THE RECENT CALIFORNIA DROUGHT

by
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ABSTRACT

The 1987-92 drought was the worst sustained drought in history (since 1850) across Central California and nearly equalled the 1929-34 drought in Northern California. The six years of drought are characterized using statewide statistics on precipitation, runoff, spring snowpack, and reservoir storage. Then, the drought in the Sacramento and San Joaquin River basins is compared with other historical droughts and the droughts shown in reconstructed runoff of the Sacramento River since the year 1560 from tree ring studies. Certain climate factors are important in understanding the drought picture for California. Some discussion of the impact on Central Valley Project and State Water Project supplies and future implications wrap up this paper.

INTRODUCTION

For the second time this century, 6 years of drought gripped Northern and Central California during 1987-92. This paper summarizes the hydrologic facts of the drought and makes comparisons with other droughts.

The drought was broken in most parts of California by the wet year 1993. But a relapse occurred in 1994, which was again critically dry, and raised fears that the drought had resumed. The drought watch of 1994 was finally washed out to sea in the two large flood events which have made 1995 one of the wetter years and have refilled all but a couple of the State's major reservoirs.

CLIMATE FACTORS

California is situated near the southern margin of the prevailing westerly wind belt, a region on the globe between 30 and 60 degrees north latitude where a continuing series of cyclonic storms progress from west to east producing periodic rainfall. To the south is a zone of semi-permanent high pressure areas with descending warm, dry air. The high pressure area which affects California is known as the Pacific High. The global zones of weather shift with the season. Much of the year California is in the high pressure belt which accounts for the fair weather and lack of precipitation during the summer. During the winter season, the storm belt shifts southward to occasionally place the State under the influence of Pacific storms to bring vitally needed rain and snow.

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Most of California's moisture originates in the Pacific Ocean to the west and southwest. Storms with a long southwesterly fetch generally produce more precipitation (sometimes floods) because these storms tap air with higher moisture content originating over warmer water. As moisture laden air is blown over mountain barriers, such as the Sierra Nevada, the air is lifted and drops additional rain or snow in the high country normally on the westerly slopes. The mountain induced precipitation is called orographic precipitation and is very important to water supply. For example, the 1600 m (one mile) high Blue Canyon weather station located northeast of Sacramento averages 1600 mm (63 inches) of precipitation a year, about 3-1/2 times the 450 mm (18 inches) expected at Sacramento in the middle of the Central Valley.

The direction of orographic wind flow is important. The greatest amount of water is wrung out when wind flow is at right angles to the mountain barrier or from southwest for the Sierra Nevada. A more southerly direction, such as occurred frequently during water year 1992, is not as productive.

Normally during the wet season, 5 to 7 major winter storms occur which drop 25 to 50 mm (1 to 2 inches) of rain in the Sacramento Valley and corresponding equivalents of rain and snow in the Sierra. A shortfall of a couple of major storms causes a dry year; conversely a couple of extra storms produce a wet runoff year. An unusually persistent Pacific High over California during the three mid-winter wet months (December through February) predisposes the year toward the dry side. On average, half the year's annual precipitation occurs during the December through January period. See Chart 1.

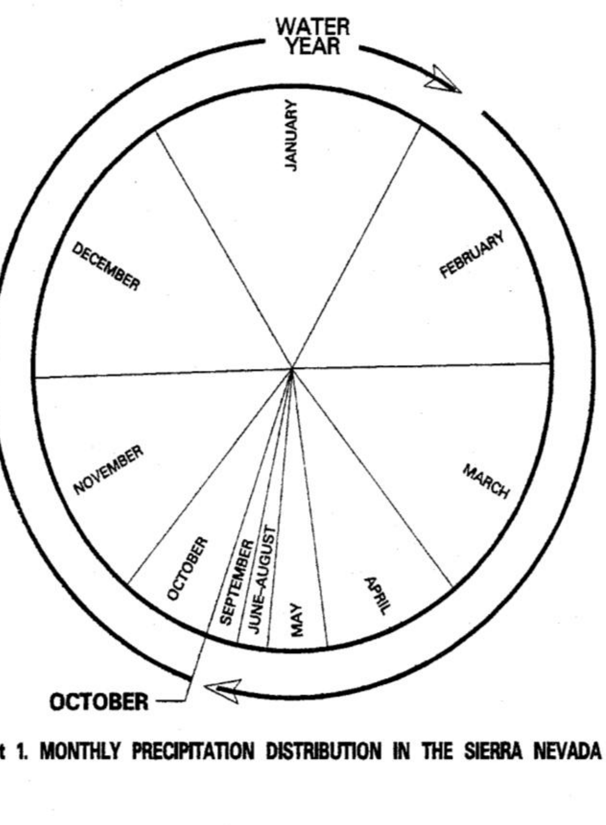


Chart 1. MONTHLY PRECIPITATION DISTRIBUTION IN THE SIERRA NEVADA

PRECIPITATION DURING THE 1987-92 DROUGHT

Statewide precipitation was below average in each year of the drought. Statewide and Northern Sierra percentages are listed on Table 1. Water year 1992 (which extended from October 1, 1991, through September 30, 1992) did produce well above average precipitation across the southern third of California. But amounts were light across the northern third of the State and especially in the Sierra Nevada. As a result, the statewide precipitation average was 86 percent and the runoff even lower at 43 percent of average. In 1989, when Sacramento basin runoff (Table 2) was about 3/4 of average, northern basins were near normal and the southern portion of the State was dry. Water year 1977, which was the driest single year of record, is also shown on Tables 1, 2, and 3.

Table 1
Percentage of Average Precipitation

		Water Year					
	1977	1987	1988	1989	1990	1991	1992
Statewide	45	61	82	86	69	76	86
Northern Sierra	38	57	70	101	72	65	72

The snowpack mirrored the precipitation deficiency. Normally the peak snow accumulation occurs near the first of April. The April 1 snowpack, then, is an important measure of prospective water supplies. Table 2, derived from DWR Bulletin No. 120 reports, gives a comparison of snowpack water content.

Table 2
Percentage of Average April 1 Snow Water Content

		Water Year					
	1977	1987	1988	1989	1990	1991	1992
Statewide	25	55	30	75	40	75	60
Northern Sierra	25	55	20	80	35	65	50
Southern Sierra	20	50	25	70	45	80	60

Table 3
Percentage of Average Runoff

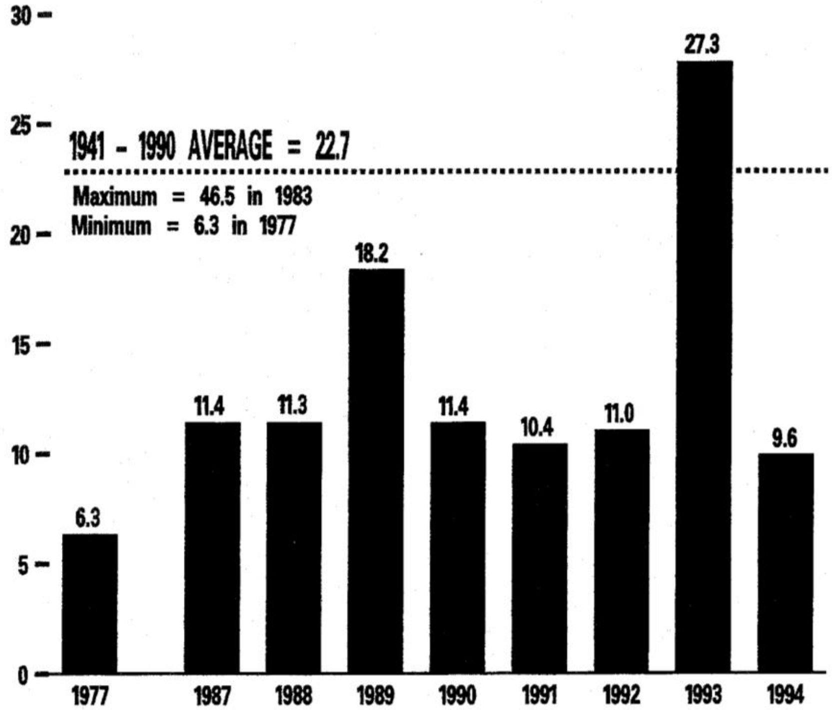
		Water Year					
	1977	1987	1988	1989	1990	1991	1992
Statewide	20	48	48	72	45	43	43
Sacramento River	28	50	50	80	50	46	48
Sacramento River (MAF)	5.1	9.2	9.2	14.8	9.2	8.4	8.9
Sacramento River ($m^3 x 10^9$)	6.3	11.4	11.3	18.2	11.4	10.4	11.0

Each drought is different. The recent drought for the Sacramento River basin is unique in that runoff in 5 of the years was very similar, about half of average. Only in 1989 was there a substantial change. The Sacramento River runoff (the sum of unimpaired runoff of the four major rivers in the basin) is also shown on Chart 2.

Chart 2. SACRAMENTO RIVER UNIMPAIRED RUNOFF

(Water Year October 1 Through September 30)

IN BILLION CUBIC METERS



The Sacramento River Runoff is the sum of unimpaired runoff from the Sacramento River at Bend Bridge, Feather River inflow to Oroville, Yuba River at Smartville and American River inflow to Folsom.

Precipitation during the 6-year 1987-92 period was about three-fourths of average. The deficit in precipitation was magnified in runoff which was about half of average over the 6-year period. A portion of each rainy season's precipitation goes into wetting the ground before runoff can begin. Therefore, the impact of a shortfall in precipitation is amplified in runoff deficits. Likewise, early and late season rainfall is not as effective in producing runoff because a larger fraction of the moisture is used by vegetation. Two of the drought years, 1989 and 1991, had unusually heavy March rainfall amounts. But the wet Marches, although helpful, were not enough to offset the precipitation deficits of the three winter season months.

Reservoir Storage

California's reservoir storage proved its worth during this drought, especially during the first three years. By 1990, however, reserves were largely depleted and major curtailments in water delivery became necessary. Chart 3 presents October 1 storage in the 155 major reservoirs within California. Chart 4 shows the same data for six reservoirs in the Central Coast hydrologic region, roughly from Santa Cruz to Santa Barbara. The improvement due to the greater Southern California precipitation amounts in March of 1991 and in 1992 is evident in Central Coast storage

Statewide carryover storage in the 155 major in-State reservoirs on October 1 of 1992 at the end of the last year of the drought was about 5 percent less than a year before. This is the lowest of the recent 6-year drought, but still nearly 6 billion cubic meters (5 MAF) over the extremely low 1977 storage amount. Combined Central Valley Project and State Water Project carryover in late 1992 was about 0.4 billion cubic meters (0.3 MAF) less than one year previous.

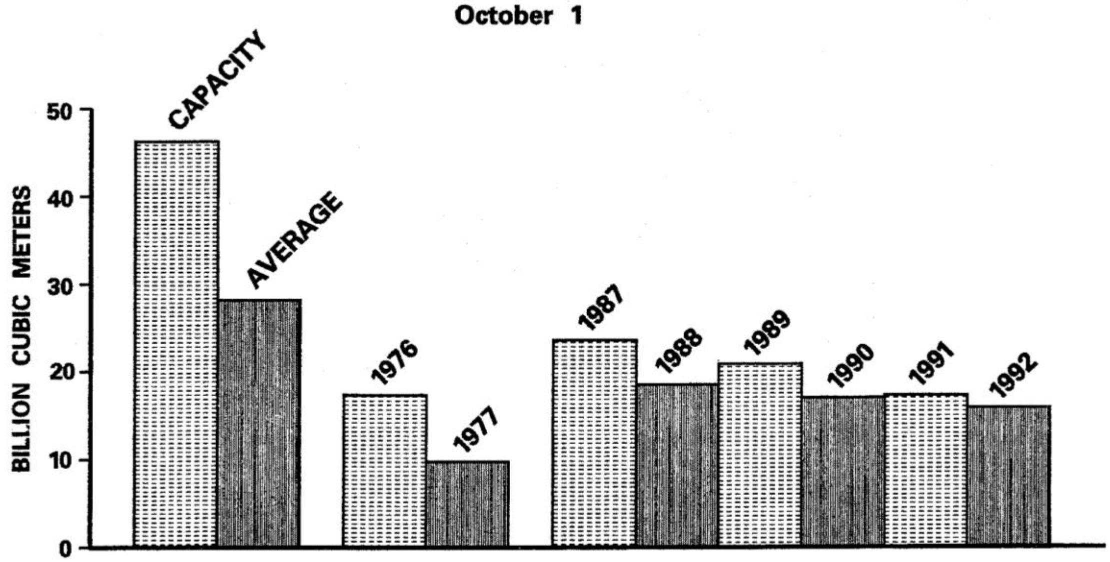
Table 4

Reservoir Storage on September 30

	1977	1986	1987	1988	1989	1990	1991	1992
In Billion Cubic Meters								
155 Major Res	9.60	33.00	23.34	18.29	20.62	16.74	17.00	15.63
Major CVP	1.62	10.40	7.73	5.67	6.29	4.91	4.06	3.84
6 Major SWP	1.80	5.24	3.71	3.05	3.55	2.31	3.00	2.84
In Million Acre-Feet								
155 Major Res	7.78	26.75	18.92	14.83	16.72	13.57	13.78	12.67
6 Major CVP	1.31	8.43	6.27	4.60	5.10	3.98	3.29	3.11
6 Major SWP	1.46	4.25	3.01	2.47	2.88	1.87	2.43	2.30
In Percent of Historical Average								
155 Major Res.	35	119	84	66	74	60	61	56
6 Major CVP	18	113	84	62	68	53	44	42
6 Major SWP	41	120	85	70	81	53	69	65

Chart 3. STORAGE IN 155 MAJOR IN-STATE RESERVOIRS

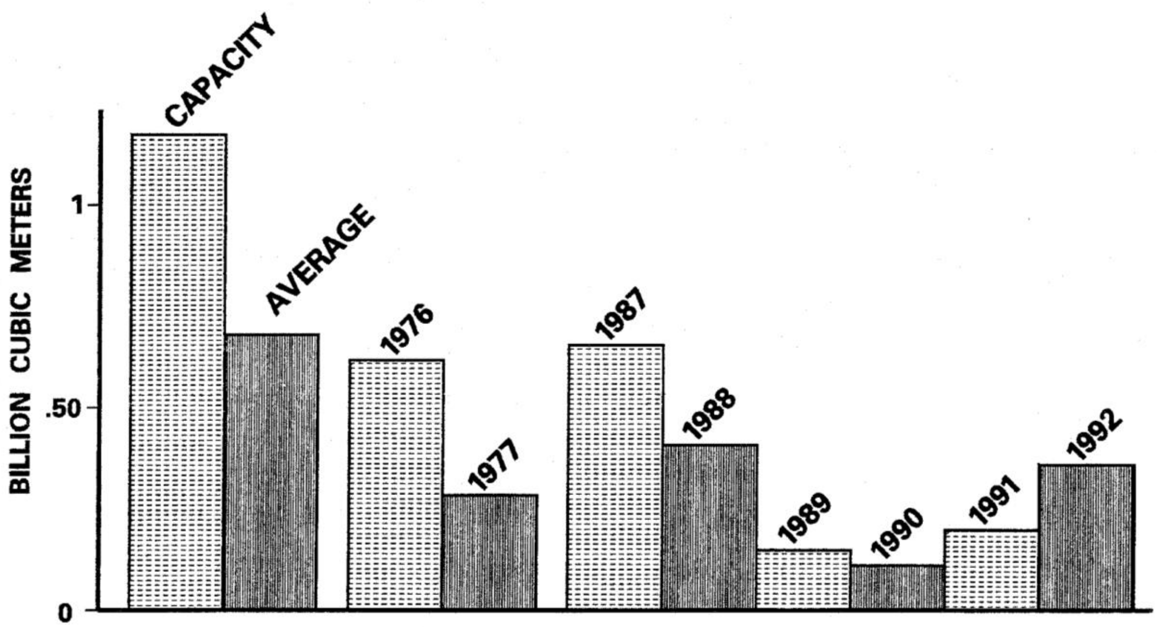
October 1



NOTE: The 1987 – 1992 storage amounts include New Melones and Warm Springs Reservoirs which began operation after 1977. 1989 – 1992 storage amounts also include the new Spicer Meadows Reservoir on the Stanislaus River.

Chart 4. STORAGE IN 6 MAJOR CENTRAL COAST RESERVOIRS

OCTOBER 1

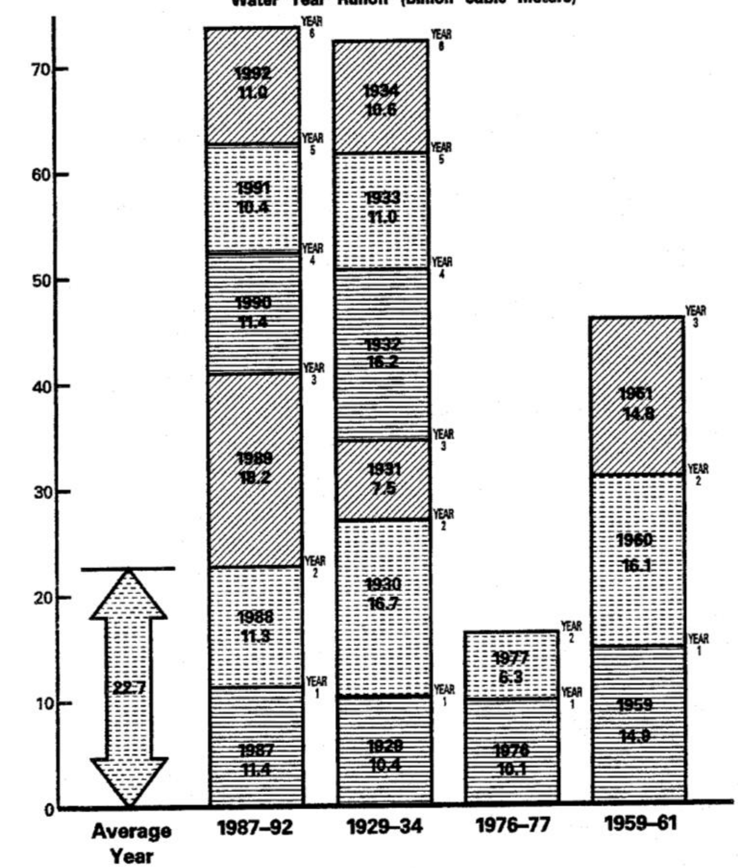


Because of federal and State Endangered Species Acts, and low reservoir temperature problems for salmon, water storage levels in the CVP and SWP system could not be drawn as low as in 1977, so probably half the 6 billion cubic meters (5 MAF) of statewide storage in excess of 1977 amounts would not have been usable in 1993 if that year had been dry. To place these storage amounts in perspective, total normal net water use in California for irrigated land and urban purposes is about 42 billion cubic meters (34 MAF). About 6 billion cubic meters (5 MAF) more is needed, on the average, for required Sacramento-San Joaquin Delta outflow to meet water quality standards. So it is quite evident that much of each year's supply must be generated from that season's runoff, with the smaller portion drawn from surface reservoir carryover storage.

Comparison with Past Droughts

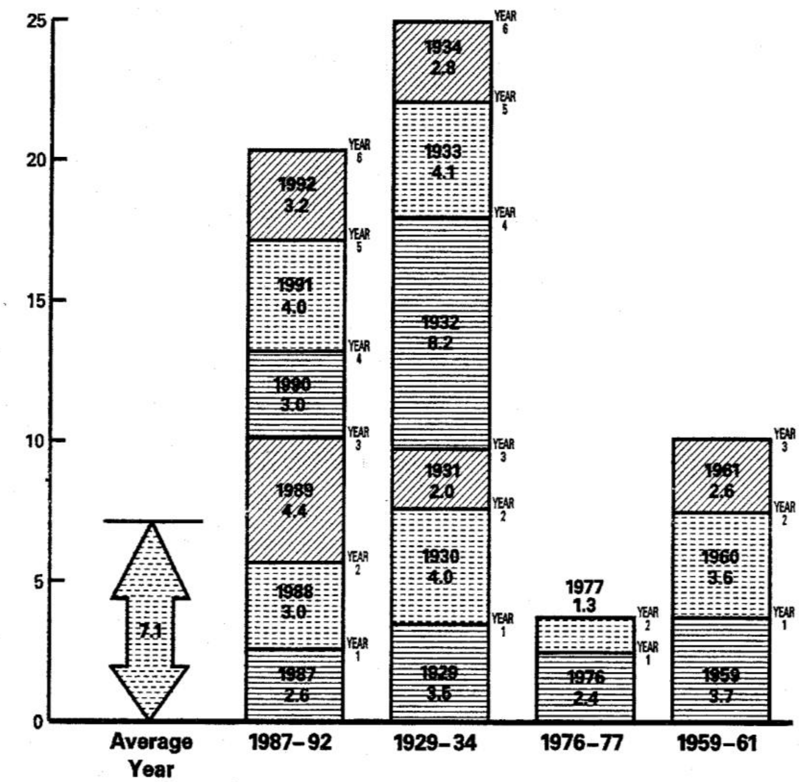
Average Sacramento River Index Runoff during the 1987-92 6-year period was about 12.3 billion cubic meters (10.0 MAF), or 54 percent of the average 22.7 billion cubic meters (18.4 MAF) of runoff. While unusual, this is not the driest of record. Runoff during the historical 6-year critical dry period from 1929 through 1934 was 1 percent less at about 12.1 billion cubic meters (9.8 MAF). (See Chart 5).

Chart 5. COMPARISON OF DROUGHTS
Sacramento River Unimpaired Runoff
Water Year Runoff (billion cubic meters)



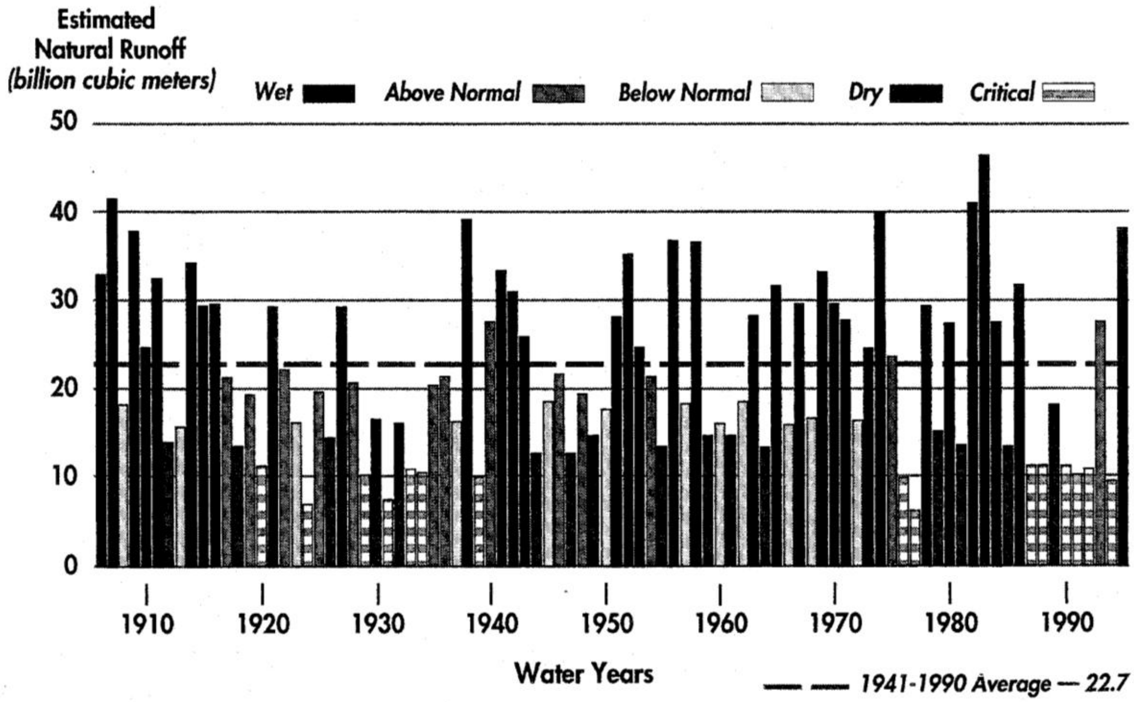
However, on the San Joaquin River system, the recent drought exceeded, by a large margin, the historical 1929-34 runoff. (See Chart 6). Because 1932 was above average in the Southern Sierra, the earlier drought was eased somewhat in that region.

Chart 6. COMPARISON OF DROUGHTS
San Joaquin River Unimpaired Runoff
Water Year Runoff (billion cubic meters)



Long droughts in excess of 3 years seem to be rare in Northern California. Except for 1929-34 period, there is no evidence of previous droughts exceeding 4 years in length from the historical runoff record (see Chart 7 for Sacramento River Runoff since 1906) or in the historical precipitation record which goes back to 1850 for a few early stations and is reasonable complete from the early 1870s when the major railroads were built. Long droughts in Southern California are more common.

Chart 7. Sacramento River Unimpaired Runoff Since 1906



NOTE: The Sacramento River runoff is the sum of unimpaired runoff from the Sacramento River at Bend Bridge, Feather River Inflow to Oroville, Yuba River at Smartville and American River Inflow to Folsom.

The estimated recurrence frequency for a 6-year period like 1987-92 for the Sacramento River region is 1.4 percent, or about once in 70 years, based on the 1906-92 record. On the San Joaquin River, where the current drought has been more severe, the estimated recurrence frequency is only about 0.3 percent, approximately a 1 in 300-year event. These statistics represent both length (6 years) and severity of drought. The following table presents estimated risk frequency of the current drought series in the two basins.

Table 5

Drought Frequency Probabilities

		Risk of Occurrence, Percent	
Water Year	Length, years	Sacramento	San Joaquin
1987	1	11	6
1987-88	2	5	2.4
1987-89	3	8	2.5
1987-90	4	4	0.8
1987-91	5	2.5	0.6
1987-92	6	1.4	0.3

It is not wise to place much trust in statistics for extreme events because the record is only about 90 years. Some long term climate reconstruction studies show periods in the past which are different than the last 90 years.

In order to get an idea of what the longer record looks like, indirect indicators of runoff are needed. The most promising tool for looking year by year into the past is by use of tree ring data. With the right selection of trees, the thickness of annual growth rings indicates the wetness of the season. Tree ring widths are not a perfect match (for example they did not reproduce the 1976-77 drought well) but have been useful to investigate how the measured runoff or precipitation record compares with a longer sweep of history.

A 420-year reconstruction of Sacramento River runoff from tree ring studies was made for the Department of Water Resources in 1986 by the Laboratory for Tree-Ring Research at the University of Arizona. See Page 28, DWR (1987) and Earle and Fritts (1986). This reconstruction showed that the 1928-34 drought was the worst in the reconstructed record which began with year 1560. Table 6 provides a listing of multi-year droughts from the reconstruction. These are runs of consecutive years under 19.4 billion cubic meters (15.7 MAF), the historic median runoff. The table shows multi-year droughts three years or more in length from the tree-ring study prior to 1900 and the measured record of similar events since 1900.

Table 6

Sacramento River Multi-Year Droughts
Reconstructed from Tree-Rings Prior to Year 1900

Period	Length (years)	Average Runoff: Billion Cubic Meters	Average Runoff: Million Acre-Feet
1579-82	4	15.3	12.4
1593-95	3	11.4	9.3
1618-20	3	16.3	13.2
1651-55	5	15.2	12.4
1719-24	6	15.5	12.6
1735-37	3	15.0	12.2
1755-60	6	16.4	13.3
1776-78	3	15.0	12.1
1793-95	3	13.2	10.7
1839-41	3	15.8	12.8
1843-46	4	15.2	12.3
1918-20 (actual)	3	14.7	12.0
1929-34 (actual)	6	12.1	9.8
1959-62 (actual)	4	16.1	13.0
1987-92 (actual)	6	12.3	10.0

Since the tree-ring reconstruction doesn't always match the measured record where there is overlap, the weight that should be given to the Table 6 information is not clear. What is apparent, is that few droughts prior to 1900 exceeded three years and none have lasted over 6 years, although there was an eight-year period of less than average runoff from 1839 through 1846.

John Bidwell, an early pioneer who arrived in California in 1841, confirmed that 1841, 1843 and 1844 were extremely dry years in the Sacramento area (Harding, 1965). He also talked about flooding in 1842 between San Jose and Sacramento.

SUMMARY

To summarize, no predictable pattern of drought is apparent. Droughts exceeding 4 years in length seem to be quite rare. There are a multitude of factors which can influence California weather, some in ways which are not understood. El Nino, the warming of the ocean in the eastern tropical Pacific, does have influences around the world. But no clear signal for Northern California is evident from the record -- some El Nino years are dry and some are wet.

Water storage to carry over supplies from the wet years to the dry years can ease the impact of drought, as noted for the Colorado River which also suffered drought at about the same time. Water deliveries there were almost unaffected. Total California in-State reservoir storage capacity is around 52 billion cubic meters (42 MAF), not greatly more than regulated demands within the State. This storage helped but is inadequate to deal with multiyear droughts. By 1990, major deficiencies in delivery of CVP and SWP supplies ensued. SWP Delta export deliveries were only 30 percent to urban contractors in 1991 and CVP "project" agricultural water customers got only 25 percent that year. A quickly formed water bank helped meet some of the most severe shortages but was too expensive for most agricultural users. The volume of ground water storage (although harder to fill) is much greater than surface storage and saved many water users from a worse fate. However, recharge and ground water storage recovery takes many years in the bigger alluvial basins.

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