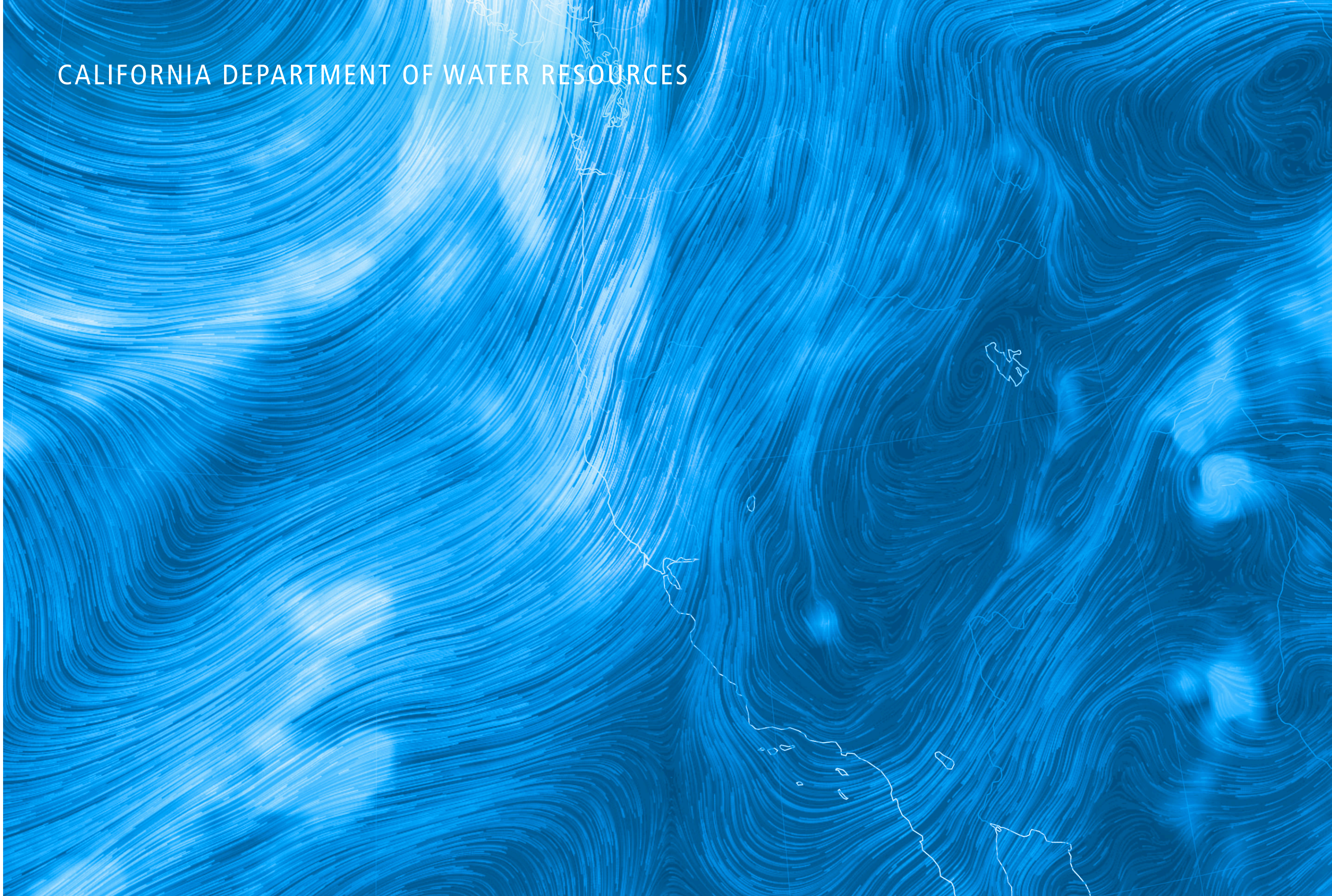
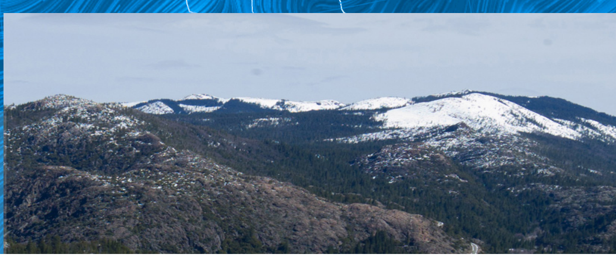
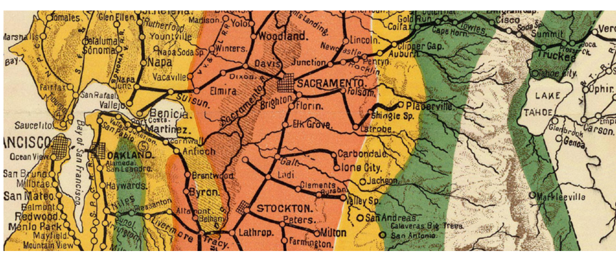
CALIFORNIA DEPARTMENT OF WATER RESOURCES







Hydroclimate Report Water Year 2015

Office of the State Climatologist

Executive Summary

Water year 2015 added a fourth year to the ongoing drought in California, with observations indicative of a changing climate, including record warmth. The Water year ended with record high temperatures, and preceded a period of historically low precipitation that started in 2012. April snowpack measurements in 2014 tied the historic record low of 1977. Expectations of a developing El Niño event in the eastern tropical Pacific fueled notions that water year 2015 would be better. However, during the first two months of the water year, warm temperatures persisted and precipitation continued to fall short of expectations. The developing El Niño event stalled as California headed into the heart of its wet season.

In 2014, the snowpack level was 25% of its average on April 1. That mark was shattered on April 1, 2015 when snowpack amounted to a meager 5% of average. Satellite-imagery compares the Sierra Nevada snowpack near the end of March 2015 to the average conditions in water year 2011. This extreme low in snowpack exceeds end-of-century climate projections. When accompanied by the record warm temperatures experienced in the 2015 water year, there is conversation of California having shifted to a new climate "normal".

Satellite depiction of peak Sierra Nevada snowpack near April 1 for average conditions in water year 2010 (left) and water year 2015 (right).

Image: NASA/MODIS

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

Introduction

The hydrology and climate of California impact the California Department of Water Resources' (DWR) mission to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments.

DWR has a long history of tracking variables that may be of use in assessing climate change impacts on water resources. With the concern of climate change and hydrologic change indicated by climate modeling simulations and measured data, DWR recognizes the need to plan for the future and to track continuing data trends. Indications of an uncertain climate future means the State will have to plan, manage, and adapt differently than in the past.

Climate change management is a core DWR value and the Department is actively planning for anticipated impacts of climate change. This report supports these efforts.

Based on current observed hydrologic and climatic trends, there is considerable evidence that the climate is shifting, no longer can stationarity be assumed in long-term planning. The future is now, and real changes need to be documented as new data become available. Following on the efforts of the National Climate Assessment and the California EPA Indicators of Climate Change in California Report (CA EPA, 2013), this report will begin documenting characteristics of a changing climate on California's water resources. By tracking change through a collection of indicators on an annual basis, it is hoped that transitions of important thresholds can be better anticipated, enabling the continued refinement of adaptation strategies.

This report includes key indicators for hydrology and climate in California and will be updated annually with the newest available data to track important trends, provide a compilation of indicators, and provide graphical visualization of data trends that are of interest to water managers, the media, State government, and the research community. Key indicators included in the Hydroclimate Report are listed in Table 1. Hydroclimate is defined in this report as natural hydrologic processes such as streamflow, snowpack, sea level, and precipitation; which are directly and indirectly linked to climate features, such as temperature trends and the nature of annual storms that bring precipitation, providing a primary source of freshwater.

Going forward, additional new data, such as information collected by atmospheric river research to better understand California's water supply and flood events may result in additional indicator metrics warranting inclusion in future reports. Therefore, the Hydroclimate Report will be a living document and will be reflective of current needs, new data sources, and analysis strategies as they come available providing the best scientific information available.

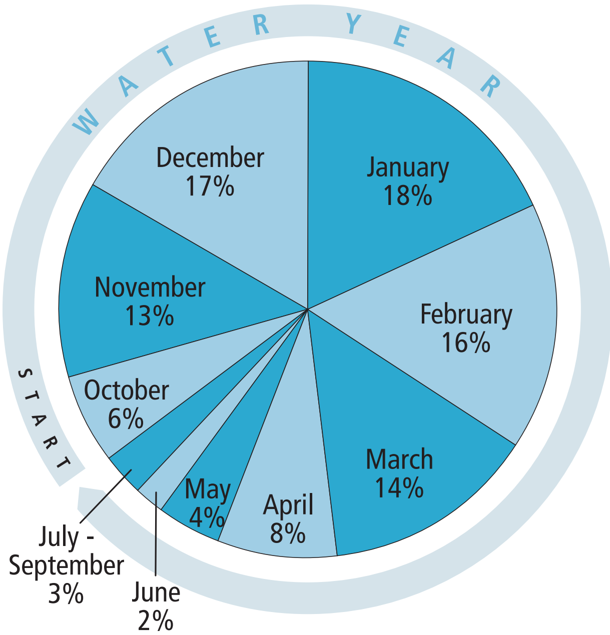
Table 1. Key Hydroclimate Indicators

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
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
Streamflow (Unimpaired)	Sacramento River Basin	April-July	1906-present	DWR
Streamflow (Unimpaired)	San Joaquin River Basin	April-July	1901-present	DWR
Rain/Snow (Percent As Rain)	Selected Sierra Watersheds	Annual Cumulative	1949-present	DWR/WRCC
Sea Level	Crescent City Tide Gauge	Monthly Mean	1933-present	NOAA
Sea Level	San Francisco Tide Gauge	Monthly Mean	1855-present	NOAA
Sea Level	La Jolla Tide Gauge	Monthly Mean	1924-present	NOAA

What Is A Water Year?

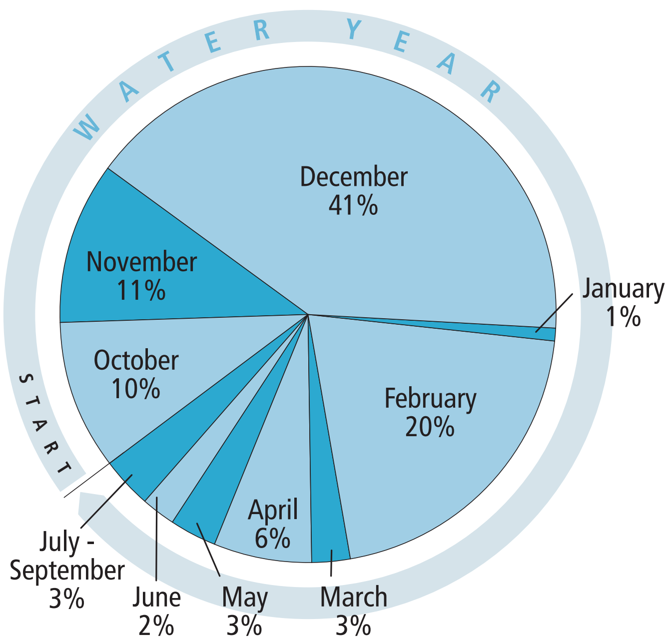
Northern Sierra 8-Station Precipitation Index (see map page 11 for locations)

Long Term Water Year Average by Month



The chart above depicts typical precipitation by month and percent of total that California receives throughout each water year. Precipitation generally arrives at the start of the water year 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 2015 by Month

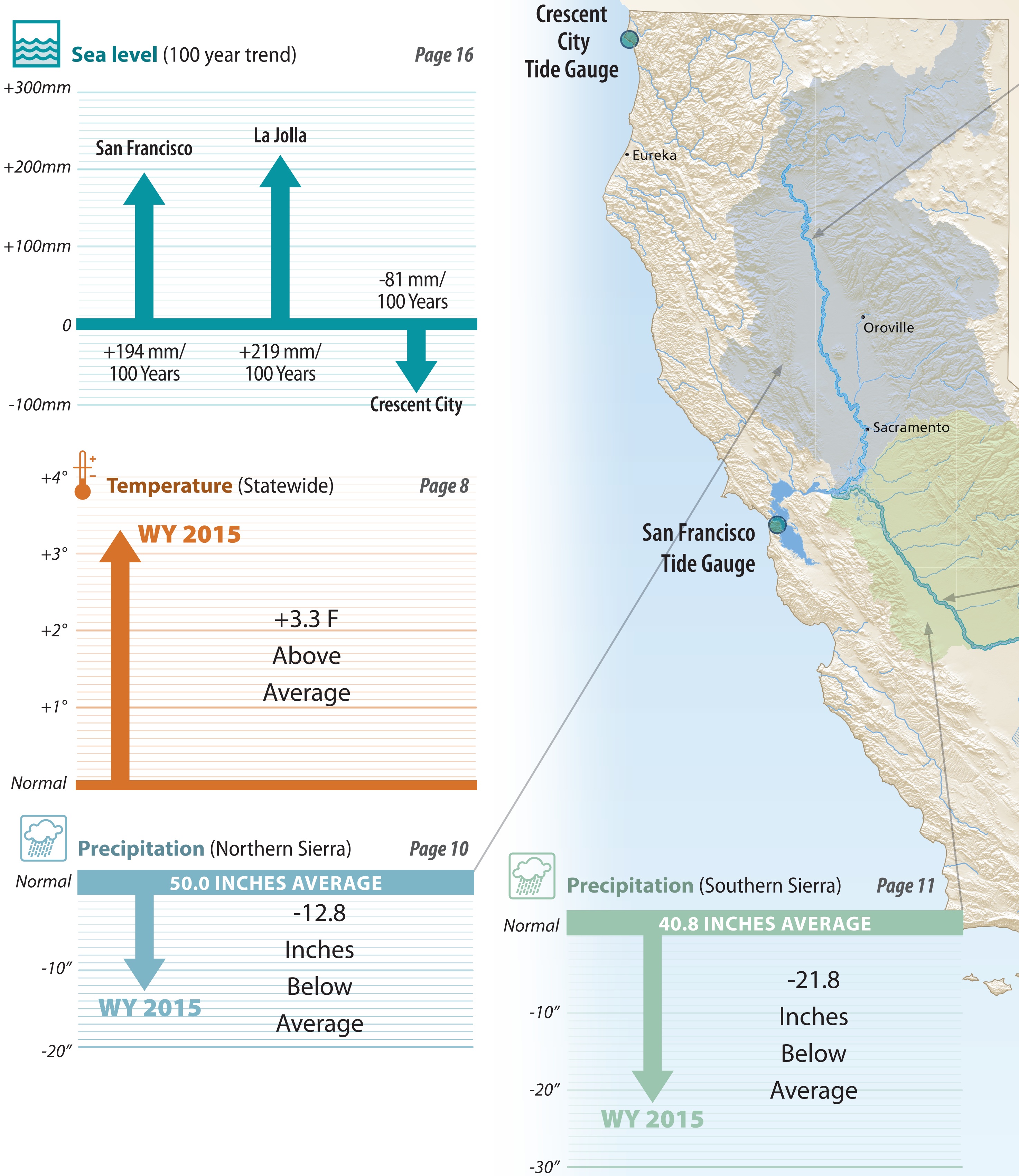


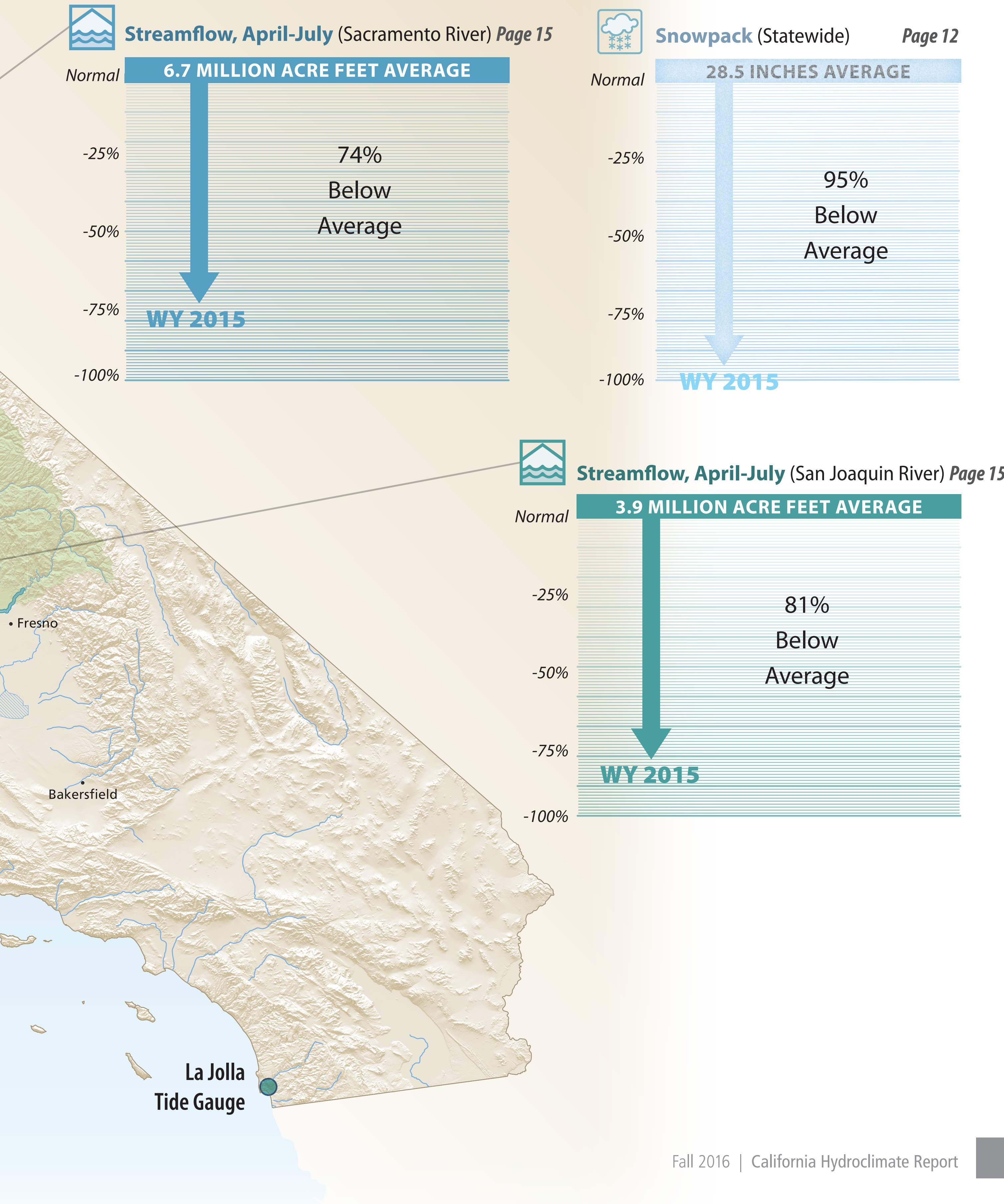
This chart represents monthly precipitation as percent of the total 2015 water year precipitation.

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. 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 2015 Water Year covers the period from Oct 1, 2014 to Sept 30, 2015.

A comparison between the pie charts shows that in 2015, 41 percent of the total water year precipitation occurred in December, however, on average December accounts for 17 percent of precipitation. Only 1 percent of the 2015 water year precipitation occurred in January, which is typically the peak of the winter precipitation at 18 percent on average. The lack of January precipitation, and corresponding absence of snowfall, led to a historically low snowpack in the Sierra Nevada.

California Hydroclimate Water Year 2015 “At A Glance”





Streamflow, April-July (Sacramento River) Page 15
6.7 MILLION ACRE FEET AVERAGE
Normal
-25%
-50%
-75%
-100%
74%
Below
Average
WY 2015
Snowpack (Statewide) Page 12
28.5 INCHES AVERAGE
Normal
-25%
-50%
-75%
-100%
95%
Below
Average
WY 2015
Streamflow, April-July (San Joaquin River) Page 15
3.9 MILLION ACRE FEET AVERAGE
Normal
-25%
-50%
-75%
-100%
81%
Below
Average
WY 2015
Fresno
Bakersfield
La Jolla
Tide Gauge

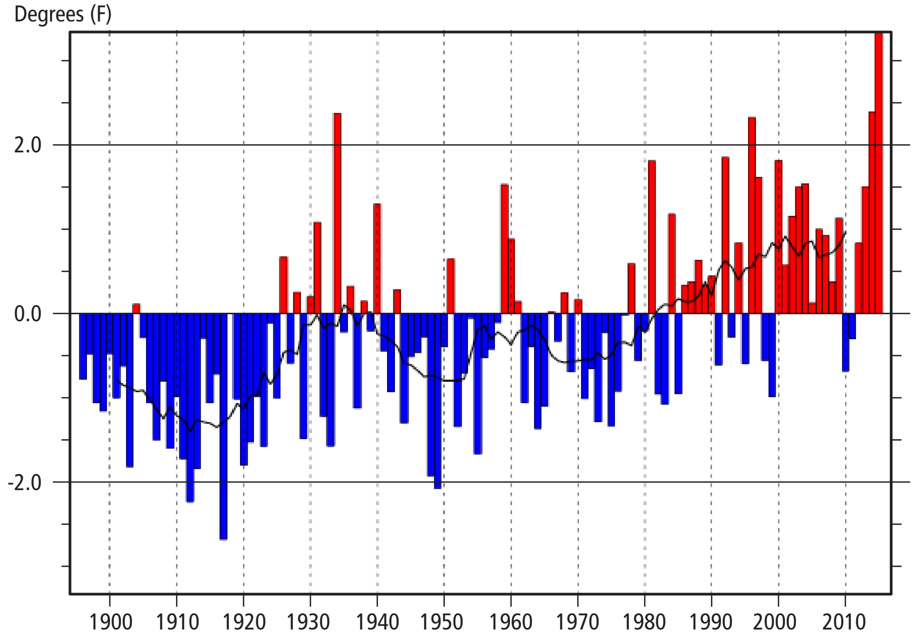
Annual Air Temperatures

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

California's temperature record reflects global temperature trends. According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 1.4 °F since 1880, and two-thirds of the warming has occurred since 1975 (Hansen et al., 2010). According to the Western Region Climate Center (WRCC), California has experienced an increase of (1.2 to 2.2 °F) in mean temperature in the past century. Both minimum and maximum annual temperatures have increased, but the minimum temperatures (+1.7 to 2.7 °F) have increased more than maximums (+0.6 to 1.8 °F) (WRCC, 2016).

Water year 2015 temperature measurements using WRCC and National Oceanic and Atmospheric Administration (NOAA) datasets demonstrate a continuing warming trend. Statewide average temperatures were ranked as the highest ever, ranking hottest in the historical record, dating back to 1895.

California statewide mean temperature departure, October through September



Black line denotes 11-year running mean

Departures from 1949-2005 base period:

Linear trend 1895-present	+1.72 ± 0.48°F/100 yr		
Linear trend 1949-present	+2.90 ± 1.19°F/100 yr		
Linear trend 1975-present	+4.05 ± 2.73°F/100 yr		
Warmest year	59.4°F (+3.3°F in 2015	Mean	56.1°F
Coldest year	53.4°F (-2.7°F) in 1917	STDEV	0.98°F
October-September 2015	59.4°F (+3.3°F)	Rank	120 of 120

Western Regional Climate Center (WRCC) California Climate Tracker

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

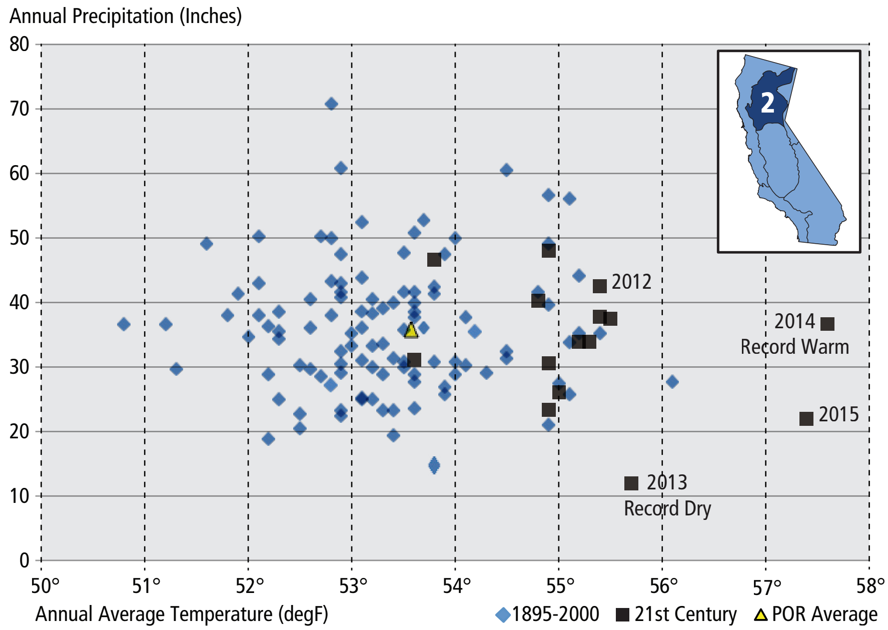
Graph shows "departures" for average (mean) and maximum temperatures each year from a long-term average (the years 1949 to 2005) i.e., the difference between each year's value and the long-term average.

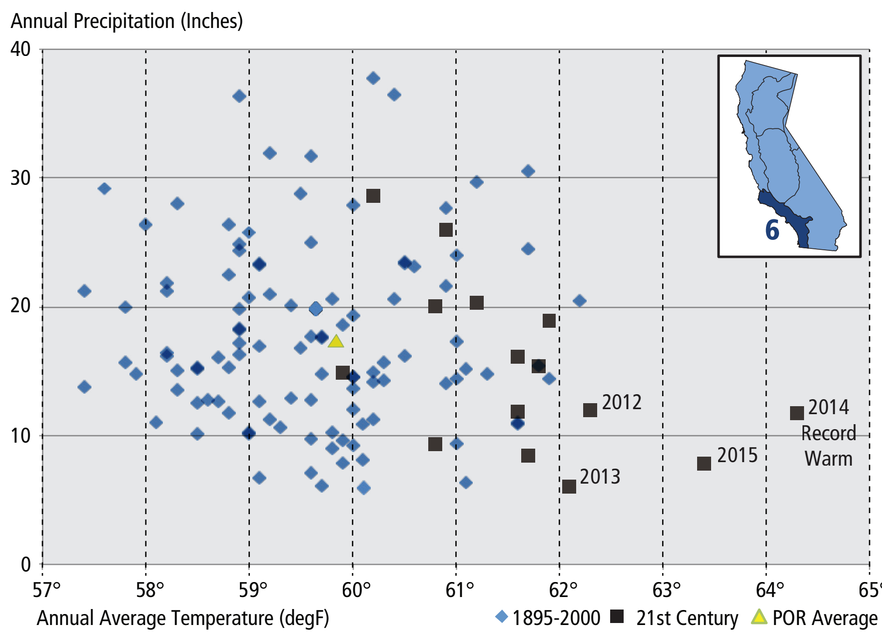
The NOAA Climate Divisional Dataset is a long-term temporally and spatially complete dataset used to generate historical climate analyses (1895-2015) for the contiguous United States. This data set is based on a calendar year instead of the hydrologic water year. There are 344 climate divisions in the US and this report's focus is on two climate divisions within California: Climate Division 2 (Sacramento Drainage) and Climate Division 6 (South Coast Drainage). For each climate division, monthly station temperature and precipitation values are computed from daily observations. Plots of annual precipitation versus annual average temperature are shown, using the annual average values from 1895-2015.

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

Data from Climate Division 6 (South Coast Drainage) depicts even more annual precipitation variation from 5 to 40 inches per calendar year. The past 15 years since the turn of the century are also extremely warm and dry, indicating a change in climate. The past three years are depicted as being some of the warmest and driest years on record, with the warmest on record occurring in 2014 and second warmest in 2015.

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. The combination of warmer temperatures and lower rainfall in the 21st Century has exacerbated the hydroclimate stress that California is currently experiencing.

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.

A limited number of precipitation-producing storms move over California every water year. Attention has recently turned to storms associated with atmospheric rivers. Atmospheric rivers are long (approximately 1000 miles), narrow (less than 100 miles wide) swaths of intense levels of water vapor extending from tropical regions into the middle latitudes. When atmospheric rivers are entrained into the leading edge of a winter storm moving over California, the result can be heavy precipitation with snow levels above 10,000 feet. If the atmospheric river storm lasts long enough, flooding can result. Shorter duration atmospheric rivers associated with cool air and lower snow levels result in storms that are beneficial to snowpack and California's water supply.

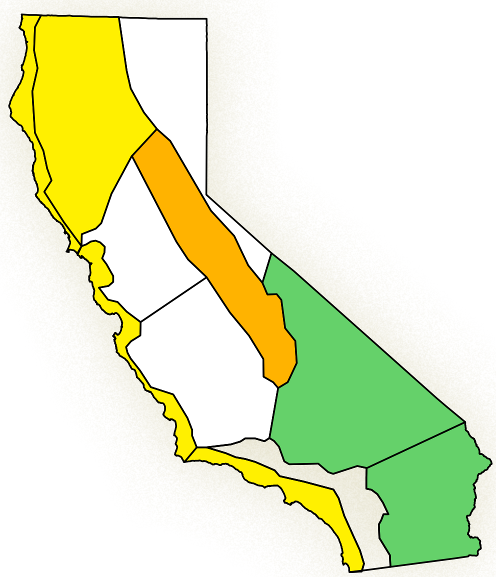
Typically, only a few strong atmospheric river storms impact California during the winter months, and on average, atmospheric river storms provide 30 to 50 percent of California's annual precipitation and 40 percent of Sierra snowpack. With warmer air, and changing ocean conditions, atmospheric river episodes have the potential to increase in duration and intensity (Dettinger, 2011).

Over the past 10 years, DWR has begun investing in observations to track the characteristics of atmospheric rivers as they make landfall in California. The amount of atmospheric moisture, structure of the winds with altitude, and freezing elevation at several locations are now monitored with each storm. This effort is being carried out in partnership with NOAA's Earth Systems Research Laboratory and the Center for Western Weather and Water Extremes (CW3E) at Scripps Institution of Oceanography. Atmospheric river data will be included in future reports.

Water Year 2015 Precipitation

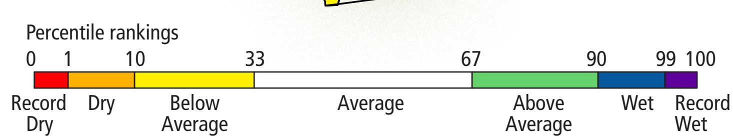
Statewide precipitation trends were analyzed by the WRCC using a data set that includes precipitation values across California. A total of 195 stations across the state are included in this analysis. Cooperative Observer Network (COOP), station data along with the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database are considered in this analysis dating back to January of 1895. PRISM analyses depict an average precipitation year for much of the Central Valley and Northeast. The Southeast experienced above average precipitation and the Coastal regions and the Northwest were drier than average.

California Climate Regions Precipitation Rankings, Water Year 2015

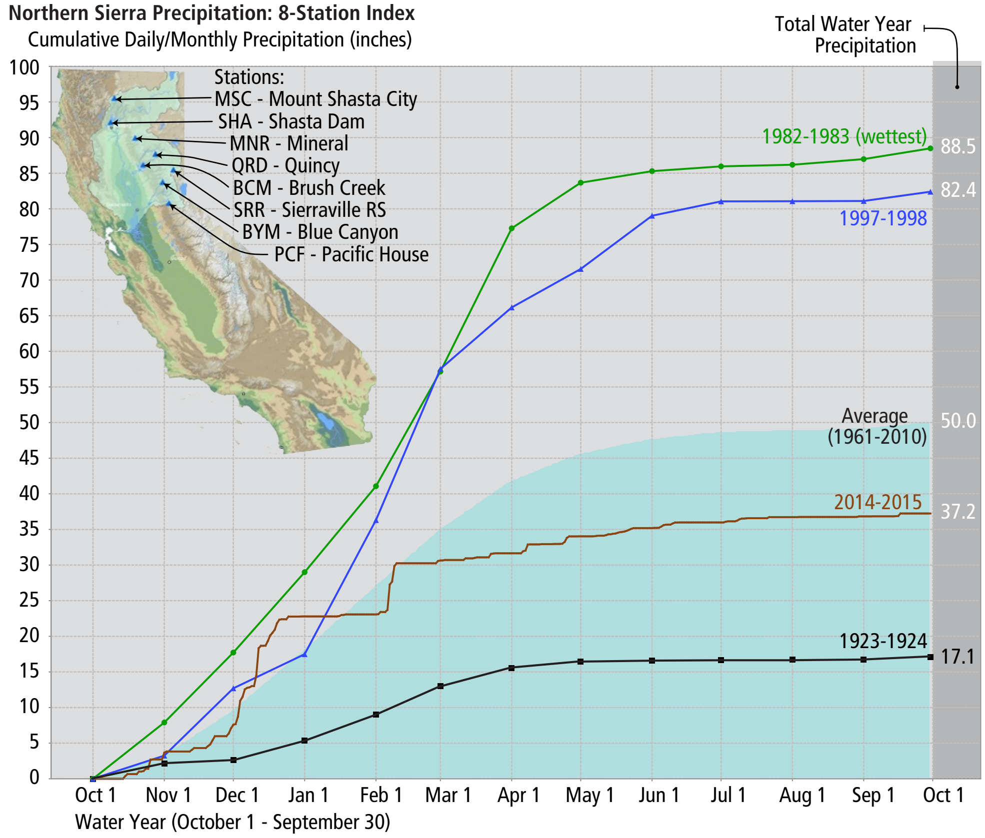


Western Regional Climate Center (WRCC) California Climate Tracker

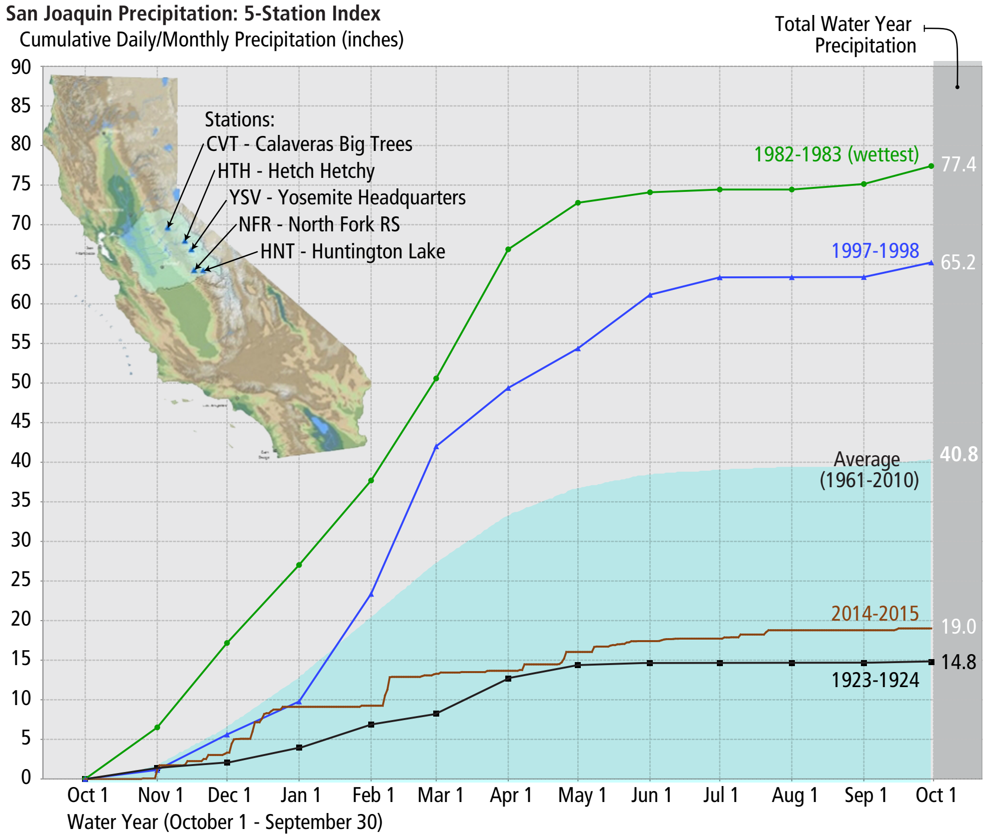
- Spatial resolution: 11 climate regions
- Temporal resolution: Monthly, Water Year



DWR Aggregate Precipitation Station Indices



Regional precipitation trends are tracked by DWR at key locations critical to water supply in the state. These precipitation station indices are located in the Northern and Southern Sierra and are used in the calculation of the water year type on the Sacramento and San Joaquin River systems. For water year 2015, the Northern Sierra Precipitation 8-Station Index shows total water year precipitation at 37.2 inches, well below the average of 50.8 inches. The graph shows that the majority of the rainfall occurred in December and February. However, water year 2015 was wetter than the driest water year in 1924 when the 8-Station Index reported 17.1 inches of precipitation.



The San Joaquin Precipitation 5-Station Index, which is representative of the Southern Sierra, received much less precipitation than the Northern Sierra. Water year 2015 had a total water year precipitation of 19.0 inches; well below the average of 40.8 inches and just above the all-time low of 14.8 inches occurring in 1924. These low precipitation values added to the continuing drought in California.

Snowpack

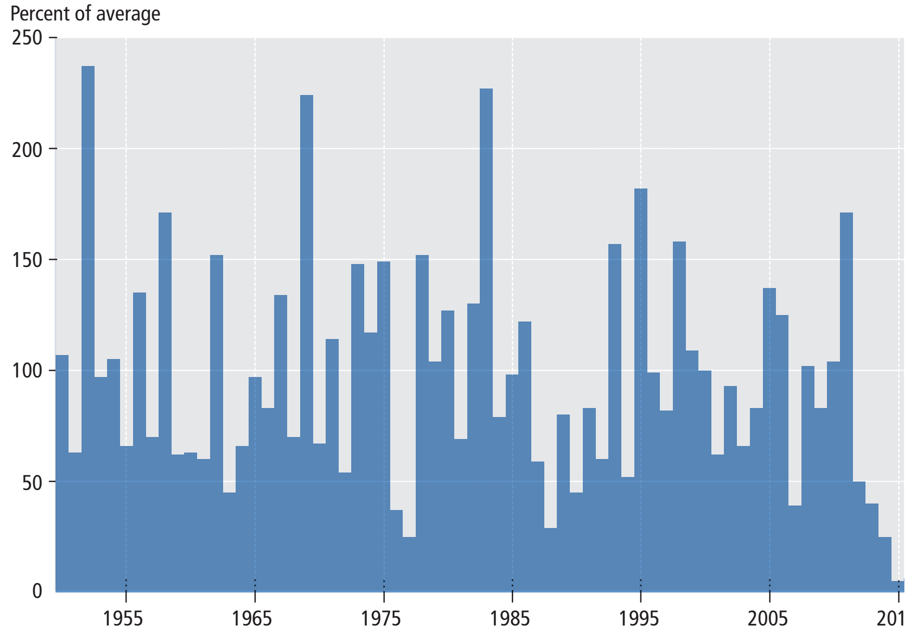
Snowpack is an essential water supply feature in California and historically provides approximately 15 million acre-feet of water accounting for one-third of the State's annual water supply. Numerous studies have reported declines in Western US snowpack in recent years and have been attributed to warming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

The California Cooperative Snow Surveys program has been actively collecting data since the 1930's and presently has approximately 130 snow sensor sites from Northern and Southern Sierra locations. A consistent long-term historical record lends this data set to making a good indicator in of snowpack in California.

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

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

Statewide snow water equivalent (April 1)



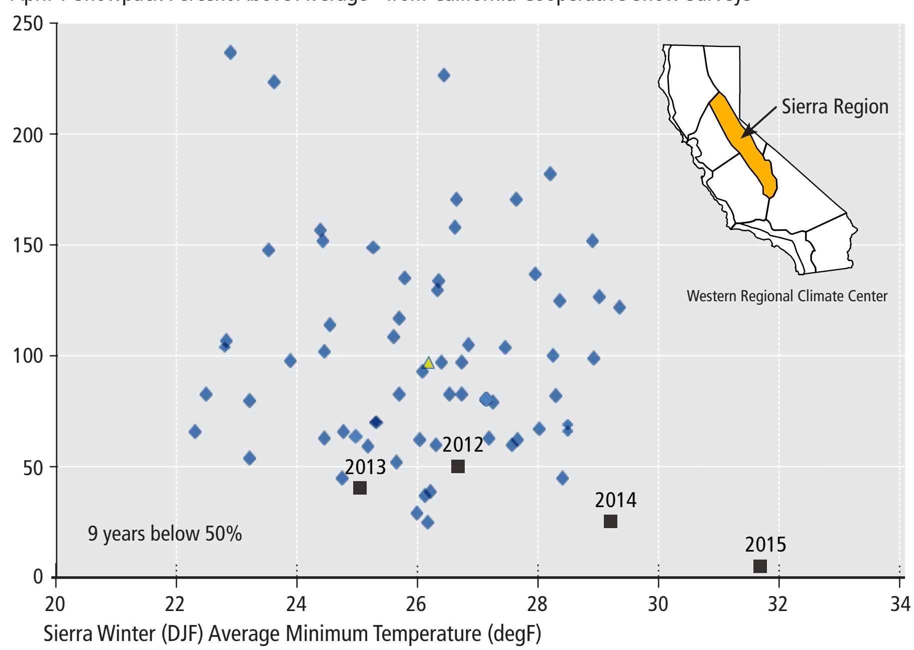
Water Year 2015 statewide snowpack water content was just 5 percent of the average amount in the northern Sierra Nevada and 6 percent of the average in the central and southern Sierra Nevada. During an April 1st snow survey the California Cooperative Snow Surveys Program found a complete absence of snow at several key sites.

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, 1950-2015

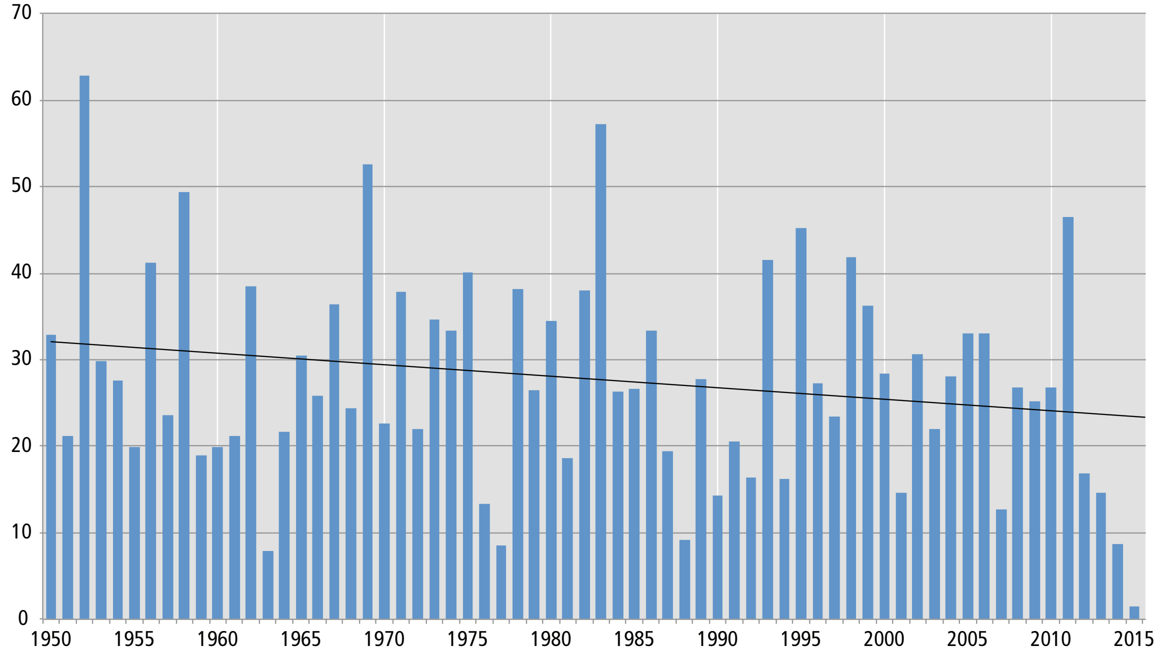
April 1 Snowpack Percent Above Average - from California Cooperative Snow Surveys



A scatterplot of April 1st snowpack vs. Sierra minimum air temperatures shows the past four years have had 50 percent or less of the average snowpack. 2015 is shown as an outlier bottom-right, being one of the driest and warmest winters since 1950. With the lack of overall precipitation and very warm winter temperatures, water year 2015 is clearly shifted beyond the historical distribution.

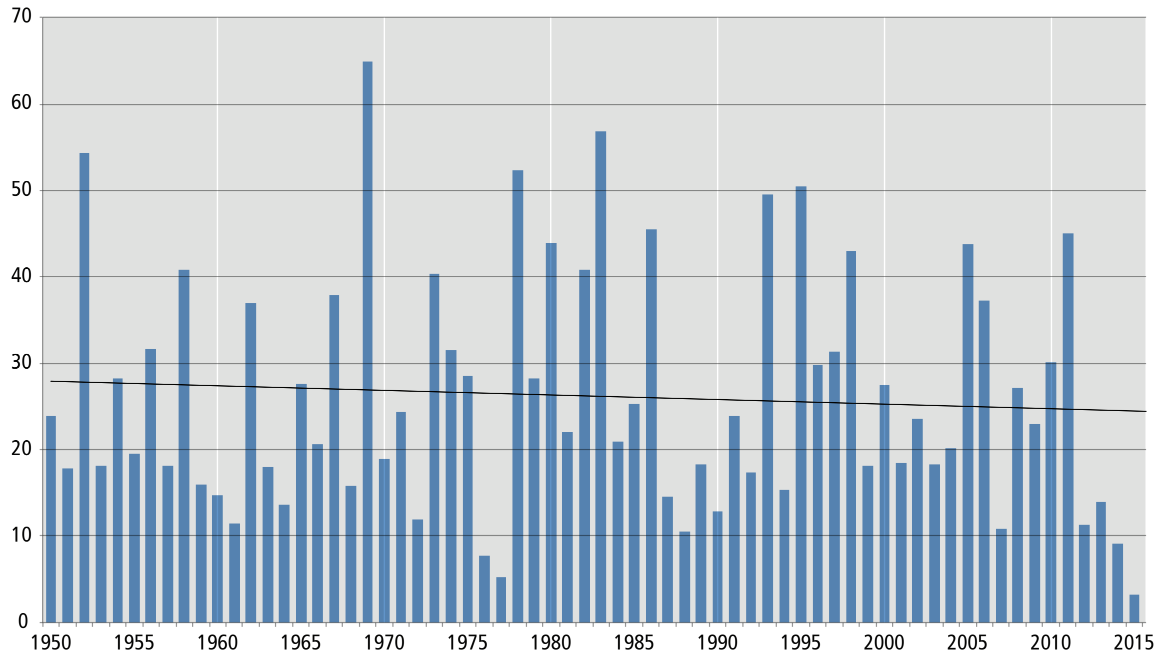
April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses

inches



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

inches



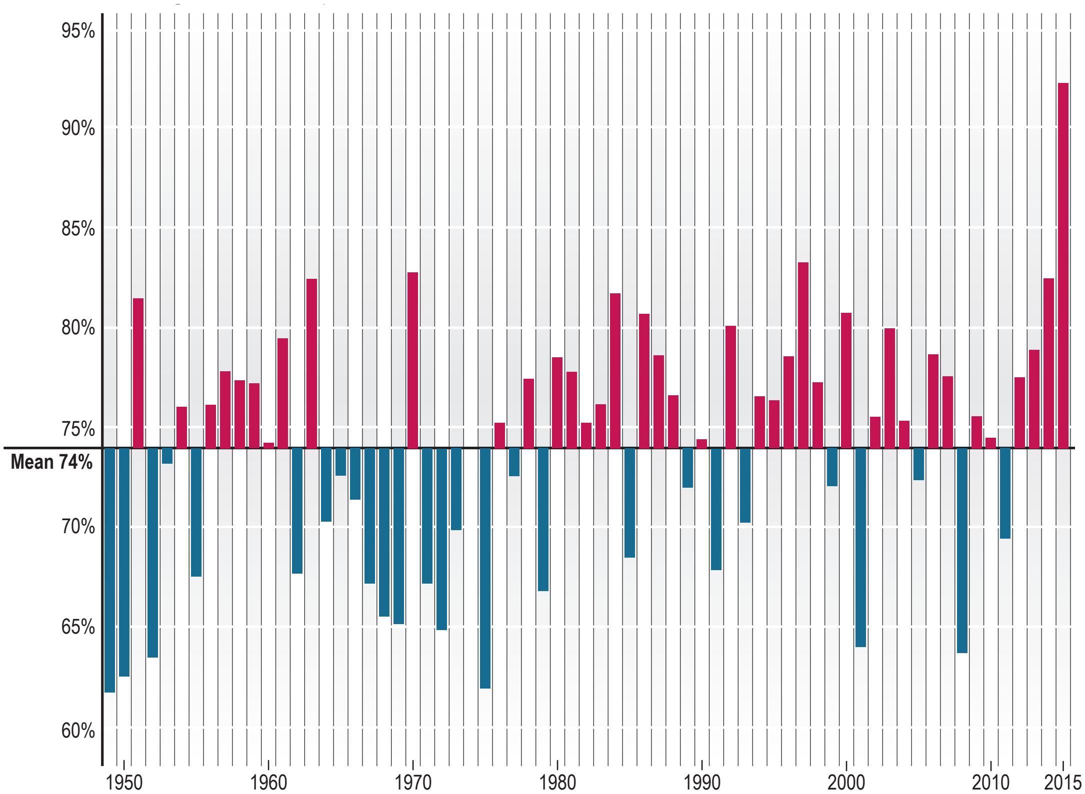
A trending decline in April 1st snowpack is apparent in the Northern Sierra 13 station group as well as the Southern Sierra 13 station group. In the 2013 EPA Indicators report, the Northern Sierra group was shown to have a 10 percent decrease while the Southern Sierra group had a 10 percent increase from 1950-2011.

A paper presented to the Western Snow Conference by Roos and Sahota (2012) concluded that over a 62-year period of analysis from 1950-2011, total precipitation had increased, and the higher elevations of the Southern Sierra 13 station group were less affected by rising snow lines. With higher elevations of the southern stations and lower freezing temperatures, snowpack had increased (see page 24). However, with the recent lack of significant precipitation, that trend of gaining snowpack has since reversed.

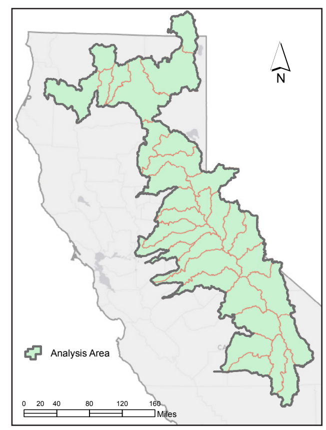
Rain/Snow Trends

In recent decades, there has been a trend toward more rain than snow in the total precipitation volume. This plays a role in reducing total snowpack. Snowpack is a vital component of California's water system, naturally storing up to one-third of the state's water supply. The chart below clearly illustrates the changes over time in the percentage of precipitation falling as rain versus snow. Values are based on the WRCC Freezing Level Tracker that models whether precipitation at a specified elevation falls as rain or as snow, using the assumption that precipitation falling below the freezing elevation (0° Celsius) is rain. The data show substantial inter-annual variability due to climate signals that occur on annual and decadal scales as variations from the analysis period mean. 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. Years with a higher percentage of rain are more common in the later period of record, in agreement with expectations under a warming climate and previous studies (DWR, 2014).

Rain as Percentage of Total Precipitation



Location of 33 watersheds sampled



Percentage of rain for the analysis period (WY 1949-2015)

- Mean for 1st half of record: 72
- Mean for second half of record: 76
- Mean for entire dataset: 74

In WY 2015 this indicator clearly reflects the effect of the exceptional temperatures had on percentage of precipitation falling as rain with over 90% of precipitation falling as rain.

Unimpaired Streamflow: Sacramento and San Joaquin River Systems

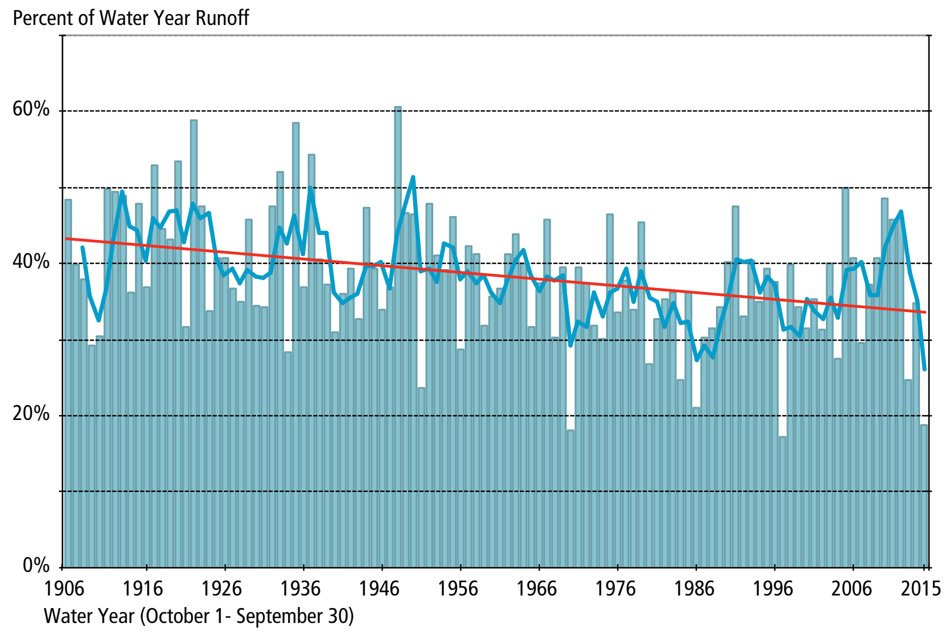
With increasing temperatures and corresponding loss of snowpack, how can a comparison be made representing spring snowmelt? Since the main watersheds in California have been altered by water development projects such as dams and diversions, historical natural hydrology flows would be difficult to compare.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

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

With the exceptional temperatures in water year 2015 and corresponding lack of precipitation falling as snow, this indicator has some of the lowest April through July flows on record.

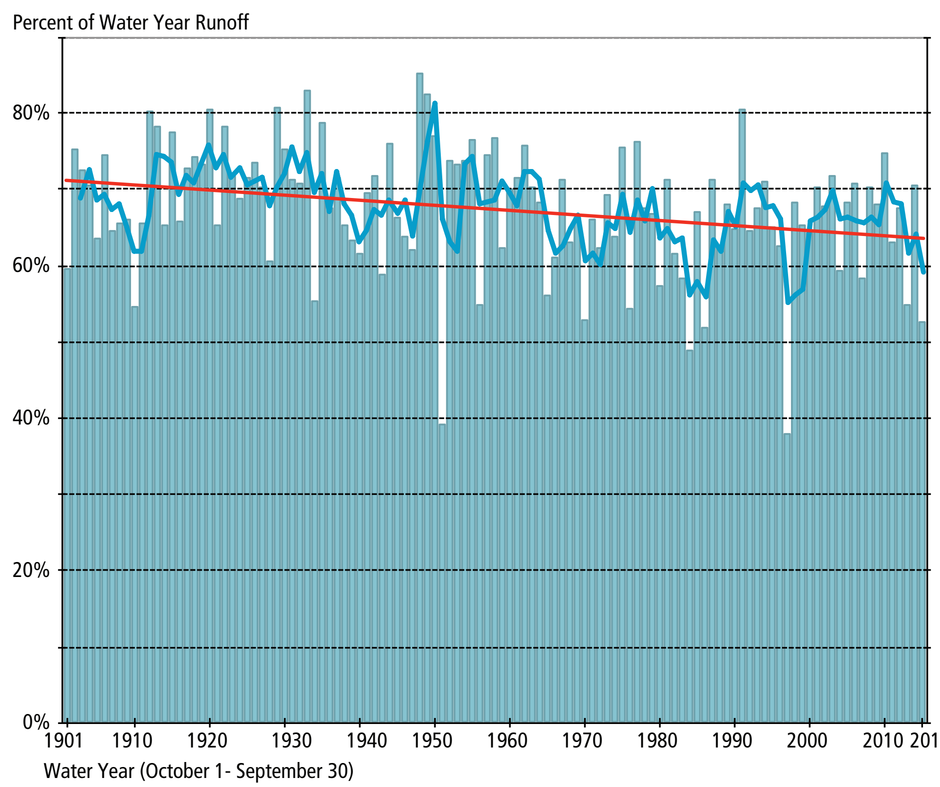
Sacramento River Runoff, April - July Runoff in percent of Water Year Runoff

— 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

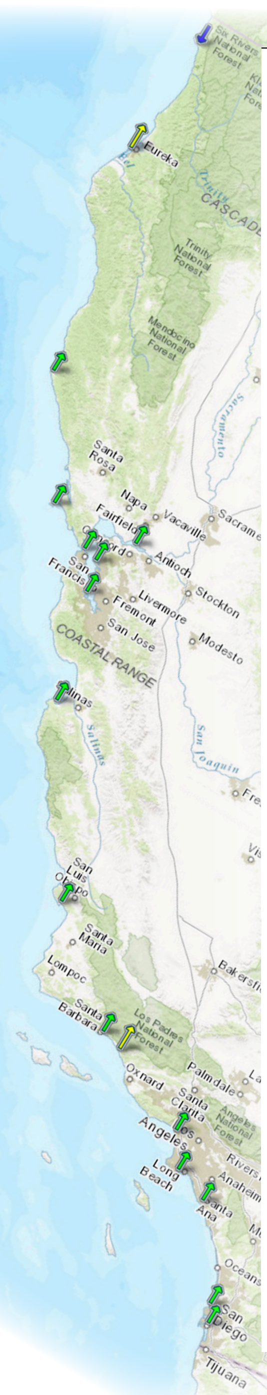


Sea Level

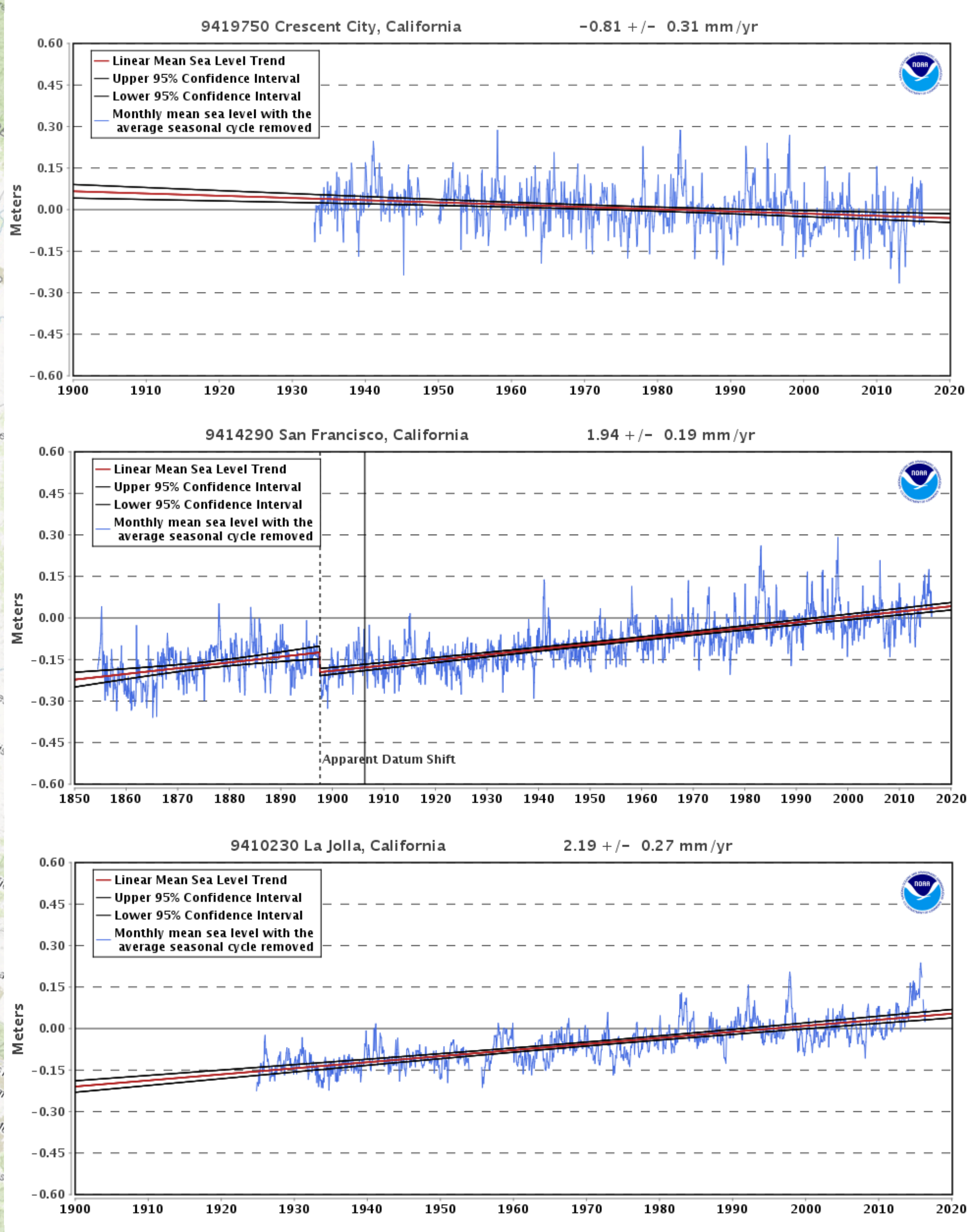
A warming climate causes sea level to rise in two ways; first, by warming the oceans, which causes the water to expand; and second, by melting terrestrial ice, which transfers water to the ocean. Recent satellite data shows that the rate of sea level rise is accelerating, with melting of terrestrial ice now the largest component of global sea level rise (about 65 percent), largely because ice loss rates are increasing. Future sea level rise along the California coast may be uneven. Models indicate that it depends on the global mean sea level rise and regional factors, such as ocean and atmospheric circulation patterns; melting of modern and ancient ice sheets; and tectonic plate movement.

During the last century, sea level at the Golden Gate tide gauge in San Francisco has shown a 7 inch increase, similar to global measurements. Sea level at the La Jolla tide gauge in Southern California has increased 8 inches and has decreased by 3 inches in Northern California at the tide gauge at Crescent City.

Although mean sea level (MSL) is expected to rise with climate change, MSL at Crescent City is trending lower due to the Cascadia Subduction Zone, where the buildup of interseismic strain is causing coastal uplift north of Cape Mendocino. Most gauge south of Cape Mendocino show relative sea-level rise, consistent with land subsidence. When adjusted for vertical land motions and for atmospheric pressure effects, the rates of relative sea-level rise along the U.S. West Coast are lower than the rate of global MSL rise (National Research Council 2012).



Mean sea level, as measured at three key coastal guages



Notable Climate Events and Weather Extremes

Water year 2015 marked the fourth year of statewide drought for California. Water year 2014 ended with record warm temperatures, and included the end of a record dry 404 day period that started at the end of 2012. The peak snowpack in 2014 tied the historic record low of 1977.

Expectations of a developing El Niño event in the eastern tropical Pacific fueled notions that water year 2015 would be wetter. However, during October and November, the first two months of the water year, warm temperatures persisted and precipitation continued to fall short of expectations. The developing El Niño event stalled as California headed into the heart of its wet season.

California's prolonged drought is believed to have been a factor in a massive mudslide on Mt. Shasta in the fall of 2014 after meltwater from a glacier sent torrents of debris and mud down the mountain. Image Source: inciweb.nwcg.gov

The months of December, January and February provide half the expected annual precipitation. This is also the main development period of California's snowpack. December opened with a low pressure system drifting down the coast. As the system approached Southern California, it encountered a surge of tropical moisture leading to a warm rain event for the state that didn't match the expected characteristics of an atmospheric river event. The heavy rain led to some minor landslides in Southern California. A second stronger storm arrived the following week hitting Northern California. Heavy rainfall was accompanied by wind speeds across the crest of the Sierra Nevada Mountains exceeding 100 mph. Reservoir storage increased by more than one million acre-feet in the northern part of the state. Uncontrolled tributary flow on the Sacramento River yielded high water and flow into the flood control bypass system. Snow accumulation was limited by warm temperatures accompanying the storm. These storms brought the seasonal precipitation totals above average and fueled expectations of a better year than the previous. High pressure over Nevada led to a Santa Ana wind event for Southern California in the final week of 2014. A cold system pushed through towards the end of the week causing some freezing temperatures in the Central Valley and snow on New Year's Eve in Needles.

January did not follow in December's footsteps. High pressure returned to California for the month leading to record dry and warm conditions. South Lake Tahoe recorded several days above 60 degrees during the month. San Francisco recorded its first rain-free January with observations dating back to the 1860s. The snow that did accumulate during December melted out from lower elevations. January closed out with another Santa Ana wind event for Southern California.

February provided a return of wet weather with a pair of atmospheric river events focused on the northern part of the State. Over a foot of rain fell above Shasta Reservoir in a seven day period. Flood stages were briefly experienced on some North Coast rivers. Rain was observed during the event at the top of Donner Pass on Interstate-80. Unfortunately, the wet pattern did not persist for the entire month resulting in another below average precipitation accumulation with warmer than average temperatures. While the winter storms provided some relief to drought impacts with increased reservoir storage in the north, the snowpack was still well below average and expectations of continuing drought started to materialize.

While the month of March provided relief in past droughts, March 2015 did not. After some early rain and snow, high pressure and warm temperatures returned. April 1 marks the traditional peak of California's snowpack. In 2014, the record low of 25% of average April 1 snowpack had

On April 1, 2015, DWR's Chief of Cooperative Snow Survey Frank Gehrke and California governor Jerry Brown found no snow during their manual survey for the media at 6,800 feet in the Sierra Nevada. This was the first time in 75 years of early-April measurements at the Phillips Station snow course that no snow was recorded. Photo: DWR

been tied. That mark was shattered on April 1, 2015 as the snowpack only amounted to 5 percent of average.

Table 2. Monthly temperature and precipitation anomalies for water year 2015 as computed by the California Climate Tracker of Western Region Climate Center.

Month	Temperature Anomaly (degrees Fahrenheit)	Precipitation Anomaly (percent of average)
October	3.9	57%
November	2.8	67%
December	3.5	180%
January	4.4	10%
February	6.9	73%
March	7.1	17%
April	2.4	66%
May	-0.7	86%
June	4.7	59%
July	-0.3	780%
August	2.1	14%
September	2.9	64%

As spring unfolded across California conditions changed for the better. While precipitation did not get to average across the state during the season, there were periods of wet weather and cooler temperatures in some locations during April and May. June's transition to summer saw a spike in hot weather suggesting a long hot summer a fourth year of drought.

July continued the pattern of hot and dry with triple digit temperatures common in the interior valleys and deserts to start the month. However, as the month unfolded, thunderstorm showers were common in the Sierra and into the northern Mojave Desert. Temperatures were cooler than average and coastal fog made an appearance. In the second half of July, moisture and remnant dynamics from Eastern Pacific Hurricane Dolores led to locally heavy rainfall, thunderstorms and localized flash flooding in southern California and the southern Sierras.

Hot weather continued in August as high pressure over the Great Basin prevented cool Pacific air from penetrating inland. Offshore flow limited coastal fog events. Mountain nighttime temperatures dropped to near freezing at the higher elevations near the end of the month.

September closed out water year 2015 with more hot, dry weather across the State. The remains of Hurricane Linda moved into the South Coast region and Southern Sierra in the middle of the month causing thunderstorms and locally heavy showers. For the city of Los Angeles, September 15, 2015 was the wettest day of 2015, second wettest day in any September, and the month ended as the third wettest as a result of the decaying tropical system. The month and water year closed out with fog along the coast and dry warm conditions inland.

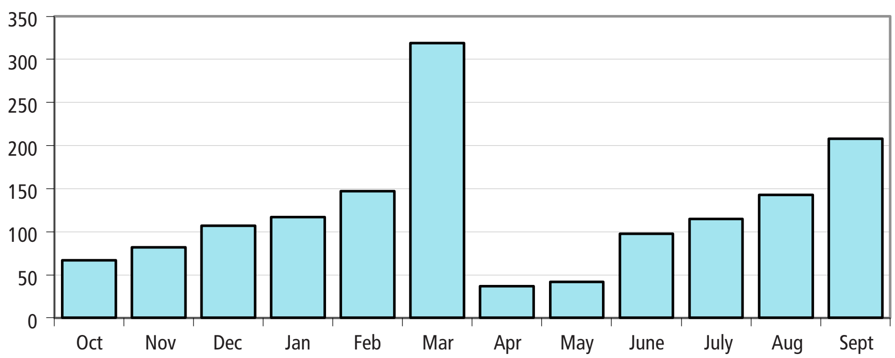
Intense rain and high winds wreaked havoc by downing trees and disrupting schools and traffic in the Bay Area, and in Lake Tahoe winds produced waves up to 5 feet high.

The Placer County Sheriff's Office posted a series of photos of surfers riding waves on the typically placid Lake Tahoe.

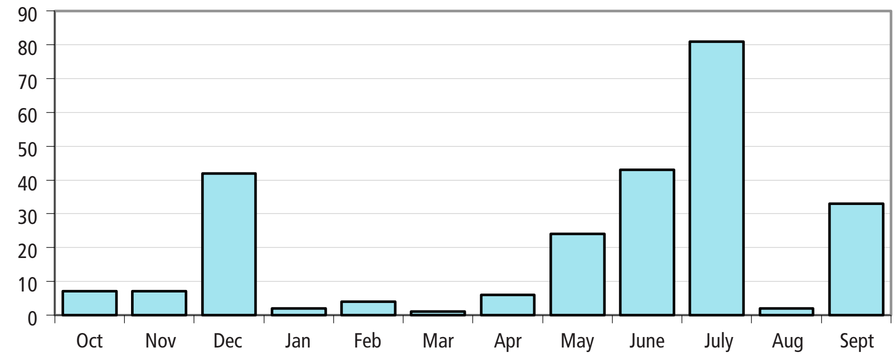
Daily temperature or precipitation records were set on 225 days of the 2015 water year. The month with the most days with records set was March with 23 while the month with the fewest was May with 10. For the water year, there were 1482 temperature records set and 252 precipitation records set. The largest monthly total for temperature records was in March 2015 with 319 records. The largest monthly total for precipitation records was in July 2015 with 81 records. A plot of the monthly distribution of temperature and precipitation records is shown (right).

Monthly distribution of temperature and precipitation records set in California during water year 2015.

Number of Statewide Temperature Records by Month for Water Year 2015



Number of Statewide Precipitation Records by Month for Water Year 2015



Glossary

• **Anomaly:** The difference of a value over a specified period from the long-term average value (e.g. 1949-2005) over the same period.

• **Average Maximum Temperature:** The average of all daily maximum temperatures over a given time period.

• **Average Mean Temperature:** The mean value of the average maximum temperature and the average minimum temperature over a given time period.

• **Average Minimum Temperature:** The average of all daily minimum temperatures over a given time period.

• **Calendar Year (to date):** The interval between January and December (or to present month), inclusive.

• **Climate:** The average weather or the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years.

• **Climate change:** A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties (often by using statistical tests), and that persists for an extended period, typically decades or longer.

• **Climate model:** A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

• **Climate variability:** Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.

• **COOP station:** Cooperative Observer Network (COOP), managed by the National Weather Service, consists of up to 12,000 weather stations across the United States that report daily measurements of precipitation and/or temperature.

• **Inhomogeneities:** Variations in data that are not attributed to climate variations. Non-climatic influences on the dataset can include abrupt changes due to changes in instrumentation or station location, as well as gradual changes due to growth of nearby vegetation or urban centers.

• **Linear Trend:** A simple method that fits a line (linear trend) to observations of a given variable over some time period. Beside each linear trend given on this set of pages is a 95% confidence interval that provides a measure as to how likely a trend is significant. For example, a trend of +2°F/100 years with an uncertainty interval of + or - 1°F/100 years says that with 95% confidence there is a positive linear trend, with a range between +1° and +3°F/100 years. On the other hand, a linear trend of + 2°F/100 years with an uncertainty interval of +/- 5°F/100 years does not provide conclusive evidence of a linear trend, as the range is between -3° to + 7°F/100 years. Confidence Intervals are calculated according to Santer et al 2000.

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

• **Percentile Ranking:** The ranking of a variable (e.g., temperature) over a given time period versus comparable time periods overall years of record, normalized to a 0 (coldest) to 100 (warmest) scale.

• **Precipitation:** The accumulation of water (in liquid form) that is deposited to the surface over a given time period.

• **Streamflow:** The amount of water flowing in a river.

• **Water Year (to date):** The interval between October and September (or to present month). For example the water year 2007 refers to the interval between October 2006 and September 2007.

Appendix

Temperature and Precipitation

WRCC California Climate Tracker

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

The state of California is dominated by its diverse topography, ranging from the coastal environs, to the great Central Valley, the Sierras and the Mohave-Sonoran Desert. California's varying landscape gives way for a number of physical mechanisms that not only influence the average climate, but also climate variability across the state. The analysis of climate variability and trends is a crucial and necessary component in understanding the role of climate change. Although there is clear indication of changes in the global surface temperature, the regional manifestation of climate change is not well quantified at the present time. Driven by the interests of the governmental, economic, and scientific communities it is pertinent to develop an objective method to define and monitor climate not only for the state as a whole, but also for its distinct climate regions.

The National Climatic Data Center (NCDC) has developed climate divisions that span the contiguous United States, whereby each state has been subdivided into 10 or fewer climate divisions. Across much of the western United States climate divisions were guided mostly by watershed and river basins, as opposed to climatological patterns. Consequently, the divisions suffer from a number of problems in the western United States, where complex topography plays a strong role in dictating regional climate patterns. For example, the current climate divisions in California make no distinction between the Sierra Nevada Mountains and the Central Valley. Not only do the Central Valley and Sierra differ greatly in terms of average temperature and precipitation, but also in terms of variations in temperature and precipitation.

Data:
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 we caution that the dataset contains larger uncertainties prior to 1918 due to the limited number of stations reporting statewide.

Methodology:
Variations in climate are at the forefront of both the public mind and of climate researchers. The initial steps in creating the California Climate Tracker were to identify cohesive regions of climate variability within the state. Using an infilled dataset an analysis is performed on the COOP station data using both

monthly precipitation and average monthly mean temperature. This analysis focuses on how stations vary with one another. 11 distinct regions across the state wherein stations located within a region vary with one another in a similar fashion. An analogous analysis is performed with the PRISM data, resulting in striking similar results. These 11 regions hereafter define the climate regions.

The collection of data from both station and PRISM data from these regions is used to create a single value for each variable for each month. This is a two-step process, dependent on the timing of data availability of both COOP station based data and the gridded PRISM based data. An effort is made to create a seamless translation between these two datasets. At the beginning of each month only COOP data is available, and often from around only 60% of the 195 stations statewide. Data are first screened for outliers (defined as a data anomaly that exceeds more than two standard deviations from any other anomaly within the state). Temperature datasets are also screened for inhomogeneities, which lead to an abrupt, non-climatic, change in the time series of a given station. An effort is then made to estimate missing stations from anomaly regression with highly correlated reference stations. At this point, the regional value is computed by the average of the collection of COOP stations within a region. Further adjustment is then made to adjust for inherent biases between the COOP based value and the PRISM-based areal average (e.g., COOP stations in mountainous terrain are generally located at elevations lower than the mean topography of the region, and are regularly warmer than the areal average of the domain of interest). Note that for the first couple weeks of each month that the most updated value is generated by station based data.

The PRISM group at Oregon State calculates monthly datasets within the first few weeks of each month. As the monthly data becomes available it is then incorporated into the California Climate Tracker by taking the areal average of the gridded data with respect to each region. Concurrent with the updating of the PRISM based values, we rerun the COOP based dataset as values continue to be ingested throughout the month. The monthly value reported at this second and final stage is a hybrid value that is weighted equally for PRISM-based data and station-based data.

The statewide average is computed by weighting the regional value by the area covered by each region. An extensive time series dating back to the late 19th century is formed for each region, and for the state as a whole. These time series are used to both categorize and track climate across the spatially diverse state of California in order to place the present climate in context to climate variations back to the late 19th century.

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 water year 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 water year runoff for the San Joaquin River (the San Joaquin four river index).

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

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

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

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

Snowpack

Bulletin 120 and Water Supply Index forecasts

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

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

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

Contrasting Snowpack Trends In The Sierra Nevada Of California (Roos and Sahota, 2012)

http://www.westernsnowconference.org/sites/westernsnowconference.org/PDFs/2012Roos.pdf

Widespread reports of decreases in western mountain snowpacks have been reported in recent years by many observers and scientists (Mote, 2003 and 2005) and attributed to global warming. In California, Sierra Nevada snowpack has been decreasing over the last 60 years. In both northern and southern regions the portion of water year runoff during the April through July snowmelt season has decreased, although less so in the southern Sierra river basins, which are higher in elevation.

Originally a group of 13 northern courses and 13 southern Sierra courses were chosen by Scripps researchers for use by the California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, for inclusion in a roughly 180 page 2009 report “Indicators of Climate Change in California” (CA EPA, 2009). The report has a large number of indicators for measured changes in economic factors, greenhouse gases, climate and temperature, physical systems, and biological systems with time. Over 30 indicators were discussed; the list included Sierra river runoff trends, the snowpack record, and two charts showing snow water content trends from1950 through 2008 for a group of northern Sierra Nevada snow courses and a group of southern Sierra Nevada snow courses.

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 water year 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 water year 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 water year 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 water year 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: http://www.waterrights.ca.gov/baydelta/d1641.htm

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

Snowpack and Snowmelt Changes- Maury Roos Chief Hydrologist, California Department of Water Resources (1/03/2012).

http://www.water.ca.gov/climatechange/blog/

Sea Level Trends

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

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

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

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

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

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

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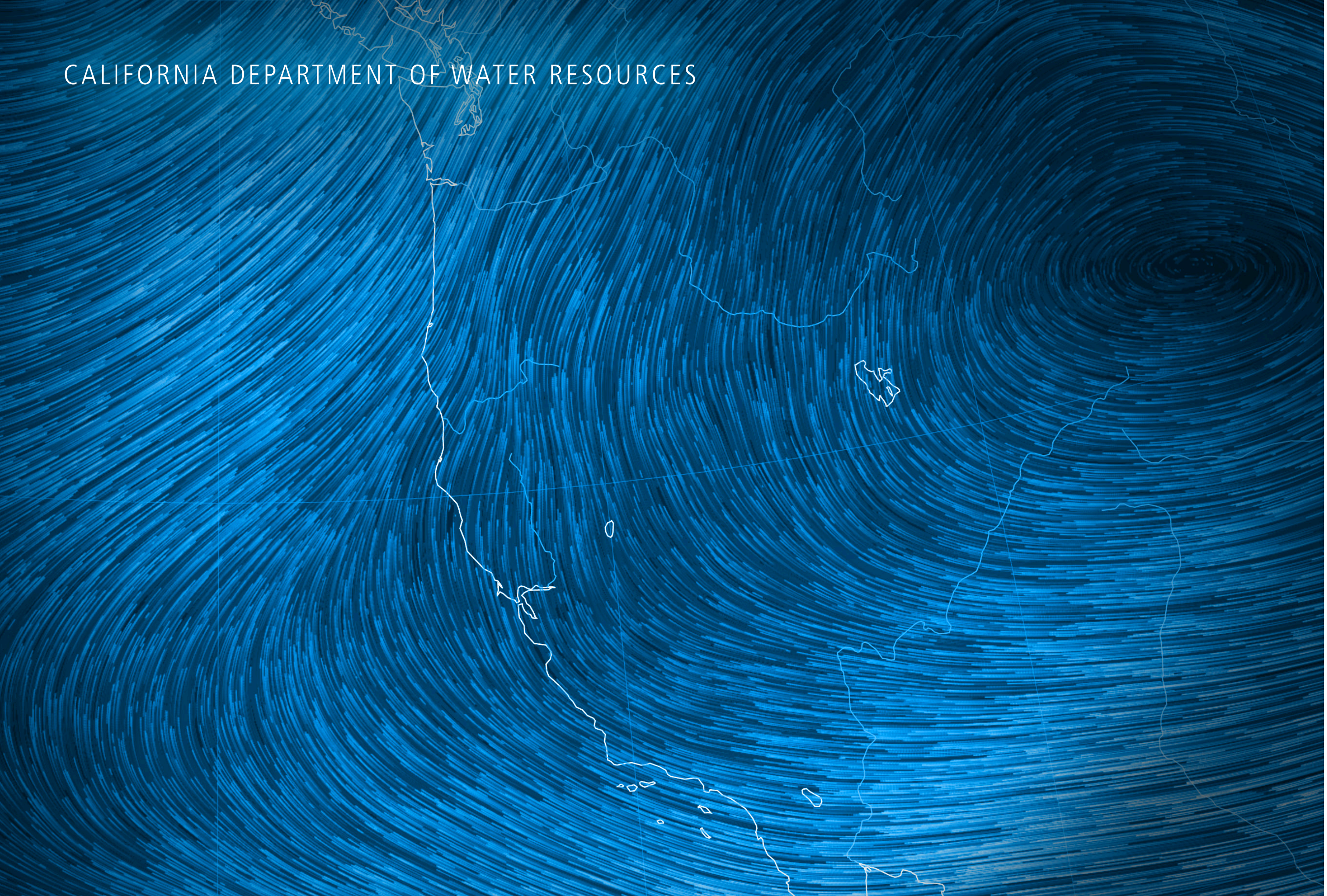

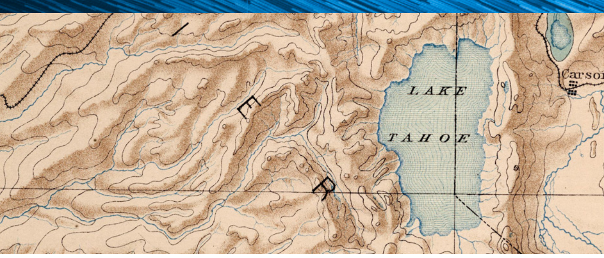

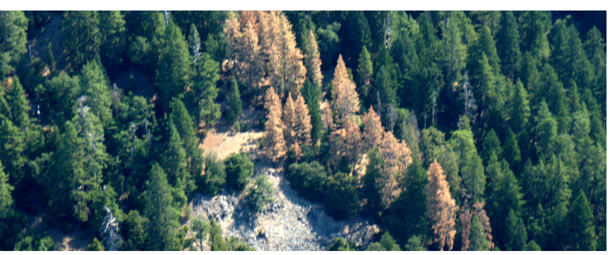

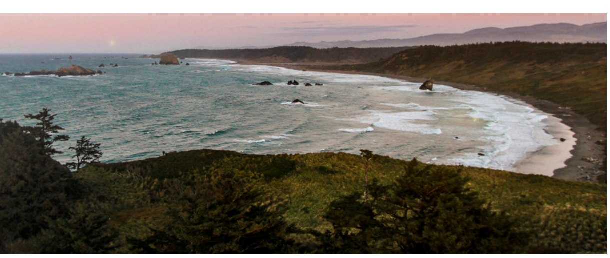

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