Actuarial Weather Extremes Series

Salinas River California Streamflow: January 2023

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Atmospheric River Impact Summary

As previously reported by the Society of Actuaries Research Institute (SOA), an atmospheric river brought record rainfall to the western coast of the United States in the last days of 2022 and through the first week of 2023 [1]. This rainfall led to widespread damage and states of emergency across California [2].

This subsequent analysis examines the impact of this record rainfall on river and stream discharge levels through California, with a detailed focus on historical observations of the Salinas River in two locations.

Data Sources

This analysis relies exclusively on the U.S. Geological Survey (USGS) data available through their web service [3]. River and stream measurements are available in 15-minute increments or in daily increments. For the following work, we used daily observations, representing the Average Daily Discharge.

Detailed analysis data can be found in Source [4] listed at the end of this report.

Methodology

To begin, we retrieved all Daily Discharge observations for all reporting USGS stations in California for the period 12/1/2022-1/15/2023. For each station, we calculated the December Mean Daily Discharge, December Maximum Daily Discharge, January Mean Daily Discharge, and January Maximum Daily Discharge. By comparing the December Mean to the January Mean and the December Maximum to the January Maximum, we were able to identify stations with significantly higher discharge rates in the first 15 days of January 2023. While a comparison of statistics across different time spans is unusual, it is suitable for the identification of relatively extreme discharge rates. Two of the stations along the Salinas River were selected for further analysis, based on their high Mean/Max ratios, proximity, and long historical record.

For both stations, we retrieved all daily mean discharge observations between 1/1/1950 and 1/15/2023. For each month in the record, we calculated the average and maximum daily mean discharge, an appropriate aggregation for analysis of extreme values. After evaluating the rank and percentile of the January 2023 values and visually inspecting the time series, we examined fitting the Annual Maximum Discharge to various distributions: Poisson, Exponential, and Power Law.

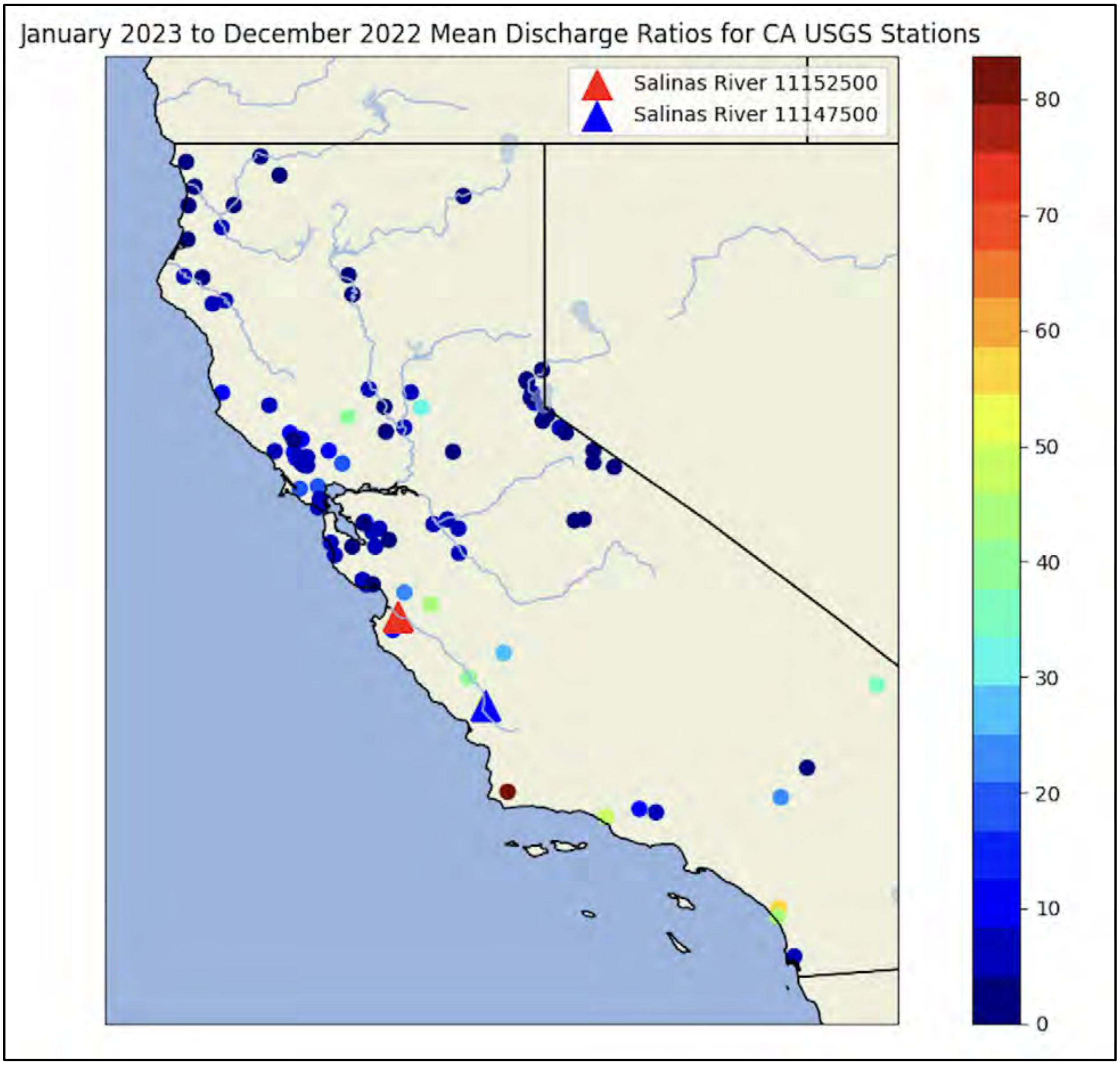
January 17, 2023

Stations Analyzed

Figure 1 plots the California USGS stations analyzed in the first stages. The two stations on the Salinas River, which are discussed in more depth below, are specifically highlighted as triangles on the map. For Station 11152500, the Mean and Maximum Ratios were 2,911 and 480, respectively. For Station 11147500, the Mean and Maximum Ratios were 52 and 13, respectively.

Figure 1

JANUARY (1-15) 2023 TO DECEMBER 2022 MEAN DAILY DISCHARGE RATIOS FOR CALIFORNIA USGS STATIONS



Results

As previously described, we first analyzed each station in California and evaluated their month-over-month changes. Table 1 below shows the top 15 stations ranked by ratio of January/December Mean Daily Discharge. The two stations highlighted in red were selected for more detailed, historical analysis.

Table 1

JANUARY 2023 TO DECEMBER 2022 MEAN AND MAXIMUM DAILY DISCHARGE RATIOS FOR THE TOP 15 CALIFORNIA USGS STATIONS

Site ID	Site Name	Latitude	Longitude	December Mean	December Max	January Average	January Max	Jan/Dec Mean	Jan/Dec Max
11152500	SALINAS R NR SPRECKELS CA	36.63	-121.67	1	24	3,002	11,700	2,911	480
11140000	SISQUOC R NR GAREY	34.89	-120.31	5	81	1,316	6,180	242	76
11133000	SANTA YNEZ R A NARROWS NR LOMPOC CA	34.64	-120.42	25	184	2,063	13,500	84	73
11046000	SANTA MARGARITA R A YSIDORA CA	33.31	-117.35	9	190	525	2,540	56	13
11147500	SALINAS R A PASO ROBLES CA	35.63	-120.68	68	1,050	3,509	13,300	52	13
11118500	VENTURA R NR VENTURA	34.35	-119.31	24	519	1,186	8,450	49	16
11157500	TRES PINOS C NR TRES PINOS CA	36.77	-121.30	11	272	484	1,870	46	7
11042000	SAN LUIS REY R A OCEANSIDE CA	33.22	-117.36	0	3	21	215	43	73
11150500	SALINAS R NR BRADLEY CA	35.93	-120.87	79	115	3,278	11,900	42	103
11451800	CACHE C A RUMSEY CA	38.89	-122.24	54	774	2,030	4,450	38	6
10251300	AMARGOSA RV AT TECOPA CA	35.85	-116.23	0	1	13	77	36	154
11424000	BEAR R NR WHEATLAND CA	39.00	-121.41	143	491	4,443	9,170	31	19
11224500	LOS GATOS C AB NUNEZ CYN NR COALINGA CA	36.21	-120.47	4	66	113	556	27	8
10261500	MOJAVE R A LO NARROWS NR VICTORVILLE CA	34.57	-117.32	10	12	239	1,360	25	113
11159000	PAJARO R A CHITTENDEN CA	36.90	-121.60	164	1,820	3,943	10,400	24	6

Figure 2 shows the Maximum Mean Daily Discharge in each month since 1950 for Station 11152500. The January 2023 value of 11,700 cubic feet/second (cfs) was the 23rd highest monthly maximum and above the 97th percentile. While this observation is not the most extreme, it was the highest since March 2001.

Figure 2

MAXIMUM MEAN DAILY DISCHARGE FOR USGS STATION 11152500 SALINAS RIVER NEAR SPRECKELS, CALIFORNIA

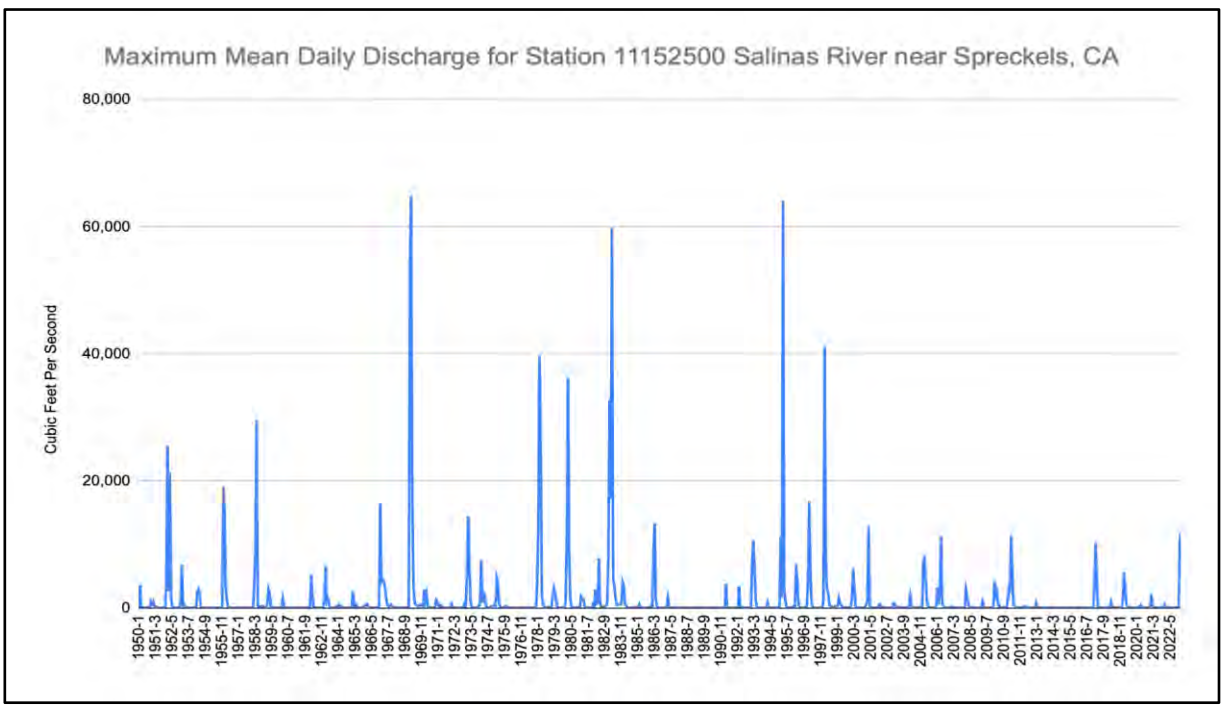


Figure 3 shows the results of fitting the observations to Poisson, Exponential, and Power Law distributions.

Figure 3

DISTRIBUTION FITS FOR STATION 11152500'S ANNUAL NUMBER OF DAYS OVER 10,000 CUBIC FEET/SECOND (CFS)

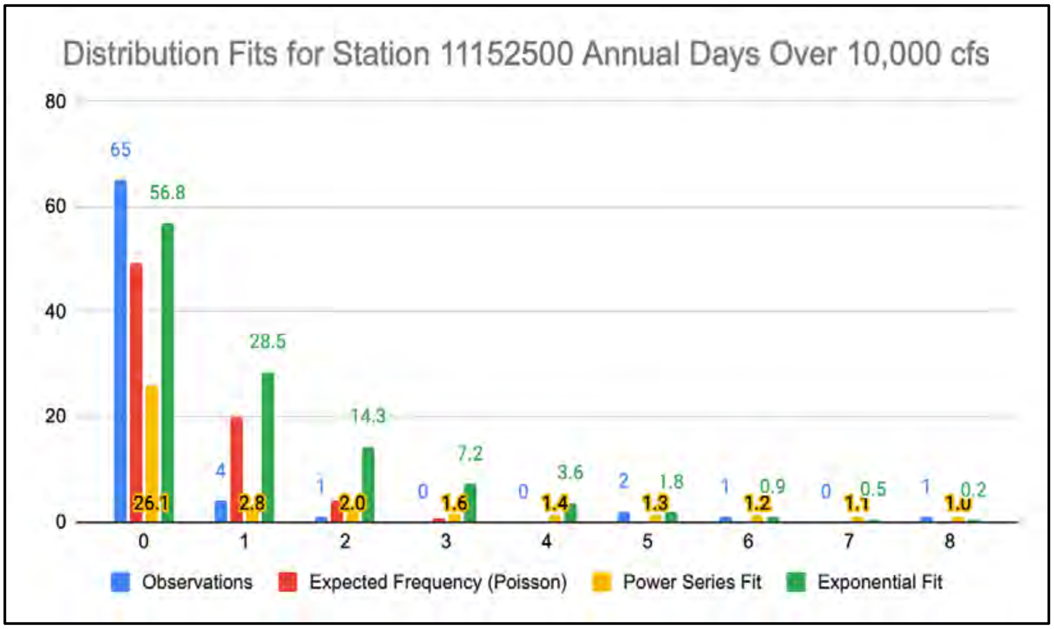


Table 2 shows the deviations of these fits from the observations. Clearly, the Poisson and Exponential distributions are the best fit for predicting the number of years below the threshold of 10,000 cfs. However, the Poisson assigns very low probabilities to higher numbers of days and therefore underestimates the likelihood of these extreme events.

Table 2

MODEL DEVIATION FROM OBSERVED FREQUENCY BY STATISTICAL DISTRIBUTION TYPE

Annual Days Over Threshold	Observations	Poisson	Power Law	Exponential
0	65	-15.7	-38.9	-8.2
1	4	16.0	-1.2	24.5
2	1	3.1	1.0	13.3
3	0	0.5	1.6	7.2
4	0	0.1	1.4	3.6
5	2	-2.0	-0.7	-0.2
6	1	-1.0	0.2	-0.1
7	0	0.0	1.1	0.5
8	1	-1.0	0.0	-0.8

The Power Law and Exponential distributions assign similar probabilities to 5+ days with low deviations and are therefore more suitable for modeling these observations. However, the Exponential fit predicts less than 1 observation for the 6–8-day buckets while the Power Law predicts more than 1 for each of these buckets. The selection of distribution for modeling such extremes may then rest on the degree of conservatism the actuary wishes to include in their model, with the Power Law distribution predicting more conservative and extreme results.

For Station 11147500–closer to Monterey Bay and the populated cities of Monterey, Salinas, and Carmel–we followed a similar analysis and observed more extreme streamflow rates. Figures 4 and 5 show that in January 2023 this station recorded its 2nd highest maximum daily discharge and its highest average monthly discharge since 1950, respectively. These historical extremes are of particular concern, given the proximity of this station to populated areas.

Figure 4

MAXIMUM MEAN DAILY DISCHARGE FOR THE SALINAS RIVER NEAR PASO ROBLES, CALIFORNIA

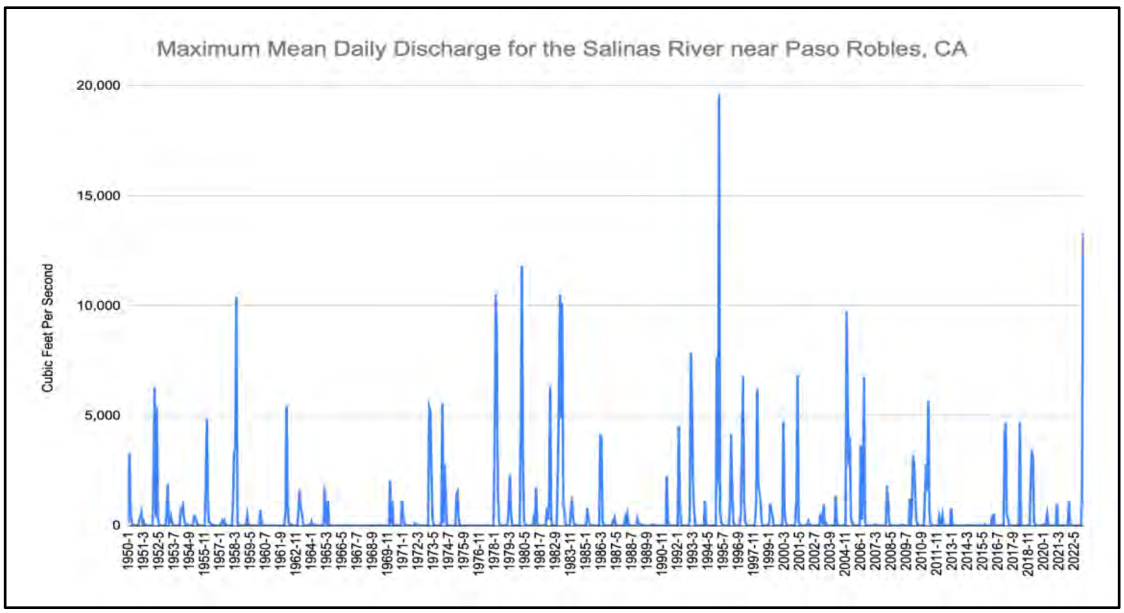


Figure 5

AVERAGE MEAN DAILY DISCHARGE FOR THE SALINAS RIVER NEAR PASO ROBLES, CALIFORNIA

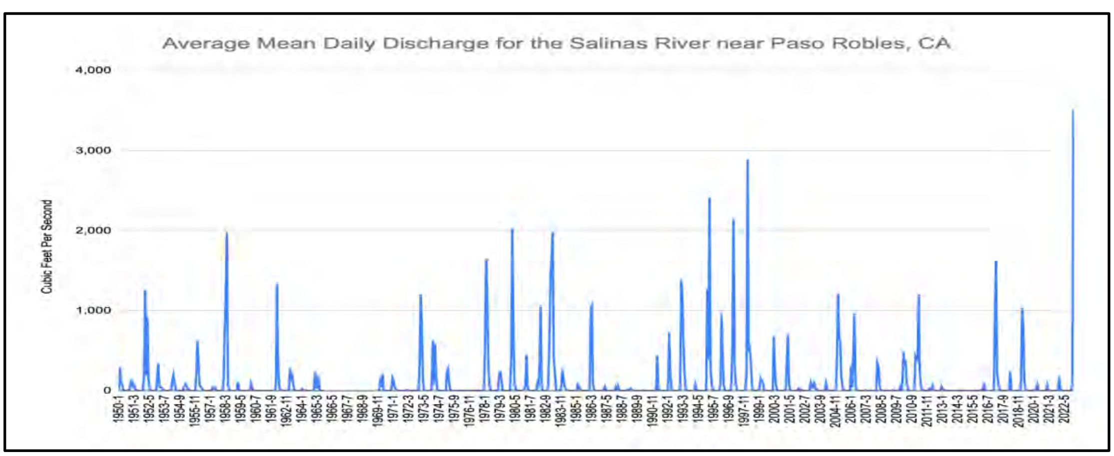
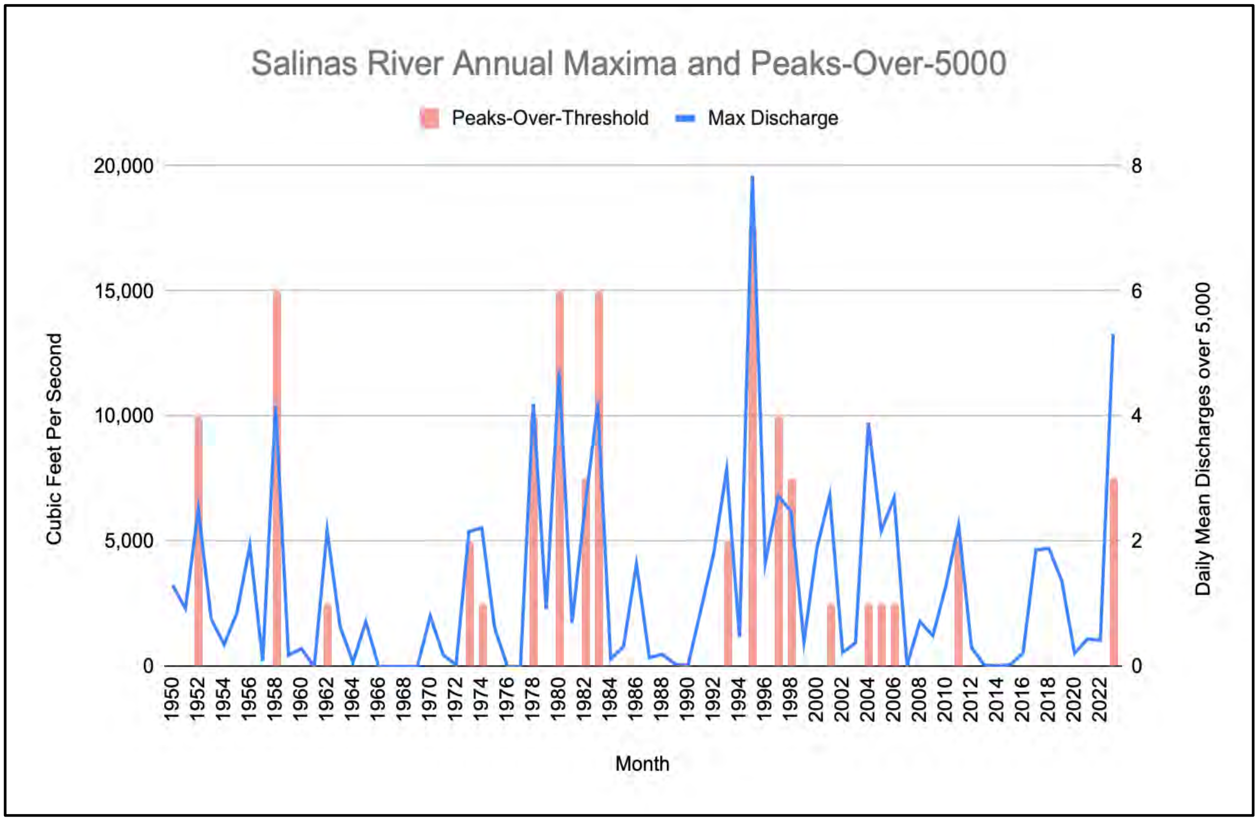


Figure 6 below shows the beginning of a common technique for modeling extreme values by focusing on the most extreme discharge observations. The two distinct approaches represented in this graphic are the Block Maximum method and the Peaks-Over-Threshold method. In the former, we record the maximum observation within a given time period, typically a year. In the latter, we create a time series by including only observations above a given value, e.g., 5,000 cfs.

From these time series, the data can be fit to a Generalized Extreme Value Distribution using maximum-likelihood estimation. The SOA's September 2022 report "A Hydro-EVT Approach to Flood Insurance Pricing" expands on modeling techniques for extreme values **[5]**.

Figure 6

ANNUAL BLOCK MAXIMA AND PEAKS-OVER-THRESHOLD METHOD AMOUNTS FOR THE SALINAS RIVER NEAR PASO ROBLES, CALIFORNIA



Sources

- **[1]** California Precipitation December 30-31, 2023
  - Society of Actuaries Research Institute
  - Actuarial Weather Extremes | SOA
  - https://www.soa.org/48dd0c/globalassets/assets/files/resources/research-report/2023/act-weather-extremes-ca-2022-12-report.pdf
  - **Date** Published: 1/12/**2023**
- [2] California declares state of emergency
  - The Guardian
  - https://www.theguardian.com/us-news/2023/jan/04/california-bomb-cyclone-storm-flooding
  - Date Accessed: 1/9/2023
- [3] USGS Daily Values Web Service
  - United States Geological Survey
  - https://waterservices.usgs.gov/rest/DV-Service.html
  - Date Accessed: 1/16/2023
- [4] Source Data Analysis
  - California Streamflow 202301
  - Date Created: 1/16/2023
  - This Google Sheet is available to the public via the link.
- [5] A Hydro-EVT Approach to Flood Insurance Pricing
  - Society of Actuaries Research Institute
  - A Hydro-EVT Approach to Flood Insurance Pricing | SOA
  - https://www.soa.org/4a818f/globalassets/assets/files/resources/research-report/2022/hydro-evt-flood-insurance.pdf
  - **Date** Published: September 2022