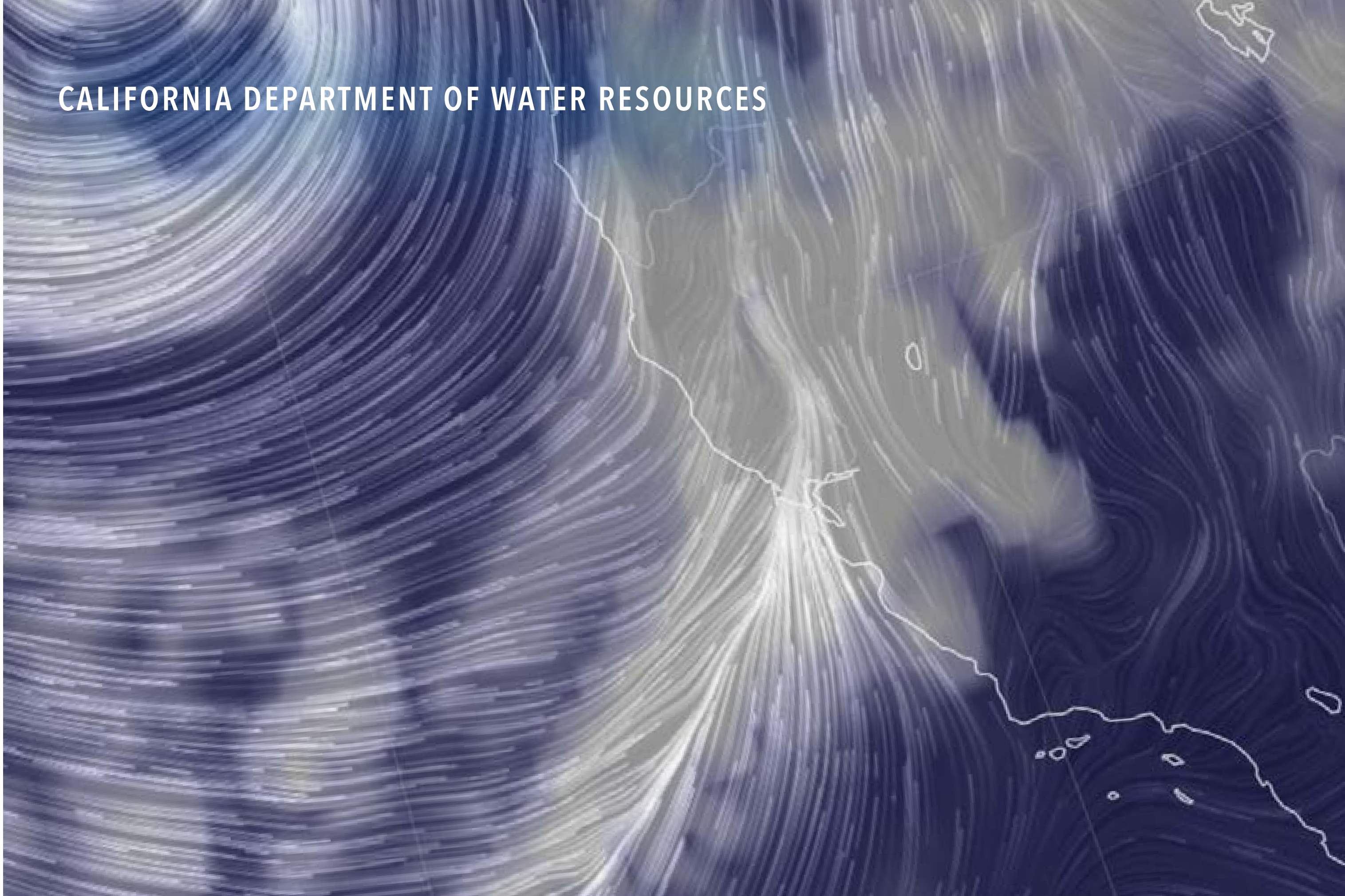
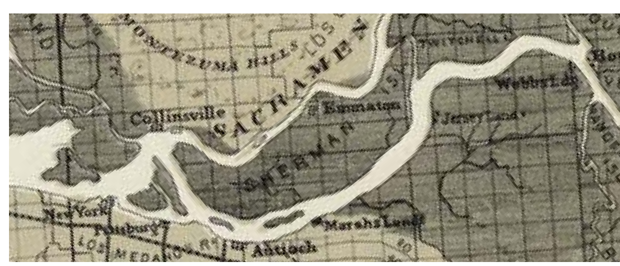
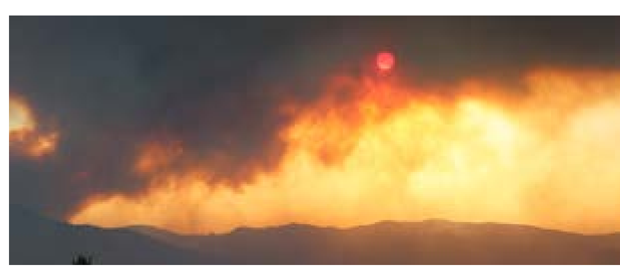
CALIFORNIA DEPARTMENT OF WATER RESOURCES

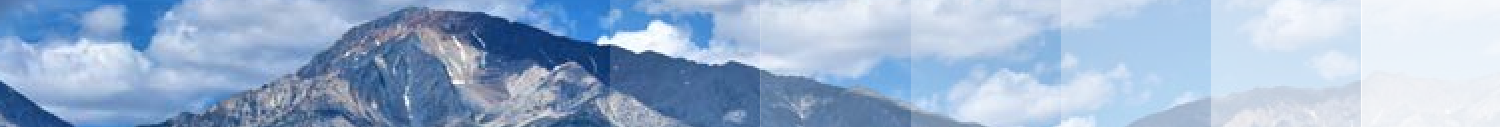






HYDROCLIMATE REPORT
Water Year 2022

Office of the State Climatologist



Executive Summary

Back and Forth Extremes and Another Year of Drought

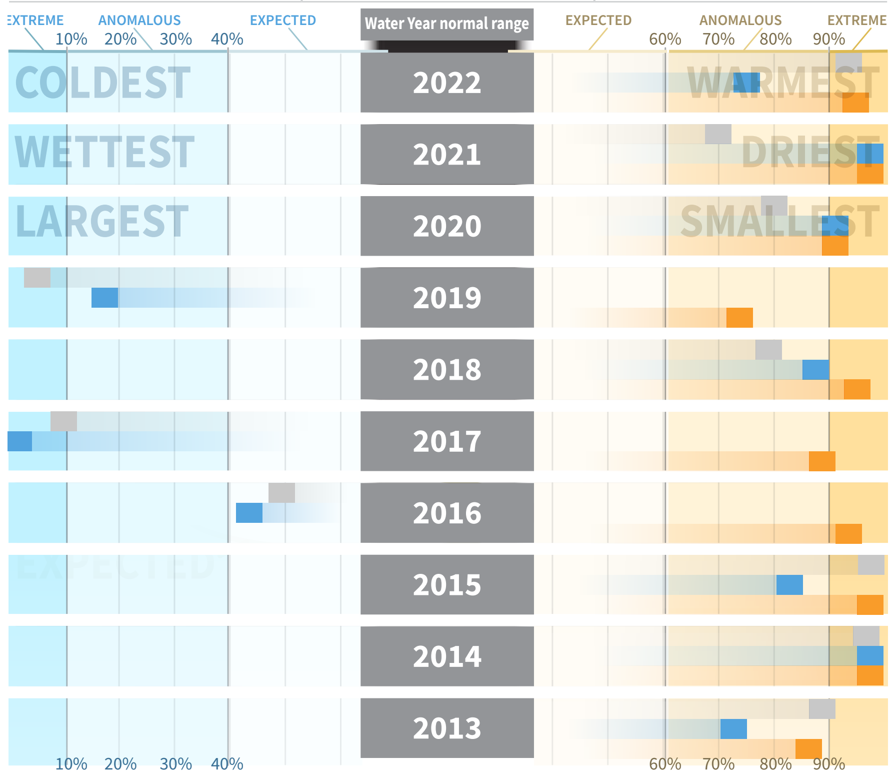
Water year (WY) 2022 set new records in extremes and variability in both temperature and precipitation. A strong start could not be sustained, and another year of drought ensued. In both precipitation and temperature, there were new extremes with a record storm in October, record snow in December, and a drier and warmer start to a calendar year than 2013. The WY ended with 77 percent of average precipitation statewide which is a distinct improvement over water year 2021 which was the second driest year in the observed record dating back to 1895. However, the three-year stretch of water year 2020/2021/2022 ended up drier than the previous record dry 3-year period of 2013/2014/2015. The record dry January through August 2022 was drier than water year 2013, the previous record. For statewide average temperature, it was the seventh warmest year with an average temperature of 59.5 degrees Fahrenheit. After a strong start that had the end-of-December snowpack at 150% of average for the date, the April 1 statewide snowpack registered only 35% of average, the fifth lowest in the period of record dating back to 1950. Runoff from the snowpack was bolstered by climatologically average precipitation conditions in April.

The summer of water year 2022 was the fourth warmest in a 128-year period of record. Summertime precipitation was above average as well. While the number of wildfires in the State was near the historical average, the number of acres burned was notably lower than 2021 or 2020. The water year closed out with two notable extremes. The first was a decaying eastern Pacific Hurricane, Kay, which made its way into southern California with tropical storm strength in early September. Record-setting precipitation and heavy winds were recorded in several locations. A few weeks later, the remnants of a typhoon made its way out of the Gulf of Alaska bringing heavy thunderstorm activity to northern California leading to localized flooding. The amplifying extremes, both wet and dry, continue California's narrative of climate change driving increasing variability and extremes in the hydrologic cycle.

To gain perspective on a decade of extreme weather, the graphic below categorizes the annual average temperature, annual precipitation, and April 1st snowpack into one of three categories: expected, anomalous or extreme based on the percentile the observation fell in. As can be seen from the graphic the past decade has only seen temperatures in the anomalous or extreme warm side of the distribution, only one year where the precipitation and snowpack fell into the expected category. Characterization of the changes in hydroclimatic metrics as the world continues to warm will be key to understanding the need and value of adaptation measures. Further work is needed to create informatics that move from awareness to actionable information.

One year in the expected category

Temperature	Precipitation	Snowpack
2 Anomalous	1 Expected	1 Expected
8 Extreme	6 Anomalous	4 Anomalous
	3 Extreme	5 Extreme



Front and back cover Earth images courtesy of earth.nullschool.net. Cover: Total Cloud Water, October 24, 2021 14:00 local time; back cover: Temperature (40+ °C in Central Valley). August 14, 2022 14:00 local time.

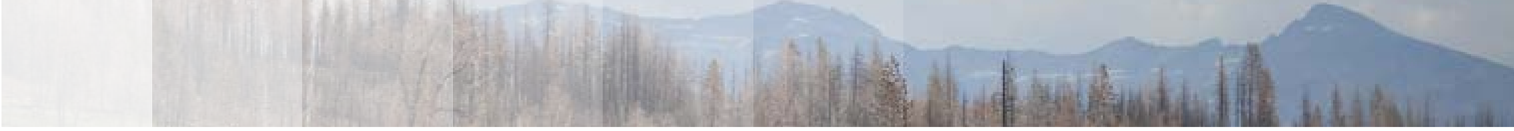
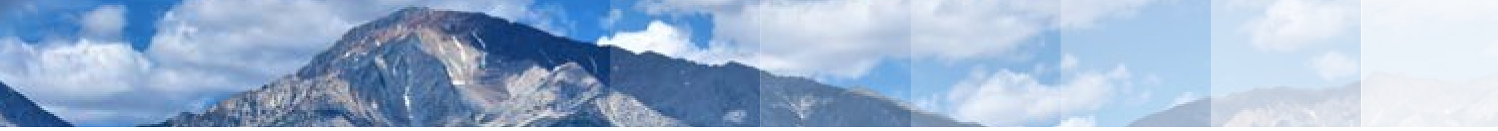


Table of Contents

The State Climatologist Office would like to thank Elissa Lynn, Jamie Anderson, Alex Perez, and the Desert Research Institute, including Western Region Climate Center, for their contributions to the annual Hydroclimate Reports.



Introduction

Welcome to the hydroclimate report for WY 2022 - an annual report highlighting weather and climate events of the water year. With the backdrop of climate change impacting water management, the report updates a collection of hydroclimate indicators important to the Department of Water Resources. By tracking climate 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 being implemented for water resources management. The indicators include metrics for precipitation, temperature, snowpack, runoff, and sea level rise.

Because atmospheric rivers, narrow corridors of intense water vapor transport in the atmosphere, are central to California's water supply and flood events and are impacted by a warming world, additional metrics have been added to describe their influence on the water year. This includes tracking the number of atmospheric rivers making landfall, their strength, and the relationship between freezing elevation (where rain transitions to snow) and precipitation.

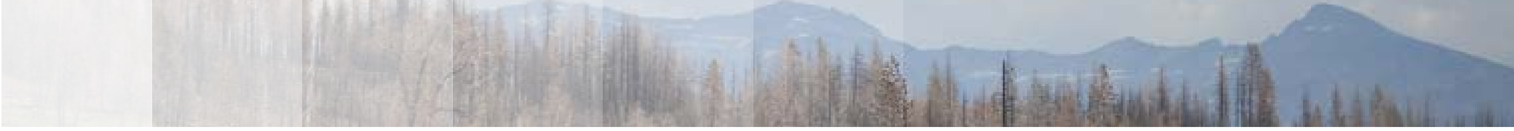
The extreme dryness of water year 2021 and new extremes in water year 2022 have motivated the development of a metric related to the anomalously warm and dry periods during the wet season (October through March) and the snowmelt season (April through July). Warming temperatures have resulted in the landscape actively drying when it is not raining during these times with resultant impacts on runoff.

Important signposts of change are also being catalogued as new extremes or important thresholds are observed, identified, and their impact realized. These events can be local to California or global.

Water year 2022 added another year to the ongoing drought and set a new record for 3-year dryness surpassing 2013-2015. However, multiple wet extremes were experienced along with new warm and dry extremes. This year's 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 finishes with signposts of change and a look ahead to the coming year showcasing potential additions to the collection of indicators presented in this report.

Key Hydroclimate Indicators

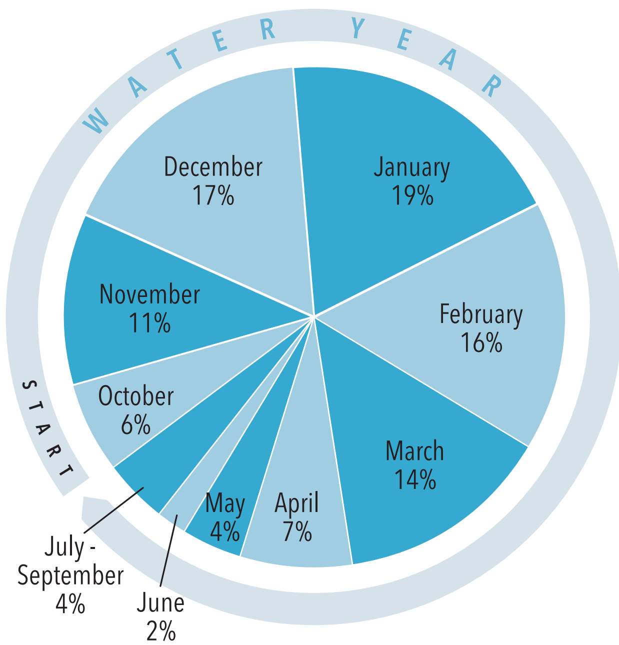
Indicators	Spatial Resolution	Temporal Resolution	Period of Record	Data Source
Temperature (Air)	WRCC Climate Regions	Monthly Mean	1895-present	WRCC
Temperature (Air)	NOAA Climate Divisions	Annual Calendar Year	1895-present	NOAA
Precipitation	WRCC Climate Regions	Monthly	1895-present	WRCC
Precipitation	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
Streamflow (Unimpaired)	Sacramento River Basin	April-July	1906-present	DWR
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?

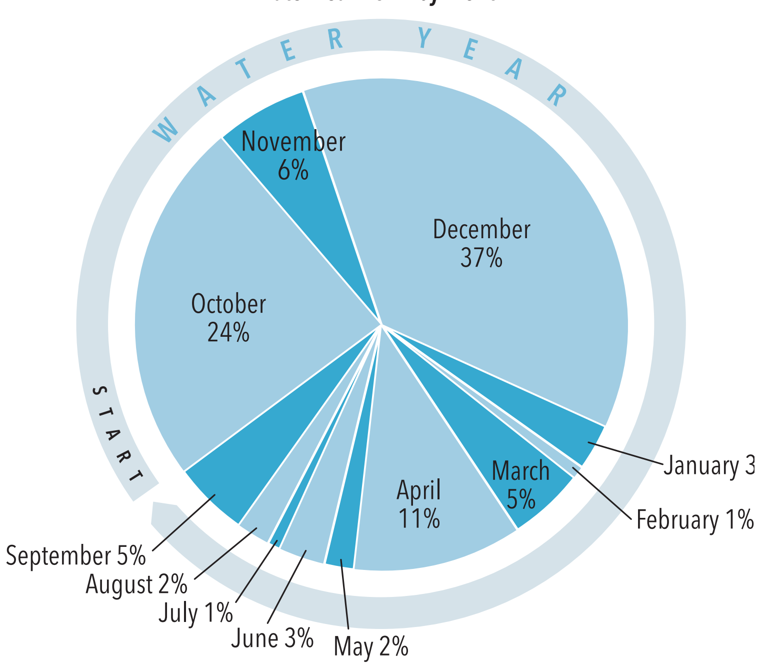
Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)

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.

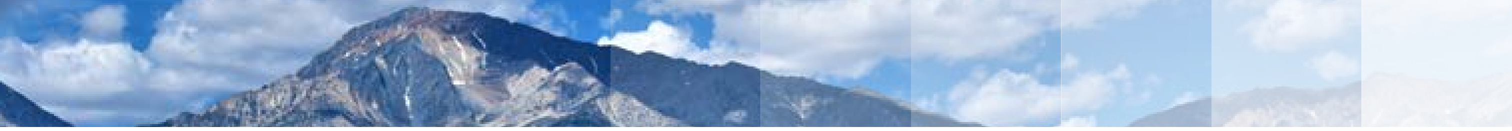
Water Year 2022 by Month



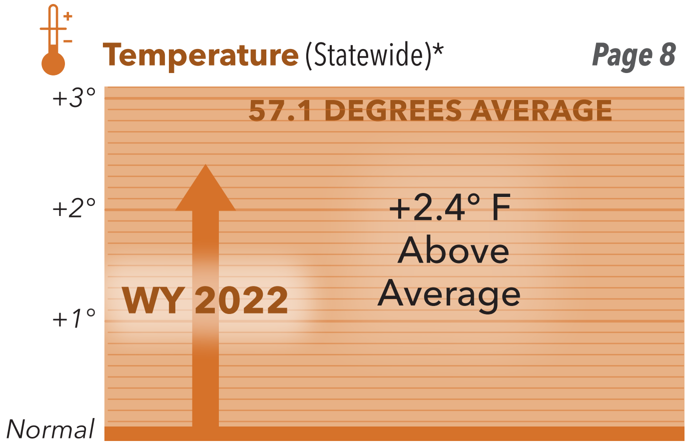
This chart represents monthly precipitation as percent of the total 2022 WY precipitation.

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 water year (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 water year in California to include the period from Oct 1 to Sept 30. The 2022 water year covers the period from October 1, 2021 to September 30, 2022.

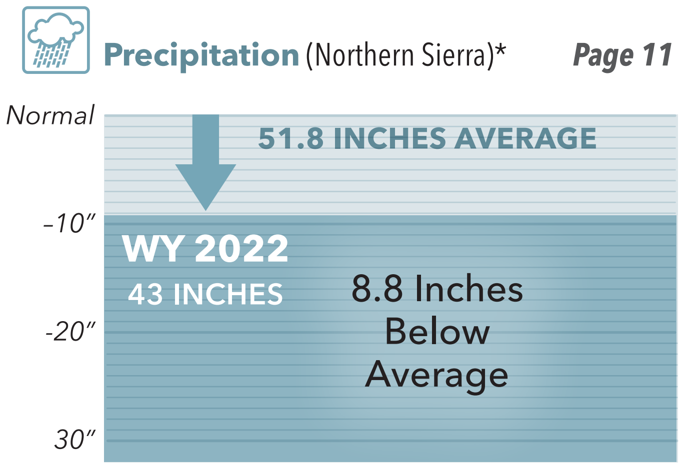
A comparison of the pie charts between the long-term average and WY 2022, shows 24 percent of the total WY precipitation occurred in October versus 6% on average. In December the percent of total year precipitation was 37% while an average accumulation would only be 17%. The wet months of January and February usually receive 19% and 16% of the total water year precipitation. In water year 2022 only 1% and 3% accumulated respectively. The total water year 2022 rainfall at 18 inches was considerably less than the long-term average at 23.5 inches.



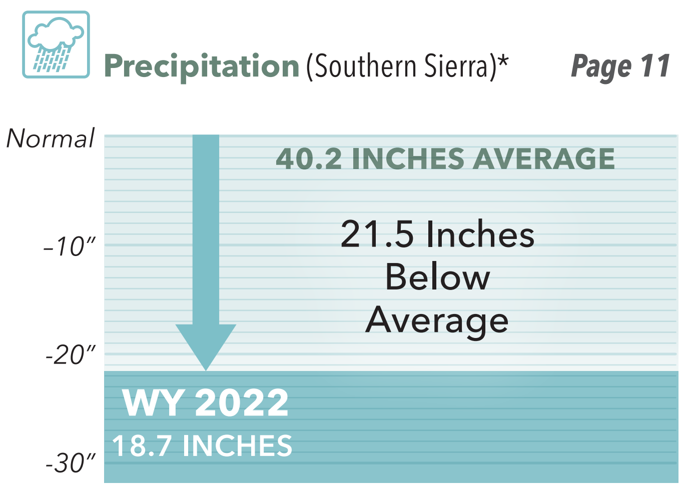
California Hydroclimate Water Year 2022 "At A Glance"



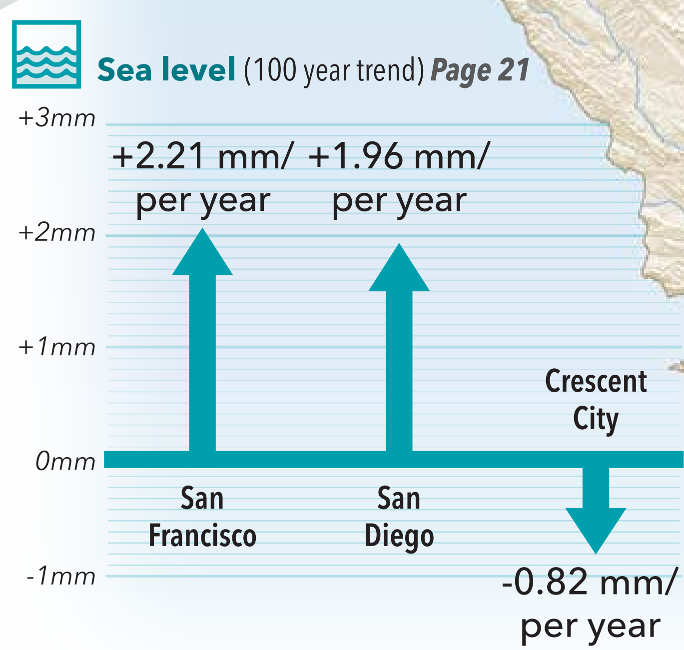
*Normal average air temperature represents 1896-2021 base period.



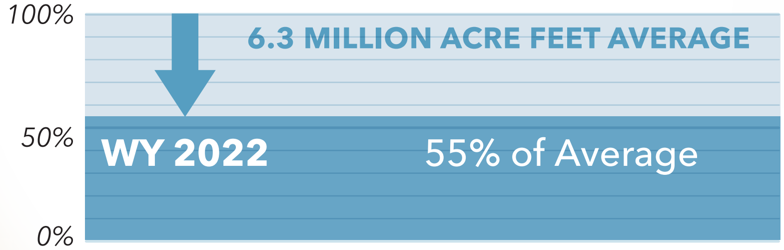
*Normal average precipitation represents 1966-2015 base period.



*Normal average precipitation represents 1966-2015 base period.

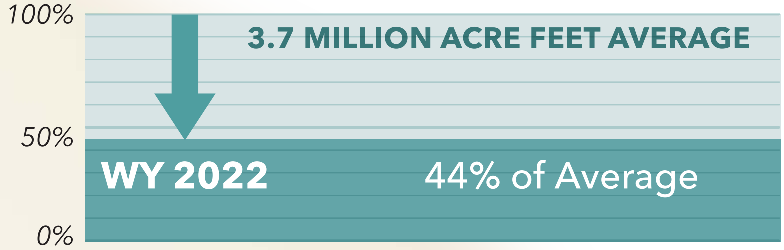


Streamflow, April-July (Sacramento River)* *Page 20*



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

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

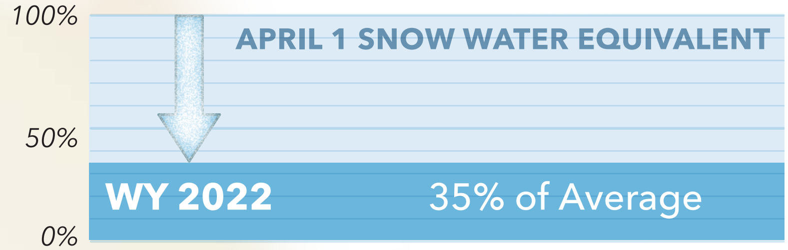


**Normal average streamflow represents 1966-2015 base period.*

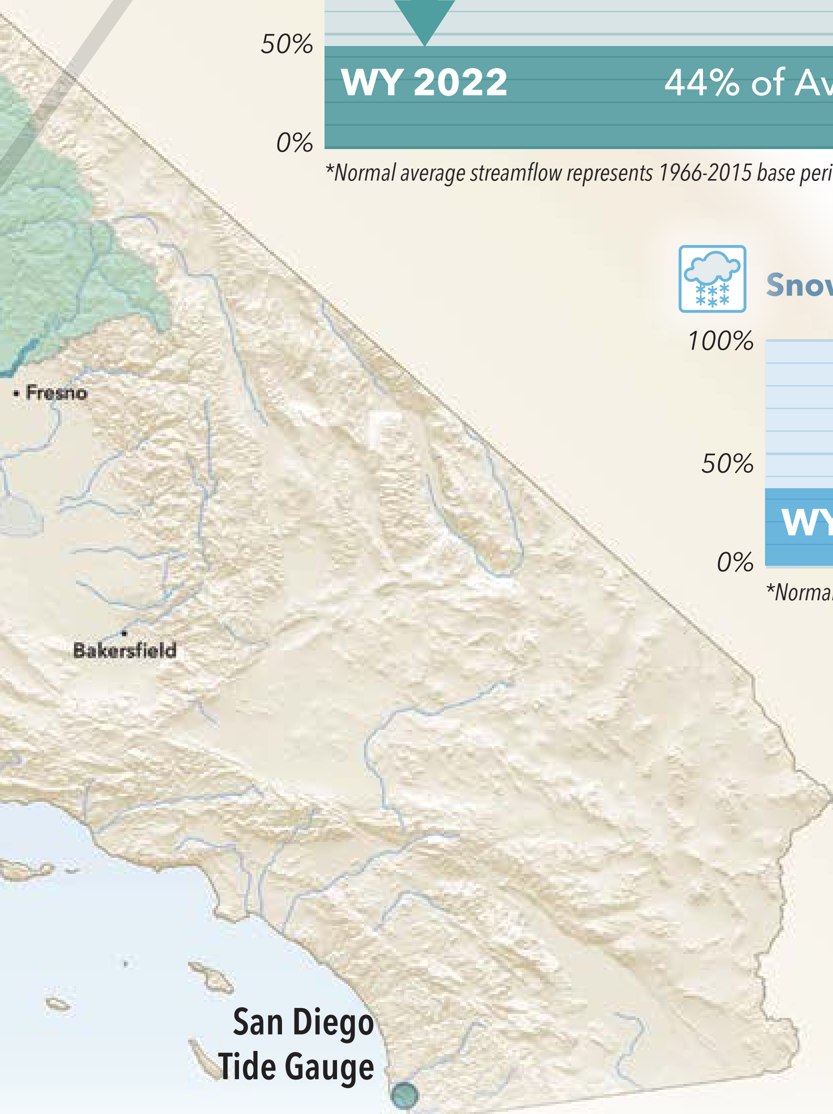
Indicators in Context

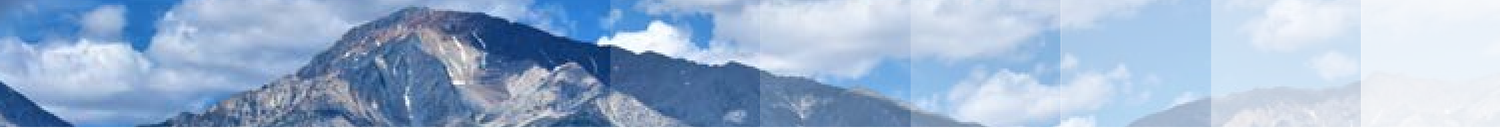
The DWR Hydroclimate Report is updated each WY to reflect key indicators that can be used to assess long-term trends and is focused on reporting characteristics of a changing climate that impact California's water resources. Also, of importance in generating data trends are annual values that represent 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 2022 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 2022 WY compared to the 1981-2010 base period. Sea level trends are depicted with their locations shown geographically on the California coast.

Snowpack (Statewide)* *Page 14*



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





Annual Air Temperatures

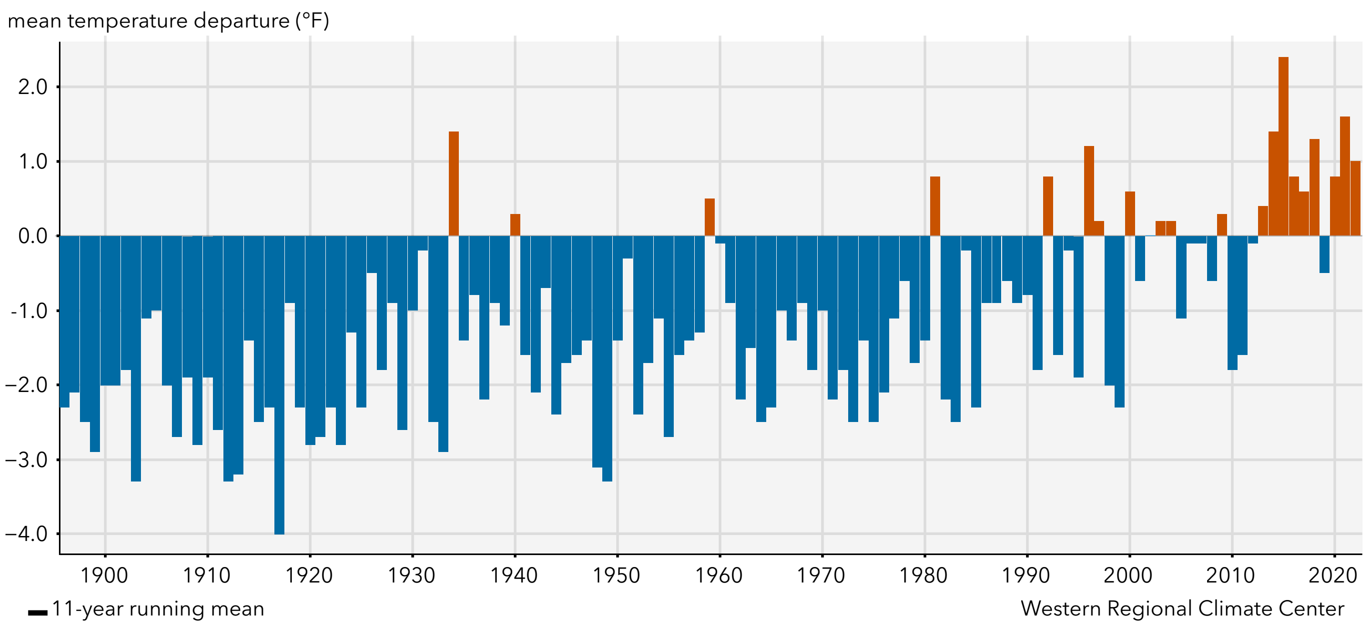
Rising temperatures are a fundamental element of climate change. California's warming over the 20th and first part of the 21st Century have followed near the global average. Data from Western Region Climate Center's California Climate Tracker show that for the statewide mean temperature water year 2022 ranks as the 7th warmest year in 127 years of record with a value of 59.5 degrees Fahrenheit. Four of the six warmer years have been in the last decade. Figure below shows the time series of departures from the 1981-2010 average temperature. Water year 2022 is the eleventh straight year with a positive departure or values greater than the 1981-2010 average temperature.

The National Oceanographic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) provides regional temperature and precipitation data through its climate division datasets. California has seven climate divisions with climate division two (CD2) representing the Sacramento River Basin, the source region for the majority of California's surface water supply and climate division six (CD6) representing the highly populated south coastal region. In the graphics below, the y-axis depicts annual accumulated precipitation, and the x-axis represents the region's annual average temperature. Squares depict values from the 21st Century. The triangle represents the period of record average. Note the majority of squares are at or near the warmest part of the distribution.

A Comment on Climate Normals

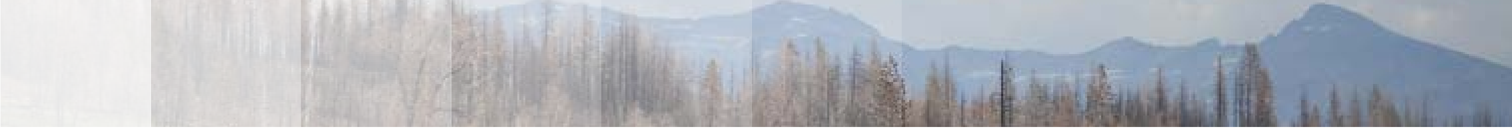
In 2021, NOAA released its latest set of climate normals, average conditions using the 30-year time period 1991-2020. This supersedes the previous normal which covered the time period 1981-2010. These averages, or normals, are updated once per decade. In this latest update, the extreme warmth from 2011 to 2020 is now incorporated into average conditions raising the average temperature from 57.7 degrees Fahrenheit to 58.4 degrees Fahrenheit. Seven years in the last decade are in the warmest 14 years including the new warmest year in the period of record for water year 2015. When creating departure from normal graphics, the increased average value as a baseline makes the departures look smaller than graphics made with the previous normal as a baseline.

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



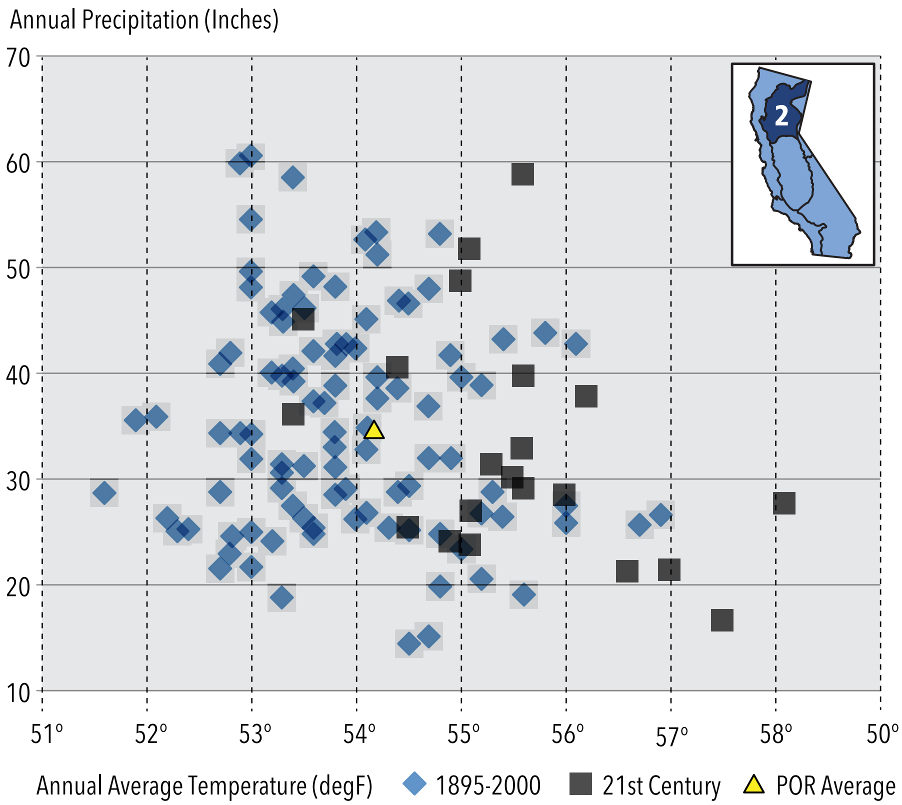
Summary statistics

1991-2020 averages	Extremes	Most recent year
Mean: 58.4°F	Warmest: 60.8°F (+ 2.4 °F from average), 2015	October 2021-September 2022 | 59.5 °F (1.1 ° from average)
Median: 58.5°F	Coldest: 54.4°F (- 3.9 °F from average), 1917	Cold Rank: 56 of 128 | Warm Rank: 7 of 127



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

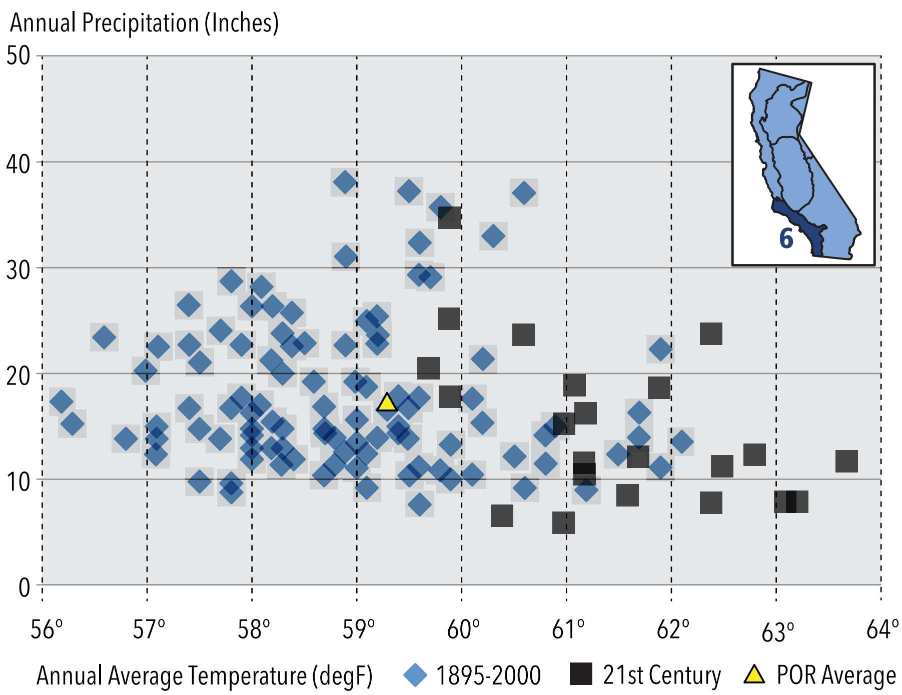
The Sacramento and South Coast Drainage Climate Division data plots show 2014 and 2015 as the warmest years on record. For water year 2022, the annual average temperature versus water year precipitation plots are depicted for the Sacramento Climate Division (56.5°F, 27.2 inches) and for the South Coast Climate Division (62.8°F,12.2 inches). The combination of warmer temperatures and lower rainfall in the 21st Century (squares) are noticeably different from historical values (diamonds) on the scatterplot graphs.

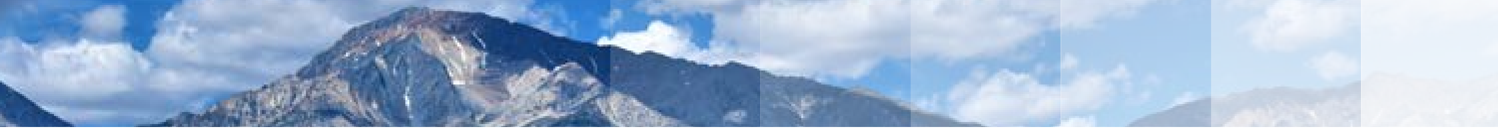


NOAA Climate Division Water Year Data

- Spatial resolution: NOAA California Climate Divisions
- Temporal resolution: Annual Mean for a Water Year

For water year 2022, in CD2, the annual average temperature was the 8th warmest in the period of record and 2.3 degrees Fahrenheit above the period of record average. Six of the top ten warmest temperatures in the period of record for this region are from the last decade. For CD6, the annual average temperature was the 5th warmest in the period of record and 3.5 degrees Fahrenheit above the period of record average. The 8 warmest temperatures in this region's period of record are from the past decade.





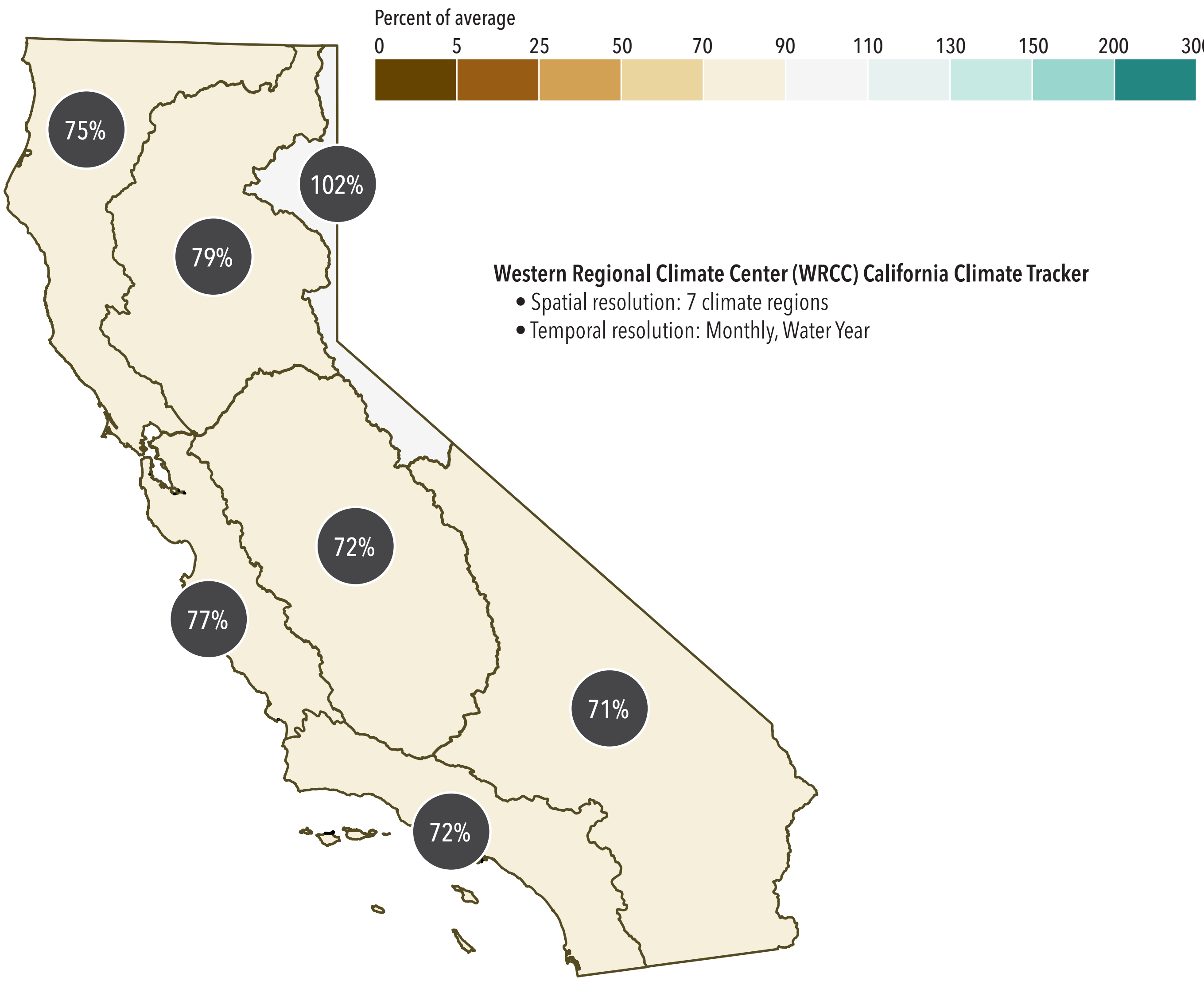
Annual Precipitation

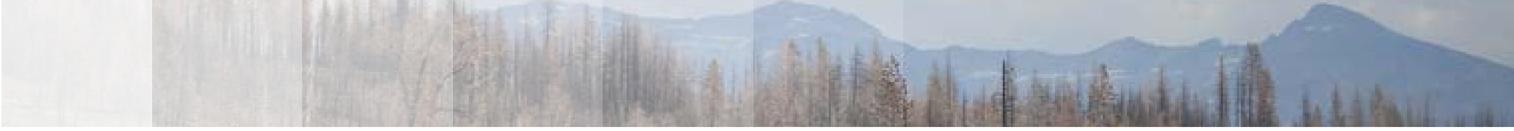
Water year 2022 continues the current drought which is the third record-setting multi-year drought in the last 15 years. From the plots for CD2 and CD6, precipitation was 78% and 70% of average respectively for those regions. Statewide, precipitation was 77% of average. A plot showing the percent of average precipitation for water year 2022 for all of California's seven climate divisions is shown below.

As a single dry year, water year 2022 does not stand out, ranking as the 31st driest water year in the period of record. However, coupled with the previous 2 dry years, the three-year accumulation set a new record for dryness. The past 3 water years have a new record cumulative deficit of precipitation beating out the previous drought's 2013-2015 deficit by almost 4 inches (24.07 versus 20.73 inches). All three multi-year droughts of the 21st century (2007-2009, 2012-2016, and 2020-2022) have 3-year accumulations of precipitation in the lowest six in the historical record. This is a sign of growing extremes on the dry side.

California by NCEI climate divisions

Precipitation percents of average from 1991-2020 computed average(s) for 2021-2022 WY (October-September)

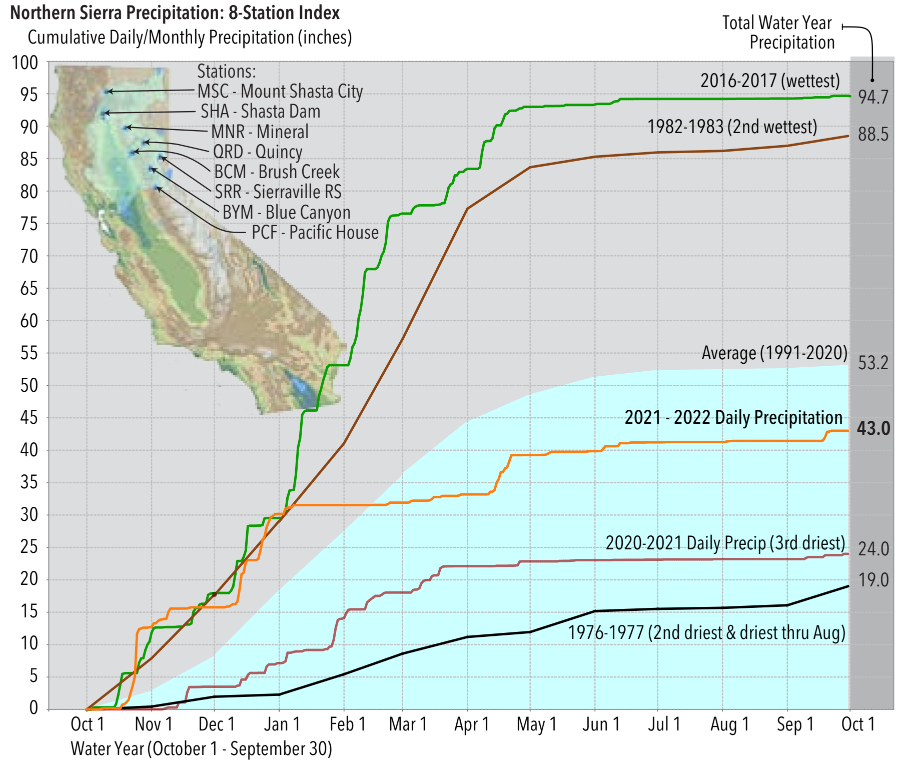




DWR Aggregate Precipitation Station Indices

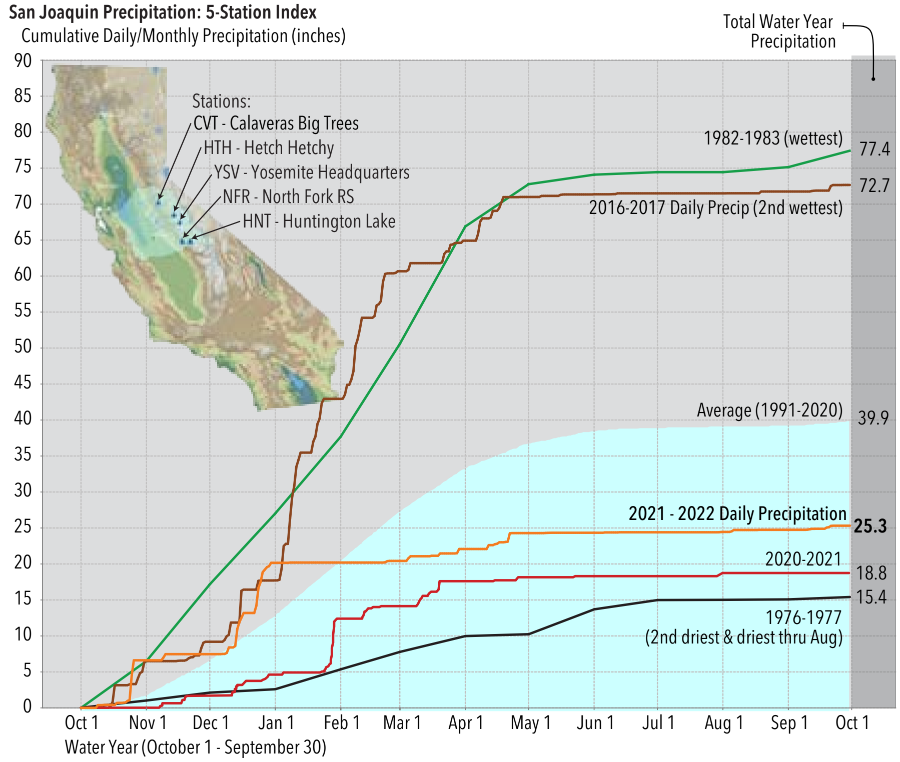
Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state. These precipitation station indices are located in the Northern and Southern Sierra and correspond well to the WY type on the Sacramento and San Joaquin River systems.

Northern Sierra Precipitation: 8-Station Index

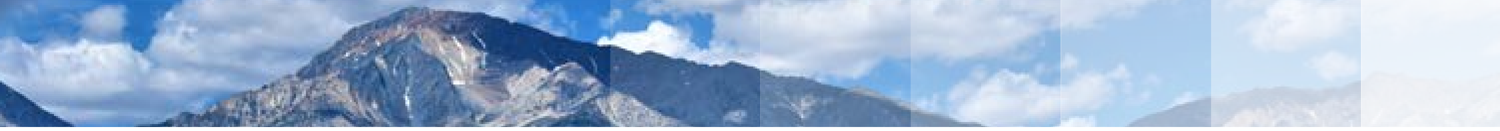


Total 2022 WY precipitation was 43.0 inches which is 8.8 inches below average or 16 percent below average. The year was characterized by a fast start in October and a strong December followed by a record dry start to a calendar year through August. Precipitation in April helped with snowmelt runoff.

San Joaquin Precipitation: 5-Station Index

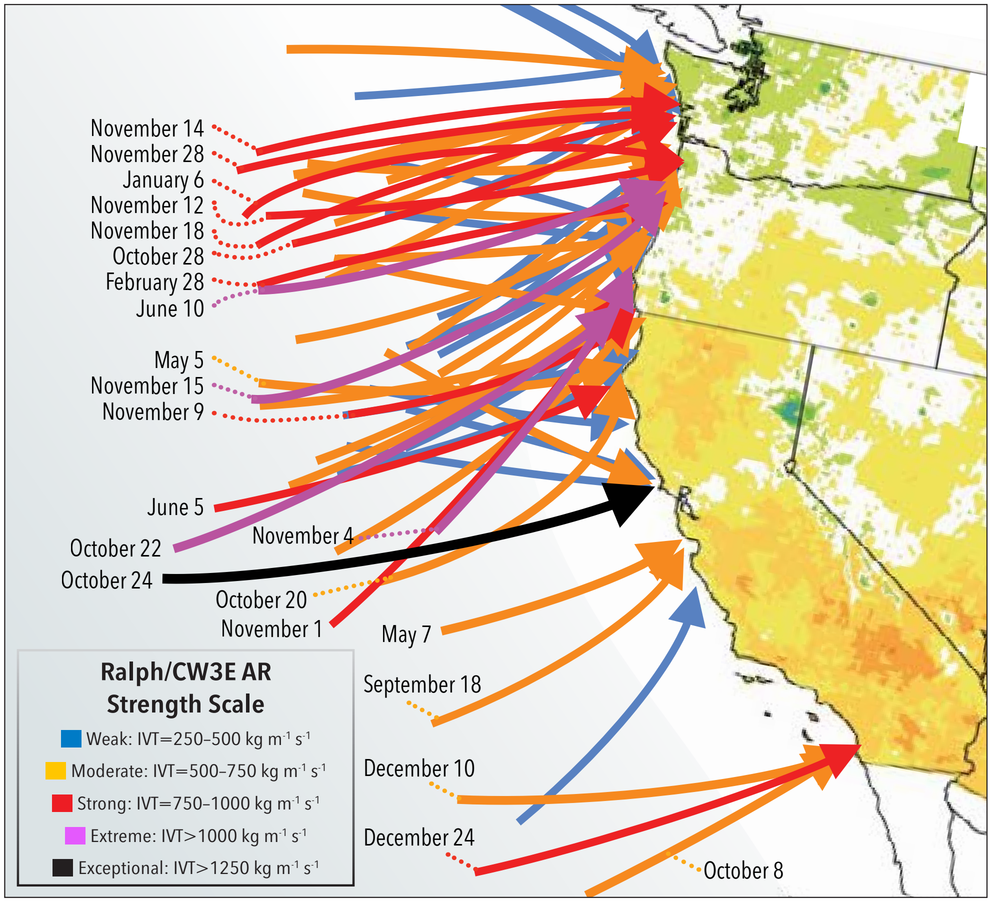


The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, typically receives less precipitation than the Northern Sierra. WY 2022 had a total WY precipitation of 25.3 inches, which was below the average of 40.2 inches for the Southern Sierra. Cumulative precipitation for WY 2022 was 37 percent below normal.



Atmospheric Rivers

Distribution of all landfalling Atmospheric Rivers on the U.S. west coast during WY 2022



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

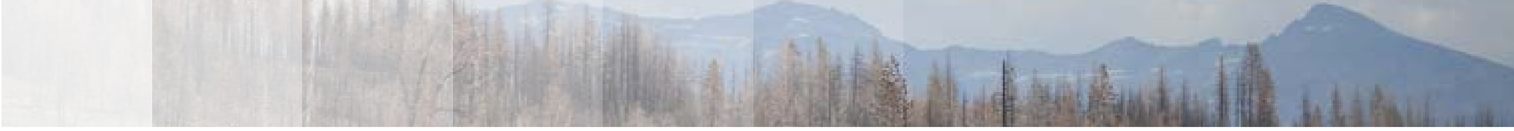
Atmospheric Rivers (ARs) are long (approximately 1000 miles), narrow (less than 250 miles wide) bands of intense water vapor concentrated in the lower atmosphere that can be entrained into the leading edge of winter storms that make landfall over California and the west coast of the United States. Typically, 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. In northern California, these storms have been associated with more than 90% of flood damages (Corringham et al, 2019). The absence of ARs are associated with drought conditions in California. 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).

Integrated Vapor Transport (IVT) is a measure of the amount of water vapor in the atmosphere above a given point combined with 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 of ARs based on IVT magnitude: 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 ARs that made landfall for the West Coast in WY 2022 as well as the location of maximum intensity of the AR when it hit the coast. Of the 61 landfalling ARs along the west coast, 43 made landfall in California including the exceptional AR in late October. Only seven ARs including October's exceptional AR made landfall from San Francisco Bay southward.

Atmospheric River strength by month and WY 2022 totals on the U.S. west coast.

AR STRENGTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	WY Total
WEAK	3	3	3	0	2	4	2	4	1	0	0	1	23
MODERATE	2	1	2	2	0	0	3	2	1	0	0	1	14
STRONG	1	2	1	0	0	0	0	0	1	0	0	0	5
EXTREME	0	0	0	0	0	0	0	0	0	0	0	0	0
EXCEPTIONAL	1	0	0	0	0	0	0	0	0	0	0	0	1
Total	7	6	6	2	2	4	5	6	3	0	0	2	43

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

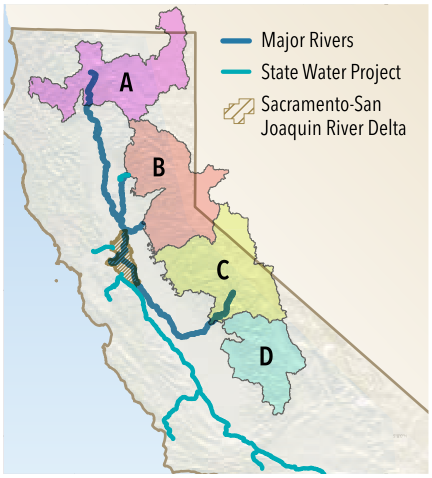


Rain/Snow Trends

A key element to California's precipitation outcome is the amount of precipitation that falls as rain or snow. This is called phase partitioning (meaning the fraction of precipitation that falls as rain vs. snow). Expectations with climate change are that more precipitation will fall as rain than snow in the future. 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- 2022. The mean for the period of record 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 in recent years. For WY 2022, the percent of precipitation that fell as rain was 77%. While snowfall was abundant in December, the record-setting precipitation from the category 5 atmospheric river in October pushes the percentage higher along with the lack of precipitation from January through March which is near the average for the entire time series and still above the average for the first half of the period. More work is needed to understand the influence of wet and dry years on the evolving trend in rain/snow partitioning.

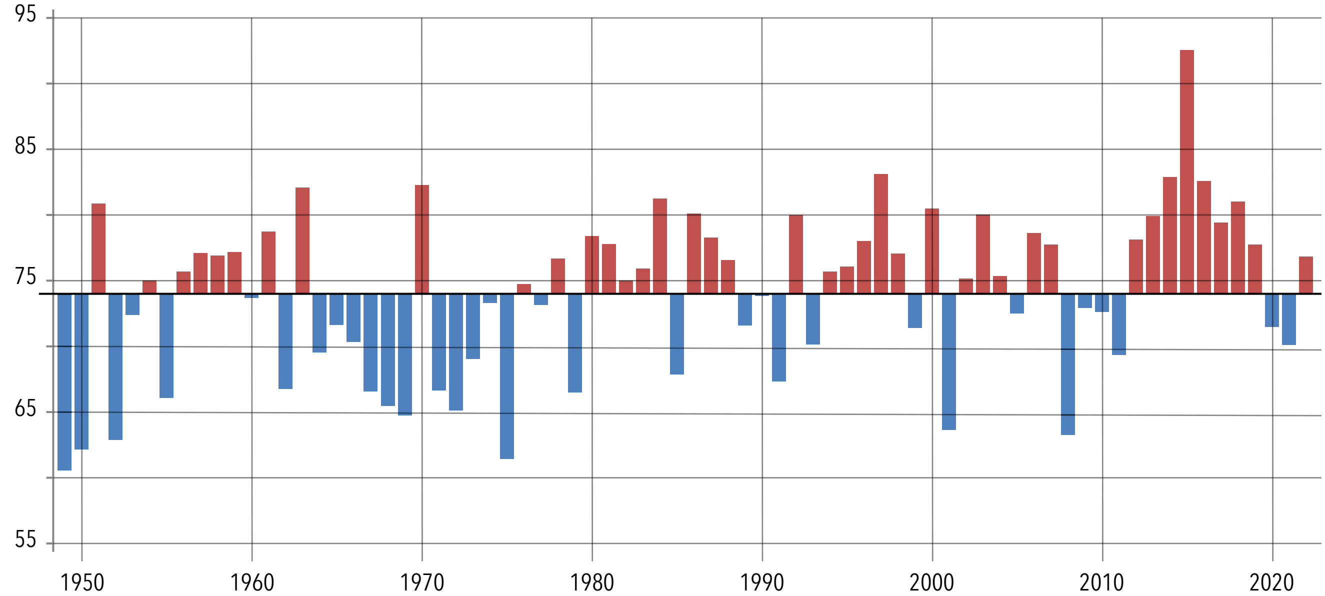
ERRATA: An error was found in the calculated value for WY2021 originally published as 92% but has been corrected to 71%. This was a result associated with elevations being incorrectly grouped and has now been vetted to be consistent with previous years. The figure includes this correction for 2021.

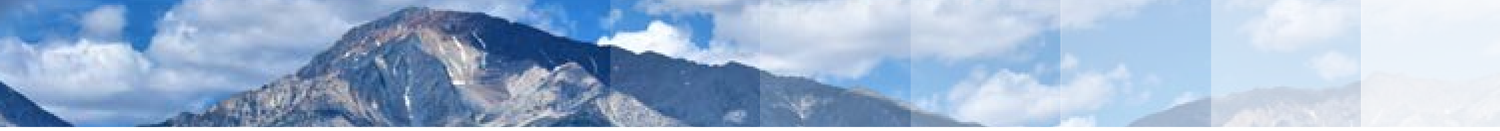
The figure below shows the analysis zones for rain/snow trends. Zone B includes Oroville reservoir, DWR's primary storage reservoir for the State Water Project.



WY percentage of rain for the analysis period WY 1949-2022 for All Zones A-D

Mean for 1st half of record: 71; mean for 2nd half of record: 76; mean for entire dataset: 74; mean for 2022 is 77%; 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.

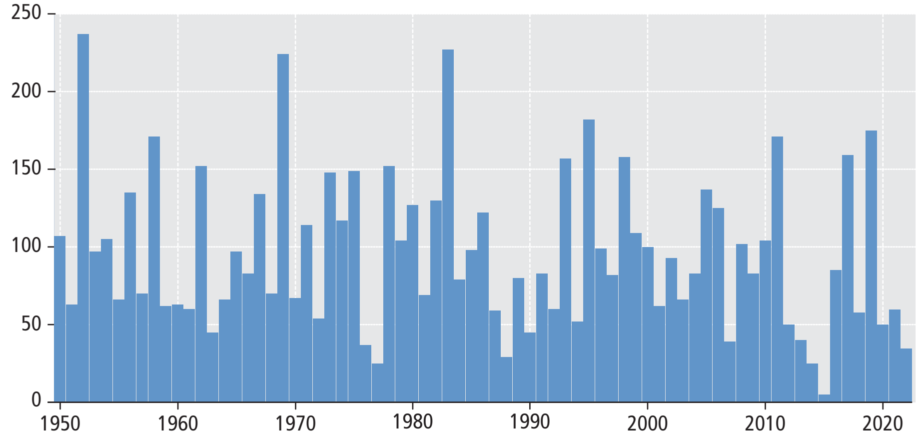




Snowpack

The California Cooperative Snow Surveys program has been actively collecting data since the 1930's from Northern and Southern Sierra locations. Monitoring tracks the amount of water in the snowpack called snow water equivalent (SWE). Snowpack in California typically begins to build in December and peaks on or around the first of April. April 1 SWE has become a marker for snowpack that is used for water management applications. The Statewide April 1st time series of percent of average snowpack is shown to the right. WY 2022 had an April 1st value of 35 percent of average as drought conditions continue in California. This is the 5th smallest snowpack and the 6th time since 2012 that the April 1 snowpack was below 50% of the long-term average. From 1950 to 2000 there were only 5 years where the snowpack was below 50% of average.

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.

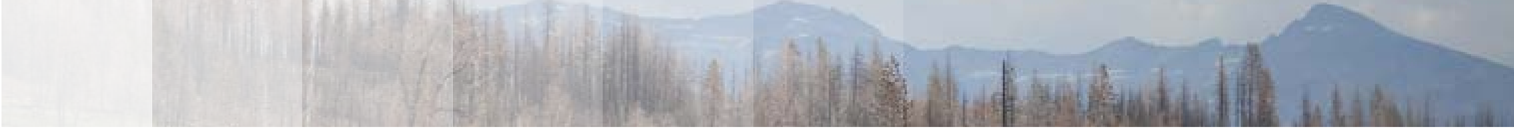
California Cooperative Snow Surveys - Snowpack

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

Adding in the perspective of a warming world, the April 1st statewide percent of average snowpack (y-axis) 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 (x-axis). WY 2022 adds another year of below average snowpack with above average Sierra winter minimum temperatures. Over the past decade, 4 years have fallen in the warmer and drier quadrant of the plot with minimum temperatures above 28 degrees Fahrenheit and percent of snowpack below 75 percent. From 1950 to 2000, only 3 values fell in this region.The California Environmental Protection Agency (EPA) Indicators of Climate Change in California (2022) 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.

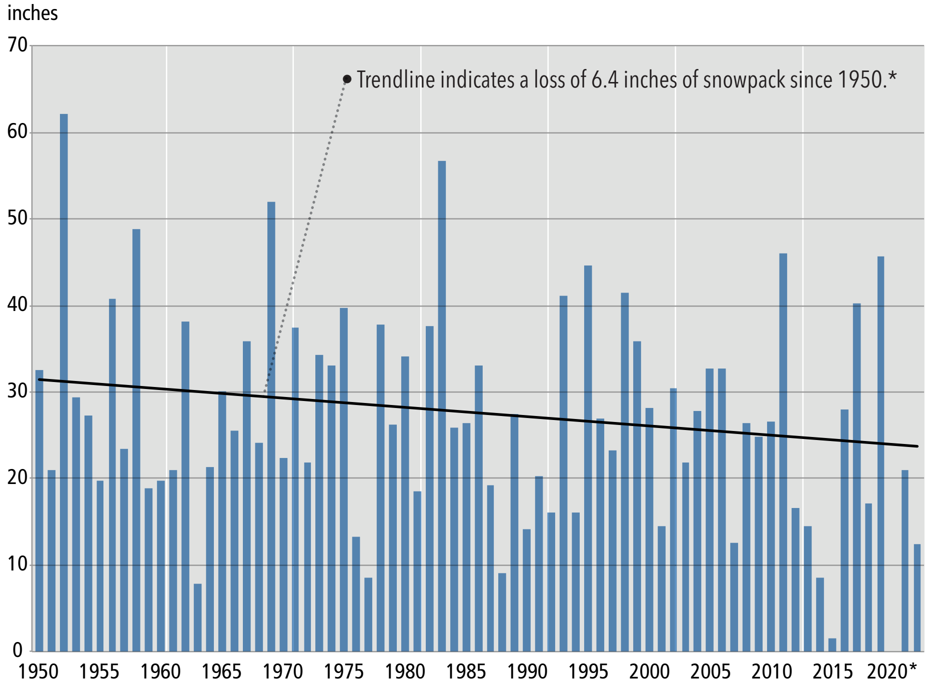
These figures illustrate the trends of April 1st snowpack for 13 Northern and 13 Southern Sierra Nevada courses representative of their regions. Due to the work and travel restrictions due to the Covid-19 pandemic, a significant percentage of the snow courses in the network were not sampled in WY 2020. Enough sampling points were measured in WY2022 to continue the plots. Up to WY 2022 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.

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

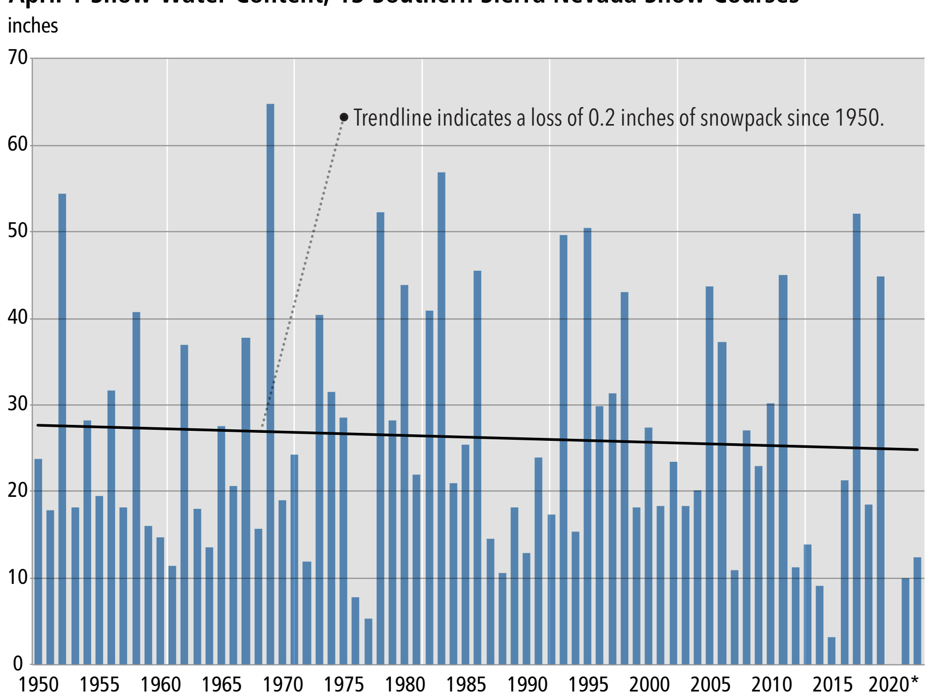


periods of heavy inflow and reduce flood hazard during cool season storms. Water captured during the flood is later released to maintain the flood pool storage capabilities during the next possible event. Flood pool releases mean this water cannot be stored for later beneficial use and must be managed 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. Runoff characteristics important to these adaptation strategies are covered in the next section.

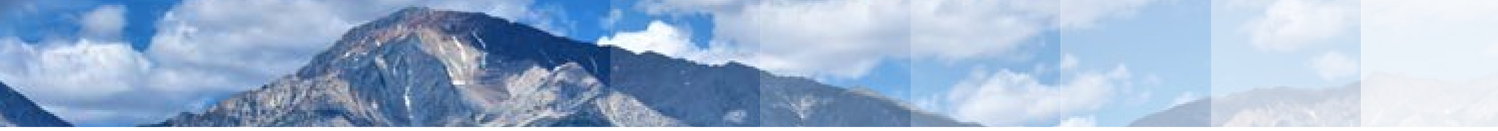
April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses



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



*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.

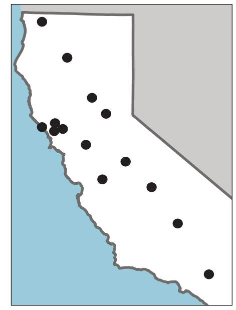


Snow-Level Radar

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.



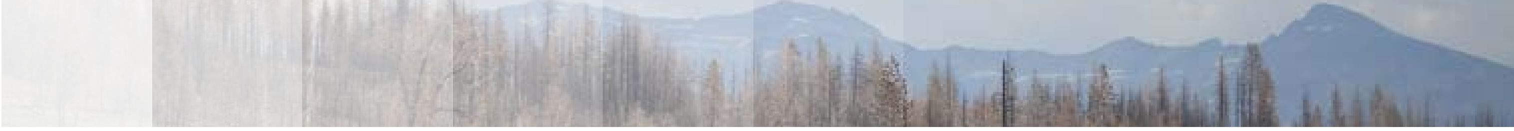
Snow-Level Radar observing station locations in California

Central Sierra Snow Lab – A Key Partnership in Observations by Dr. Andrew Schwartz, CSSL Lead Scientist

The University of California, Berkeley Central Sierra Snow Laboratory (CSSL) has been conducting cutting-edge scientific work related to weather, climate, and water resources for over 76 years. Originally developed in 1946 as part of the Cooperative Snow Investigations program between the National Weather Bureau and Army Corps of Engineers, the lab has made significant contributions to the fields of snow physics, meteorology, climatology, and hydrology. Much of the work conducted at the lab has been in collaboration with the California Department of Water Resources (DWR), which has been involved at the site since 1956.

Over the last 77 years, the CSSL has continued daily measurements of snowfall, snowpack, and weather parameters that have resulted in some of the longest continual records in the world. It is one of the few labs that has on-site staff year-round that utilizes interval boards to measure new snowfall and its snow water equivalent during periods of snowfall. These staff also ensure the continued operation of the facility and maintenance of instrumentation throughout some of the most severe weather that occurs in North America.

One of the primary functions of the lab historically has been the testing and comparison of new instrumentation and measurement techniques to older methods, a focus that continues at the lab



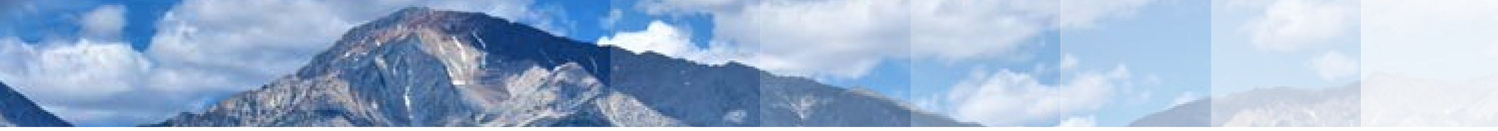
Left: CSSL Lead Scientist Dr. Andrew Schwartz (right) and DWR Electrical Engineers Bryan Prestel (center) and Nick Ellis (left) discuss maintaining and upgrading the Statewide Monitoring Network next to an instrumentation tower. **Above:** CSSL's main study site as viewed from above the main lab building with older climatological infrastructure dating over 60 years old and new tower infrastructure (center) under construction to accommodate the next generation of snow measurement and monitoring projects.

today. A joint project between the CSSL and DWR with support from the National Weather Service aims to make these comparisons easier and more streamlined through installation of a new state-of-the-art platform and instrumentation system called the Sky-to-Stream measurement system. The system will focus on hydrometeorological measurements from the moment precipitation falls from the sky until it exits the study area through runoff, including measurements of snowpack mass and energy balance, soil properties, and streamflow characteristics.

Not only will this project allow for more comprehensive measurement of climatological and hydrological characteristics at the CSSL, but it will enable better evaluation of experimental sensors through its inclusion of well-established instrumentation – a priority in the collaboration between CSSL and DWR.

Though much of the work that the CSSL and DWR has been centered around instrumentation, there are a wide range of other unique collaborative efforts. The CSSL conducts the Onion Creek Snow Survey once a month from Feb-May in addition to updating the snow survey manual and training DWR personnel on correct measurement techniques when needed. The CSSL also has a primary role in the development and continued operation of the California Cooperative Snow Surveys Data Acquisition Round Table (CCSS DART) committee that seeks to standardize and improve hydrometeorological measurements throughout California.

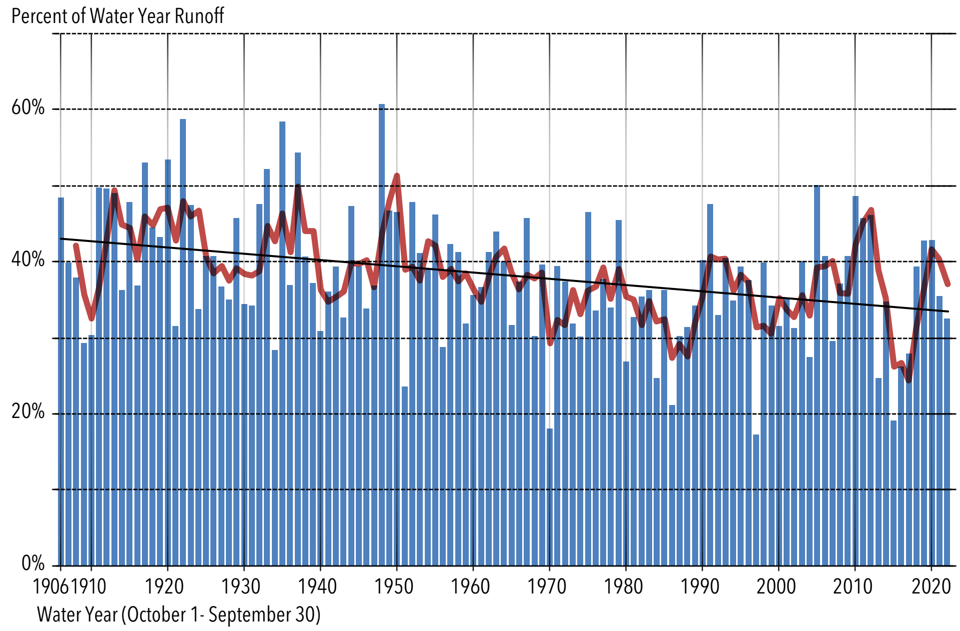
The CSSL and DWR partnership continues to benefit the state and its residents as we work together to improve water monitoring, modelling, and managing capabilities just as we have for decades. Climate change, shifting precipitation patterns, and increase stress on water resources are providing new challenges but also new avenues for collaboration. With any luck, our partnership will allow us to address these challenges and will continue to yield the same positive results and progress that it has for decades. For more information on the CSSL, please go to: https://cssl.berkeley.edu/



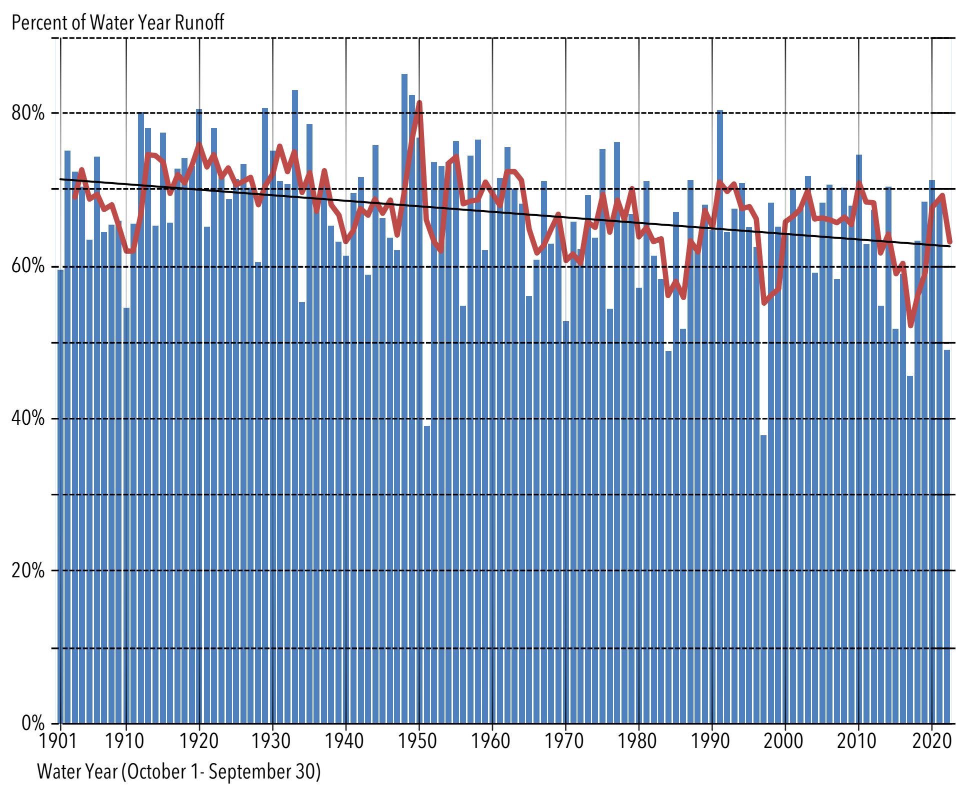
Unimpaired Streamflow: Sacramento and San Joaquin River Systems

Changes in runoff timing and magnitude are important to water resources management in California. The expected transition from snow to rain will shift more runoff to the winter season and decrease the amount of runoff in the spring season. Lower elevation watersheds like those found in the Sacramento Basin are expected to show more impacts sooner than the higher elevations of the Central and Southern Sierra. 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 changes during the spring months was developed by DWR Chief Hydrologist Maury Roos in 1987. The method calculates the fraction of water-year runoff that occurs during the typical snowmelt season from April through July. Analyzing the time series of this fraction, a distinct trend in spring flow loss is apparent. Currently, over the period of record, data indicate an 8.25 percentage point decline per century on the Sacramento and 7.37 percentage point decline per century on the San Joaquin River systems. With below average precipitation and snowpack, WY 2022 April through July streamflow was 52 percent of average at 3.49 million-acre feet in the Sacramento River and 42 percent of average at 1.63 million-acre feet in the San Joaquin River.

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



Dryness Indicator

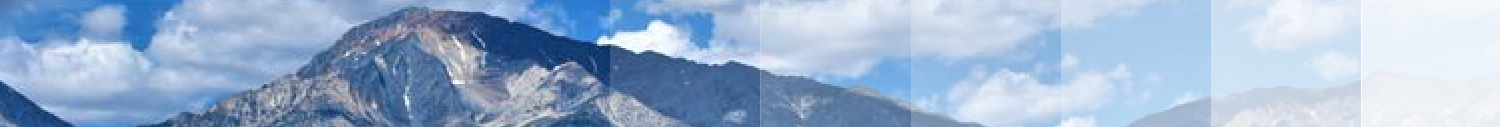
California's surface water supply is influenced by geographic and seasonal variability which are subject to inter-annual climatic variability in precipitation and runoff. Runoff from the Sacramento and San Joaquin River basins provides much of the State's surface water supply and are classified using a WY type index system for water quality management in the Sacramento-San Joaquin Delta. Each water year, both river basins are classified as one of five types: a "wet" year classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical). Differences in geology and runoff timing due to snowmelt result in different equations to compute the water year type (CSWRCB, 1999). These designations are primarily used for managing water quality conditions in the Delta. For water year 2022, both the Sacramento and San Joaquin indices fell into the critically dry category due to low runoff in both winter and spring. This is the second critical year designation in a row for the current drought. Multiple critical year designations have happened in the 1987-1992 drought and the 2012-2016 droughts as well.

While studies by Null and Viers (2013) and He et al. (2021) suggest that the changing runoff timing associated with climate change will have an impact on the frequency of occurrence of the different categories, more work is needed to develop better indicators of surface water availability through the year as runoff timing impacts are realized with improved observations and hydrologic modeling capabilities.

An important side-effect of warming air temperatures is that it increases atmospheric thirst, meaning that the atmosphere will pull more water from plants, soils, rivers, and lakes if it is available. While there has been a steady increase in atmospheric thirst over time, it is not all that variable from year to year. In contrast, the amount of water from precipitation and snowpack is quite variable. Climatic water deficit (CWD) is a dryness metric that incorporates both atmospheric thirst and precipitation. It characterizes how much more water would have evaporated or transpired from the soils if it were available and is calculated as the difference between atmospheric thirst (measured as potential evapotranspiration) and water availability in the soils (measured as actual evapotranspiration).

In water year 2022, October to December started out with a couple of large rain events which limited CWD. With the record dry next seven months, CWD was higher than average for the remainder of the year, especially in February and March, when there was very little precipitation. The total Water Year CWD tended to be larger in central and southern California, while a few places in northern California were below average due to the wetter patterns in Oct-Dec and April-July in the northern part of the state.

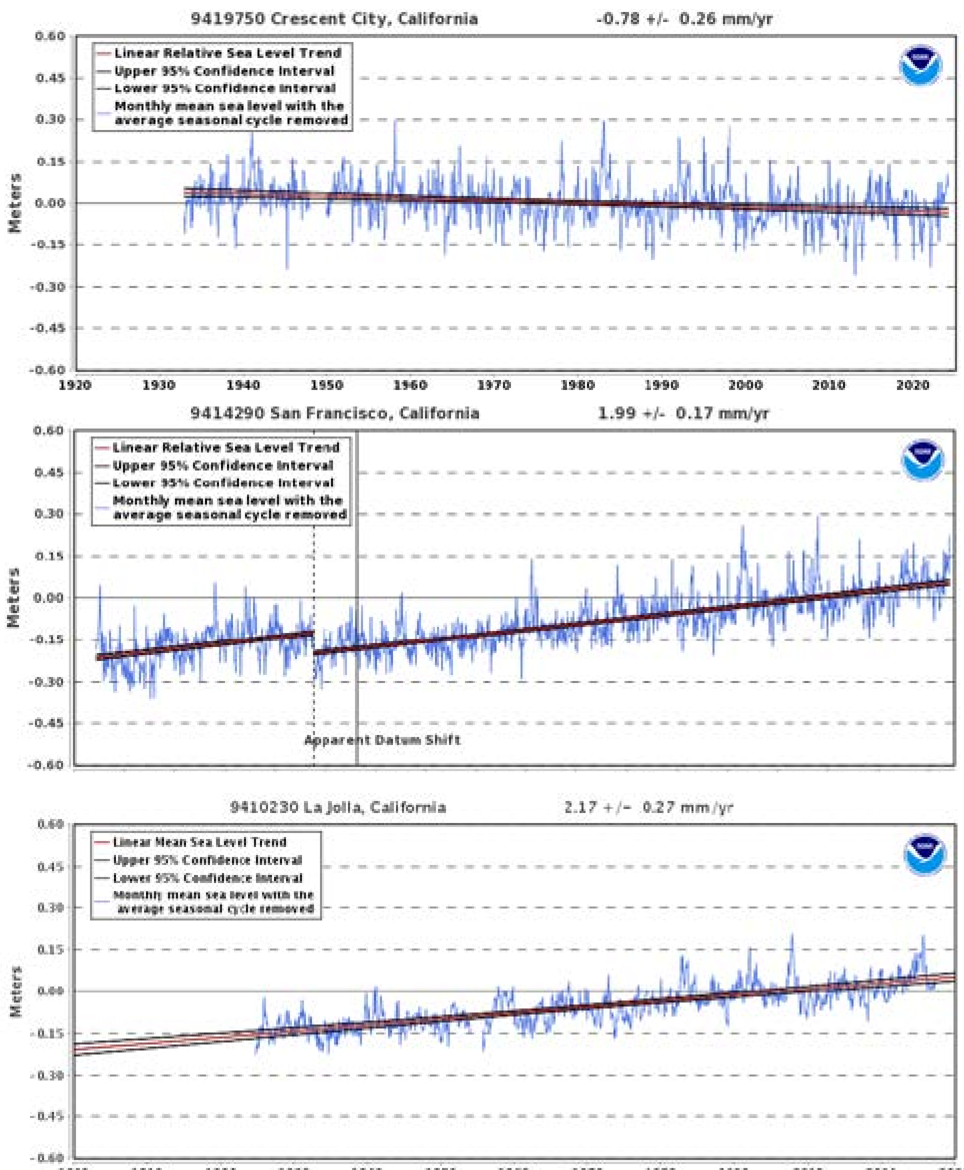
Climatic water deficit anamoly (%)



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 to illustrate the range of changes 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 while 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

The "Signposts of Change" section in this report highlights key climatic events during water year 2022 (October 2021-September 2022) that reflect increasing temperatures, changes in precipitation and extreme events. All-time record temperature were set during three heatwaves; February 8-11 (4 days, San Francisco & Salinas), March 21-24 (3 days, Sacramento, Stockton, Modesto, Red Bluff, and Death Valley on March 26) and August 30-September 10 (12 days, Burbank, Long Beach, Death Valley). On September 6, Sacramento (116°F), Stockton (115°F, tie), and San Jose (109°F) experienced their warmest day ever recorded. November 2021 and September 2022 had the warmest average nighttime low temperatures on record for those months.

Record heat conditions were also experienced in Africa and western Europe. Global ocean heat rose to an all-time high, and the four highest annual global ocean heat content measurements have all occurred in the previous four years (2019-2022). Artic ice extent was the lowest ever.

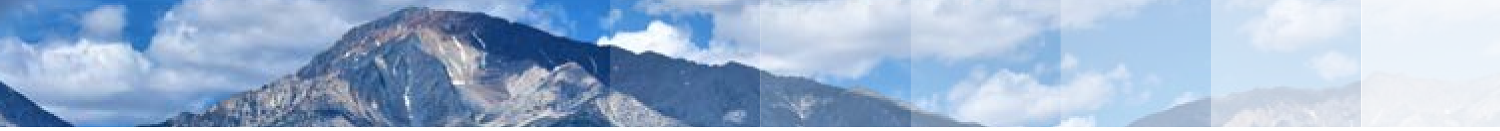
October started the water year with a series of 3 atmospheric river storms. On October 24, record low atmospheric pressure in the Pacific Northwest Ocean fueled a record setting bomb cyclone that produced atmospheric river level 5 conditions in California. Sacramento (5.44"), Santa Rosa (7.83"), and Blue Canyon (10.44") had their highest ever 24-hour precipitation. San Francisco (4.02"), Oakland (4.28"), Napa (5.35"), and Kentfield (11.09") set records for October precipitation.

Wet conditions continued into December when the U.C. Berkeley Snow lab had record snowfall of 214 inches. In a whiplash of conditions, January and February were the second driest on record. Dry conditions in the west lead to Lake Powell (April) and Lake Mead (July), important water supply reservoirs, falling to their lowest levels ever. Increased monsoon activity led to flooding conditions in Death Valley when on August 5th they had a daily record 1.7 inches of rain.

Summary of Signposts of Climate Change for Water Year 2022 (Oct 2021-Sept 2022)

California and Western North America

November 2021	**Highest statewide average minimum temperature on record for November**
October 24, 2021	**Record setting bomb cyclone** with atmospheric river level 5 conditions in California*
	It was the **third atmospheric river storm** to impact California **in 6-days** (atmospheric river storms on October 19 & 21 had level 2/3 conditions)
	Lowest atmospheric pressure ever recorded in the Pacific Northwest Ocean (942.5hPa)
	All-time record 24-hour precipitation in **Sacramento** (5.44"), **Santa Rosa** (7.83"), **Blue Canyon** (10.44"). **Record precipitation for October** in **San Francisco** (4.02"), **Oakland** (4.28"), **Napa** (5.35")1, and **Kentfield** (11.09")[1].
	Second highest recorded wave event offshore of Point Reyes (50-60 feet)
December 2021	**Snowiest December on record** at **U.C. Berkeley's Central Sierra Snow Lab** (214 inches of snow)
January & February 2022	**Second driest January** and **February in California**
February 8-11, 2022	**Heatwave, San Francisco** and **Salinas record high temperatures** for **February**
March 21-24, 2022	**Record breaking daily high temperatures** in S**acramento**, **Stockton**, **Modesto**, and **Red Bluff**
March 26, 2022	**Warmest March daily temperature** on record in **Death Valley** (104°F) and **Las Vegas** (93°F)



California and Western North America, continued

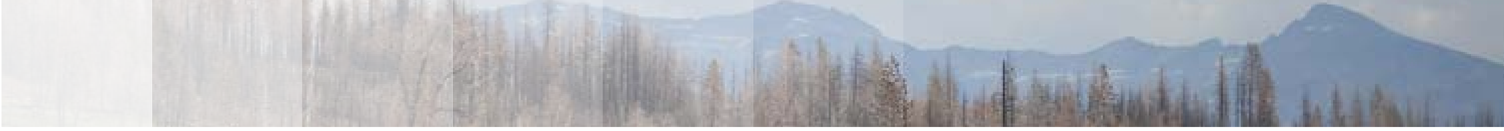
April 2022	**Lake Powell record low water level**
May 25, 2022	**Record high temperatures** in **Northern CA** (Redding, Sacramento, Stockton, Modesto)
May 25, 2022	**Record warm nighttime low temperatures** in **Redding** and **Red Bluff**
July 2022	**Lake Mead record low** water levels
August 5, 2022	**Record daily rainfall** in **Death Valley** (1.70") and flooding due to a strong monsoon
August 30, 2022 – September 10, 2022	**12-day heatwave** in the **western United States** broke nearly 1,000 daily heat records
August 31, 2022	**August record temperature** in **Burbank** (112°F)
September 4, 2022	**Record high temperatures** in **Burbank** (110°F, tie) and **Long Beach** (109°F). **Tied record high overnight low temperatures** in **San Diego** (78°F) and **Burban**k (82°F).
September 6, 2022	**All-time record high temperature** recorded in **Sacramento** (116°F), **Stockton** (115°F, tie), and **San Jose** (109°F). September record high temperatures was tied in Death Valley (125°F).
September 2022	**Highest statewide average minimum temperature** on record for September

Global

November 2021	**Warmest November on record** for **Africa**
May 2022	**Warmest May for contiguous United States**
June 2022	**Record low arctic ice extent** for **June**
July 2022	**Record warm temperatures for July** in **Western Europe**
August & September 2022	**Warmest August and September on record** for **North America**
2022	**46th-consecutive year** (since 1977) **with global temperatures rising above the 20th-century average**
2022	**Highest recorded global ocean heat content.** The four highest ocean heat contents have all occurred in the last four years (2019-2022).

*Atmospheric River Condition Scale Ranges from 1-5 https://cw3e.ucsd.edu/arscale/

Data sources: xmACIS2, NOAA Climate at a Glance, NOAA Annual Climate Report 2022



Notable Climate Events and Weather Extremes

Water year 2022 provided more extremes, more variability, and another year of drought. In fact, water years 2020-2022 now rank as the driest three-year period in the observed record beating out water years 2013-2015. October started with record setting rainfall as a category 5 atmospheric river impacted California. Record low pressure was recorded off of Aberdeen, Washington that was lower than the Columbus Day storm of 1962. A dry November led to below average conditions setting in again for the water year.

December provided a swing back to wet conditions with record snowfall falling at the Central Sierra Snow Laboratory. Wetter than average conditions were statewide with the central and southern coasts and Sierra receiving the most precipitation. At the end of the calendar year, snowpack was 157% of average for that time of year and half of a total seasonal snowpack.

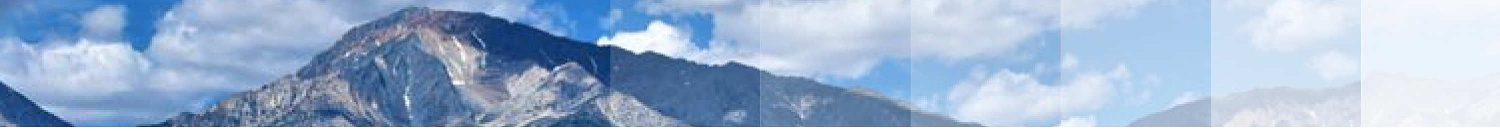
With the new calendar year came a new dry extreme. January 2022 registered as the third driest January in the historical record. No new snowpack development happened during the month. February 2022 was the second driest February in the historical record nearly reaching the record dryness recorded in 2020. March 2022 was the tenth driest march recording less than one inch of precipitation. After an above average start to the wet season, the driest start to a calendar year followed. January through March 2022 accumulated only 57% of the previous record low January through March precipitation set in 2013. In addition, the mean statewide temperature was 2.8 degrees Fahrenheit warmer than 2013 and sixth warmest overall.

April 1 is the historical average for the peak snowpack. October through March accounts for 80% of the statewide precipitation, on average. April through July is the historical period when the seasonal snowpack melts providing key streamflow for beneficial use. On April 1, the statewide snowpack was estimated to be 35% of average which is the fifth lowest value in a period of record dating back to 1950. In water year 2021, record heat and dryness impacted the spring runoff. In water year 2022, conditions improved with the April through June precipitation reaching 91% of average and temperatures cooling by almost three degrees Fahrenheit relative to 2021 but still remaining above average.

July through September of water year 2022 provided more heat and added above average precipitation. The Labor Day weekend heat wave set numerous all time daily high temperature records and had record warm low temperatures as well. For statewide average temperature, water year 2022 tied water year 2020 as the warmest July through September in a period of record

Satellite imagery from NASA showing a 942.5 mbar bomb cyclone approaching the Pacific Northwest on October 24, 2021.

The Mill Fire was a fast-moving, deadly and destructive wildfire that burned during the 2022 California wildfire season, destroying parts of the communities of Weed, Lake Shastina and Edgewood in Siskiyou County in California. Photo by CalFire.

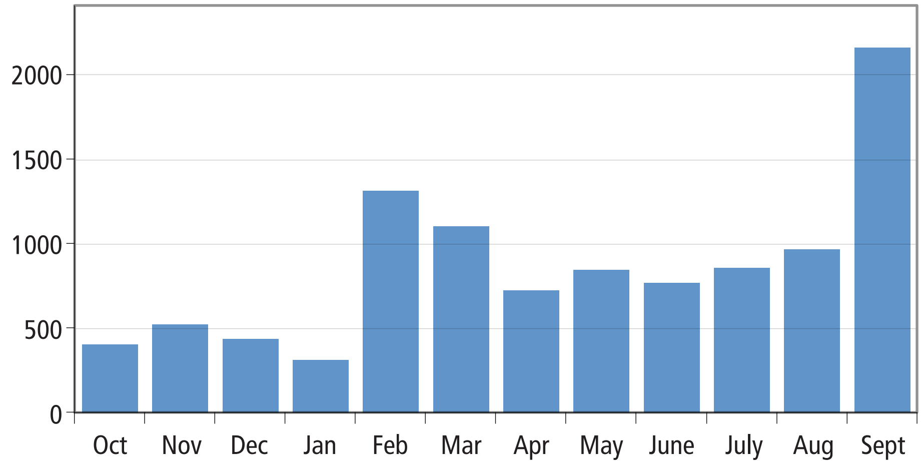


extending back to 1896. Water Year 2021 was only one tenth of a degree Fahrenheit cooler. On the precipitation side, a decaying tropical system, Kay, impacted southern California as the storm moved from the Pacific Ocean across Baja California and into the Gulf of California adding a wet extreme to close out the water year but not closing out the record setting drought.

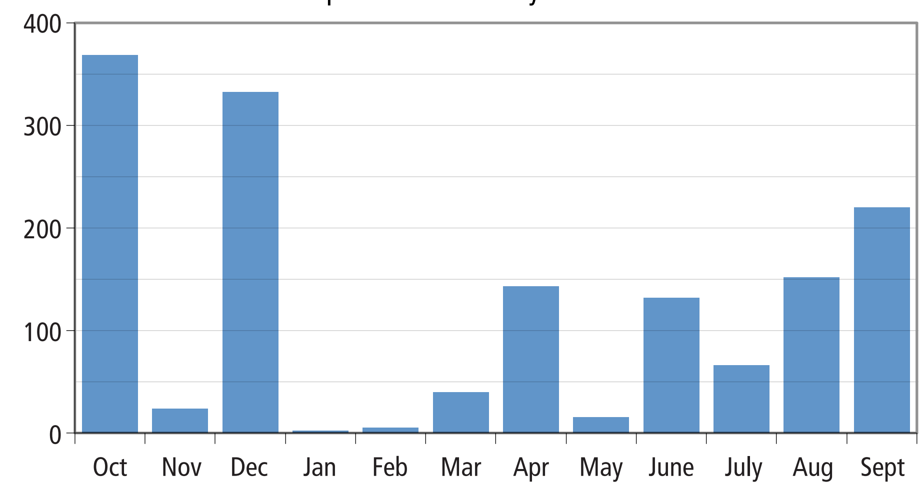
For water year 2022, there were 1,503 daily precipitation records tied or set and 10,445 daily temperature records set or tied. The impact of the extreme heat in September can be seen in the graphic of monthly distribution of temperature records as over 2,000 records were set in that one month. Fore precipitation, the wet extremes in October and December stand out with over 300 daily precipitation records set or tied in each of those months.

For three-year periods, water years 2020 to 2022 ranks as the driest 3-year period with only 65.4% of average precipitation. The previous record was 2013-2015 which accumulated 69.9%. As for mean temperature, the three-year period from 2020-2022 ranks as the fourth warmest. The three higher three-year periods were within the previous five years and were less than one half of one-degree Fahrenheit warmer. The tale of increasing extremes continues.

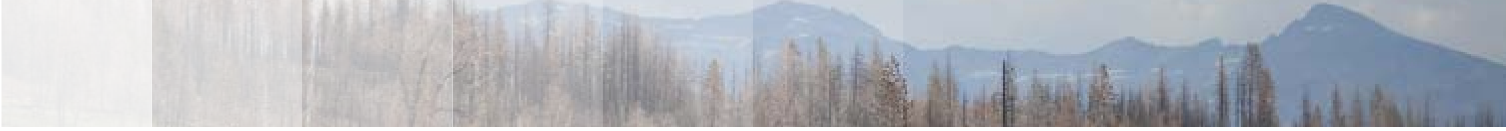
Number of Statewide Temperature Records by Month for Water Year 2022



Number of Statewide Precipitation Records by Month for Water Year 2022



A light smoke fills the air across campus along the First Street Promenade on Monday, August 15, 2022 in Chico, California, the first of seven days at or over the century mark for temperature. For the month of August in Chico, one day, August 1, was below 90 °F. Photo by California State University, Chico.



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.

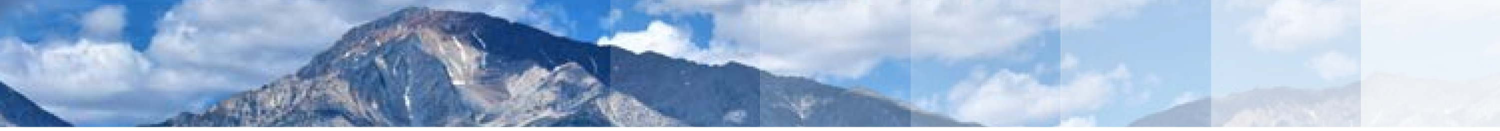
- **PRISM:** Parameter-elevation Relationships on Independent Slopes Model. A model that incorporates point measurements and topographic database to create a high resolution gridded climate database. More information on PRISM is available from Oregon Climate Service.

- **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/

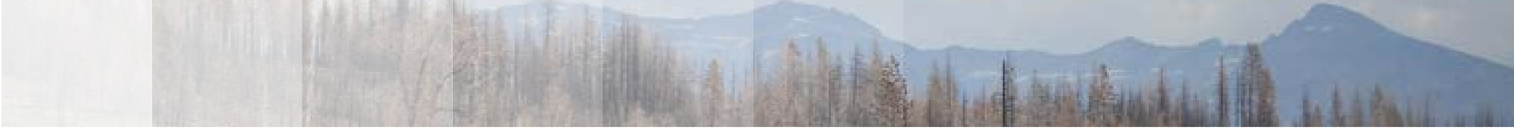
The Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, UCSD has developed a method in order to characterize atmospheric river (AR) events that make landfall along the US west coast. ARs are Identified using 6 hourly GFS Analysis derived integrated water vapor data. Arrows 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.

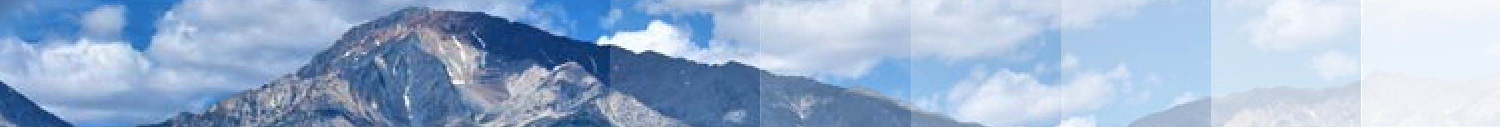
Decision 1641: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/decision_1641/

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.

Alonzo, Amy, (2022). Tahoe sets new December snowfall record with nearly 18 feet of powder, ***Reno Gazette Journal***, January 3, 2022. https://www.rgj.com/story/news/2022/01/03/north-tahoe-nevada-breaks-snowfall-record-december-18-feet-powder/9081201002/

Applied Climate Information System (ACIS) https://xmacis.rcc-acis.org/

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.

Carrigg, David, (2021). BC Cyclone "Bomb" Update: Record Low Barometric Pressure Recorded in Tofino | BC Hydro Issues Regional Alerts | Several ferries canceled Monday morning. The Canadian News, October 25, 2021. https://thecanadian.news/bc-cyclone-bomb-update-record-low-barometric-pressure-recorded-in-tofino-bc-hydro-issues-regional-alerts-several-ferries-canceled-monday-morning/

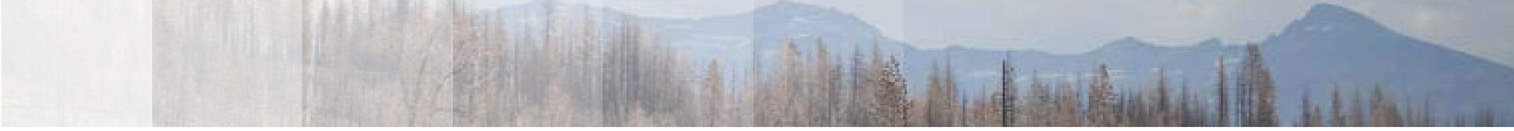
Center for Western Weather and Water Extremes, (2021). CW3E Event Summary: 19-26 October 2021, Scripps Institute of Oceanography at the University of California San Diego, posted 10-28-2021, https://cw3e.ucsd.edu/cw3e-event-summary-19-26-october-2021/

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 Ocean and Atmospheric Administration, 2021 & 2022. Monthly Global Climate Reports, National Centers for Environmental Information, https://www.ncei.noaa.gov/access/monitoring/monthly-report/

National Ocean and Atmospheric Administration, 2022 was world's 6th-warmest year on record, Antarctic sea ice coverage melted to near-record lows, January 12, 2023, https://www.noaa.gov/news/2022-was-worlds-6th-warmest-year-on-record#:~:text=Below%20are%20highlights%20from%20NOAA's%202022%20annual%20global%20climate%20report%3A&text=Earth's%20average%20land%20and%20ocean,in%20the%201880%2D2022%20record.

National Weather Service, 2021. Atmospheric River Brings Historic Rainfall to the Bay Area. https://www.weather.gov/mtr/AtmosphericRiver_10_24-25_2021#:~:text=Atmospheric%20River%20October%2024%2D25%2C%202021&text=Higher%20elevations%20of%20the%20North,the%20risk%20of%20fire%20season

National Weather Service, 2021. Fall 2021 NorCal Climate Summary. https://www.weather.gov/sto/Fall2021ClimateSummaryforNorthernCA

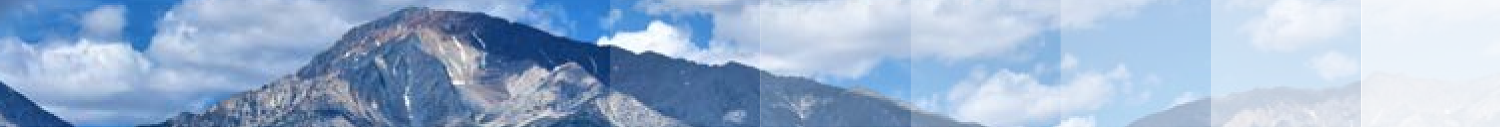
National Weather Service, 2022. Spring 2022 NorCal Climate Summary. https://www.weather.gov/sto/Spring2022ClimateSummaryforNorthernCA

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.

Rosenthal, Zach, (2022) Death Valley is sizzling weeks after record rainiest day, ***Washington Pos***t, September 2, 2022. https://www.washingtonpost.com/climate-environment/2022/09/02/death-valley-heatwave-rain-record/

Samenow, Jason, (2022). No September on record in the West has seen a heat wave like this; In just the past week, nearly 1,000 heat records have been broken, ***The Washington Post***, Sept 8, 2022 updated Sept 9, 2022, https://www.washingtonpost.com/climate-environment/2022/09/08/western-heatwave-records-california-climate/

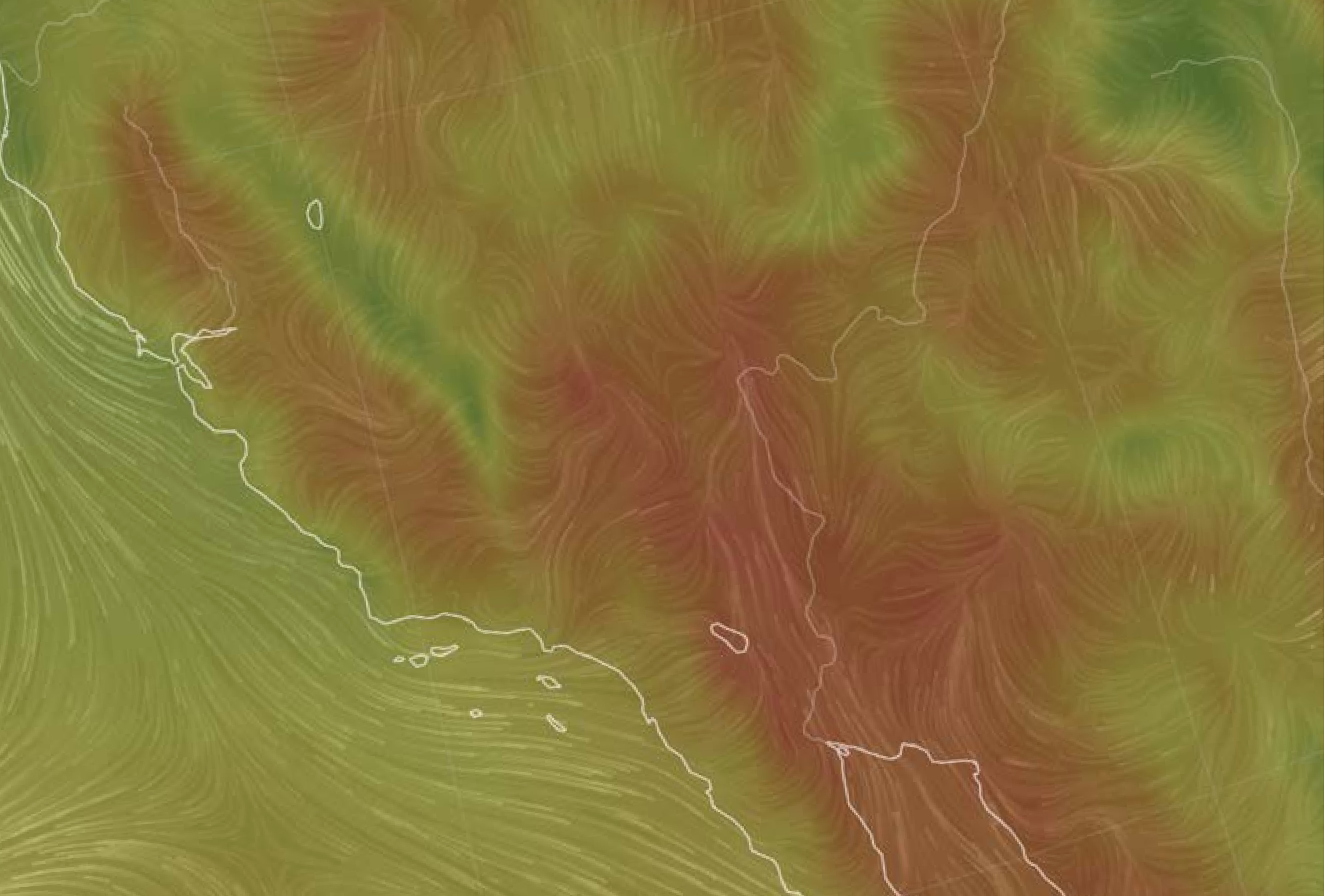
Santer, B., et al. 2000. Statistical significance of trends and trend differences in layer-average atmospheric temperature time series. ***Journal of Geophysical Research.*** 105 7337-7356.

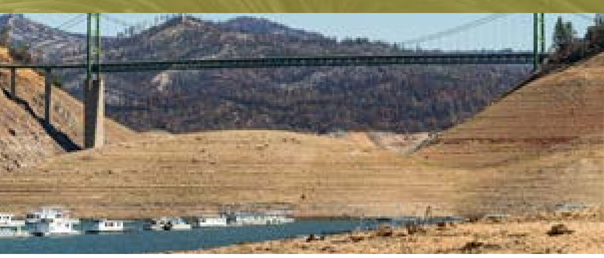
Scott, M. 2021. A late-summer heatwave and rain at Greenland's summit, Climate.gov, National Atmospheric and Atmospheric Administration, August 24, 2021. https://www.climate.gov/news-features/event-tracker/late-summer-heatwave-and-rain-greenlands-summit

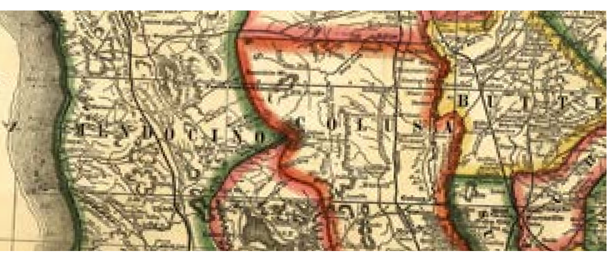
Sheets, Connor, Andrew J. Campa, Ruben Vives, (2022). Even higher temps expected on Labor Day as SoCal heat wave sets records, ***Los Angeles Times***, Sept 4, 2022 updated Sept 5, 2022. https://www.latimes.com/california/story/2022-09-04/searing-temperatures-continue-to-roast-southern-california-increasing-fire-risks

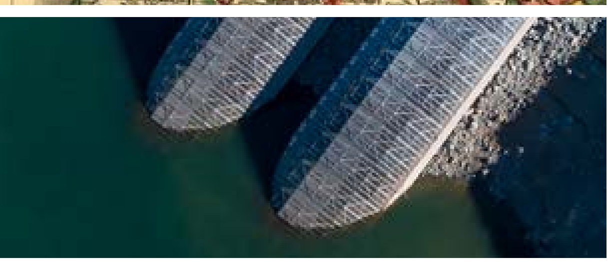
Wigglesworth, A. and Smith, H. 2021. Caldor, Dixie fires 1st to burn on 1 side of Sierra to other, ***Los Angeles Times***, August 31, 2021. https://www.latimes.com/california/story/2021-08-31/caldor-and-dixie-fires-first-burn-from-one-side-of-sierra-to-the-other WRCC. 2020. "California Climate Tracker."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

Low water drought conditions continue to expose more of the four intake towers at Hoover Dam, a 726-foot concrete archgravity dam, built on the Colorado River and the Nevada and Arizona border. The dam formed Lake Mead, which extends for 115 miles upstream, and is considered one of the largest artificial lakes in the world with 750 miles of shoreline. Continued drought in water year 2022 has pushed lake levels close to shortage criteria triggers. The reservoir helps provide water for 25 million people in Nevada, Arizona, and California, plus recreation with boating, fishing, and swimming. Photo taken March 2, 2022, by Christopher Clark / U.S. Department of the Interior - Bureau of Reclamation.









California State Climatologist

Dr. Michael Anderson

Michael.L.Anderson@water.ca.gov

Released July 2024

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

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

water.ca.gov/CaliforniaHydroclimateReports