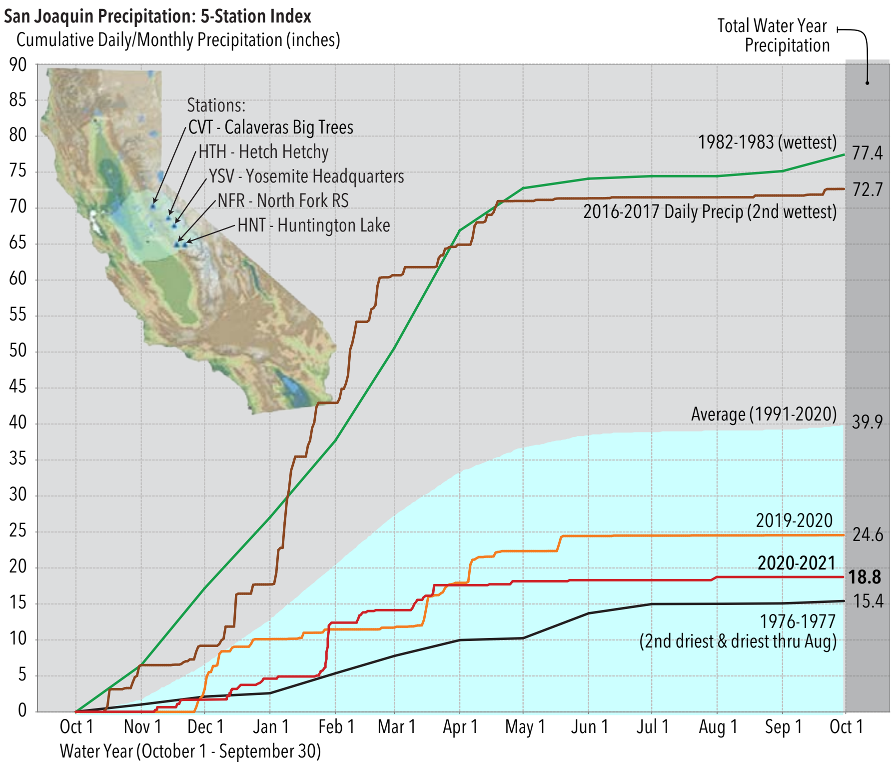


DWR Aggregate Precipitation Station Indices

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



For WY 2021, the Northern Sierra Precipitation 8-Station Index shows total WY precipitation at 31.7 inches, well below the long-term average of 51.8 inches. Accumulated precipitation in for the WY was 20.1 inches below average, and 39 percent below normal. The year was characterized by almost no precipitation in February and very dry summer months.

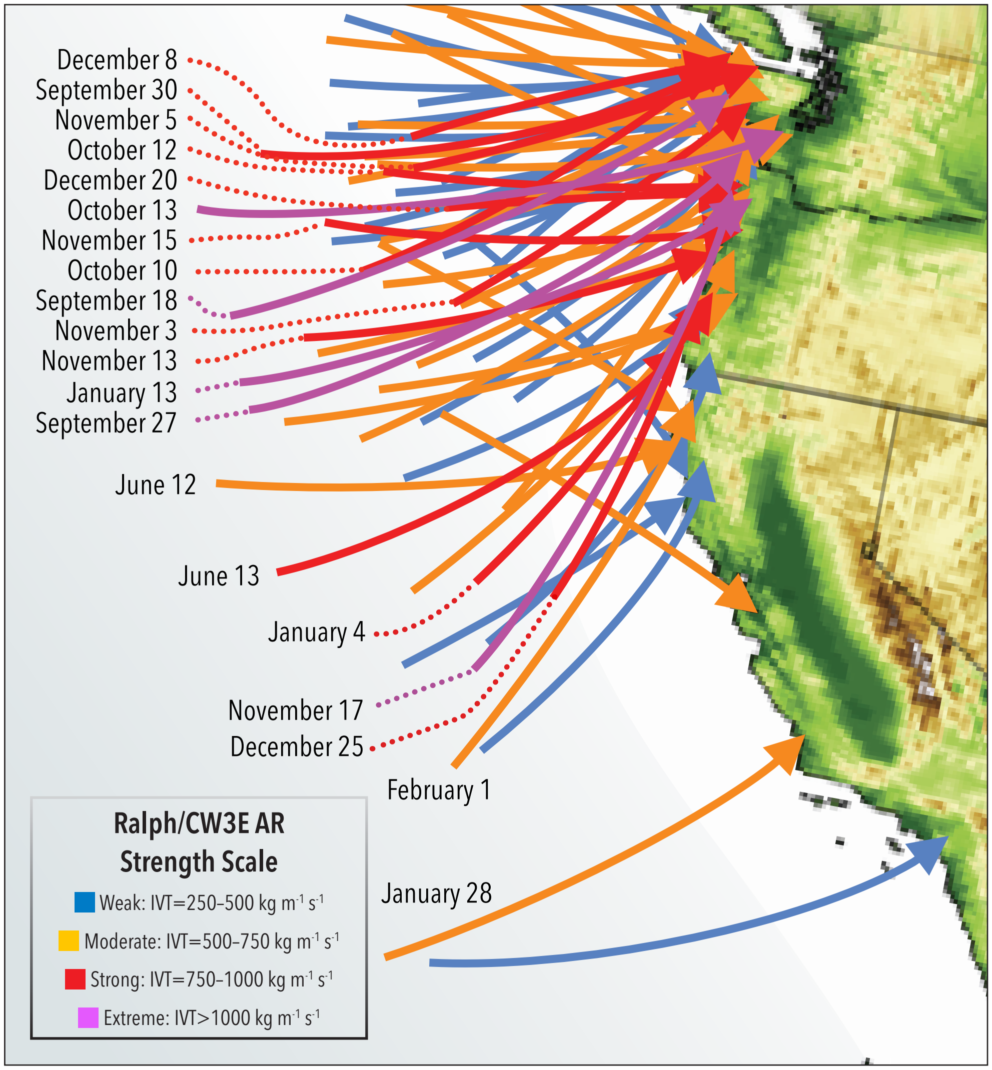


The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, typically receives less precipitation than the Northern Sierra. WY 2021 had a total WY precipitation of 18.8 inches, which was below the average of 40.2 inches for the Southern Sierra. Cumulative precipitation for WY 2021 was 39 percent below normal.

Atmospheric Rivers

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 250 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).

Distribution of all landfalling Atmospheric Rivers on the U.S. west coast during WY 2021



Graphic: Center For Western Weather and Water Extremes (CW3E) Scripps Institution of Oceanography. Produced by C. Hecht and F. M. Ralph

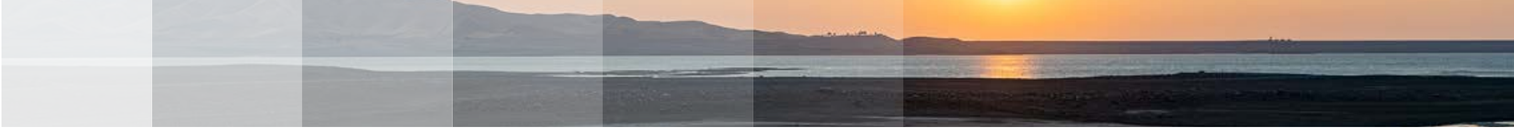
Atmospheric River strength by month and WY 2021 totals on the U.S. west coast.

AR STRENGTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
WEAK	0	3	1	4	3	4	3	1	3	0	1	2	25
MODERATE	4	1	5	4	5	2	0	1	1	0	2	2	27
STRONG	2	4	3	1	0	0	0	0	1	0	0	1	12
EXTREME	1	1	0	1	0	0	0	0	0	0	0	2	5
Total	7	9	9	10	8	6	3	2	5	0	3	7	69

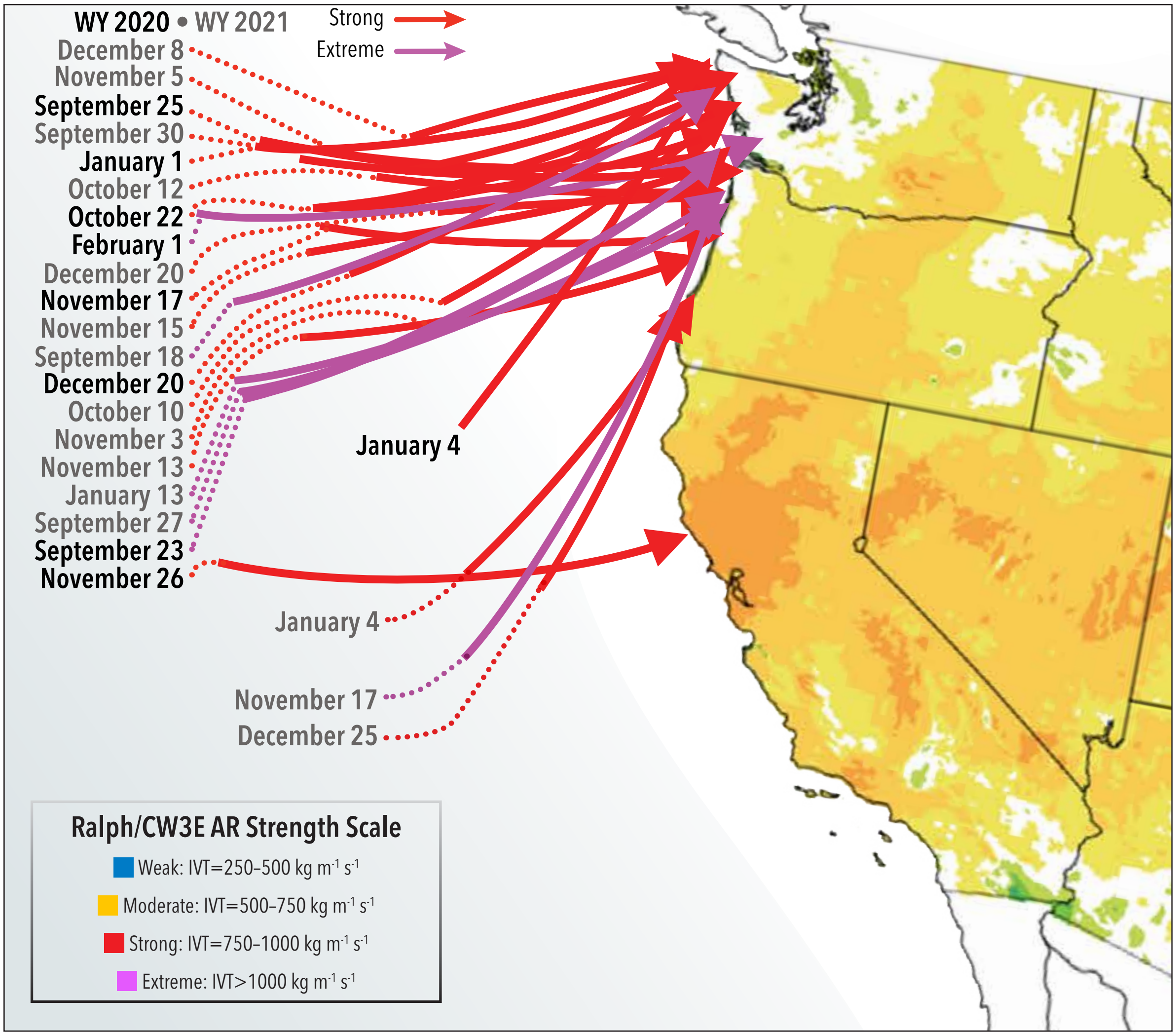
Atmospheric River strength by month and WY 2021 totals for California.

AR STRENGTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
WEAK	1	1	4	4	2	5	1	0	0	0	1	0	19
MODERATE	1	2	2	3	3	0	0	0	2	0	0	2	15
STRONG	0	1	1	0	0	0	0	0	0	0	0	0	2
EXTREME	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	4	7	7	5	5	1	0	2	0	1	2	36

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



Distribution of 36 Strong and Extreme Atmospheric Rivers on the U.S. west coast during WY 2020 and WY 2021



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 five categories: weak, moderate, strong, extreme and exceptional. The categories are evenly divided in increments of 250 flux units of IVT with exceptional being stronger than 1250 flux units.

The figure shows a characterization of the 69 ARs that made landfall for the West Coast in WY 2021 as well as the location of maximum intensity of the AR when it hit the coast. Of the 69 landfalling ARs, only 36 made landfall in California and only two of those reached the strong category.

WY 2020 and WY 2021: Lack of Strong and Greater ARs

On average California experiences 7 atmospheric rivers classified as strong or greater. For the past two WYs combined, there have been only three. The lack of significant storms is a key element to the record dry conditions that have manifested in this time.

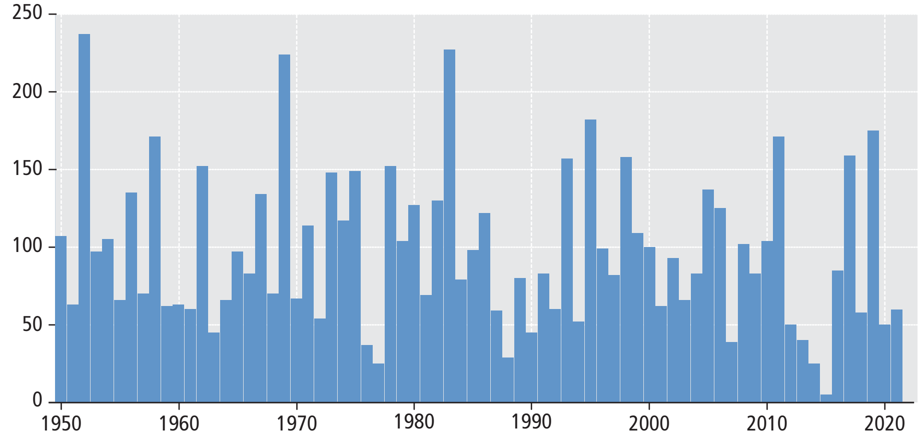
Table: Center F

Snowpack

The California Cooperative Snow Surveys program has been actively collecting data since the 1930's from Northern and Southern Sierra locations. April 1st Snow Water Equivalent (SWE), or snow-water content, is historically the date when the maximum snow accumulation has occurred at monitoring locations throughout the Sierra. The Statewide April 1st time series of percent of average snowpack is shown to the right. WY 2021 had an April 1st value of 60 percent of average. Adding in the perspective of a warming world, the April 1st statewide percent of average snowpack is plotted with the winter (December/January/February) minimum temperature from the Sierra climate region from the Western Region Climate Center's California Climate Tracker. WY 2021 adds another year of below average snowpack with above average Sierra winter minimum temperatures.

The California Environmental Protection Agency (EPA) Indicators of Climate Change in California (2018) report uses 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. These time series are depicted in Figures on page 15 with values presented being the April 1st Snow Water Equivalent (SWE).

Statewide snow water equivalent (April 1)
Percent of average

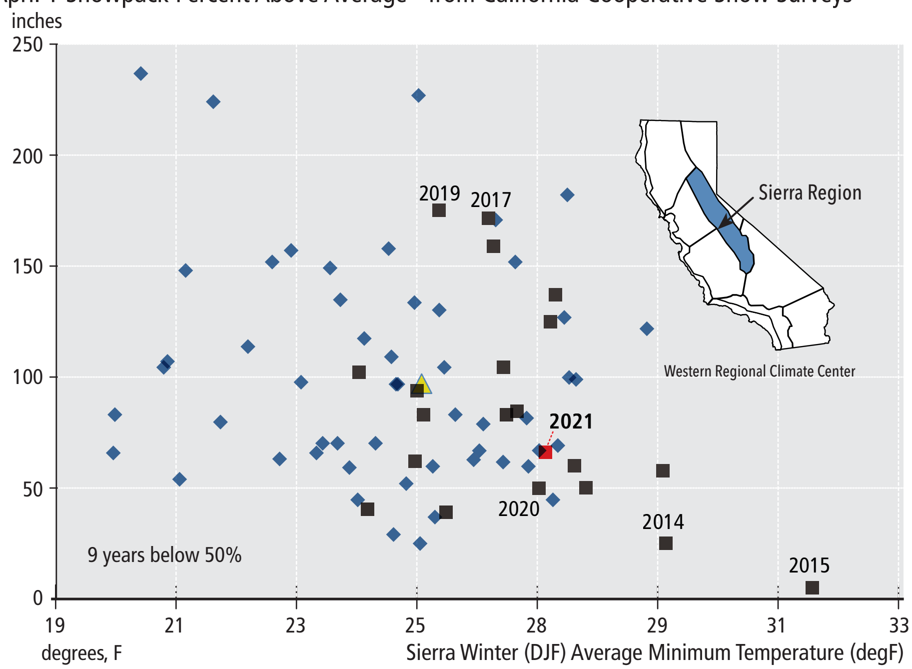


The April 1st snowpack for WY 2021 was 60 percent of the long-term average as of April 1. The peak snowpack was prior to April 1 at 64 percent. This was the tenth year in the 21st century with a snowpack below 75 percent of average on April 1 speaking to the narrative of a shrinking snowpack in a warming world.

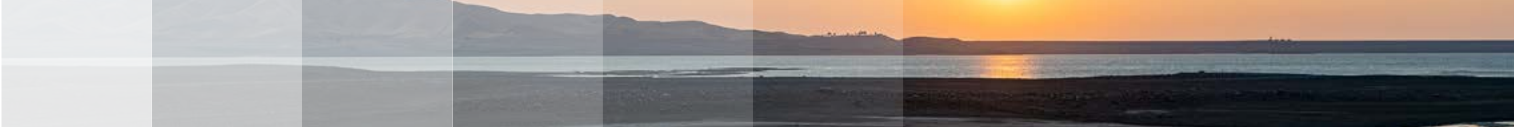
California Cooperative Snow Surveys - Snowpack

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

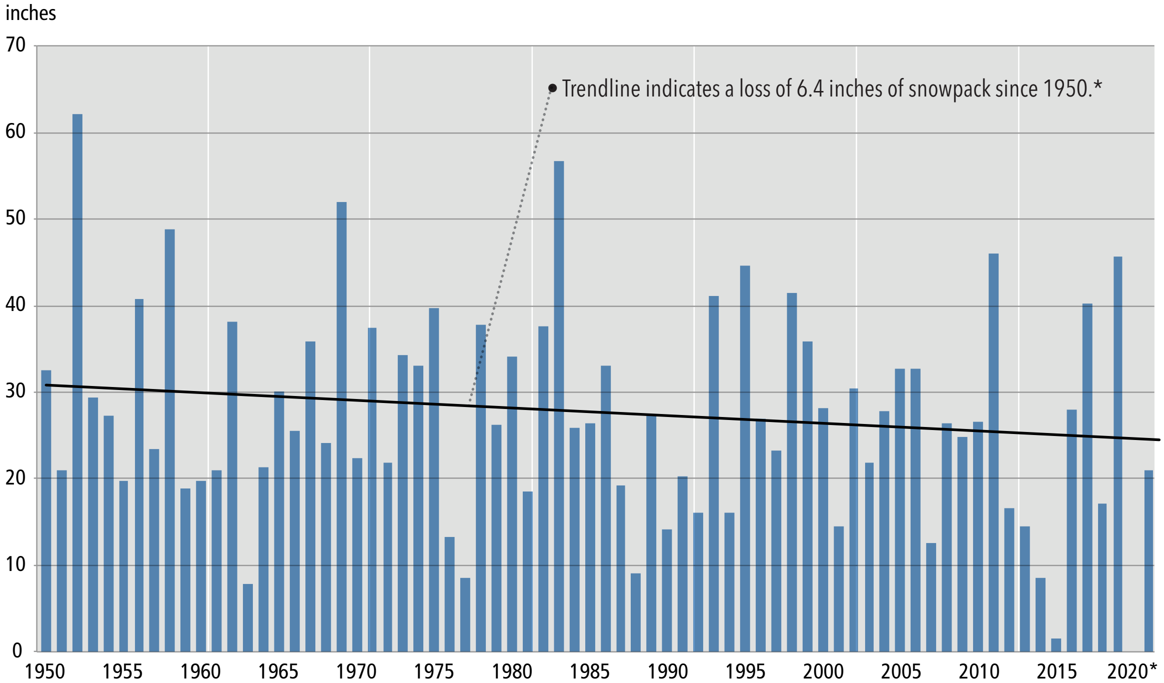
Sierra snowpack vs Winter Temperature, 1950-2021
April 1 Snowpack Percent Above Average - from California Cooperative Snow Surveys



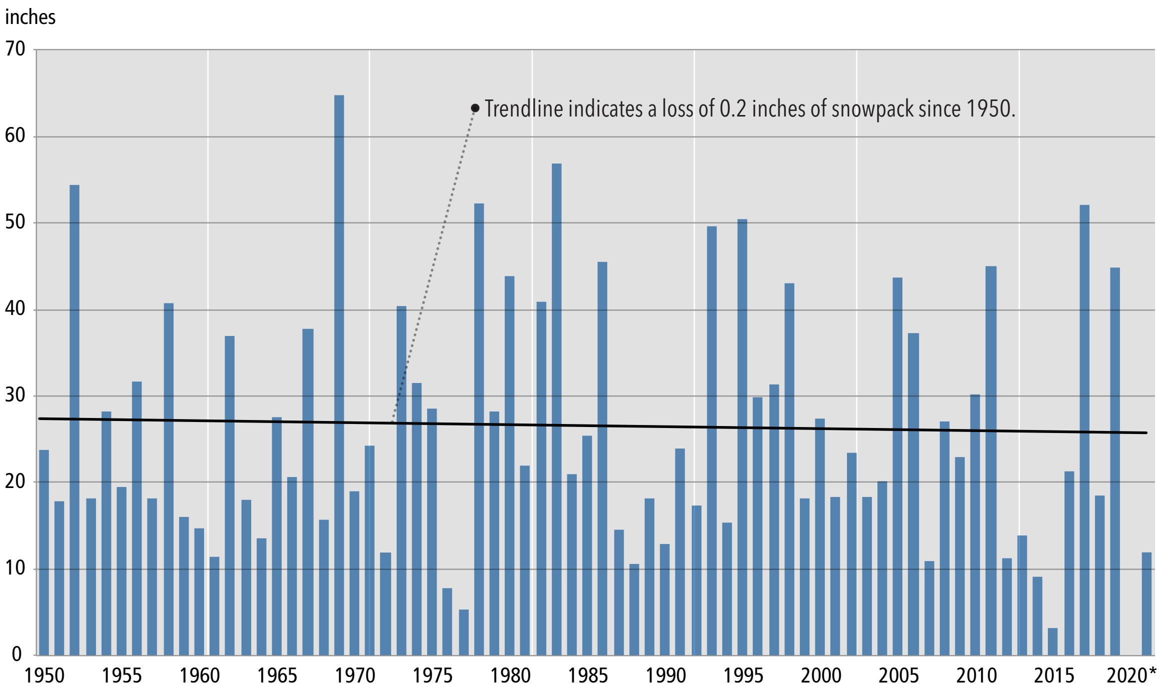
A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past seven years labeled as boxes.



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. Due to the work and travel restrictions due to the Covid-19 pandemic, a significant percentage of the snowcourses in the network were not sampled in WY 2020. Enough sampling points were measured in WY2021 to continue the plots. Up to WY 2021 the Northern Sierra trend indicates a loss of 0.96 inches per decade where the Southern Sierra trend indicated a loss of 0.21 inches per decade. The larger loss per decade in the Northern Sierra is primarily due to the lower elevation of the watersheds in the region where the transition from snow to rain will happen sooner.

*WY 2020 is not included in the figure(s) and trend(s). Due to the work and travel restrictions related to the COVID-19 Pandemic many snowcourses were not measured, leading to a data gap for WY 2020. Figures and trends will be updated in future reports when a sufficient amount of snowcourses have been sampled.

Water Year Type

California's water supply is influenced by geographic and seasonal variability which are subject to inter-annual climatic variability with year to year changes in precipitation and runoff. Runoff from the Sacramento and San Joaquin River basins provides much of the State's surface water supply and are classified using a WY type index system. Each WY, both river basins are classified as one of five WY types; a "wet" year classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical). Since the Sacramento River basin is rain-dominated and the San Joaquin River basin is snow-dominated, each basin has a separate method for determining WY types for that basin (CSWRCB, 1999). 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 water supply trends. These WY type classifications and "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 (see appendix for more detail).

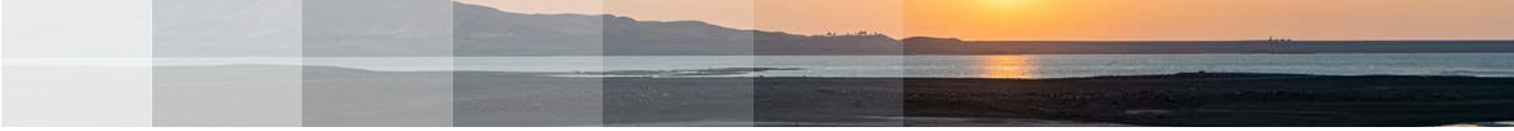
The WY classification system for the Sacramento and San Joaquin River basins was designed based on historical hydrology and the assumption that the climate does not change over time (stationarity). With climate change and changing hydroclimatic conditions there is debate whether this stationary approach to the WY indices will be adequate to inform water management decisions in the future. A 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 and earlier snowmelt runoff resulting in changes to streamflow timing. These shifts in temperature and runoff indicate that the climate is changing over time (non-stationarity). A recent study by He et al. (2021) also used the current WY classification system with future runoff projections. Generally, projections show increases in October to March runoff. For the rain-dominated Sacramento River basin, the projected April to July runoff decreases, whereas for the snow-dominated San Joaquin Basin, the change in April to July runoff depended on the climate model used. These runoff changes result in changes in the projected WY types. The study highlights non-stationarity and long-term uncertainties in the results with runoff being more sensitive to the greenhouse gas emissions scenario used and WY types being more sensitive to the climate model used. Climate-adaptive WY typing methods could be explored in the future, which would take into account uncertainty in future climate and the hydro-climatic non-stationarity that has already been observed in the historical record.

Low water conditions at Lake Oroville reveal the intake structure. The lake was at 26 percent of total capacity. Photo taken July 26, 2021.

The Sacramento Valley 40-30-30 Index based on flow in million-acre feet for WY 2020 was 35 percent of average with an index value of 3.8 classified as a "Critical" WY type.

The San Joaquin River upstream from Millerton Lake State Recreation Area. Photo taken on January 4, 2021, by Benjamin Cossel/BLM.

The San Joaquin Valley 60-20-20 Index based on flow in million-acre feet for WY 2020 was 33 percent of average with an index value of 1.32 classified as a "Critical" WY type.



Sacramento River Runoff

Water Year Index	WATER YEAR TYPE
WY 1983 Wettest Year ... 15.3	WET (INDEX VALUES)
WY 2017 ... 14.2	WET
WY 2019 ... 10.3	WET
	9.2
WY 1966-2016 Average ... 8.0	ABOVE NORMAL
	7.8
WY 2018 ... 7.1	BELOW NORMAL
WY 2016 ... 6.7	BELOW NORMAL
	6.5
WY 2020 ... 6.1	DRY
WY 2013 ... 5.8	DRY
	5.4
WY 2014 ... 4.1	CRITICAL
WY 2015 ... 4.0	CRITICAL
WY 2021 ... 3.8	CRITICAL
WY 1977 (minimum) Driest Year ... 3.1	CRITICAL

San Joaquin River Runoff

Water Year Index	WATER YEAR TYPE
WY 1983 Wettest Year ... 7.2	WET (INDEX VALUES)
WY 2017 ... 6.5	WET
WY 2019 ... 4.9	WET
	3.8
WY 1966-2016 Average ... 3.2	ABOVE NORMAL
	3.1
WY 2018 ... 3.0	BELOW NORMAL
	2.5
WY 2016 ... 2.4	DRY
WY 2020 ... 2.3	DRY
	2.1
WY 2013 ... 1.7	CRITICAL
WY 2021 ... 1.32	CRITICAL
WY 2014 ... 1.2	CRITICAL
WY 2015 (minimum) Driest Year ... 0.8	CRITICAL

Rain/Snow Trends

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). Lynn et al. (2020) 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.

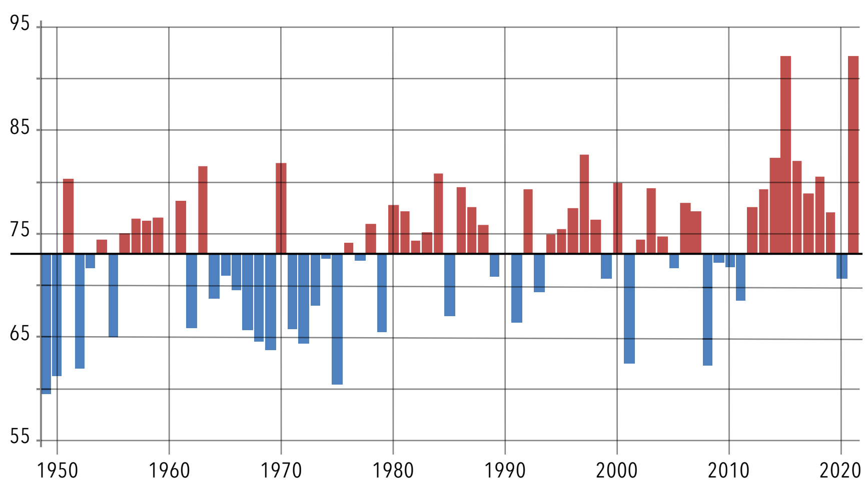
The figure shows the annual percentage of rain of total precipitation for all Zones A-D (see figure), from 1949- 2021. The mean for the period of average shows rain is 74 percent of total precipitation, with substantial interannual variability due to climate signals that occur on annual or multi-annual timescales. Years that have a higher percentage of rain than the mean are more common and occur more continually in recent years. The past ten years have seen rain making up 81% of total precipitation, meaning only 19% of all the precip in these zones has fallen as snow (the % of snow had been 29% in the first half of the record, from 1949-1985). For WY 2021, the percent of precipitation that fell as rain was 92%, due to the limited amount of total precipitation. The limited number of storms amplifies the influence of atmospheric rivers which drop more rain than snow.

Snowpack declines are projected to continue into the 21st century and be further influenced by more frequent and greater wet and dry extremes. Additional analysis (DWR 2020) indicates that the highest elevation regions in the Sierra Nevada have not experienced significant declines in precipitation falling as snow, to date, during winter and spring. With continued warming, these areas are expected to undergo declines in the snow fraction of the total precipitation. Many current multipurpose reservoir management paradigms require reservoir storage space allocated to attenuate periods of heavy inflow and reduce flood hazard during cool season storms. Water captured during the flood is later released to maintain the flood pool storage capabilities during the next possible event. Flood pool releases mean this water cannot be stored for later beneficial use and must be managed as a hazard rather than a resource. Work is in progress to develop adaptation strategies such as forecast- informed reservoir operations and managed aquifer recharge to enable more flexibility to meet the growing water management challenge of more rain and less snow.

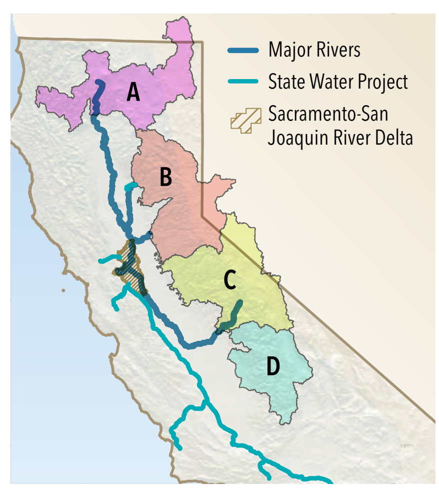
WY percentage of rain for the analysis period WY 1949-2021 for All Zones A-D

For 1st half of record: 71; mean for 2nd half of record: 76; mean for entire dataset: 74; mean for 2021:92; mean for the last decade:81

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



The figure below shows the analysis zones for rain/snow trends. Zone B includes Oroville reservoir, DWR's primary storage reservoir for the State Water Project.

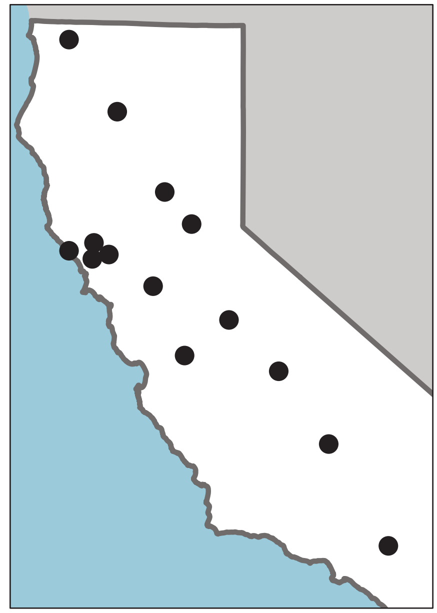


Snow-Level Radar

Snow-Level Radar is an 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, to provide high resolution observations during storms and information on extreme precipitation events and long-term climate observations.

This indicator provides 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 for flood management and water supply forecasting.

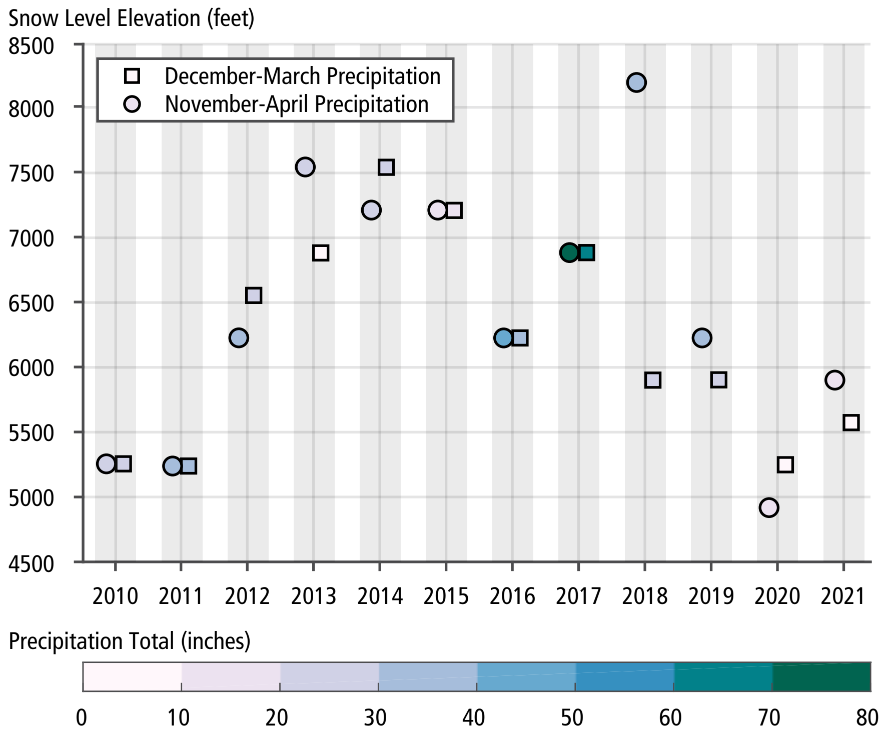
A recent study that employed snow-level sensing radar measurements identified a statistically significant trend in higher winter snow levels in the northern Sierra Nevada between 2008-2017 (Hatchett et al., 2017). However, due to the short duration of the snow level dataset, continued collection of observations is needed to determine if the upward 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

Average Elevation for Rain/Snow Boundary

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. The first period, 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. WY 2020 demostrated the lowest snow level elevations in the record since WY 2010, however with overall low storm precipitation totals this correlates with the statewide April 1 SWE being at 50 percent below normal for the 2020 WY. Dot/square colors correspond to total precipitation for the respective time periods, shown in the colorbar at the bottom.



Unimpaired Streamflow: Sacramento and San Joaquin River Systems

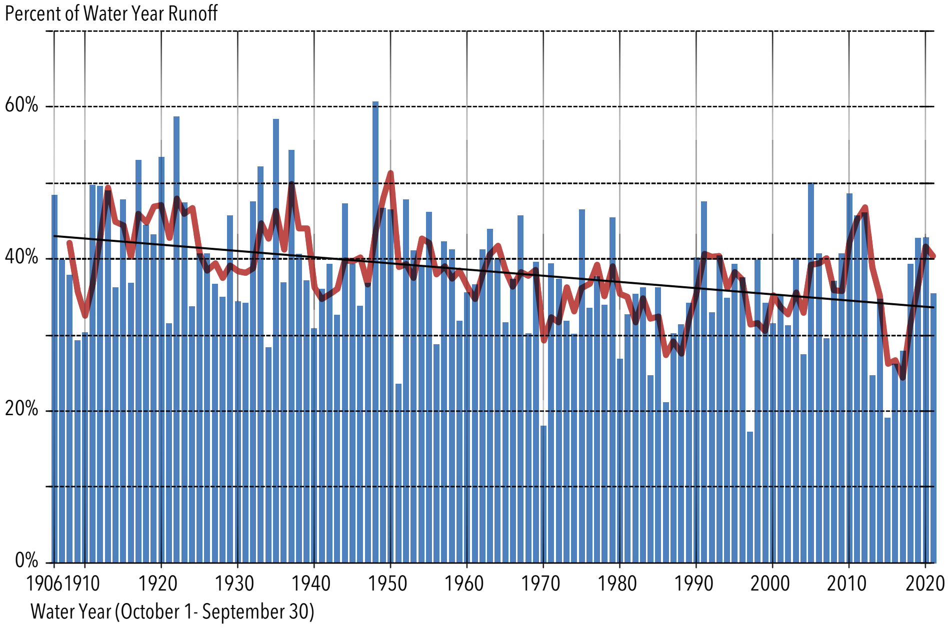
With increasing temperatures and corresponding loss of snowpack, how can a comparison be made representing spring snowmelt? Since the main watersheds in California have been altered by water development projects such as dams and diversions, historical natural hydrology flows would be difficult to compare. 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 below average precipitation and snowpack, WY 2021 April through July streamflow was 66 percent below average at 4.1 million-acre feet in the Sacramento River and 58 percent below average at 2.1 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.

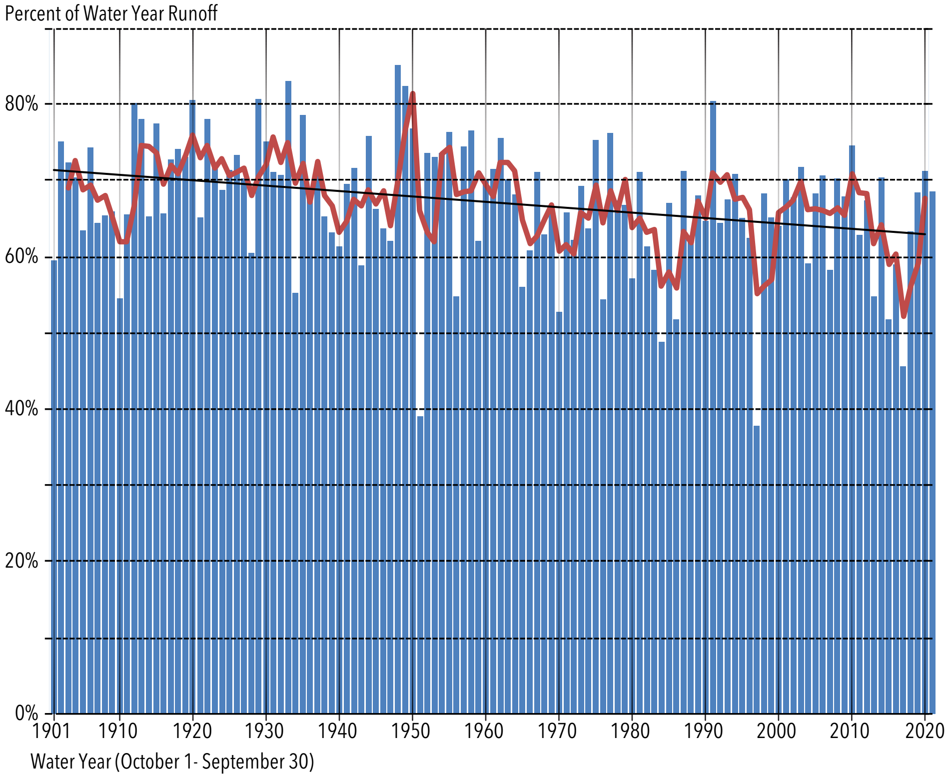
Sacramento River Runoff, April - July Runoff in percent of Water Year Runoff

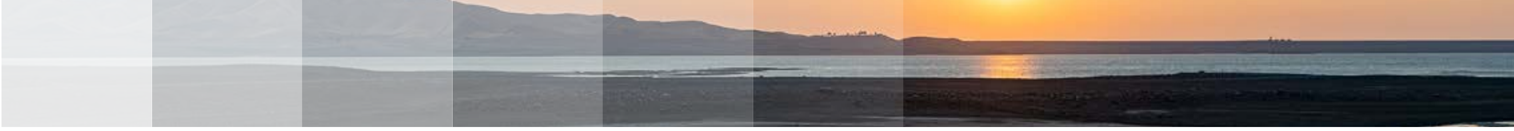
Linear Regression (least squares) line showing historical trend — 3-year running average



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

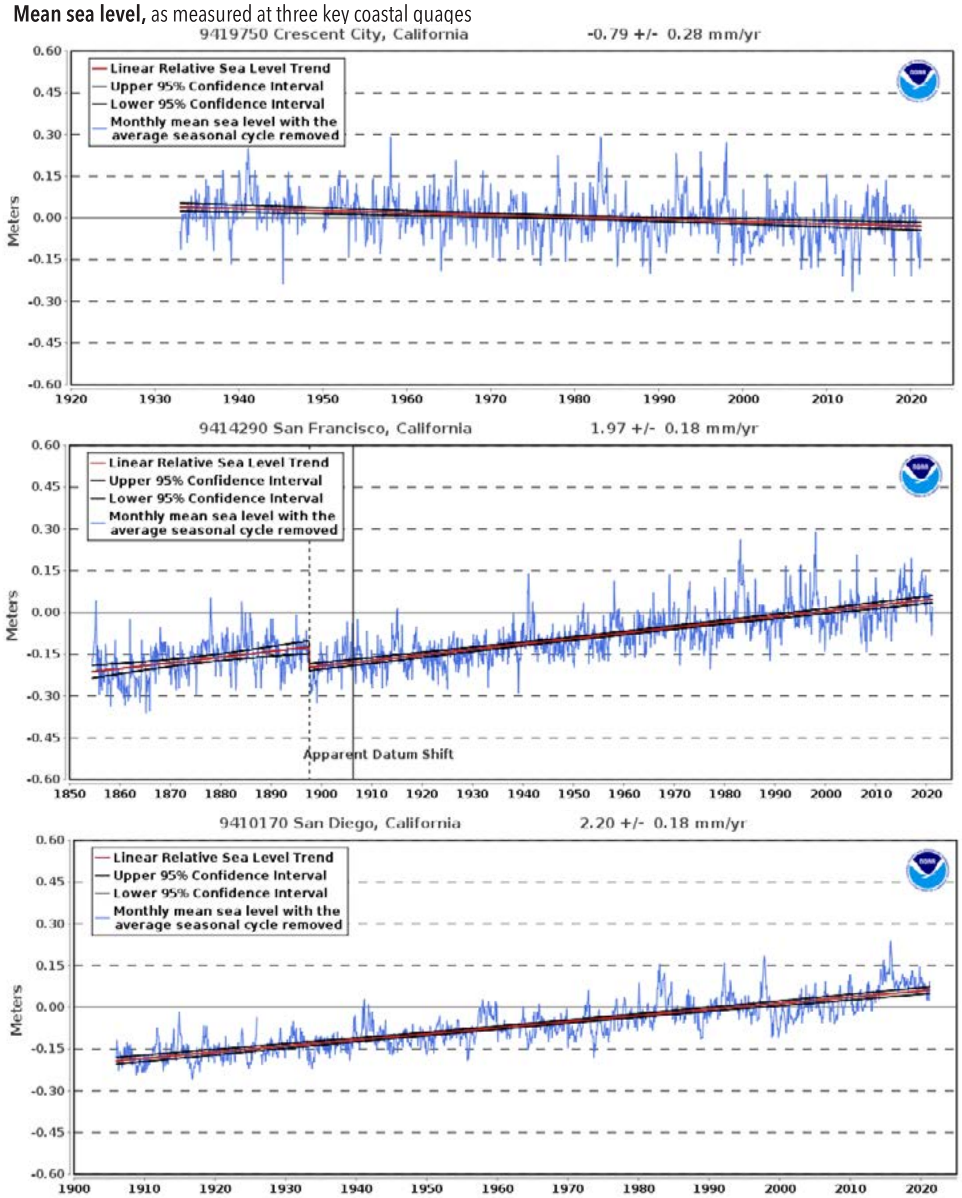
Sea level is tracked along the California coast by the National Oceanic and Atmospheric Administration (NOAA) at 12 active tide gauges, which range in their periods of record from 39 years (Point Arena) to 162 years (San Francisco). Mean sea level at three key coastal tide gauges Crescent City, San Francisco Golden Gate, and 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 replaced by 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



Signposts of Change

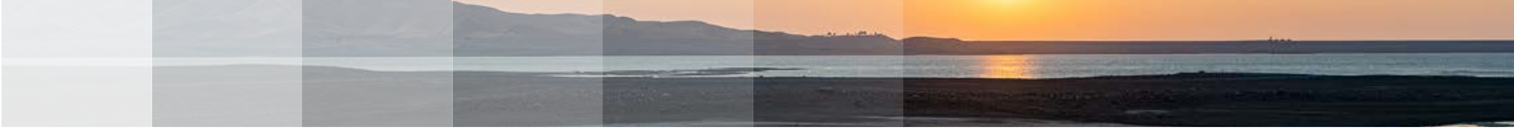
Welcome to "Signposts of Change." This section highlights key climatic events during WY 2021 that show significant effects of increasing temperatures, changing precipitation patterns, and more extreme precipitation.

Global greenhouse gases were at their highest levels ever in 2021 (Blunden and Boyer, 2022). Extreme temperatures dominated the summer of 2021. In late June, the west coast of North America had the most extreme heat wave in recorded history with the most temperature records broken by the largest amounts (Masters, 2022). On June 29 it was 121°F (49.6°C) in Lytton, British Columbia, Canada, which was then ravaged by wildfires the next day. On June 30th, Fort Smith, Northwest Territories, Canada's temperature of 103.8°F (39.9°C) was the highest ever recorded north of 60°N (Blunden and Boyer, 2022). The extreme heat continued with July being the Earth's hottest month in recorded history (NOAA, 2021). In August, temperatures at the 10,551 ft summit of Greenland's Ice Sheet rose above freezing, and rain fell for the first time on record (Scott, 2021). For the 10th consecutive year, global sea levels were at the highest levels since satellite measurements began in 1993 (Blunden and Boyer, 2022).

The warm conditions in WY2021 were accompanied by extremely dry conditions. July 2021 was the driest month in California since records began in 1895 (Ramirez et al, 2021). According to the California Climate Tracker, WY2020 to WY2021 was the driest two-year period in California with a record low 28.2 inches of precipitation. Extreme dry conditions throughout the West lead to record low reservoir levels in Lake Powell (Ramirez and Passantino, 2021) and Lake Mead (Carlowicz and Hansen, 2021), which store Colorado River water and provide part of southern California's water supply. In August in Northern California, the Hyatt Powerplant was forced to close for the first time due to low water levels (DWR, 2021). That same month, the peak of Mount Shasta was anomalously snow free (Neumann, 2021), and the Caldor and Dixie wildfires became the first wildfires to burn over the crest of the Sierra Nevada from the west slope to the east slope (Wigglesworth and Smith, 2021).

Summary of Signposts of Climate Change for Water Year 2021 (Oct 2020-Sept 2021)

PERIOD	SIGNPOST of CHANGE
California and Western North America	**Incident**
June 2021	Most extreme West Coast heat wave (most records broken by largest amounts)
July 2021	Driest month on record for California (record started in 1895)
July 2021	Lake Powell and Lake Mead reach record low water levels
August 2021	Hyatt Powerplant forced to shut down for the first time due to low water levels
August 2021	Mt. Shasta has no snow at the peak
August 2021	Caldor and Dixie Wildfires are first ever to cross the crest of the Sierra Nevada
WY2020-21	Driest 2-year period on record with 28.2 inches total precipitation (28.7in WY1976-77)
Global	**Incident**
July 2021	Earth's hottest month on record
August 2021	First time rain fell at the summit of Greenland's Ice Sheet (10,551 ft elevation)
2021	Atmospheric greenhouse gas concentrations were the highest on record
2021	Highest global sea levels on record



Notable Climate Events and Weather Extremes

WY 2021 continued the narrative of more heat and more variability. In addition, it was the driest year in nearly a century. October started dry, ranking as the 4th driest October statewide with records dating back to 1895. The dryness continued into November with the first precipitation arriving in the middle of the month. November finished below normal for precipitation as well finishing about half of average. December was largely dry with only two small storms passing through. With precipitation about half of average, the seasonal snowpack similarly started development slowly reaching 50% of average to date at the end of the month.

January started and ended with a storm with dry conditions in between. The largest storm of the year was at the end of January with multiple days of rain and strong damaging winds. It was a cold storm which deposited snow at lower elevations. The statewide snowpack jumped to 68% of average based on the automated snow sensors. It would be discovered in later analysis that the distribution of snowpack in the Sierra Nevada was not following historical patterns due to the limited storm activity of the season. February was largely dry with the exception of a storm in the middle of the month. Both February and March recorded below average precipitation. Statewide October-March precipitation finished fourth driest in 126 years of record. Statewide snowpack numbers fell to about 60% of average. Then the extreme conditions kicked in.

April 1 is the historical average for the peak snowpack. October through March accounts on average for 80% of the statewide precipitation. April through July is the historical period when the seasonal snowpack melts providing key streamflow for beneficial use. WY 2021 was different than all the years in the observed record before it. The April/May/June precipitation was the lowest on record with only about half an inch falling versus an average of about three inches. It was also the warmest on record with a value that was four degrees Fahrenheit above average.

These extremes coupled with the dry extremes to start the year led to spring runoff well below what was expected and outside the historical relationships between snowpack, precipitation, and runoff. A number of drought related consequences resulted as summer began.

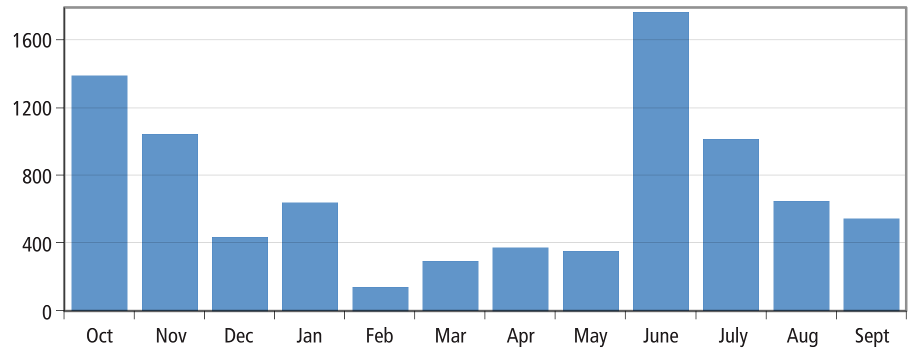
WY 2020 ranks as the warmest mean statewide temperature on record for July/August/September with a value of 75.9 degrees Fahrenheit. WY 2021 set a record for warmest July for statewide average temperature. August is on average the warmest month of the year for California. The warmest year in the historical record was 2020 and WY 2021 was ranked sixth warmest. At the end of September WY 2021 recorded a July/August/September value of 75.8 degrees Fahrenheit almost equaling the previous year's record heat. Fires again played a significant role in summer and fall of 2021 with significant fires burning large parts of the state. The Dixie fire in the Feather River watershed ended as the second largest fire in history and second fire to consume more than 750,000 acres.

A man cleans up in Sacramento County after a storm. Photo taken January 27, 2021. Right: Governor Newsom after a press conference on a dry Lake Mendocino, where he proclaimed a regional drought emergency for the Russian River watershed. Photo taken April 21, 2021.

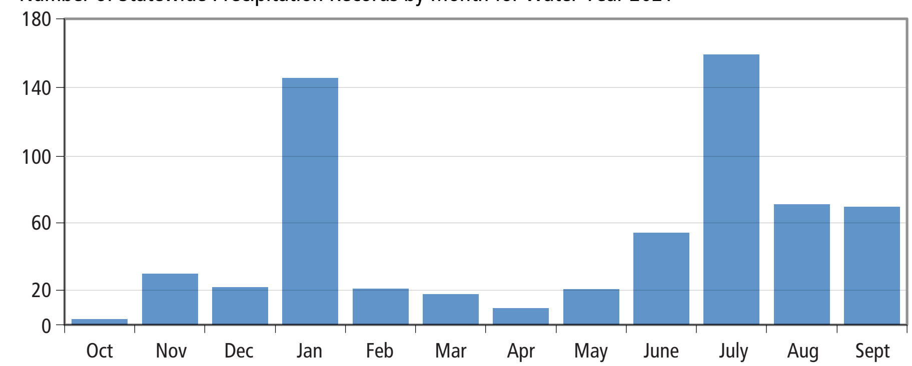
WY 2021 finished with record low reservoir storage to add to its list of records or near records. It was the second driest single year on record for statewide precipitation and second warmest in history. Coupled with the record-setting WY 2020, the two-year period ended as the driest two-year period for statewide precipitation beating out the record setting drought of 1976/1977. In a progression from extreme to episodic to common, this is the third record-setting multi-year drought of the 21st Century with an expectation of more extremes and impacts to come.

The graphics to the right depict the monthly distribution of new extreme temperature and precipitation records for WY 2021. For WY 2021 there were a total of 623 new daily precipitation records and 8,629 new daily temperature records. The extreme months of October, November, June, and July stand out with more than 1,000 temperature records in each of those months.

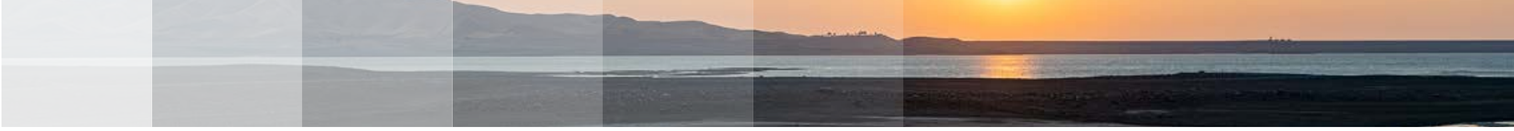
Number of Statewide Temperature Records by Month for Water Year 2021



Number of Statewide Precipitation Records by Month for Water Year 2021



The Fawn Fire, five miles northeast of Lake Shasta, began September 22, 2021, and burned 8,578 acres in Shasta County before being contained on October 2. Photo by CalFire

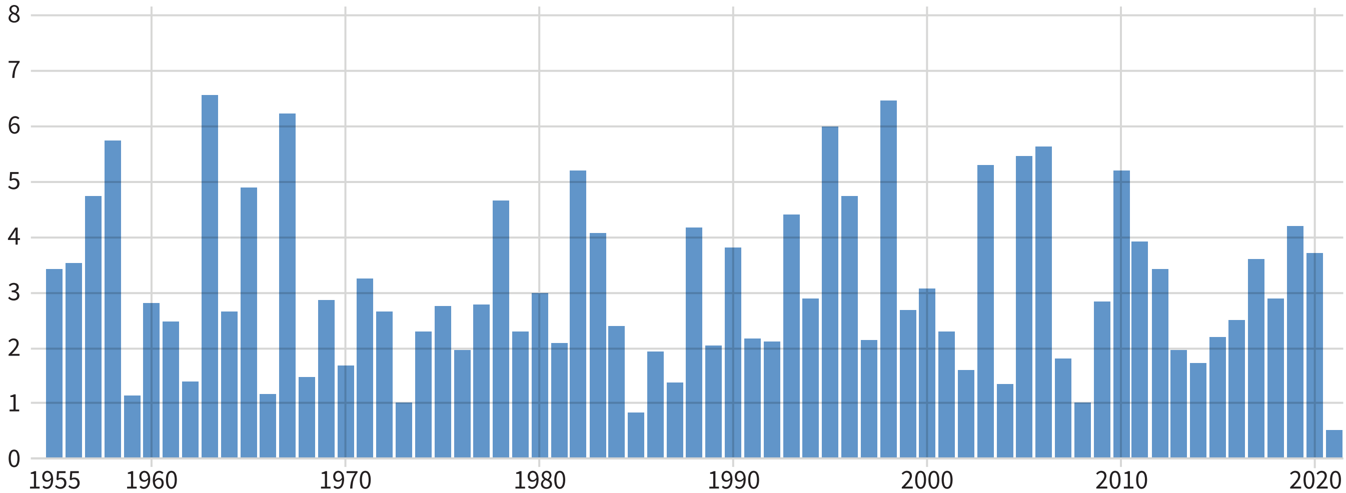


Dryness Indicator

The climate change narrative includes greater wet and dry extremes, more dry days, and warmer temperatures. This can lead to increased episodes of drought as well as aridification – the permanent drying of the landscape. There is no one indicator that can cover all facets of these impacts of changing precipitation and increasing temperatures. Candidate metrics of consecutive dry day runs in winter, monthly, seasonal, and annual precipitation deficit will be considered. For WY 2022, the Hydroclimate Report will be rolling out a suite of indicators that explore the observed data to determine if there are metrics that show change and how those metrics align with the cycle of floods and droughts in California. With three record-setting droughts in the last 15 years, it is imperative to be able to identify metrics that can help California implement adaptation strategies in a timely manner to adapt to a warming world with different patterns of precipitation impacting water management.

Statewide April/May/June Precipitation

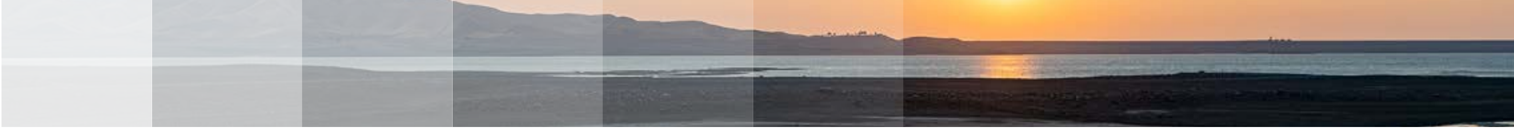
in inches



The River Complex Fire started July 30, 2021, from multiple lightning fires. Located west of Weed in northern California, the fire burned over 200,000 acres before containment.

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.
- **Aridification:** the gradual transition of a region from a wetter to a drier climate, primarily referring to the reduction of atmospheric water vapor due to higher temperatures, reduced precipitation and increased evaporation.
- **Atmospheric Rivers:** long, narrow bands of intense water vapor concentrated in the lower atmosphere that transport most of the water vapor outside of the tropics. When atmospheric rivers make landfall, they often release this water vapor in the form of rain or snow. Abbreviated as A/Rs, they are critical to water supply in the West Coast.
- **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.

https://cdec.water.ca.gov/reportapp/javareports?name=PLOT_ESI.pdf

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

https://cdec.water.ca.gov/reportapp/javareports?name=PLOT_FSI.pdf

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.

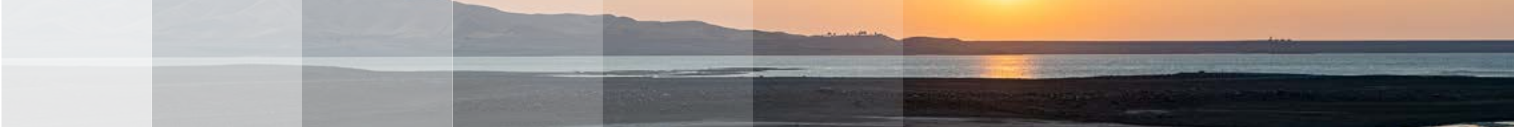
Decision 1641: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/decision_1641/

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

SEA LEVEL TRENDS

https://tidesandcurrents.noaa.gov/sltrends/

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.

REFERENCES

Abatzoglou, J.T., K.T. Redmond, L.M. Edwards, 2009, Classification of Regional Climate Variability in the State of California, ***Journal of Applied Meteorology and Climatology***, 48, 1527-1541.

Ault, T. and St. George, S. 2010. The Magnitude of Decadal and Multidecadal Variability in North American Precipitation. ***Journal of Climate***. 23, 842-850.

Blunden, J. and T. Boyer, Eds., 2022: "State of the Climate in 2021". ***Bull. Amer. Meteor. Soc.***, 103 (8), Si–S465, https://doi.org/10.1175/2022BAMSStateoftheClimate.1Carlowicz M. and Hansen K., 2021. Lake Mead Drops to a Record Low, Nasa Earth Observatory, https://earthobservatory.nasa.gov/images/148758/lake-mead-drops-to-a-record-low

California Environmental Protection Agency. 2013. ***Indicators of Climate Change in California.***

California Department of Water Resources. 2014. ***Estimating Historical California Precipitation Phase Trends Using Gridded Precipitation, Precipitation Phase, and Elevation Data.*** Memorandum report.

California State Water Resources Control Board (CSWRCB). Water Right Decision 1641; CSWRCB: Sacramento, CA, USA, 1999; p. 225.

Dettinger, Michael. (2016). Historical and Future Relations Between Large Storms and Droughts in California. ***San Francisco Estuary and Watershed Science***, 14(2).

DWR, 2021. DWR Statement on the Status of Hyatt Powerplant at Lake Oroville, California Department of Water Resources, August 5, 2021. https://water.ca.gov/News/News-Releases/2021/Aug-21/Hyatt-Statement

Hansen, J., R. Ruedy, M. Sato, and K. Lo.2010. Global surface temperature change. ***Reviews of Geophysics***, 48 (RG4004).

Hatchett, B.J., B. Daudert, C.B. Garner, N.S. Oakley, A.E. Putnam, A.B. White. Winter Snow Level Rise in the Northern Sierra Nevada from 2008 to 2017. *Water* 2017, 9, 899.

He M, Anderson J, Lynn E, Arnold W. Projected Changes in Water Year Types and Hydrological Drought in California's Central Valley in the 21st Century. ***Climate***. 2021; 9(2):26. https://doi.org/10.3390/cli9020026

IPCC. 2019. Summary for Policymakers. ***Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.*** P.R. Shukla, et al.

Karl, T. and Koss, W.,1984. Historical Climatology Series 4-3: Regional and National Monthly, Seasonal and Annual Temperature Weighted by Area, 1895-1983. From NOAA Institutional Repository: https://repository.library.noaa.gov/view/noaa/10238.

Lavers, D.A., D.E. Waliser, F.M. Ralph and M.D. Dettinger, 2016: Predictability of horizontal water vapor transport relative to precipitation: Enhancing situational awareness for forecasting Western U.S. extreme precipitation and flooding. ***Geophysical Research Letters***, 43, 2275-2282.

Lynn, E., Cuthbertson, A., He, M., Vasquez, J. P., Anderson, M. L., Coombe, P., Abatzoglou, J. T., and Hatchett, B. J.: Technical note: Precipitation-phase partitioning at landscape scales to regional scales, ***Hydrology and Earth Systems Sciences***, 24, 5317–5328, https://doi.org/10.5194/hess-24-5317-2020, 2020.

Lukovic´, J., Chiang, J. C. H., Blagojevic´, D., & Sekulic´, A. 2021. A later onset of the rainy season in California. ***Geophysical Research Letters***, 48, e2020GL090350.

Masters, Jeff 2022. The top 10 global weather and climate change events of 2021, ***Yale Climate Connections***, January 11, 2022. https://yaleclimateconnections.org/2022/01/the-top-10-global-weather-and-climate-change-events-of-2021/

Mote, P.W. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. ***Geophysical Research Letters 30 (12): 1601.***

Mote, Philip W. 2006. Climate Driven Variability and Trends in Mountain Snowpack in Western North America. ***Journal of Climate***, 19 6209-1620.

National Research Council. 2012. ***Sea-Level Rise for the Coasts of California, Oregon, and Washington.***

Neumann, E. 2021. Snow-Free View of Mount Shasta Prompts Climate Worries, Jefferson Public Radio, August 26, 2021. https://www.ijpr.org/environment-energy-and-transportation/2021-08-26/snow-free-view-of-mount-shasta-prompts-climate-worries

NOAA National Centers for Environmental Information, ***State of the Climate: Global Climate Report for Annual 2020***, published online January 2021, retrieved from https://www.ncdc.noaa.gov/sotc/global/202013.

NOAA, 2021. It's official: July was Earth's hottest month on record, National Oceanic and Atmospheric Administration, August 13, 2021. https://www.noaa.gov/news/its-official-july-2021-was-earths-hottest-month-on-record

Null, S. E., and J. H. Viers (2013), In bad waters: Water year classification in nonstationary climates, ***Water Resources Research***, 49.

Pierce, D. W., T. Das, D. R. Cayan, E. P. Maurer, N. L. Miller, Y. Bao, M. Kanamitsu, K. Yoshimura, M. A. Snyder, L. C. Sloan, G. Franco, M. Tyree, 2013. Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. ***Climate Dynamics,*** 40 839-856.

Ramirez, R., Miller, B., and Weir, B., 2021a. From floods and wildfires to inaction and urgency: These are the top climate and weather stories of 2021, CNN, December 22, 2021. https://www.cnn.com/2021/12/22/us/top-climate-weather-stories-of-2021/index.html

Ramirez, R. and Passantino, J., 2021b. Lake Powell hits lowest level on record in climate change-fueled water crisis, CNN, July 26, 2021. https://www.cnn.com/2021/07/26/us/lake-powell-drought-water-shortage-climate/index.html

Roos, M. 1987. Possible changes in California snowmelt patterns, Proc., 4th Pacific Climate Workshop, Pacific Grove, California, 22-31.

Roos, M. 2008. Poster paper, Changing Sierra Nevada Runoff Patterns, CALFED Science Conference, Oct 2008, Sacramento, California.

Roos, M. and Fabbiani-Leon, A. 2017. Recent Changes in the Sierra Snowpack of California, 85th Annual Western Snow Conference, April 2017, Boise, Idaho.

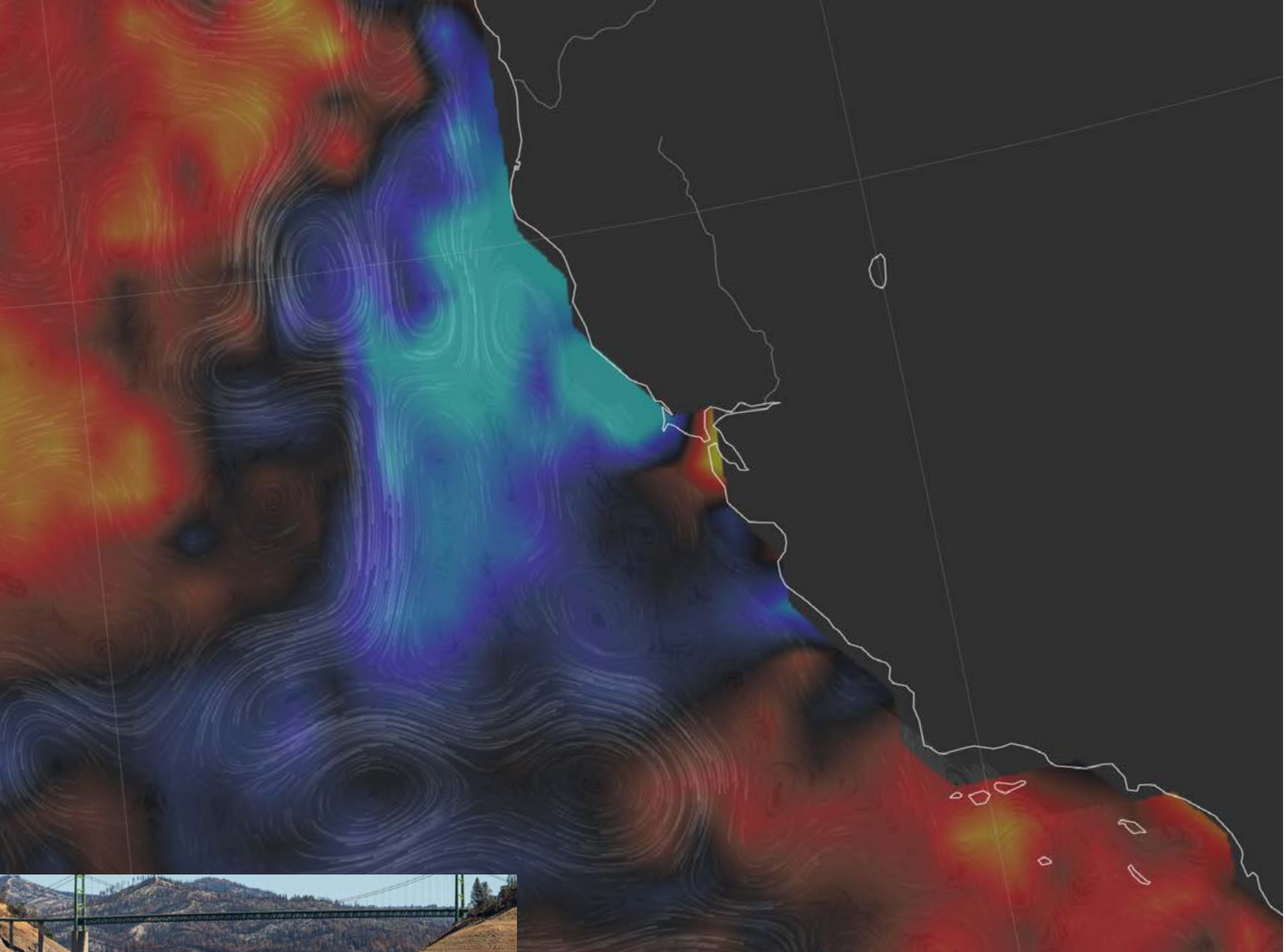
Roos, M. and Sahota, S. 2012. Contrasting Snowpack Trends In The Sierra Nevada Of California, 80th Annual Western Snow Conference, May 2012, Anchorage, Alaska.

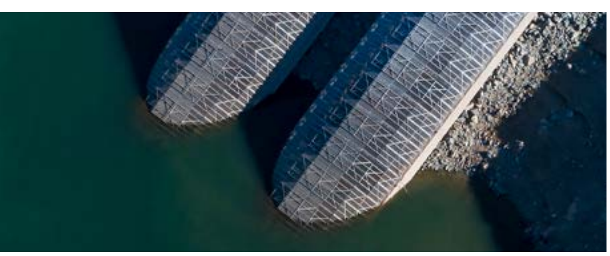
Santer, B., et al. 2000. Statistical significance of trends and trend differences in layer-average atmospheric temperature time series. ***Journal of Geophysical Research.*** 105 7337-7356.

Scott, M. 2021. A late-summer heatwave and rain at Greenland's summit, Climate.gov, National Atmospheric and Atmospheric Administration, August 24, 2021. https://www.climate.gov/news-features/event-tracker/late-summer-heatwave-and-rain-greenlands-summit

Wigglesworth, A. and Smith, H. 2021. Caldor, Dixie fires 1st to burn on 1 side of Sierra to other, ***Los Angeles Times***, August 31, 2021. https://www.latimes.com/california/story/2021-08-31/caldor-and-dixie-fires-first-burn-from-one-side-of-sierra-to-the-other WRCC. 2020. "California Climate Tracker." Western Regional Climate Center. Retrieved March 27, 2020, https://wrcc.dri.edu/Climate/Tracker/CA/index.html.

Photos of Douglas Alden, CW3E Research & Development Engineer, John Deane, NPS Physical Science Technician, and Kerstin Paulsson, CW3E Field Researcher, at the Dana Meadows site in Tuolumne Watershed, CA. This site is part of the Scripps Hydroclimate Network and supports the goals of the California AR Program. Taken: June, 2021 by CW3E Field Staff.





California State Climatologist

Dr. Michael Anderson

Michael.L.Anderson@water.ca.gov

Released December 2022

Mailing address: P.O. Box 219000, Sacramento, CA 95821-9000

For all **California Hydroclimate Reports**, please go to:

water.ca.gov/climate-meteorology